TRANSPORTATION TECHNOLOGY SUPPORT
FOR DEVELOPING COUNTRIES

COMPENDIUM 12

Surface Treatment

Tratamiento de superficie

Revêtements superficiels

prepared under contract AID/OTR-C-1591, project 931-1116,
U.S. Agency for International Development

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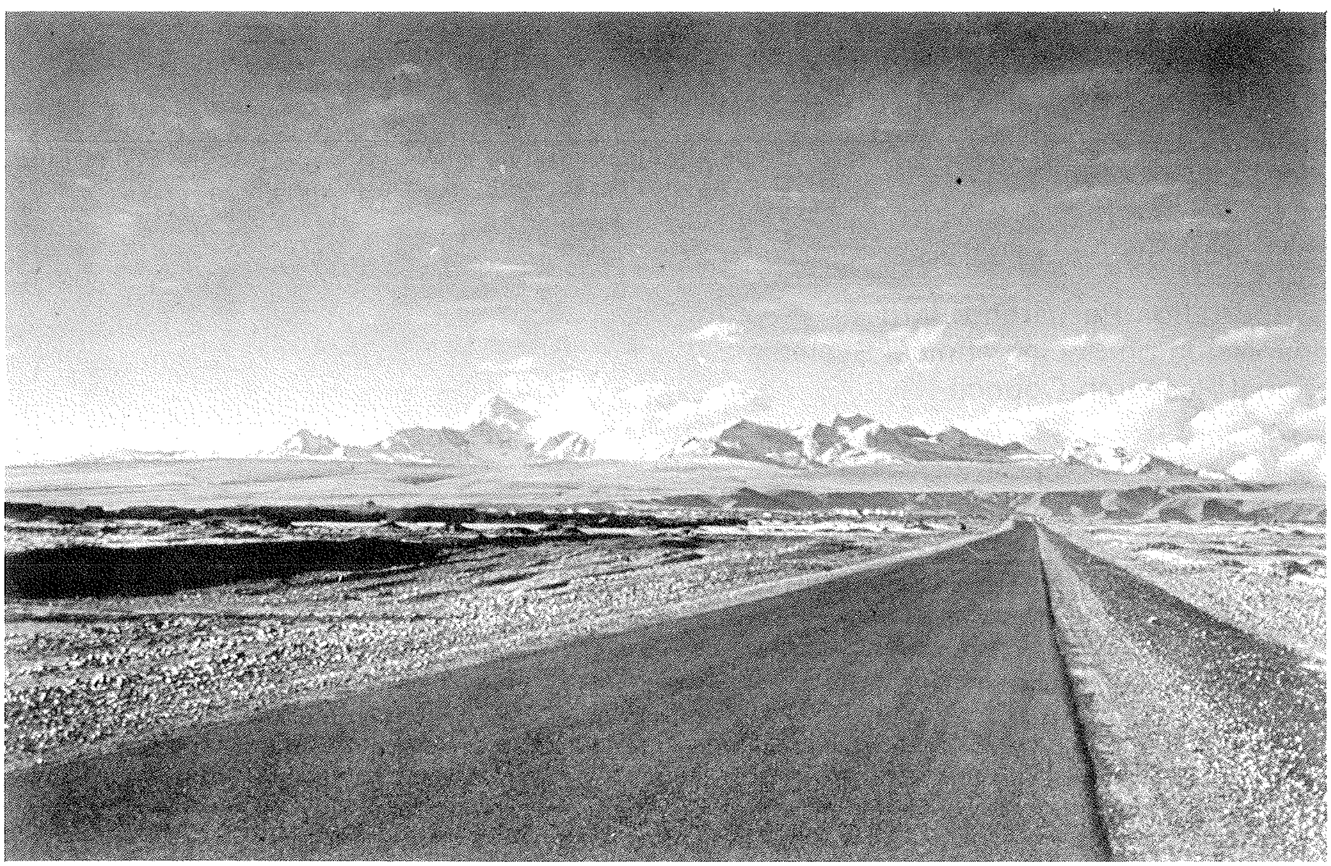
Notice

The project that is the subject of this report was approved by the Governing Board of the National Research Council, whose members are drawn from the councils of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine. The members of the committee responsible for the report were chosen for their special competence and with regard for appropriate balance.

This report has been reviewed by a group other than the authors according to procedures approved by a Report Review Committee consisting of members of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine.

Cover photo: View of double-surface treated road, South America.



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The development of agriculture, the distribution of food, the provision of health services, and the access to information through educational services and other forms of communication in rural regions of developing countries all heavily depend on transport facilities. Although rail and water facilities may play important roles in certain areas, a dominant and universal need is for road systems that provide an assured and yet relatively inexpensive means for the movement of people and goods. The bulk of this need is for low-volume roads that generally carry only 5 to 10 vehicles a day and that seldom carry as many as 400 vehicles a day.

The planning, design, construction, and maintenance of low-volume roads for rural regions of developing countries can be greatly enhanced with respect to economics, quality, and performance by the use of low-volume road technology that is available in many parts of the world. Much of this technology has been produced during the developmental phases of what are now the more developed countries, and some is continually produced in both the less and the more developed countries. Some of the technology has been documented in papers, articles, and reports that have been written by experts in the field. But much of the technology is

Descripción del proyecto

En las regiones rurales de países en desarrollo, el desarrollo de la agricultura, la distribución de víveres, la provisión de servicios de sanidad, y el acceso a información por medio de servicios educacionales y otras formas de comunicación, dependen en gran parte de los medios de transporte. Aunque en ciertas áreas los medios de ferrocarril y agua desempeñan un papel importante, existe una necesidad universal y dominante de crear sistemas viales que provean un medio asegurado pero relativamente poco costoso para el movimiento de gente y mercancías. La mayor parte de esta necesidad se solucionaría con la construcción de caminos de bajo volúmen que generalmente moverían únicamente de 5 a 10 vehículos por día y que pocas veces moverían tanto como 400 vehículos por día.

El planeamiento, diseño, construcción y mantenimiento de caminos de bajo volúmen para regiones rurales de países en desarrollo pueden ser mejorados, con respecto al costo, calidad, y rendimiento, por el uso de la tecnología de caminos de bajo volúmen que se encuentra disponible en muchas partes del mundo. Mucha de esta tecnología ha sido producida durante las épocas de desarrollo de lo que ahora son los países más desarrollados, y alguna se produce contínuamente en estos países así como en los países menos desarrollados. Parte de la tecnología se ha documentado en disertaciones, artículos, e informes que han sido escritos por expertos en el campo. Pero mucha de la tecnología no está documentada y existe principalmente en la memoria de aquellos que han desa-

Description du projet

Dans les régions rurales des pays en voie de développement, l'exploitation agricole, la distribution des produits alimentaires, l'accès aux services médicaux, l'accès aux matériaux et aux marchandises, à l'information et aux autrès services, dépendent en grande partie des moyens de transport. Bien que les transports par voie ferrée et par voie navigable jouent un rôle important dans certaines régions, un besoin dominant et universel éxiste d'un réseau routier qui puisse assurer avec certitude et d'une façon relativement bon marché, le déplacement des habitants, et le transport des marchandises. La plus grande partie de ce besoin peut être satisfaite par la construction de routes à faible capacité, capables d'accommoder un trafic de 5 a 10 véhicules par jour, ou plus rarement, jusqu'à 400 véhicules par jour.

L'utilisation des connaissances actuelles en technologie, qui sont accéssibles dans beauundocumented and exists mainly in the minds of those who have developed and applied the technology through necessity. In either case, existing knowledge about low-volume road technology is widely dispersed geographically, is quite varied in the language and the form of its existence, and is not readily available for application to the needs of developing countries.

In October 1977 the Transportation Research Board (TRB) began this 3-year special project under the sponsorship of the U.S. Agency for International Development (AID) to enhance rural transportation in developing countries by providing improved access to existing information on the planning, design, construction, and maintenance of low-volume roads. With advice and guidance from a project steering committee, TRB defines, produces, and transmits information products through a network of correspondents in developing countries. Broad goals for the ultimate impact of the project work are to promote effective use of existing information in the economic development of transportation infrastructure and thereby to enhance other aspects of rural development throughout the world.

In addition to the packaging and distribution of technical information, personal interactions with users are provided through field visits, con-

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rrollado y aplicado la tecnología por necesidad. En cualquier caso, los conocimientos en existencia sobre la tecnología de caminos de bajo volúmen están grandemente esparcidos geográficamente, varian bastante con respecto al idioma y su forma, y no se encuentran fácilmente disponibles para su aplicación a las necesidades de los países en desarrollo.

En octubre de 1977 el Transportation Research Board (TRB) comenzó este proyecto especial de tres años de duración bajo el patrocinio de la U.S. Agency for International Development (AID) para mejorar el transporte rural en los países en desarrollo acrecentando la disponibilidad de la información en existencia sobre el planeamiento, diseño, construcción, y mantenimiento de caminos de bajo volúmen. Con el consejo y dirección de un comité de iniciativas para el proyecto, el TRB define, produce, y transmite productos informativos a través de una red de corresponsales en países en desarrollo. Las metas generales para el impacto final del trabajo del proyecto son la promoción del uso efectivo de la información en existencia en el desarrollo económico de la infraestructura de transporte y de esta forma mejorar otros aspectos del desarrollo rural a través del mundo.

Además de la recolección y distribución de la

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coup de pays, peut faciliter l'étude des projets de construction, tracé et entretien, de routes à faible capacité dans les régions rurales des pays en voie de développement, surtout en ce qui concerne l'économie, la qualité, et la performance de ces routes. La majeure partie de cette technologie a été produite durant la phase de développement des pays que l'on appelle maintenant développés, et elle continue à être produite à la fois dans ces pays et dans les pays en voie de développement. Certains aspects de cette technologie ont été documentés dans des articles ou rapports écrits par des experts. Mais une grande partie des connaissances n'existe que dans l'esprit de ceux qui ont eu besoin de développer et appliquer cette technologie. De plus, dans ces deux cas, les écrits et connaissances sur la technologie des routes à faible capacité, sont dispersés géographiquement, sont écrits dans des langues différentes, et ne sont pas assez aisément accessibles pour être appliqués aux besoins des pays en voie de développement.

En octobre 1977, le Transportation Research Board (TRB) initia ce projet, d'une duré de 3 ans, sous le patronage de l'U.S. Agency for International Development (AID), pour améliorer le transport rural dans les pays en voie de développement, en rendant plus accessible la documentation existante sur la conception, le tracé, la construction, et l'entretien des routes à faible capacité. Avec le conseil, et sous la conduite d'un comité de direction, TRB définit, produit, et transmet cette documentation à l'aide d'un réseau de correspondants dans les pays en voie de développement. Nous espérons que le résultat final de ce projet sera de favoriser l'utilisation de cette documentation, pour aider au développement économique de l'infrastructure des transports, et de cette façon mettre en valeur d'autres aspects d'exploitation rurale à travers le monde.

ferences in the United States and abroad, and other forms of communication.

Steering Committee

The Steering Committee is composed of experts who have knowledge of the physical and social characteristics of developing countries, knowledge of the needs of developing countries for transportation, knowledge of existing transportation technology, and experience in its use.

Major functions of the Steering Committee are to assist in the definition of users and their needs, the definition of information products that match user needs, and the identification of informational and human resources for development of the information products. Through its membership the committee provides liaison with project-related activities and provides guidance for interactions with users. In general the Steering Committee gives overview advice and direction for all aspects of the project work.

The project staff has responsibility for the preparation and transmittal of information products, the development of a correspondence network throughout the user community, and interactions with users.

Information Products

Three types of information products are prepared: compendiums of documented information on relatively narrow topics, syntheses of knowledge and practice on somewhat broader

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información técnica, se provee acciones recíprocas personales con los usuarios por medio de visitas de campo, conferencias en los Estados Unidos de Norte América y en el extranjero, y otras formas de comunicación.

Comité de iniciativas

El comité de iniciativas se compone de expertos que tienen conocimiento de las características físicas y sociales de los países en desarrollo, conocimiento de las necesidades de transporte de los países en desarrollo, conocimiento de la tecnología de transporte en existencia, y experiencia en su uso.

Las funciones importantes del comité de iniciativas son las de ayudar en la definición de usuarios y sus necesidades, de productos informativos que se asemejan a las necesidades del usuario, y la identificación de recursos de conocimientos y humanos para el desarrollo de los productos informativos. A través de sus miembros el comité provee vínculos con actividades relacionadas con el proyecto y también una guía para la interacción con los usuarios. En general el comité de iniciativas proporciona consejos y dirección general para todos los aspectos del trabajo de proyecto.

El personal de proyecto es responsable de la preparación y transmisión de los productos informativos, el desarrollo de una red de corresponsales a través de la comunidad de usuarios, y la interacción con los usuarios.

Productos informativos

Se preparan tres tipos de productos informativos: los compendios de la información documentada sobre temas relativamente limitados, la síntesis del conocimiento y práctica sobre temas

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En plus de la dissémination de cette documentation technique, des visites, des conférences aux Etats Unis et à l'étranger, et d'autres formes de communication permettront une interaction constante avec les usagers.

Comité de direction

Le comité de direction est composé d'experts qui ont à la fois des connaissances sur les caractéristiques physiques et sociales des pays en voie de développement, sur leurs besoins au point de vue transports, sur la technologie actuelle des transports, et ont aussi de l'expérience quant à l'utilisation pratique de cette technologie.

Les fonctions majeures de ce comité sont d'abord d'aider à définir les usagers et leurs besoins, puis de définir leurs besoins en matière de documentation, et d'identifier les ressources documentaires et humaines nécessaires pour le développement de cette documentation. Par l'intermédiaire des ses membres, le comité pourvoit à la liaison entre les différentes fonctions relatives au projet, et dirige l'interaction avec les usagers. En général, le comité de direction conseille et dirige toutes les phases du projet.

Notre personnel est responsable de la préparation et de la dissémination des documents, du développement d'un réseau de correspondants pris dans la communauté d'usagers, et de l'interaction avec les usagers.

La documentation

Trois genres de documents sont preparés: des recueils dont le sujet est relativement limité, des subjects, and proceedings of low-volume road conferences that are totally or partially supported by the project. Compendiums are prepared by project staff at the rate of about 6 per year; consultants are employed to prepare syntheses at the rate of 2 per year. At least one conference proceedings will be published during the 3-year period. In summary, this project aims to produce and distribute between 20 and 30 publications that cover much of what is known about low-volume road technology.

Interactions With Users

A number of mechanisms are used to provide interactions between the project and the user community. Project news is published in each issue of *Transportation Research News.* Feedback forms are transmitted with the information products so that recipients have an opportunity to say how the products are beneficial and how they may be improved. Through semiannual visits to developing countries, the project staff acquires first-hand suggestions for the project work and can assist directly in specific technical problems. Additional opportunities for interaction with users arise through international and in-country conferences in which there is project participation. Finally, annual colloquiums are held for students from developing countries who are enrolled at U.S. universities.

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un poco más amplios, y los expedientes de conferencias de caminos de bajo volúmen que están totalmente o parcialmente amparados por el proyecto. El personal de proyecto prepara los compendios a razón de unos 6 por año; se utilizan consultores para preparar las síntesis a razón de 2 por año. Se publicará por lo menos un expediente de conferencia durante el período de tres años. En breve, este proyecto pretende producir y distribuir entre 20 y 30 publicaciones que cubren mucho de lo que se conoce de la tecnología de caminos de bajo volúmen.

Interacción con los usuarios

Se utilizan varios mecanismos para proveer las interacciones entre el proyecto y la comunidad de usuarios. Se publican las noticias del proyecto en cada edición de la *Transportation Research News.* Se transmiten, con los productos informativos, formularios de retroacción para que los recipientes tengan oportunidad de decir cómo benefician los productos y cómo pueden ser mejorados. A través de visitas semianuales a los países en desarrollo, el personal del proyecto adquiere directamente de fuentes originales sugerencias para el trabajo del proyecto y puede asistir directamente en problemas técnicos específicos. Surgen oportunidades adicionales para la interacción con los usuarios a través de conferencias internacionales y nacionales en donde participa el proyecto. Finalmente, se organizan diálogos con estudiantes de países en desarrollo que están inscriptos en universidades norteamericanas.

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synthèses de connaissances et de pratique sur des sujets beaucoup plus généraux, et finalement des comptes-rendus de conférences sur les routes à faible capacité, qui seront organisées complètement ou en partie par notre projet. Environ 6 recueils par an sont preparés par notre personnel. Deux synthèses par an sont écrites par des experts pris à l'extérieur. Les comptes-rendus d'au moins une conférence seront écrits dans une période de 3 ans. En résumé, l'objet de ce projet est de produire et disséminer entre 20 et 30 documents qui couvriront l'essentiel des connaissances sur la technologie des routes à faible capacité.

Interaction avec les usagers

Un certain nombre de mécanismes sont utilisés pour assurer l'interaction entre le personnel du projet et la communauté d'usagers. Un bulletin d'information est publié dans chaque numéro de *Transportation Research News.* Des formulaires sont joints aux documents, afin que les usagers aient l'opportunité de juger de la valeur de ces documents et de donner leur avis sur les moyens de les améliorer. Au cours de visites semi-annuelles dans les pays en voie de développement notre personnel obtient de première main des suggestions sur le bon fonctionnement du projet et peut aider à résoudre sur place certains problèmes techniques spécifiques. En outre, des conférences tenues soit aux Etats Unis, soit à l'étranger, sont l'occasion d'un échange d'idées entre notre personnel et les usagers. Finalement, des colloques annuels sont organisés pour les étudiants des pays en voie de développement qui étudient dans les universités américaines.

Foreword and Acknowledgments

This book is the fourteenth product of the Transportation Research Board's project on Transportation Technology Support for Developing Countries under the sponsorship of the U.S. Agency for International Development. The objective of this book is that it provide useful and practical information for those in developing countries who have direct responsibility for decisions on surface treatment for roads. Feedback from correspondents in developing countries will be solicited and used to assess the degree to which this objective has been attained and to influence the nature of later products.

Acknowledgment is made to the following publishers for their kind permission to reprint the selected text portions of this compendium: Association of Asphalt Paving Technologists, Minneapolis, Minnesota; Hashemite Kingdom of Jordan, Ministry of Public Works; National Association of Australian State Road Authorities; National Institute for Transport and Road Research, South Africa; Roads and Streets, Barrington, Illinois; The Asphalt Institute, College Park, Maryland; and Transport and Road Research Laboratory, U.K.

Prefacio y agradecimientos

Este libro es el décimocuarto producto del proyecto del Transportation Research Board sobre Apoyo de Tecnología de Transporte para Países en Desarrollo bajo el patrocinio de la U.S. Agency for International Development. El objetivo de este libro es el de proveer información útil y práctica para aquellos en países en desarrollo quienes tienen responsabilidad directa para las decisiones en el tratamiento de superficies de caminos. Se pedirá a los corresponsales en los países en desarrollo información sobre los resultados, para utilizarse en el asesoramiento del grado al cual se ha obtenido ese objectivo y para influenciar la naturaleza de productos subsequentes.

Se reconoce a los siguientes editores por el permiso dado para reimprimir las porciones de texto seleccionadas para este compendio: Association of Asphalt Paving Technologists, Minneapolis, Minnesota; Hashemite Kingdom of Jordan, Ministry of Public Works; National Association of Australian State Road Authorities; National Institute for Transport and Road Research, South Africa; Roads and Streets, Barrington, Illinois; The Asphalt Institute, College Park, Maryland; y Transport and Road Research Laboratory, U.K.

Avant-propos et remerciements

Ce livre représente le quatorzième volume du projet du Transportation Research Board sur la Technologie des transports à l'usage des pays en voie de développement. Ce projet est placé sous le patronage de l'U.S. Agency for International Development. L'objet de ce recueil est de réunir une documentation pratique et utile qui puisse aider les personnes responsables des revêtements superficiels. La réaction des correspondants des pays en voie de développement sera sollicitée et utilisée pour évaluer à quel point le but proposé de ce projet a été atteint, et pour influencer la nature des ouvrages à venir.

Nous remercions les éditeurs qui ont gracieusement donné leur permission de reproduire les textes sélectionnés pour ce recueil: Association of Asphalt Paving Technologists, Minneapolis, Minnesota; Hashemite Kingdom of Jordan, Ministry of Public Works; National Association of Australian State Road Authorities; National Institute for Transport and Road Research, South Africa; Roads and Streets, Barrington, Illinois; The Asphalt Institute, College Park, Maryland; et Transport and Road Research Laboratory, U.K.

Appreciation is also expressed to libraries and information services that provided references and documents from which final selections were made for the selected texts and bibliography of this compendium. Special acknowledgment is made to the U.S. Department of Transportation Library Services Division and to the Library and Information Service of the U.K. Transport and Road Research Laboratory (TRRL).

Finally, the Transportation Research Board acknowledges the valuable advice and direction that have been provided by the project Steering Committee and is especially grateful to R.G. Hicks, Oregon State University, W. Ronald Hudson, University of Texas at Austin, and Melvin B. Larsen, Illinois Department of Transportation, who provided special assistance on this particular compendium.

También se reconoce a las bibliotecas y servicios de información que proveen las referencias y documentos de los cuales se hacen las selecciones finales para los textos seleccionados y la bibliografía en este compendio. Se hace un especial reconocimiento a la Library Services Division del U.S. Department of Transportation y el Library and Information Service del U.K. Transport and Road Research Laboratory (TRRL).

Finalmente, el Transportation Research Board agradece el consejo y dirección valiosos provistos por el comité de iniciativas, con especial reconocimiento a los señores R.G. Hicks, Oregon State University, W. Ronald Hudson, University of Texas at Austin, y Melvin B. Larsen, Illinois Department of Transportation, que prestaron ayuda especial para este compendio en particular.

Nos remerciements aussi aux bibliothèques et bureaux de documentation qui nous ont fourni les documents et les références utilisés dans les textes choisis et bibliographie de ce recueil. Nous remercions spécialement la U.S. Department of Transportation Library Services Division et les Library and Information Service of the U.K. Transport and Road Research Laboratory (TRRL).

Finalement, le Transportation Research Board reconnait la grande valeur de la direction et de l'assistance des membres du comité de direction et les remercie de leur concours et de la façon dont ils dirigent le projet, spécialement Messieurs R.G. Hicks, Oregon State University, W. Ronald Hudson, University of Texas at Austin, et Melvin B. Larsen, Illinois Department of Transportation, qui ont bien voulu prêter leur assistance à la préparation de ce récueil.

Overview

Background and Scope

The overview of Compendium 1 includes this definition of a low-volume rural road as used in subsequent volumes in this series of publications. Two levels of traffic volume can be identified: less than 50 ADT (class 1) and 50 to 400 ADT (class 2). Class 1 roads are generally unsurfaced or are graded in situ. Class 2 roads generally have granular surfaces such as gravel, crushed stone, laterite, or stabilized soil; they generally do not have a high type of paved surface but, at the upper traffic volumes, may be primed, have single surface treatments, or be chip sealed.

For purposes of Compendium 12, a prime coat is defined as an application of a low-viscosity liquid bituminous material to a non-bituminous base as a preliminary treatment before the application of a bituminous surfacing. Such surfacing promotes adhesion between the base and the surfacing and assists in sealing the voids and in binding the aggregate near the surface of the base. Single-surface treatments are defined as a single application of asphalt binder to a prepared surface, followed by a single application of cover aggregate. The cover aggregate may consist of graded aggregate or one size aggregate. A chip seal is a surface treatment that uses a cover aggregate of crushed fragments of stone produced either from quarried rock or from clean hard gravel. The term seal

Vista General

Antecedentes y alcance

El resumen del Compendio 1 contiene la siguiente definición de un camino rural de bajo volumen que se utiliza en volúmenes subsecuentes de esta serie de publicaciones. Se pueden identificar dos niveles de volumen de tráfico: volúmenes de menos de 50 ADT (clase 1), y volúmenes de entre 50 y 400 ADT (clase 2). Los caminos de clase 1 generalmente no son revestidos o son nivelados en situ. Los caminos de clase 2 generalmente tienen superficies granulares tales como grava, piedra triturada, laterita, o suelo estabilizado; por lo común no tienen una clase alta de superficie pavimentada, pero a los niveles más altos de volumen de tráfico, pueden ser imprimados, tener tratamiento de superficie de una sola capa, o ser sellados con astillas.

Para el Compendio 12 una capa de imprimación se definirá como la aplicación de un material bituminoso líquido de poca viscosidad sobre una base no bituminosa como tratamiento preliminar antes de la aplicación de una capa superficial bituminosa. Este tratamiento de superficie

Exposé

Historique et description

L'exposé de notre premier recueil comprend la définition d'une route rurale à faible trafic. Nous avons retenu cette définition dans les différents volumes de cette série de publications. Deux niveau de trafic sont identifiés: un traffic journalier moyen (TJM) de moins de 50 (classe 1) et un TJM de 50 à 400 (classe 2). Les routes de la classe 1 ont généralement le terrain naturel comme surface, ou sont nivelées sans apport de matériaux. Les routes de la classe 2 ont un revêtement, soit en graviers soit en roche concassée, soit en latérite ou en sol stabilisé. En général, elles n'ont pas un revêtement de qualité supérieure, mais pour les limites maximales de trafic, elles peuvent être imprégnées, avoir un enduit superficiel monocouche, ou être gravillonées.

Dans le recueil no. 12, l'imprégnation est définie comme étant l'infiltration de bitume fluidifié de faible viscosité dans une base non bitumineuse, préliminairement à l'application d'un enduit superficiel bitumineux. Ce traitement coat is used herein as a general classification for surface treatment that includes, but is not limited to, sand-seal, chip seal, slurry seal, and fog seal.

Compendium 7 examined road gravels and Compendium 8 considered chemical soil stabilization. Both types of construction are suitable for surface treatment, unless the mechanically stabilized gravel contains an excess of fine material. In fact, chemically stabilized soil requires surface treatment of some sort both to waterproof the stabilized soil and to prevent surface destruction through abrasion.

Compendium 12 considers several types of surface treatment: (a) temporary surface treatments used either on class 1 or class 2 roads to control dust and retard the formation of corrugations, (b) asphaltic-sprayed membranes (prime coats) to protect stabilized soil, and (c) chip-seal surface treatments that provide relatively permanent wearing surfaces for the higher traffic volumes described above.

The selected texts do not attempt to establish a definitive volume at which any particular treatment should be used because local conditions and conventions vary between countries. Furthermore, economic considerations often override the normal traffic volume criteria for the use of surface treatments. Maintenance philosophies may also dictate the level of traffic at which a

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facilita la adherencia entre la base y la capa superficial y ayuda a sellar los vacíos y enlazar el agregado cerca de la superficie de la base. Un tratamiento de superficie de una sola capa se define como una sola aplicación de enlazador asfáltico a una superficie preparada, seguida por una sola aplicación de agregado de revestimiento. Esta agregado de revestimiento puede consistir en agregado graduado o de tamaño uniforme. El sellado con astillas es un tratamiento de superficie que utiliza un revestimiento de agregado de fragmentos de piedra triturados, producidos de piedra de cantera o grava dura y limpia. De ahora en adelante el término "capa selladora" se utilizará como una clasificación general para el tratamiento de superficie que incluye, pero no se limita a, sellado con arena, con astillas, con fangos, y "fog seal" (capa final de asfalto muy fluido).

El Compendio 7 examinó las gravas para caminos, y el Compendio 8 estudió la estabilización química de suelos. Ambos tipos de construcción son apropiados para el tratamiento de superficie, al menos que la grava estabilizada mecánicamente contenga excesivo material fino. En realidad, el suelo estabilizado químicamente necesita algún tipo de tratamiento de superficie para impermeabilizar el suelo estabilizado y para evitar destrucción de la superficie por desgaste.

El Compendio 12 estudia varios tipos de tratamiento de superficie: (a) tratamientos de superficie provisorios, que se utilizan en los caminos de clase 1 ó 2 para controlar el polvo y demorar la formación de corrugaciones, (b) membranas asfálticas aplicadas por rociadura (capas de imprimación) para proteger el suelo estabilizado, y (c) tratamientos de superficie de sellado con astillas, que suministran superficies de rodadura relativamente permanentes para los volúmenes de tránsito más altos descritos arriba.

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provoque l'adhérence entre la base et le revêtement et aide à sceller les vides et à accrocher les agrégats à la surface de la base. Les enduits monocouches sont définis comme étant une seule application de liant asphaltique sur une surface préparée, recouverte par une seule application de granulats. Ces granulats peuvent être tous de même calibre ou avoir une granulométrie variable.

On peut sceller la surface en utilisant de la pierre concassée provenant de carrière ou du gravier à la condition qu'il soit dur et propre. Le terme "couche de scellement" sera utilisé dans ce recueil pour designer un traitement de surface en général qui comprend (mais, n'est pas limité à) l'application de gravillons de coulis bitumineux, de fog-seal (pulvérisation très légère d'une émulsion de bitume diluée à rupture lente) ou de sable.

Dans le recueil no. 7, nous avons examiné les graviers et dans le recueil no. 8 nous avons considéré le traitement chimique des sols. Ces deux types de construction sont valables sauf si le gravier stabilisé mécaniquement contient un excès de fines. Les sols traités chimiquement ont besoin d'être revêtus d'une façon ou d'une autre, pour à la fois imperméabiliser le sol traité, et prévenir la destruction de la surface par abrasion.

Dans le recueil no. 12, nous allons examiner plusieurs sortes de traitements et revêtements: (a) les traitements temporaires utilisés pour les routes des deux classes pour contrôler la poussière et la formation de la tôle ondulée, (b) les pellicules bitumineuses pulverisées (couche d'impression ou d'apprêt) qui protègent les sols stabilisés, et (c) le gravillonnage qui donne une surface de roulement relativement permanente permanent surface is applied.

This compendium describes the materials that can be used for surface treatments, the equipment used for the various types of surface treatments, the currently accepted method of designing surface treatments, and the construction techniques used to construct and maintain surface treatments.

Rationale for This Compendium

Many materials may be used for dust control. Some of these materials work for only short periods because they are soluble in water and are washed away during rainstorms. Others are longer lasting. Some materials can be spread or sprayed onto the road surface; others work better if they are mixed with the roadway soil. Some materials remain plastic so that the roadway may be reshaped, and others form a more brittle surface. Many of the materials are only cost-effective if they are available locally. In this compendium, dust-laying is considered a temporary solution. Although some of the materials used in more permanent surface treatment operations (i.e., tars and bitumens) can also be used as dust palliatives, they are treated here as a stage in the construction of more permanent surface treatments.

Los textos seleccionados no tratan de establecer un volumen definitivo en donde se deberá utilizar algún tratamiento especial, ya que las condiciones y costumbres locales varían de país en país. Además, seguidas veces las consideraciones económicas son más importantes que los criterios normales de volumen de tráfico para el uso de tratamientos de superficie. Las filosofías de conservación también pueden dictar el nivel de tráfico en que se aplicará una superficie permanente al camino.

Este compendio describe los materiales y equipo que se pueden utilizar para los diversos tipos de tratamiento de superficie, el método de diseño aceptado hoy en día, y las técnicas utilizadas de construcción y conservación.

Exposición razonada para este compendio

Hay muchos materiales que se pueden utilizar para el control del polvo. Algunos de estos materiales sólo sirven para cortos períodos porque son solubles en agua y son arrastrados por el agua de lluvia. Otros duran más. Algunos materiales pueden colocarse sobre la superficie del camino esparciéndose o por rociado; otros tienen más éxito si se los mezcla con el suelo de la calzada. Algunos materiales permanecen plásticos y así es posible reperfilar la calzada, y otros forman una superficie más quebradiza. Muchos sólo son económicamente practicables si se encuentran localmente. En este compendio se considera que la fijación del polvo es solamente

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pour les volumes de trafic plus élevés dont nous avons parlé précédemment.

Dans les textes choisis on n'essait pas d'établir un volume de trafic précis, à partir duquel un genre particulier de traitement ou de revêtement devrait être utilisé, car les conditions et les conventions varient d'un pays à l'autre. En outre les considérations économiques l'emportent souvent sur les critères normaux de volume de trafic, quand il s'agit de revêtir ou non une route. Différentes philosophies d'entretien peuvent aussi dicter différents seuils de bitumage.

Dans ce recueil nous allons discuter des matériaux utilisés pour les différents types de revêtement, le matériel pour les appliquer, la méthode actuellement utilisée pour les calculer, et les techniques de construction et d'entretien de ceux-ci.

Objectif de ce recueil

On peut utiliser beaucoup de matériaux pour le contrôle de la poussière. Certains sont seulement efficaces pour de courtes périodes, car ils sont hydrosolubles et chaque averse les emporte. D'autres durent plus longtemp. On peut étaler ou pulvériser certains d'entre eux sur la surface de la route, d'autres agissent mieux s'ils sont mélangés au matériau de surface. Certains matériaux restent plastiques et l'on peut reprofiler la route, d'autres forment une surface plus fragile. Beaucoup de ces matériaux ne sont rentables que si on peut se les procurer localement. Dans ce recueil, les mesures antipoussière sont considérées comme solutions temporaires. Bien que certains matériaux utilisés pour des revêtements permanents (goudrons et bitumes) servent aussi au contrôle de la poussière, ils seront traités ici comme une étape de la construction de revêtements plus permanents.

Le second niveau du revêtement d'une route est l'application d'une couche d'imprégnation qui assurera l'imperméabilité, et luttera temporairement contre l'abrasion de la couche de base. Normalement, on répand du goudron ou du bitume. L'imprégnation d'une couche de

The second level of surface treatment is the application of a prime coat that provides waterproofing and temporary abrasion protection of the base course. This usually consists of spraying a coating of tar or bitumen. Priming of a gravel base course improves the adhesion of the final seal coat and also prevents the absorption of the seal coat binder by the granular material. The use of crusher fines to eliminate any small depressions in a base course before priming should be prohibited. Otherwise, they will absorb the prime coat without providing adhesion to the underlying base course, resulting in the stripping or peeling of the surface in the affected area.

Chemically stabilized base courses are relatively impervious so less prime is usually required. Soil-cement base courses should be primed as soon as practical because the membrane formed assists in the proper curing of the soil-cement mixture. Lime-stabilized base courses should not be primed immediately because it takes several days to complete the soil-lime pozzolanic reaction. The lime-stabilized base should be kept moist during this period.

In no case should traffic be allowed on the

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una solución provisoria. Aunque algunos de los materiales utilizados en las operaciones de tratamiento de superficie más permanente (p.ej., alquitrán y betún) también pueden utilizarse en la fijación de polvo, en este compendio tales materiales se consideran como una etapa en la construcción de tratamientos de superficie más permanentes.

El segundo nivel de tratamiento de superficie es la aplicación de una capa de imprimación que provee impermeabilidad y protección provisoria contra el desgaste de la capa de base. Esto generalmente consiste en la aplicación por rociadura de una capa de alquitrán o betún. La imprimación de una capa de base de grava mejora la adhesión de la capa selladora final y también impide que el material granular absorba el enlazador de la capa selladora. Se debería prohibir el uso de finos triturados para eliminar las pequeñas depresiones en una capa de base, ya que absorben la capa de imprimación sin proveer adhesión a la capa de base debajo de ella, y esto resulta en el descascarado de la superficie en las zonas afectadas.

Ya que las capas de base estabilizadas químicamente son relativamente impermeables, generalmente requieren menos imprimación. Las capas de base de suelo-cemento deberán imprimarse tan pronto como sea practicable porque la membrana que se forma ayuda en el correcto fraguado de la mezcla suelo-cemento. Las capas de base estabilizadas con cal no deberán imprimarse inmediatamente porque la reacción pozolánica del suelo-cal requiere varios días para completarse. Durante este período la base deberá mantenerse húmeda.

En ningún caso deberá permitirse tránsito sobre la capa de base entre la preparación final de la capa de base y la operación de imprimación. El tránsito podrá utilizar la base imprimada después de que haya endurecido. Si es imposible esperar hasta que la imprimación haya en-

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base en graviers augmente l'adhérence de l'enduit d'usure ou de scellement, et aussi empêche l'absorption du liant d'usure par le matériau graveleux. On ne devrait pas utiliser des fines de concassage pour remplir les petites dépressions de la couche de base, car elles absorbent le liant d'imprégnation sans adhérer à la couche de base, ce qui provoque le désenrobage ou la pelade de la surface à ces endroits.

Les couches de base traitées chimiquement sont relativement étanches et requièrent moins de liant d'imprégnation. Les couches de base en sol-ciment devraient être imprégnées aussi rapidement que possible car la membrane ainsi formée favorise la cure du mélange. Les couches de base traitées à la chaux ne devraient pas être imprégnées immédiatement, car les réactions pouzzolaniques sol/chaux durent quelques jours, et on doit garder la base humide durant cette période.

La circulation ne doit absolument pas être permise entre la préparation finale de la couche de base et l'application du liant d'imprégnation. On peut reprendre la circulation quand la couche d'imprégnation est prise. S'il est impossible d'attendre la prise complete de la couche d'imprégnation, on peut répandre du sable après la prise initiale, pour que les pneus n'arrachent pas la membrane asphaltique. Si la surface de la couche d'imprégnation devient sale ou sèche à cause du trafic ou d'une trop longue exposition, il se peut qu'il soit nécessaire d'appliquer un enduit s'accrochage, c'est à dire de ré-imprégner la surface pour assurer l'adhérence de l'enduit superficiel. Il n'est pas très prudent d'attendre très longtemps avant d'appliquer l'enduit superficiel final sur une base stabilisée chimiquement et imprégnée. D'un autre côté on peut permettre un faible volume de trafic pendant plusieurs mois sur une route stabibase course between the final preparation of the base course and the priming activity. Traffic may use the primed base after the prime has set. If it is impossible to wait for the prime to completely set before opening the road to traffic, sand may be spread after the initial set to prevent tires from picking up the asphaltic membrane. If the surface of the prime coat becomes dirty or dried up due to traffic or long exposure, it may be necessary to apply a tack coat, i.e., respray the surface to ensure proper adhesion of the surface treatment binder. It is usually unwise to allow too much time to elapse before applying the final surface treatment to primed chemically stabilized bases. However, several months of low-volume traffic may be allowed on primed mechanically stabilized bases if care is taken to repair any defects as soon as they occur. No attempt should be made to eliminate the use of a prime coat by increasing the binder content of the surface treatment.

The third level of surface treatment is the chip-seal surface treatment. This type of surface treatment is adequate for traffic volumes well above those considered in this project. This treatment also may be the most overall cost-effective procedure for roads in the less-than-400 ADT classification. This type of surface treatment (a) eliminates dust, (b) seals and protects the base and adds resistance to the abrasive traffic action, (c) provides skid resistance, (d) provides a waterproof cover over the lower

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durecido completamente, se podrá esparcir arena después del endurecimiento inicial para evitar que los neumáticos alcen la membrana asfáltica. Si la superficie de la capa de imprimación se ensucie o seque debido al tránsito o por estar expuesta durante mucho tiempo, podría ser necesario aplicar una capa ligante, es decir, rociar la superficie de nuevo para asegurar la correcta adhesión del enlazador de tratamiento de superficie. Es generalmente imprudente permitir que pase mucho tiempo antes de la aplicación de la capa final de tratamiento de superficie en las bases imprimadas químicamente estabilizadas. Sin embargo, sobre las bases imprimadas estabilizadas mecánicamente se puede permitir un volumen bajo de tráfico durante varios meses, si se repara cualquier defecto en cuanto aparezca. No se deberá tratar de eliminar el uso de una capa de imprimación aumentando el contenido enlazante del tratamiento de superficie.

El tercer nivel de tratamiento de superficie es el de sellado con astillas. Este tipo es adecuado para volúmenes de tráfico bastante más grandes que los volúmenes de que se trata este proyecto. Puede considerarse el procedimiento más efectivo en lo que respecta al costo para los caminos en la clasificación de menos de 400 ADT. Este tipo de tratamiento de superficie (a) elimina el polvo, (b) sella y protege la base y añade resistencia contra la acción desgastadora del tránsito, (c) provee resistencia contra el patinazo, (d) proporciona una capa impermeable al agua sobre las capas inferiores de pavimento, (e) mejora las cualidades de rodadura

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lisée mécaniquement et imprégnée, à condition d'avoir soin de réparer les dégradations sitôt qu'elles apparaissent. On ne devrait jamais essayer de remplacer un enduit d'imprégnation par un enduit superficiel contenant une plus forte dose de liant.

Le troisième niveau de revêtement est l'emploi d'une couche de gravillons. Ce genre de traitement est adéquat pour des volumes de trafic bien supérieurs à ceux dont nous parlons dans ce projet. C'est aussi peut être la méthode la plus totalement rentable pour les routes de moins de 400 TJM. Ce type de traitement (a) élimine la poussière, (b) scelle et protège la base et augmente sa résistance à l'action abrasive du trafic, (c) augmente la résistance au dérapage, (d) pourvoit les couches de dessous d'une couverture étanche, (e) améliore la qualité de roulement, (f) réfléchit la lumière, (g) permet l'application de signalisation horizontale, et (h) réduit les coûts à l'usager. Il n'augmente pas la solidité essentielle de la chaussée mais permet une meilleure utilisation de celle-ci et pour plus longtemps.

Les premiers revêtements par gravillonnage furent construits par tâtonnements. Les prescriptions tirées de ces expériences avaient tendance à être empiriques, désignant un type spécifique de liant et une gamme de quantité d'application très limitée pour celui-ci et les gravillons. Cette approche empirique fût la cause de beaucoup d'échecs et d'appréhension parmi les ingénieurs qui en faisaient la pratique. Le calcul d'un revêtement superficiel en gravillons basé sur des critères approuvés et suivis soigneusement, réduit de façon substantielle les possibilités d'erreur.

Les principes de base du dimensionnement des enduits superficiels bitumineux de routes rurales furent mis à jour, à l'origine, par F.M. Hanson et publiés dans les ***Proceedings, New Zealand Society of Civil Engineers*** (Vol. 21, pavement layers, (e) improves the riding qualities of the road, (f) provides light-reflecting characteristics, (g) permits the application of painted lane delineation, and (h) reduces the user's costs. It does not add basic strength to the pavement structure, but it may better use the existing strength and for a longer period of time.

Early chip-seal surface treatments were built by trial and error. Specifications developed from these experiments tended to be empirical, designating a specific binder type and a very limited range of application quantities for both chips and binder. This empirical approach led to many failures and much apprehension among practicing engineers. The design of a chip-seal surface treatment based on accepted and on carefully followed criteria reduces the chances of errors substantially.

The basic principles of the engineering design of bituminous surface treatments of rural highways were originally developed by F.M. Hanson and were published in ***Proceedings, New Zealand Society of Civil Engineers*** (Vol. 21, 1934-1935). N.W. McLeod expanded on these principles in 1960 (see Additional Reference No. 10) and further amplified these design criteria in Selected Text No. 8 (1969) of this compendium.

Hanson determined that a single-surface treatment consisted of a layer of single chips. Furthermore, due to the compaction under traffic, each stone eventually ended up lying flat, with its smallest dimension perpendicular to the road surface. From this was developed the concept of average least dimension (ALD). Aggregate passing and retained on the same sieve sizes can have different average least dimensions. The nearer the aggregate shape is to a perfect cube, the larger its ALD. By spreading a sample of the aggregate to be used so that a known area (such as a pan) is completely covered by a layer one stone thick, the amount of cover material can be determined. By measuring the least dimension of each of the aggregate pieces in the pan with calipers, the average least dimension can be calculated. Another method is to try to pass each stone individually

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del camino, (f) posee mejores características fotoreflectoras, (g) admite la aplicación de líneas divisorias pintadas, y (h) reduce los costos del usuario. No aumenta la resistencia básica de la estructura del pavimento, pero utiliza mejor la resistencia existente y durante un período de tiempo más largo.

Los primeros tratamientos de superficie de sellado con astillas se construyeron por el método de tanteos. Las especificaciones producidas por estos experimentos tendían a ser empíricas, designando un enlazador de tipo específico y una variación limitada de cantidades de astillas y enlazador a aplicar. Esto llevó a muchos fracasos, y los ingenieros que ejercitaban sospechaban el proceso. Si se diseña un tratamiento de superficie de sellado con astillas basado en criterios aceptados y cuidadosamente observados, se reduce substancialmente la posibilidad de errores.

Los principios básicos del diseño ingenieril de tratamientos bituminosos de superficie de caminos rurales originalmente fueron desarrollados por F.M. Hanson y fueron publicados en ***Proceedings, New Zealand Society of Civil Engineers*** (Actas de la Sociedad de Ingerieros Civiles de Nueva Zelandia, Vol. 21, 1934-1935). N.W. McLeod amplificó estos principios en 1960 (véase Referencia Adicional No. 10) y amplió otra vez más los criterios de diseño presentados en el Texto Seleccionado Nº 8 (1969) de este compendio.

1934-1935). N. W. McLeod developpa ces principes en 1960 (voir Additional Reference No. 10) et amplifia les critères de dimensionnement dans le texte choisi no. 8 (1969) de ce recueil.

Hanson détermina qu'un enduit superficiel monocouche consistait en une couche de gravillons de l'épaisseur d'une seul gravillon. De plus, il détermina que dû au compactage causé par la circulation, chaque gravillon éventuellement finissait par se placer horizontalement sur le sol avec sa plus petite dimension perpendiculaire à la surface de la chaussée. On tira de cela le concept de la "moyenne des dimensions minimales" (ALD). Des granulats passants et refusés par la même ouverture de maille d'un tamis peuvent avoir des moyennes de dimensions minimales différentes. Plus la forme du granulat se rapproche de celle d'un cube, plus son ALD est élevée. En étalant un échantillon du granulat à utiliser de façon à ce que une surface determinée (par exemple une cuvette) soit complètement recouverte par une couche de granulat de l'épaisseur d'une pierre, on peut déterminer son pouvoir couvrant. En mesurant la dimension minimale de chaque granulat de la cuvette avec un pied à coulisse, on peut calculer la moyenne des dimensions minimales. Une autre méthode est de cribler chaque pierre une par une, sur des grilles à fentes. Le pourcentage passant les fentes détermine le coéfficient d'aplatissement through a slotted sieve. The percentage passing the appropriate slots determines the Flakiness Index (i.e., the total weight of the material passing the appropriate slotted sieve openings expressed as a percentage of the combined weight of the fractions tested on the slotted sieve). The relation of the Flakiness Index to the sieve sizes used can be entered in a nomograph to determine the ALD. Therefore, the first step in the design of a surface treatment is the determination of the amount of cover aggregate and the average least dimension of that cover aggregate.

The next step is to determine the amount of binder required. Hanson assumed that (a) the aggregate as spread consisted of 50 percent voids, (b) rolling reduced the void percentage to 30 percent, and (c) traffic further reduced the void percentage to 20 percent. (Selected Text No. 8 covers all of these assumptions and their modifications in much greater detail.) The amount of the binder is determined as the quantity that will fill the 20 percent void to a depth of 70 percent of the ALD. The binder amount is then corrected by a traffic factor that reduces the final binder content in proportion to the increase in traffic volume.

Current Australian specifications call for one size aggregate for single-surface treatments. One size aggregate is defined as having 60-70 percent of the particles passing the specified nominal size retained on the sieve with an open-

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Hanson determinó que un tratamiento de superficie de una sola capa consistía en una capa de astillas del espesor de una sola astilla. Además, debido a la acción compactante del tránsito, cada piedra terminaba por presentar su cara más plana paralela a la superficie, y su dimensión más pequeña perpendicular a ella. De esto se desarrolló el concepto del "promedio de dimensiones menores" (Average Least Dimension: ALD). Agregados que pasan y que se retienen en los mismos tamaños de tamiz pueden poseer distintos promedios de dimensiones menores. Cuanto más se asemeja la forma del agregado a la de un cubo, más grande será el ALD. Si se esparce una muestra del agregado a utilizarse sobre un área de dimensiones conocidas (como por ejemplo una cacerola) hasta cubrirla totalmente con una capa del espesor de una piedra, se puede determinar la cantidad de material de revestimiento que se necesitará. Y el ALD se puede calcular midiendo la dimensión más pequeña de cada uno de los pedazos de agregado en la cacerola con un calibrador. Otro método es el de tratar de pasar cada piedra individualmente por un tamiz acanalado. El porcentaje que pasa por las canaletas apropiadas determina el índice de planeidad (Flakiness Index, el peso total del material que pasa por las aberturas de tamiz acanalado apropiadas, expresado como un porcentaje del peso combinado de las fracciones ensayadas en el tamiz acanalado). La relación entre el índice de planeidad y los tamaños de tamiz utilizados puede anotarse en un nomógrafo, y así determinarse el ALD. Por lo tanto, el primer paso en el diseño de un tratamiento de superficie es la determinación de la cantidad de agregado de revestimiento y el promedio de dimensiones menores de éste.

El siguiente paso es la determinación de la cantidad de enlazador requerida. Hanson asumió que (a) el agregado, en el momento del esparcido, consistía en vacíos en un 50 por ciento,

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(le poids total du matériau passant les fentes exprimé comme pourcentage du poids combiné des fractions que l'on essaye de cribler sur les grilles à fentes). Le rapport du coefficient d'aplatissement aux mailles de tamis utilisées peut être inscrit dans une abaque pour déterminer l'ALD. Il en ressort que la première étape du dimensionnement d'un revêtement superficiel est la détermination de la quantité de granulats de surface, et de la moyenne des dimensions minimales de ceux-ci.

La seconde étape est la détermination de la quantité de liant nécessaire. Hanson supposa que: (a) les granulats répandus ont 50 pour cent de vides, (b) le roulage réduit le pourcentage de vides à 30 pour cent, et (c) la circulation réduit le pourcentage de vides à 20 pour cent. (Le texte no. 8 embrasse ces suppositions et leurs modifications en détail). La quantité de liant est déterminée comme étant celle qui remplira les 20 pour cent de vides à une profondeur égale à 70 pour cent de l'ALD. Cette quantité de liant est ensuite modifiée par un facteur de trafic qui réduit la quantité finale de liant en proportion avec les augmentations de volume de trafic.

Les spécifications actuelles australiennes exigent une granulométrie serrée (uniforme) pour les revêtements monocouches. La définition de granulats de composition uniforme est la suivante: 60 à 70 pour cent des granulats passants une ouverture de maille spécifiée, et refusés par un tamis dont l'ouverture de maille est 0,7 de la maille du premier tamis. Comme nous, venons d'en faire mention ci-dessus, la situation ing 0.7 of that size. As mentioned above, the ideal situation is to have the cover stone embedded for 70 percent of its depth in binder. Any cover stone embedded less than 50 percent of its depth will probably be whipped out by traffic; all stones with a minimum dimension of 70 percent or less of the ALD will be completely submerged by the binder. In a typical Australian one-size gradation, perhaps 3 percent of the aggregate would be embedded less than 50 percent and approximately 15 percent would be fully submerged.

U.S. specifications (AASHO M 43, ASTM D 448) for standard sizes of coarse aggregate, when compared to Australian specifications, are basically graded aggregates and are much more difficult to work with. However, they are much less expensive to produce than the Australian one-size gradation. Therefore, many roads have been and will continue to be surface treated with these graded aggregates. The design methods that use both types of aggregate are included in this compendium. The successive applications of multiple-surface treatments normally use aggregate that is half the size of the previously applied aggregate to promote meshing of the layers.

The binder depth in the foregoing discussion is the depth of the asphaltic or tar base material. The application rate must be increased by the amount of cutter stock in cut-back asphalts or the amount of water in asphalt emulsions. The design quantities are based on volumes at 15°C (60°F). Therefore, the application rate must be further increased to account for the higher application temperature.

The proper grade of asphalt binder to use for surface treatment is a function of the tempera-

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(b) el arrollado reducía el porcentaje de vacíos a 30 por ciento, y (c) el tránsito lo reducía aún más a 20 por ciento. (El Texto Seleccionado Nº 8 examina todas estas suposiciones y sus modificaciones con mucho más detalle.) La cantidad del enlazador se define como la cantidad que llenará el vacío de 20 por ciento hasta una profundidad de 70 por ciento del ALD. Luego esta cantidad se corrige por un factor de tránsito que reduce el contenido final de enlazador en proporción al aumento en el volumen de tráfico.

Las especificaciones actuales de Australia requieren un tamaño uniforme de agregado para tratamientos de superficie de una sola capa. El agregado de tamaño uniforme se define como el de que el 60-70 por ciento de partículas que pasan por el tamiz de tamaño nominal especificado, es retenido por el tamiz con aberturas de 0,7 de aquel tamaño. Como se menciona arriba, la situación ideal es cuando el 70 por ciento de la piedra revestidora está enclavado en el enlazador. Un agregado enclavado hasta menos del 50 por ciento de su profundidad total probablemente será arrebatado por el tránsito; todas las piedras con una dimensión mínima de 70 por ciento o menos del ALD se sumergirán completamente en el enlazador. Del agregado de tamaño uniforme típico australiano quizás un 3 por ciento sería sumergido menos de un 50 por ciento y aproximadamente un 15 por ciento sería sumergido completamente.

Las especificaciones estadounidenses (AASHO M 43, ASTM D 448) para los tamaños normales de agregados gruesos, cuando se los compara con las especificaciones australianas, son básicamente agregados graduados y son mucho más difíciles de utilizar. Sin embargo, son mucho más baratos de producir que los de tamaño uniforme en Australia. Por lo tanto, las superficies de muchos caminos han sido, y

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idéale est celle où le granulat est encastré à 70 pour cent dans le liant. Un granulat encastré à moins de 50 pour cent de sa hauteur sera probablement arraché par la circulation; tous les granulats qui ont une dimension minimale de 70 pour cent ou moins de l'ALD, seront complètement submergés par le liant. Dans une granulométrie serrée typique australienne on trouvera 3 pour cent des granulats encastrés à moins de 50 pour cent, et approximativement 15 pour cent complétement submergés par le liant. Les normes américaines (AASHO M 43, ASTM D 448) pour des agrégats grossiers, quand on les compare aux normes australiennes, requièrent une granulométrie étalée beaucoup plus difficile à mettre en oeuvre. D'un autre côté, le prix de revient de granulats à granulométrie étalée, est beaucoup plus modeste que celui de granulats à granulométrie serrée comme le demandent les normes australiennes. Ce qui explique que beaucoup de routes ont été, et continuent à être, revêtues de granulats à granulométrie étalée. Les méthodes de dimensionnements pour les deux sortes d'agrégats sont incluses dans ce recueil. Quand on construit un revêtement multicouches on utilise, à l'ordinaire, par couches successives, des granulats dont les dimensions sont la moitié des dimensions des granulats de la couche précédente, pour faciliter l'engrenage des différents couches.

ture of the surface to which it is applied. It must be fluid enough so that it will rapidly wet the cover material but must not be so fluid that it will flow along the surface. The application temperature is of course that temperature at which the binder can be sprayed, normally at a Saybolt Furol Viscosity of around 50 (Kinematic Viscosity of around 100). However, the binder temperature is reduced to the road surface temperature within a minute of the time it is applied. Because tar tends to oxidize and become brittle in the presence of sunlight and air, it is not commonly used as a binder in single-surface treatments unless locally available at a much lower cost than asphaltic binder. It may be used in the lower courses of multiple-surface treatments if the final treatment is an asphalt that will cover the tar.

Because the amount of binder and chips is rather carefully determined, it follows that the actual rates of application must also be carefully controlled. In fact, field control is the most vital ingredient in the achievement of a satisfactory seal coat. The binder distributor must be carefully calibrated before it is used and must be maintained in good condition thereafter. The operator must be thoroughly trained because most operational errors are not discovered until premature failure occurs. When more than one application of binder is applied to a surface treatment, the distributor should be run in opposite directions each time so that spray bar discrepancies will not be compounded. One of the more common defects that can occur in the construction of a surface treatment is "shelling out" (i.e., the loss of streaks of cover aggregate some six months to a year after application of the seal coat). This is caused by uneven application of the binder material.

The chip spreader should also be carefully calibrated. Ideally the chips should drop directly

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serán tratadas con estos agregados graduados. Los métodos de diseño que utilizan ambos tipos de agregado han sido incluídos en este compendio. Cada aplicación sucesiva, en los tratamientos de superficie múltiples, normalmente utiliza un agregado que es la mitad del tamaño del agregado anterior para obtener un buen engranaje entre las capas.

El espesor del enlazante del cual se habla arriba es el espesor del material asfáltico o alquitranoso. La velocidad de aplicación deberá aumentarse según la cantidad de líquido cortante en los asfaltos rebajados o la cantidad de agua en las emulsiones asfálticas. Las cantidades de diseño se basan en volúmenes a 60°F (15°C). Por lo tanto, la velocidad de aplicación deberá aumentarse aún más a causa de la mayor temperatura de aplicación.

La calidad correcta de enlazador asfáltico en el tratamiento de superficie es una función de la temperatura de la superficie en donde se aplica. Deberá ser lo suficientemente líquido para mojar rápidamente el material revestidor pero no tan líquido que fluya sobre la superficie. Por supuesto, la temperatura de aplicación es aquella que permite esparcir el enlazador por rociado, normalmente a una Viscosidad Saybolt Furol de alrededor de 50 (Viscosidad Cinemática de aproximadamente 100). Sin embargo, la temperatura del enlazador se reduce a la temperatura de la superficie del camino en el primer minuto después de aplicarse. Ya que el alquitrán tiende a oxidarse y resquebrarse cuando se lo expone al sol y al aire, generalmente no se utiliza como enlazador en los tratamientos de superficie de una sola capa, al menos que se puede obtener localmente a un costo mucho más bajo que el del enlazador asfáltico. Se puede utilizar en las capas inferiores de tratamientos de superficie múltiples si la capa final es un asfalto que cu-

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L'épaisseur du liant dans la discussion qui va suivre est la profondeur du matériau de base soit bitume, soit goudron. Le taux de répandage doit être augmenté par la quantité d'huile de fluxage pour les bitumes fluidifiés, ou la quantité d'eau pour les émulsions de bitume. Les quantités pour le dimensionnement sont basées sur les volumes à une température de 15°C (60°F). Donc le taux de répandage doit être augmenté encore plus à cause de la température de répandage qui est plus élevée.

La classe de liant bitumineux à utiliser pour les revêtements superficiels est fonction de la température de la surface sur laquelle on va l'appliquer. Le liant doit être assez fluide pour mouiller rapidement les granulats, mais cependant il ne doit pas être si liquide qu'il coule sur la surface. La température de répandage est celle à laquelle le liant peut être pulverisé, normalement à une vicosité Saybolt Furol de 50 (viscosité cinématique d'à peu près 100). Toutefois la température du liant se réduit à la température de la surface sur laquelle il est épandu dans la minute qui suit l'épandage. Le goudron s'oxyde et devient cassant dès son exposition à l'air et au soleil ce qui explique que l'on ne l'utilise pas soucent comme liant pour les traitements monocouche, à moins qu'on en trouve localement à des prix beaucoup plus bas que ceux des liants bitumineux. On peut utiliser le gouddown onto the binder rather than be broadcast so that the larger stones will not roll and become covered with binder. Usually an additional quantity of chips is applied to allow for whipoff under traffic; however, surplus chips should be broomed from the roadway and areas with deficiencies in chips should be covered by hand immediately. The chips should be applied as soon after the binder as possible to ensure good embedment. The rolling operation should immediately follow the chipping application for the same reason. Both steel-wheel and rubber-tired rollers are used in surface treatment work. Rubber-tired rollers, however, are the most suitable for single-surface treatments because they provide better embedment with less crushing of the aggregate. Roller tire pressure must be carefully maintained to ensure proper tire contact area. This, in turn, controls unit compactive effort. Stockpiles should be located so that the delivery trucks do not have to travel over newly placed surface treatment.

The texts describe various defects that may occur on surface-treated roads. Perhaps the most common defect is bleeding. Traffic is the determining factor in bleeding because bleeding usually starts in wheel paths and is often confined to these areas and at intersections. Sometimes surface treatments that have been designed in full compliance with the principles outlined above will still bleed. If a properly designed surface treatment bleeds, it is usually caused by (a) a soft base that causes intrusion of fines into the voids, which normally would con-

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brirá el alquitrán.

Si la cantidad de enlazante y astillas se determina cuidadosamente, igual cuidado se deberá tener en el control de las velocidades de aplicación. En realidad, el control en la obra es el ingrediente más importante en la realización de una capa selladora satisfactoria. El distribuidor de enlazante deberá calibrarse cuidadosamente antes de usarse y mantenerse así de ahí en adelante. El operador debe estar bien entrenado porque la mayoría de los errores que puede cometer no se descubren hasta que ocurre un fracaso precoz de la capa. Cuando se aplica más de una capa de enlazante, en cada vuelta se deberá operar el distribuidor en direcciones opuestas para que no se multiplique cualquier variante en la barra rociadora. Uno de los defectos comunes en la construcción de un tratamiento de superficie es el descascaramiento ("shelling out", la pérdida de fajas del agregado revestidor, de 6 a 12 meses después de su aplicación). Esto es causado por la aplicación del material enlazante en forma irregular.

El esparcidor de astillas deberá también calibrarse cuidadosamente. Las astillas deberán caerse directa y verticalmente al enlazante, en vez de ser diseminadas, para que las piedras más grandes no rueden y se cubran con el enlazante. Es común aplicar una cantidad adicional de astillas para compensar el arrebatamiento producido por el tránsito; sin embargo, las astillas sobrantes deberán ser barridas fuera de la calzada, y las áreas deficientes cubiertas a mano inmediatamente. Para asegurar un buen enclavado de las astillas, éstas deberán colocarse lo más pronto posible después del enlazante. Por la misma razón se deberá seguir a esto con la operación de apisonado. Para este trabajo se utilizan los rodillos con rueda de acero y con neumáticos de goma. Los rodillos con llantas neumáticas son los más apropiados para los tratamientos de superficie de una sola capa porque proveen mejor enclavado y menos trituración del agregado. Se deberá mantener cuidadosamente la presión correcta de los neumáticos para asegurar un buen contacto con la su-

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ron pour les couches inférieures des revêtements multicouches si la couche de surface est en bitume et recouvre celles en goudron.

Comme les quantités de liant et de granulats sont determinées soigneusement il s'en suit que les taux d'épandage doivent aussi être contrôlés soigneusement. En fait, le contrôle sur le chantier est le plus important élement de la réussite d'une couche de scellement. La rampe de distribution doit être soigneusement calibrée avant son utilisation et doit ensuite être conservée en parfait état. Le conducteur doit avoir une bonne formation professionnelle car la plupart des erreurs de mise en oeuvre ne sont découvertes que lorsqu'une rupture prématurée se produit. Quand le revêtement est multicouches, la rampe de distribution devrait être dirigée dans le sens opposé à chaque passe de façon à ce que les petites déviations du jet ne s'ajoutent pas l'une sur l'autre au même endroit. Une des défectuosités les plus communes qui peut se produire dans l'exécution d'un revêtement superficiel est le plumage localisé (c'est à dire l'arrachement de gravillons en bande longitudinale six mois ou un an après l'application de la couche de scellement). Ceci est causé par une application irrégulière du liant. La gravillonneuse devrait aussi être calibrée soigneusement. L'idéal serait que tain binder, and causes the excess binder to rise to the surface during warm weather; (b) excess whipoff; or (c) the consolidation of the chippings below the 20 percent void level due to a very hard base (such as a previous surface treatment) or to the crushing of a weak aggregate into additional fines that replace the binder. Traffic densities and base hardness are judgmental factors that are not yet objectively measurable.

The opening of a new surface treatment to traffic is a function of the type of binder used. In general, the road should not be opened until the binder has set to the point where traffic will not cause any damage. However this is not always possible. In such cases, traffic speed should be rigidly controlled until the binder has set to prevent high-speed whipoff. The most critical time of the day to open a new surface treatment is between mid-day and late afternoon because

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perficie. Esto, a su vez, controla el esfuerzo compactivo. Las pilas de materiales deberán ubicarse donde los camiones de entrega no tengan que rodar sobre un tratamiento de superficie nuevo.

Los textos describen varios defectos que pueden ocurrir en los caminos con tratamiento de superficie. Quizás el defecto más común es la exudación. El tránsito es el factor determinante de la exudación, como es indicado en el hecho de que la exudación generalmente comienza en las rodadas y muchas veces está limitada a estas zonas y a las intersecciones. A veces los tratamientos de superficie construídos con total cumplimiento de los principios presentados arriba pueden sufrir la exudación. Si esto ocurre es generalmente causado por (a) una base blanda que causa la intrusión de los finos en los vacíos, que normalmente contendrían el enlazante, y el enlazante sobrante sube hacia la superficie en tiempo caluroso; (b) mucho arrebatamiento; o (c) la consolidación de las astillas debajo del nivel de 20 por ciento de vacíos debida a una base excesivamente dura (tal como un tratamiento de superficie anterior) o a la trituración de un agregado débil hasta formarse finos adicionales que reemplazan el enlazante. Las densidades de tránsito y firmeza de la base son factores afectados por criterio personal y todavía no son objetivamente medibles.

El abrir un nuevo tratamiento de superficie al uso del tránsito depende del tipo de enlazante utilizado. En general, el camino no debe abrirse hasta que el enlazante se haya secado lo suficiente para que el tránsito no cause ningún daño. Sin embargo, esto no siempre es posible. En tales casos el tránsito deberá ser rígidamente controlado hasta que el enlazante se haya secado para evitar arrebatamiento por altas velocidades. La peor parte del día para abrir el camino es entre mediodía y una hora avanzada de la tarde, porque es cuando la

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les gravillons tombent directement sur le liant plutôt que d'être répandus à la volée, car de cette façon les plus gros caillous n'auront pas tendance à rouler sur le liant et en être recouverts. D'habitude, on applique une quantité additionnelle de gravillons pour tenir compte des arrachements dûs à la circulation; toutefois il faut balayer l'excès de gravillons de la surface de la route et recouvrir immédiatement à la main les endroits où il y a carence de gravillons. Les gravillons devraient être répandus aussitôt que possible après l'épandage du liant pour assurer leur mouillage. Le cylindrage devrait suivre immédiatement le gravillonnage pour la même raison. A cet effet, on emploie soit des cylindres ou rouleaux à pneus. Les rouleaux à pneus sont les plus appropiés pour les enduits monocouches car ils permettent le mieux l'enchâssement des gravillons sans les écraser. La pression de gonflage des pneus doit être soigneusement entretenue pour assurer une surface de contact correcte. Ceci, à son tour contrôle l'effort compactif de l'engin. Les stocks de gravillons devraient être situés de façon à ce que les camions de livraison n'aient pas à rouler sur un enduit qui vient d'être posé.

Dans les textes qui suivent, on va décrire une variété de dégradations que l'on peut trouver sur les chaussées revêtues d'un enduit superficiel. Peut-être la plus commune de celles-ci est le ressuage. La circulation est le facteur déterminant du ressuage, qui commence habituellement dans les traces des roues, et est souvent limité à ces endroits et aux intersections. Quelquefois, un enduit superficiel qui a été dimensioné conformément aux principes que nous venons d'énoncer, sera victime du ressuage. Dans ce cas, le ressuage est usuellement causé par (a) une base trop molle qui est la cause de l'intrusion de fines dans les vides qui normalement doivent contenir du liant, et provoque la remontée de l'excès de liant à la surface par temps chaud; (b) des rejets excessifs; ou (c) la consolidation des gravillons à moins du niveau de 20 the road surface temperatures are highest then, and the binder, which is at the same temperature, is least able to hold the cover stone.

Discussion of Selected Texts

The first text, *Dust-Laying on Unsurfaced Earth and Gravel Roads,* was published as *Overseas Bulletin No. 14* (Road Research Laboratory, UK, 1971). It lists the principal binding agents used in dust-laying as follows: (a) water, fresh or sea; (b) deliquescent and hygroscopic chemicals such as calcium chloride and magnesium chloride; (c) other inorganic chemicals such as sodium and potassium silicates; (d) organic, non-bituminous binders, including a variety of industrial waste products such as sulphite liquor and molasses residues, animal fats, and vegetable oil; and (e) coal tar and bituminous materials. The methods of application, rates of spread, advantages and disadvantages, and comparative (although outdated) costs are listed for the major categories of binding agents.

The second text, *Guide on Prime Coats, Tack Coats, and Temporary Surfacings for the Protection of Bases,* was published as *Technical Recommendations for Highways, TRH 1* (National Institute for Road Research, South Africa, 1970). It deals principally with prime coats and temporary surfacings for granular road bases that use

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temperatura de la superficie del camino es la más alta y el enlazante, a la misma temperatura, provee la mínima adherencia para la piedra revestidora.

Presentación de los textos seleccionados

El primer texto, *Dust-Laying on Unsurfaced Earth and Gravel Roads* (Fijación de polvo en los caminos sin revestimiento de tierra y de grava), fué publicado como *Overseas Bulletin No. 14* (Boletín extranjero Nº 14, Road Research Laboratory, Gran Bretaña, 1971). Nombra los distintos agentes enlazantes utilizados para la fijación de polvo, como sigue: (a) agua, dulce o de mar; (b) productos químicos delicuescentes e higroscópicos tales como cloruro de calcio y de magnesio; (c) otros productos químicos inorgánicos tales como silicatos de sodio y de potasio; (d) enlazantes orgánicos no bituminosos, incluyendo una diversidad de productos de desperdicio industrial tales como solución de sulfito y residuos de melaza, grasa animal, y aceites vegetales; y (e) alquitrán de carbón y materiales bituminosos. Se han catalogado los métodos de aplicación, tasas de aplicación, ventajas y desventajas, y costos comparativos (ya sin vigencia) para las grandes categorías de agentes enlazantes.

El segundo texto, *Guide on Prime Coats, Tack Coats and Temporary Surfacings for the Protection of Bases* (Guía para capas de imprimación, capas de ligazón y superficies provisorias para la protección de bases), fué publicado como *Technical Recommendations for Highways, TRH 1* (Recomendaciones técnicas para caminos, National Institute for Road Research, Africa del Sur, 1970). Trata principalmente con las capas de imprimación y superficies provisorias para bases de caminos granulares que utilizan betunes rebajados, y alquitrán de hornos de coque, alquitrán de fábricas de gas, y alquitrán de temperatura baja. Examina la existencia de sales solubles (sulfatos y cloruros) en las capas inferiores. Estos pueden provocar la formación de ampollas en la superficie imprimada, que se afloja y se vuelve polvorienta. Si se encuentran

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pour cent de vides, causée par une base très dure (comme sur une surface déjà revêtue) ou par l'écrasement de granulats trop friables, produisant un excès de fines qui prennent la place du liant. Les densités de trafic et la dureté de la base sont de facteurs subjectifs que l'on a pas pû encore mesurer objectivement.

L'ouverture au trafic d'une surface qui vient d'être enduite est fonction du liant utilisé. En général, la route devrait être fermée au traffic jusqu'à la prise du liant, de façon que la circulation ne l'endommage pas. Cependant ceci n'est pas toujours possible. Dans ces cas, la vitesse de circulation doit être strictement contrôlée jusqu'à la prise du liant afin d'éviter les arrachements causés par la grande vitesse. La période la plus délicate de la journée pour ouvrir la route à la circulation se situe entre midi et la fin de l'après midi, car c'est à ce moment que la temperature de la chaussée est la plus élévée, et que le liant, qui est à la même température, a le plus de difficultés à retenir les gravillons.

Discussion des textes choisis

Le premier texte, *Dust-Laying on Unsurfaced Earth and Gravel Roads* (Suppression de la poussière sur les routes non revêtues en terre et cut-back bitumens, coke-oven tar, gas-works tar, and low-temperature tar. It addresses the presence of soluble salts (sulphates and chlorides) in the underlying layers. These can cause blisters on the primed surface that leave the surface in a loose and powdery condition. The use of a higher rate of application of a higher-viscosity prime to give a thicker bituminous coating, followed by the immediate construction of the final surface treatment, is recommended if soluble salts are present.

The text describes the use of additional tack coats on primed areas before the final surface treatment where areas of exceptionally high shearing stresses are induced, such as on steep gradients and sharp bends. It also describes the Australian practice of constructing a temporary surfacing called Primerseal to protect base

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tales sales, se recomienda el uso de una mayor tasa de aplicación de un imprimidor de mayor viscosidad para proveer un revestimiento bituminoso más espeso, siguiendo esto con la inmediata construcción del tratamiento de superficie final.

El texto describe el uso de capas ligantes adicionales en las áreas imprimadas antes del tratamiento de superficie final donde ocurren grandes esfuerzos cortantes, como por ejemplo en pendientes empinadas o curvas agudas. También describe la costumbre australiana de colocar un revestimiento provisorio llamado "Primeseal", que protege las capas de base que han de utilizarse durante largos períodos de tiempo antes de aplicarse el tratamiento de superficie final. El "Primeseal" consiste en la aplicación inmediata de una capa de agregado mixto pequeño a la capa de imprimación recientemente aplicada por rociadura.

Nótese que aunque en el texto aparecen únicamente unidades métricas, la última página consiste en tablas de conversión para las unidades británicas y métricas. La conversión de galones por yarda cuadrada a litros por metro cuadrado es para galones imperiales, que son un 10,1 por ciento mayor que los galones norteamericanos utilizados en algunos de los textos subsiguientes.

El tercer texto, ***Specification for Performance Requirements for Mechanical Sprayers of Bituminous Materials*** (Especificación para los requisitos de rendimiento de rociadores mecánicos de materiales bituminosos, 2nd. ed.) y el que lo acompaña, ***Metric Addendum*** (Apéndice métrico), fueron publicados por el National Association of Australian State Road Authorities en 1969. Describe los requisitos para los rociadores que se utilizan en la distribución de materiales bituminosos calientes y/o fríos en el revestimiento bituminoso por rociadura. Como ya se ha dicho, la correcta aplicación de las capas de imprimación y enlazante bituminoso en el tratamiento de superficie es un factor clave en la realización favorable de la obra. El equipo utilizado deberá esparcir el material con tasa uniforme y temperatura correcta. Una tasa uniforme de aplicación exige un movimiento hacia adelante constante del distribuidor sobre varios cambios de pendiente, temperatura constante del enlazante,

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en gravier) constitue *l'Overseas Bulletin No. 14* (Road Research Laboratory, U.K., 1971). On y énumère les liants principaux utilisés pour la suppression de la poussière: (a) l'eau, douce ou salée; (b) les agents chimiques deliquescents ou hygroscopiques, tels que le chlorure de calcium ou de magnesium; (c) d'autres agents chimiques inorganiques comme des silicates de soude et de potasse; (d) des liants organiques non-bitumineux comprenant entr'autres des sous-produits industriels tels que les solutions de sulfite, la mélasse, les huiles animales et végétales; et (e) le goudron et les matériaux hydrocarbonés. Les méthodes de mise en oeuvre, la vitesse de répandage, les avantages et inconvénients et les coûts comparés (bien que pas au cours du jour) c•s classes principales de liants hydrocarbonés sont énumérés.

Le deuxième texte, *Guide on Prime Coats, Tack Coats and Temporary Surfacing for the Protection of Bases* (Guide pour les couches d'impression, couches d'accrochage et revêtements provisoires pour la protection des couches de base), a été publié comme *Technical Recommendations for Highways TRH 1* par le National Institute for Road Research, Afrique du Sud, en 1970. On y traite principalement des couches d'impression et revêtements temporaires pour des bases en granulats utilisant des bitumes fluidifiés, des goudrons provenants d'usines de coke métallurgique, d'usines à gaz d'éclairage, et d'usines de carbonisation à basse température. La présence de sels solubles (sulfates et chlorures) dans les sous-couches est discutée. Ces sels peuvent causer des boursouflures, ou cloques, sur la surface imprégnée, et la rendre friable et poudreuse. Si ces sels solubles sont présents, on recommande l'emploi d'un enduit plus visqueux et à un plus haut dosage, pour avoir un enduit bitucourses that are to be used for long periods before the final surface treatment is applied. Primerseal is constructed by immediately applying a layer of small graded aggregate to the freshly sprayed prime coat.

Please note that, although the text is written in metric units, the last page consists of conversion tables for the British and metric units. The gallon per square yard to liter per square meter conversion is for Imperial gallons that are 20.1 percent larger than the U.S. gallons used in some of the later texts.

The third text, ***Specification for Performance Requirements for Mechanical Sprayers of Bituminous Materials*** (2nd ed.), and its companion, ***Metric Addendum,*** were published by the National Association of Australian State Road Authorities in 1969. It describes the requirements for sprayers to be used for the distribution of hot and/or cold bituminous materials in sprayed bituminous surfacing. As previously stated, the accurate application of both prime coats and the bituminous binder for surface treatment is a key to successful construction. The equipment used must be able to spray material at a constant rate and at a proper temperature. An even application rate requires a constant forward speed of the distributor over various changes in grade, constant temperature of the binder, constant pumping pressure, constant spray bar height, and properly cleaned and adjusted spray nozzles.

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presión constante de bombeo, altura constante de la barra rociadora, y boquillas rociadoras correctamente limpiadas y ajustadas.

Además de la descripción de los criterios para la construcción y equipo de un distribuidor que satisface los requisitos mencionados arriba, este texto incluye un apéndice. El apéndice describe los métodos que se utilizan para ensayar los rociadores mecánicos para asegurarse de su cumplimiento con los requisitos. El texto original utiliza galones imperiales (277,42 pulgadas cúbicas), en lugar del galón norteamericano (231 pulgadas cúbicas). El Apéndice métrico consiste en la conversión de galones imperiales a litros.

El cuarto texto, extraído de ***Asphalt Surface Treatments and Asphalt Penetration Macadam*** (Tratamientos de superficie asfálticos y macadam de penetración asfáltico, The Asphalt Institute, MS - 13, 2nd. ed., 1975), presenta una lista general de tipos de tratamientos de superficie asfálticos, definidos como aplicaciones de asfalto y asfalto-agregado generalmente de menos de una pulgada de espesor, sobre cualquier tipo de superficie de camino. Estos incluyen los tratamientos de superficie mezclados en situ y en la planta que no han sido incluídos en este compendio. Se incluyen tablas para la correcta selección del tipo de asfalto para el tratamiento de superficie y de la relación

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mineux plus épais, que l'on recouvre immédiatement par la couche de surface finale.

Dans ce texte on recommande aussi l'emploi d'enduits d'accrochage par dessus la couche d'impression et avant le revêtement final, dans les endroits où une extrèmement forte tension de cisaillement est provoquée, comme dans les tournants très aigus ou les fortes déclivités. On y décrit aussi la technique australienne qui consiste à appliquer un enduit provisoire appelé Primerseal pour protéger la couche de base quand celle-ci doit être utilisée longtemps avant que l'on applique le revêtement final. Ce Primerseal consiste en l'application de gravillons d'une certaine classe granulaire et de petit calibre, immédiatement après l'épandage de la couche d'impression.

Il faut noter que, bien que le système métrique soit utilisé dans ce texte, la dernière page contient une table de conversion des unités britanniques et métriques. Le gallon par yard carré converti en litre par métre carré, est le gallon impérial qui est 20.1 pour cent plus grand que le gallon U.S. utilisé dans certains des textes qui vont suivre.

Le troisième texte, ***Specification for Performance Requirements for Mechanical – Sprayers of Bituminous Materials, 2nd ed.*** (Spécification pour les caractéristiques exigibles des répandeuses mécaniques de matériaux bitumineux, 2^{ieme} édition), et son supplément ***Metric Addendum*** (Supplément métrique) one été publiés par la ***National Association of Australian State Road Authorities*** en 1969. On y décrit les conditions requises des répandeuses utilisés pour l'application de matériaux bitumineux à chaud ou à froid des revêtements hydrocarbonés. Comme nous l'avons dit auparavant, l'épandage précis de la couche d'impression et du revêtement hydrocarboné est la clef de voûte de la réussite du projet. Le matériel doit être capable de répandre le matériau à un dosage uniforme et une température correcte. Pour obtenir un dosage régulier il faut que le distributeur avance à une vitesse

This text not only describes the criteria for the construction and equipment of a distributor that will meet the above requirements but also includes an appendix. The appendix describes the methods of testing mechanical sprayers to ensure that they meet the requirements. The original text is written in Imperial gallons (277.42 in^3) rather than U.S. gallons (231 in^3). The included *Metric Addendum* covers the conversion from Imperial gallons to liters.

The fourth text, excerpted from *Asphalt Surface Treatments and Asphalt Penetration Macadam* (The Asphalt Institute, MS-13, 2nd ed., 1975), presents an overall list of types of asphaltic surface treatments, which are defined as asphalt and asphalt-aggregate applications, and usually less than 1-in thick, to any kind of road surface. These include mixed-in-place surface treatments and plant-mixed surface treatments that are not included in this compendium. Tables for the selection of the proper type of asphalt for surface treatment and temperature viscosity for handling liquid asphalt are included. These tables apply to the newer designation of cut-back asphalt grades (70, 250, 800, and 3000); however, Selected Text No. 8 contains similar tables for some of the older designations of asphalt cutbacks (0, 1, 2, etc.) that are still used in some countries.

A generalized description of the materials and equipment used in surface treatment work is included with illustrations. A table that gives gen-

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temperatura-viscosidad para el manejo del asfalto líquido. Estas tablas son aplicables en las designaciones más nuevas de variantes de asfaltos rebajados (70, 250, 800, y 3000); sin embargo, el Texto Seleccionado Nº 8 tiene tablas similares para algunas de las designaciones más antiguas de asfaltos rebajados (0, 1, 2, etc.) que aún se utilizan en algunos países.

Se incluye, con ilustraciones, una descripción generalizada de los materiales y equipo utilizados en el trabajo de tratamiento de superficie. También se incluye una tabla que provee datos generales de distribuidores de asfalto, facilitados por nueve fabricantes de distribuidores. Los varios apéndices que se mencionan no han sido reproducidos porque la información que contienen se incluye con más detalle en los textos.

Este texto utiliza la medida para galones norteamericanos (1 gal. U.S. = 3,785 l; 1 gal. U.S./yd^2 = 4,527 l/m^2).

Hasta 1970 el Asphalt Institute incluía especificaciones para asfaltos líquidos rebajados en sus varias publicaciones. Estas especificaciones le permitían al usuario determinar en su propio laboratorio la aceptabilidad de los asfaltos rebajados fabricados comercialmente. En las muchas ocasiones en las áreas remotas de países en desarrollo donde lo único disponible era el cemento asfáltico en tambores, estas especificaciones podrían utilizarse para asegurarse de la mezcla satisfactoria en situ de los asfaltos rebajados.

En diciembre de 1970 el Consejo de Administración del Asphalt Institute ordenó el cese del

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constante, quelle que soit la déclivité de la route, que le liant reste à une température constante, que la pression de la pompe reste constante que la hauteur de la rampe soit toujours constante, et que les becs soient nettoyés avec soin et bien réglés.

Ce texte contient non seulement les critères de construction d'une répandeuse et de ses accessoires qui réponde à ces exigences, mais aussi une annexe. Dans cette annexe, on fait la description des essais à effectuer pour assurer le contrôle de qualité de ces répandeuses mécaniques. Le texte original utilise le gallon impérial britannique (277.42 pouces cubes) plutôt que le gallon U.S. (231 pouces cubes). Dans le Supplément métrique on convertit le gallon impérial en litres.

Le quatrième texte, qui est extrait de ***Asphalt Surface Treatment and Asphalt Penetration Macadam*** (Revêtements superficiels au bitume, et empierrement par pénétration de bitume) publié par the Asphalt Institute (MS-13, 2nd ed., 1975), contient une liste des différentes sortes de traitements bitumineux définis comme étant l'application d'une mince couche de bitume ou de bitume et granulats généralement de moins d'un pouce d'épaisseur, sur n'importe quelle sorte de surface routière. Sont inclus les mélanges en place et les mélanges en centrale qui ne sont pas vraiment du ressort de ce recueil. Il y a aussi des tableaux pour faire la sélection du bitume adéquat pour différentes sortes de traitements de surface, et le rapport température-viscosité pour la mise en oeuvre du bitume liquide. Ces tableaux se réfèrent aux nouvelles désignations de classe de bitume fluidifié (70, 250, 800, et 3000) mais le texte choisi no. 8 contient de mêmes tableaux pour certaines anciènnes désignations de bitume fluidifié (0, 1, 2, etc.) encore utilisées dans certains pays.

eral asphalt distributor data furnished by nine distributor manufacturers is also included. The various appendixes mentioned in this text are not reproduced because the information contained is included in the texts in greater detail.

This text uses the measure for U.S. gallons (1 U.S. gal = 3.785 L; 1 U.S. gal/yd² = 4.527 L/m²).

The Asphalt Institute included specifications for cut-back liquid asphalts in its various publications until 1970. These specifications allowed users to determine the acceptability of commercially manufactured cutbacks in their own laboratories. In the many instances in remote areas of developing countries where asphaltic cement in drums was all that was available, these specifications could be used to assure that the on-site blending of cut-back asphalts was satisfactory.

In December 1970, the Board of Directors of the Asphalt Institute ordered the end of the development, promulgation, and publication of its own product specifications. The Board directed that the latest standard, tentative, or interim specifications adopted or that may be adopted by ASTM or AASHO, or both, should be accepted.

The specifications of these agencies, or references thereto, are printed in the Asphalt Institution publication SS-2 (see Additional Reference No. 11). The tests referenced in SS-2 can be found in the ***1979 Annual Book of ASTM Standards, Part 15*** (see Additional Reference No. 12). Users of cut-back asphalts in elevated areas should pay special attention to the tables in ASTM D 402 that indicate corrected fractional distillation temperatures for altitudes above

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desarrollo, promulgación, y publicación de sus propias especificaciones de producto. Indicó que debería aceptarse la última norma, tentativa, o especificaciones interinas que fuesen adoptadas o habían de adoptarse, por la ASTM o AASHO, o ambas.

Las especificaciones, o referencias a ellas, de estas agencias, han sido imprimidas en la publicación SS - 2 del Asphalt Institute (véase Referencia Adicional Nº 11). Los ensayos a los cuales se refiere en el SS - 2 pueden encontrarse en la Parte 15 del ***1979 Annual Book of ASTM Standards*** (Libro Anual de Normas ASTM, 1979, véase Referencia Adicional Nº 12). Los usuarios de asfaltos rebajados en regiones elevadas deberán prestar especial atención a las tablas de ASTM D 402, que indican las temperaturas corregidas de destilación fraccional para alturas de más de 500 piés (150 m).

El quinto texto se extrajo de ***Specifications for Asphalt Cements and Liquid Asphalts*** (Especificaciones para cementos asfálticos y asfaltos líquidos, The Asphalt Institute, Specification Series Nº 2, SS - 2, enero de 1964). Las tablas que se han extraído no son de las especificaciones actuales norteamericanas para asfaltos rebajados o emulsionados. Han sido incluídas en este compendio porque son representativas de los asfaltos rebajados y las emulsiones que se utilizaban durante el desarrollo del diseño de tratamiento de superficie examinado en el Texto Seleccionado Nº 8, y mencionado en otros textos. Por razón de que este texto fué publicado durante el período de transición entre la terminología previa y la actual para las clases de asfaltos rebajados, se han incluído ambos tipos de tablas de especificaciones para hacer la comparación. Cualquiera de los dos grupos de especificaciones puede servir para la producción en el campo de material rebajado. Se han incluído las últimas tablas de especificaciones para asfaltos emulsionados en el próximo texto. La comparación de las tablas del SS - 2 actual (véase Referencia Adicional Nº 11) con las ta-

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Une description générale des matériaux et du matériel utilisés pour les traitements superficiels est incluse, avec des illustrations. On y inclut aussi un tableau de données générales sur les répandeuses de neuf fabricants. Les annexes dont on parle dans le texte ne sont pas reproduites, car les informations qu'elles contiennent sont données dans le texte lui-même en plus grands détails.

Les mesures utilisées dans ce texte sont en gallons U.S. (1 U.S. gal. = 3.785 L; 1 U.S. gal/yd² = 4.527 L/m²).

L'Asphalt Institute, dans ses publications, a continué d'inclure des spécifications pour les bitumes fluidifiés jusqu'en 1970. Ces spécifications permettaient aux utilisateurs de déterminer eux-mêmes, dans leurs laboratoires, la réception des bitumes fluidifiés fabriqués commercialement. Souvent, dans les régions isolées des pays en voie de développement, où le ciment asphaltique en baril était seul disponible, ces spécifications pouvaient être utilisées pour être sûr que le mélange en place du bitume fluidifié était correct.

En Décembre 1970, le comité directeur de l'Asphalt Institute ordonna la cessation des dé-

150 m (500 ft).

The fifth text is excerpted from ***Specifications for Asphalt Cements and Liquid Asphalts*** (The Asphalt Institute, Specification Series No. 2, SS-2, January 1964). The tables excerpted in this text are not from the current U.S. specifications for cut-back or emulsified asphalts. They are included in this compendium because they are representative of the asphalt cutbacks and emulsions in use during the development of the surface-treatment design discussed in Selected Text No. 8 and referenced in other texts. Because this text was published during the transition period between the previous and current grade terminology for cut-back asphalts, both types of specification tables are included for comparison. Either set of specifications should be suitable for the field production of cut-back material. The latest specification tables for emulsified asphalts are included in the next text. Comparison of the tables in the current SS-2 (see Additional Reference No. 11) to the tables in this text will permit the user to select the new designation that most nearly duplicates the asphaltic materials used in the examples throughout this compendium.

The sixth text, excerpted from ***A Basic Asphalt Emulsion Manual*** (The Asphalt Institute, 1979), describes (a) the chemistry of asphalt emulsions; (b) the storing, handling, and sampling of asphalt emulsions; and (c) the selection of the right type of asphalt emulsion. Asphalt emulsions were limited in use long after highway engineers accepted cut-back asphalts as a viable tool. This was due to the limited types available and the lack of knowledge about their use.

Asphalt emulsions are now becoming more widely accepted and used due to (a) the re-

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blas en este texto le permitirá al usuario seleccionar la nueva designación que más se acerca a los materiales asfálticos utilizados en los ejemplos que se encuentran en este compendio.

El sexto texto, extraído de ***A Basic Asphalt Emulsion Manual*** (Un manual básico para la emulsión asfáltica, The Asphalt Institute, 1979), describe (a) la química de las emulsiones asfálticas; (b) el almacenamiento, manejo y muestreo de emulsiones asfálticas; y (c) la selección del tipo correcto de emulsión asfáltica. Las emulsiones asfálticas se utilizaban en forma muy limitada durante mucho tiempo después de que los ingenieros viales habían aceptado el uso de los asfaltos rebajados. Esto se debía a los pocos tipos disponibles y la falta de conocimiento en su uso.

Ultimamente las emulsiones asfálticas son más generalmente aceptadas y utilizadas debido al uso reducido de destilados de petroleo costosos en su manufactura y en el calentamiento del producto manufacturado, y a la reducción de la contaminación atmosférica al ser aplicadas. El texto indica que hay tres categorías de emulsiones: aniónica, catiónica, e iniónica. Las primeras dos son las que comúnmente se utilizan en trabajos viales. Estas clasificaciones se derivan de las cargas eléctricas que envuelven las partículas asfálticas. Si el tipo de emulsión tiene una "C" adelante, esto significa catiónico, y si no hay letra, significa aniónico. En los trabajos de tratamiento de superficie las emulsiones aniónicas sirven para los agregados silíceos tales como piedra arenisca, cuarzo, y grava silícea. Las emulsiones catiónicas sirven

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veloppement, promulgation et publication des spécifications de ses propres produits. Le comité ordonna que les demières spécifications en date (normes, spécifications provisoires ou intérimaires) adoptées, ou en puissance d'être adoptées, par l'ASTM ou AASHO, ou les deux, soient acceptées.

Les spécifications de ces deux organismes et leur références sont imprimées dans la publication SS-2 de l'Asphalt Institute (voir Additional Reference No. 2). Les essais dont on parle dans SS-2 se trouvent dans le ***1979 Annual Book of ASTM Standards, Part 15*** (voir Additional Reference No. 12). Les utilisateurs de bitume fluidifié en altitude, devraient particulièrement noter les tableaux de l'ASTM D 402 qui indiquent les temperatures de distillation fractionnée pour les altitudes supérieurs à 500 pieds (150 m).

Le cinquième texte est extrait de ***Specifications for Asphalt Cements and Liquid Asphalts,*** (Asphalt Institute, Specification Series No. 2, SS-2, January 1964). (Spécifications pour les ciments asphaltiques et les bitumes asphaltiques fluides). Les tableaux de ce texte ne sont pas pour les spécifications qui sont en vigueur actuellement aux Etats Unis d'Amérique pour les bitumes fluidifiés ou émulsionnés. Nous les reproduisons dans ce recueil car ils sont représentatifs des bitumes fluidifiés et émulsionnés que l'on utilisait durant le développement du traitement de surface dont il est question dans le texte no. 8 et auquel on fait mention dans d'autres texduced use of high-cost petroleum distillates in their manufacture and in the heating of the manufactured material and (b) the reduction in atmospheric pollution during their application. The text notes that asphalt emulsions are divided into three categories: anionic, cationic, and non-ionic. The first two are most commonly used in highway work. These classifications evolve from the electrical charges surrounding the asphalt particles. The letter "C" in front of the emulsion type denotes cationic. No letter indicates anionic. In surface-treatment work, anionic emulsions are suitable for siliceous aggregates such as sandstone, quartz, and siliceous gravel. Cationic emulsions are suitable for dolomite, some limestones, and other calcareous materials. Cationic emulsions are considered to be more effective for use under difficult conditions such as cool, damp weather. High-float emulsions, which permit the retention of a thicker asphalt film on the aggregate particles, are suitable for use in the surface treatment of low-volume roads (a maximum of from 200 to 300 ADT) where plentiful supplies of sandy gravel are available. They should not be specified, however, for higher traffic volumes.

Emulsified asphalts require careful handling — not for the safety aspects so important in han-

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para la dolomita, algunas piedras calizas, y otros materiales calcáreos; y se consideran más efectivas en condiciones dificultosas tales como tiempo frío y húmedo. Las emulsiones denominadas "high-float", que permiten la retención de una película asfáltica más espesa sobre las partículas de agregado, son apropiadas para tratamientos de superficie en caminos de bajo volumen (con un máximo de entre 200 y 300 ADT) donde se encuentran disponibles amplios recursos de grava arenosa. Sin embargo, no deberán especificarse para caminos de volumen más alto.

Las emulsiones asfálticas requieren manejo cuidadoso, no tanto en el aspecto de seguridad tan importante en el manejo de asfaltos rebajados, sino para evitar roturas prematuras. Cuando se mezclan las emulsiones asfálticas catiónicas y aniónicas, también se producen roturas, (separación en agua y asfalto coagulado). La manufactura de emulsiones requiere que se lleve a cabo en condiciones controladas y en una planta con equipo complejo; así que es improbable que cualquiera que esté actualmente produciendo asfaltos rebajados en instalaciones básicas en situ, pueda producir emulsiones satisfactorias en las mismas circunstancias.

El séptimo texto se titula ***Seven fundamentals for durable spraybar work–jobs you can be proud of*** (Siete principios fundamentales para obtener, con barra rociadora, aplicaciones duraderas de que se puede estar bien satisfecho, *Roads and Streets,* agosto de 1975). Este artículo examina una presentación dada por el autor del próximo texto. La presentación tuvo lugar en la Asphalt Emulsion Manufacturers Association, y da importancia al uso de emulsiones como material enlazante en el trabajo de tratamiento de superficies. Sin embargo, presenta en forma breve, las premisas básicas del siguiente

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tes. Les deux sortes de spécifications sont incluses pour faire la comparaison car ce texte a été publié durant la période de transition entre l'ancienne et la nouvelle terminologie des classes de bitume fluidifié. Les anciènnes et les nouvelles spécifications sont correctes pour la production en chantier de matériau fluidifié. Les derniers tableaux de spécifications pour les émulsions de bitume sont incluses dans le texte qui suit. La comparaison entre les tableaux de la publication SS-2 en vigueur (voir Additional Reference No. 11) et les tableaux de ce texte, permettra la sélection de la nouvelle désignation qui se rapproche le plus des matériaux bitumineux utilisés dans les exemples de ce recueil.

Le sixième texte est extrait de ***A Basic Asphalt Emulsion Manual*** Asphalt Institute, 1979, (Manuel de base des émulsions de bitume), On décrit (a) la chimie des émulsions de bitume; (b) le stockage, la manutention et l'échantillonage des émulsions de bitume; et (c) la sélection de l'émulsion de bitume appropriée. L'utilisation des émulsions de bitume a été plutôt limitée pendant longtemps après que les ingénieurs routiers aient accepté d'utiliser les bitumes fluidifiés. Ceci était dû au fait qu'il y en avait peu de sortes disponibles, et que l'on ne savait pas grand chose sur la façon de les utiliser.

Maintenant, on emploie beaucoup plus fréquemment les émulsions de bitume car on use moins de distillats de pétrole dans leur fabrication et dans leur réchauffage, ce qui est plus économique, et aussi leur application cause moins de pollution atmosphérique. Les émulsions de bitume sont divisées en trois catégories: anionique (ou basique), cationique (ou acide) et non-ionogènes. Les deux premières sont normalement utilisées en travaux roudling cut-back asphalts but to prevent premature breaking. The mixing of cationic and anionic emulsified asphalts will also cause breaking (i.e., the separation into water and coagulated asphalt). Emulsion manufacture must take place in controlled conditions in a rather elaborate plant so it is unlikely that anyone who is now preparing cutbacks in basic on-site facilities will soon successfully produce emulsions under the same circumstances.

The seventh text, *Seven Fundamentals for Durable Spray Bar Work – Jobs You Can Be Proud Of,* appeared in ***Roads and Streets*** (August 1975). This article reviews a presentation given by the author of the next text. The presentation, made to the Asphalt Emulsion Manufacturers Association, stresses the use of emulsions as binder material in surface-treatment work. However, it presents, in rather concise form, the basic premises of the following text. The tables are more readable and, although one cannot design a surface treatment from this text, it makes the next text much more understandable at first reading.

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texto. Las tablas son más claras y aunque no se puede diseñar un tratamiento de superficie usando este texto, le permite al lector comprender más del próximo texto la primera vez que lo lee.

El octavo texto es un artículo titulado ***A General Method of Design of Seal Coats and Surface Treatments*** (Un método general de diseño de capas de imprimación y tratamientos de superficie, *Proceedings of The Association of Asphalt Paving Technologists,* Vol. 38, 1969). Presenta la lógica ingenieril en el diseño de tratamientos de superficie, comenzando con la necesidad absoluta de una fundación fuerte. Repasa los agregados revestidores de tamaño uniforme, desarrollados en Nueva Zelandia y Australia, y los graduados, utilizados en los Estados Unidos. Compara el uso del promedio de dimensiones menores con el módulo de extensión de los agregados de revestimiento para determinar el espesor medio de un tratamiento de superficie. Se evalúa la fracción de huecos de una capa suelta de agregado como función de la gravedad específica del agregado de revestimiento.

Se habla de la influencia del tamaño del agregado de revestimiento sobre su comportamiento en servicio, y se determina la sensitividad de diversos tamaños de agregado a los errores de aplicación de enlazante. Esta sensitividad indica que a medida que se aumenta el tamaño de las astillas de piedra más grande es el márgen de seguridad contra la exudación y/o pérdida de piedra revestidora.

Se evalúa la selección del enlazante asfáltico, y se describe el método de seleccionar la calidad y la cantidad. Aunque aquí se utilizan los diversos asfaltos RC como ejemplos, el mismo procedimiento es válido para los asfaltos MC. El

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tiers. Ces classes sont derivées de la charge électrique entourant les globules de bitume. La lettre "C" précédant le genre d'émulsion indique que celle-ci est cationique. On ne met pas de lettre pour indiquer une émulsion anionique. Dans les traitements superficiels, on utilise les émulsions anioniques pour les agrégats siliceux tels que le grès, le quartz et les graviers siliceux. Les émulsions cationiques réussissent bien avec les dolomites, certains calcaires et autres matériaux calcaires. Les émulsions cationiques sont considérées comme étant plus efficaces quand les conditions d'application sont dificiles, c'est à dire quand le temps est frais et humide. Les émulsions "High Float", qui permettent d'avoir une membrane de bitume plus épaisse sur les agrégats, conviennent particulièrement aux routes économiques (TJM 200 à 300) dans les régions où l'on peut trouver des quantités de gravier sableux. On ne doit pas les recommander cependant pour de plus hauts volumes de trafic.

Les émulsions de bitume doivent être manipulées avec soin, non pas pour les raisons de sécurité qui sont si importantes lorsqu'on manipule le bitume fludifié, mais pour en éviter la rupture prématurée. Le mélange d'émulsions cationiques et anioniques sera cause aussi de rupture (séparation en eau et globules coagulés de bitume). La fabrication des émulsions doit se faire sous conditions controlées et dans des centrales sophistiquées. De ce fait, il y a peu de chances que quiconque qui actuellement prépare des bitumes fluidifiés sur le chantier, réussisse a fabriquer des émulsions dans les mêmes circonstances.

Le septième texte, ***Seven Fundamentals for Durable Spray Bar Work — Jobs You Can Be Proud Of*** (Sept règles de base pour réussir, à la rampe d'épandage, des applications durables dont on peut être fier) a été dans ***Roads and Streets*** (Août 1975). Cet article examine une communication donnée par l'auteur du texte sui-

The eighth text is a paper entitled *A General Method of Design of Seal Coats and Surface Treatments,* which appeared in the *Proceedings of the Association of Asphalt Paving Technologists* (Vol. 38, 1969). It presents the engineering logic of surface-treatment design, beginning with the absolute need for a strong foundation. It reviews cover aggregates, both single size as developed in New Zealand and Australia and graded as used in the United States. It compares the use of the average least dimension to the Spread Modulus of cover aggregates in determining the average thickness of a surface treatment. The voids fraction of a loose layer of aggregate as a function of the specific gravity of the cover aggregate is evaluated.

The influence of cover aggregate size on service performance is discussed, and the sensitivity of various sizes of aggregate to errors in binder application is determined. The latter indicates that the margin of safety against bleeding and/or cover stone loss is much greater as the size of the stone chips is increased.

The choice of asphalt binders is evaluated, and the method of selecting both the grade and quantity is described. Although this paper uses the various RC asphalts as examples, the same procedures are valid for MC asphalts. The slower curing time of MC asphalts should cause no problem for surface treatments on new construction that will not come under general traffic immediately and certainly has additional safety factors, especially if the cutback is to be man-

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fraguado más lento de los asfaltos MC no debería presentar problema para los tratamientos de superficie en las construcciones nuevas que no serán utilizadas inmediatamente por el tráfico general, y sin duda provee factores de seguridad adicionales, especialmente si el usuario fabrica su propio asfalto rebajado. Una alternativa viable sería el uso de cemento asfáltico como enlazante. Por razón de que varían tanto las propiedades individuales de cementos asfálticos de distintas fuentes, las temperaturas de rociado, por ejemplo, deberán evaluarse por producto en vez de basarse en las cifras del texto.

La cantidad del enlazante asfáltico residual a utilizarse es influenciada por (a) el volumen de tráfico, (b) absorción por el agregado revestidor, y (c) la textura de la superficie en que se aplicará. La cantidad del enlazante asfáltico total a aplicarse es una función de la cantidad de asfalto residual en el enlazante asfáltico seleccionado (100 por ciento en los cementos asfálticos) y la temperatura de aplicación.

El objetivo principal de cualquier método adecuado de diseño para tratamientos de superficie es el de obtener respuestas a cada una de las siguientes seis preguntas básicas:

1. ¿Qué tipo y tamaño de agregado de revestimiento se utilizarán?
2. ¿Cuánto peso de agregado revestidor por unidad cuadrada de medida se deberá

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vant. Cette communication présentée à l'Asphalt Emulsion Manufacturers Association, recommande l'emploi des émulsions de bitume comme liant dans les traitements superficiels. On va trouver, dans cet article, présentés de façon concise, les principes de base du texte suivant. Les tableaux sont plus faciles à lire, et, bien qu'on ne puisse calculer un traitement de surface à partir de cet article, il permet de comprendre le texte suivant du premier coup.

Le huitième texte, intitulé *A General Method of Design of Seal Coats and Surface Treatments* (Méthode générale pour le dimensionnement des couches de scellement et traitements de surface), est une communication publiée dans les *Proceedings of the Association of Asphalt Paving Technologists* (Vol. 38, 1969). On présente la logique du dimensionnement des traitements de surface, en commençant par le besoin impératif d'une solide fondation. On passe en revue les agrégats de surface, à granulométrie uniforme comme en Nouvelle Zélande et en Australie, et à granulométrie variable comme aux Etats Unis. On compare l'utilisation de la méthode de la moyenne des dimensions minimales à celle dite du "Spread Modulus" (mesure, en pouces, de l'épaisseur moyenne d'une couche d'agrégats de surface de granulométrie variable) pour déterminer l'épaisseur moyenne du traitement de surface. Le pourcentage de vides d'une couche d'agrégats non agglomérés, comme fonction du poids volumétrique de l'agrégat d'épandage, est évalué.

L'influence du calibre de l'agrégat d'épandage sur le rendement est discutée et la sensitivité des differentes tailles d'agrégats aux erreurs d'application des liants est déterminée. Cette dernière indique que la marge de sécurité contre le ressuage et/ou les pertes de granulats d'épandage est beaucoup plus grande à mesure que la taille des agrégats augmente.

Le choix des liants bitumineux est évalué, et la méthode de sélection de la classe de qualité et de la quantité, est décrite. Bien que dans cette ufactured by the user. The use of asphaltic cement for binder is also a viable alternative. Because the properties of the individual asphaltic cements from different sources vary so much, the spraying temperatures, for example, need to be evaluated by product rather than taken from the figures in the text.

The quantity of the residual asphalt binder to be used is influenced by (a) traffic volume, (b) absorption into the cover aggregate, and (c) the texture of the surface to which it is applied. The quantity of the total asphalt binder to be applied is a function of the amount of residual asphalt in the asphalt binder selected (100 percent in asphaltic cements) and the temperature of application.

The principal objective of any adequate method of design for surface treatments is to obtain answers to each of the following six basic questions:

1. What type and size of cover aggregate are to be used?
2. How much weight of cover aggregate should be applied per square unit of measure?
3. What type and grade of asphalt binder are to be selected?
4. What spraying temperature should be specified for the asphalt binder?
5. What should be the rate (in volume per unit of square measure) of binder application measured at 15°C (60°F)?
6. What should be the rate (in the same units) of binder application at the spraying temperature?

The text describes the design techniques used to answer these questions and presents

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aplicar?

3. ¿Qué tipo y calidad de enlazante asfáltico se seleccionarán?
4. ¿Qué temperatura de rociado se especificará para el enlazante asfáltico?
5. ¿Cuál debería ser la tasa (volumen por unidad de medida cuadrada) de aplicación de enlazante medida a 60°F (15°C)?
6. ¿Cuál debería ser la tasa (en las mismas unidades) de aplicación de enlazante medida a la temperatura de rociado?

El texto describe las técnicas de diseño que se utilizan para contestar estas preguntas y presenta ejemplos de cálculos, utilizando los principios derivados. También describe el equipo de construcción y procedimientos que se utilizan para aplicar las cantidades correctas de materiales en forma precisa y uniforme sobre la superficie del camino en condiciones favorables de tiempo y de otros factores. El texto estudia la protección del tratamiento de superficie contra daño causado por los vehículos durante la cons-

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communication on utilise comme exemples les bitumes à séchage rapide (RC) les mêmes techniques sont valables pour les bitumes à séchage moyen (MC). Le séchage plus lent des bitumes MC ne devrait causer aucun problème aux traitements superficiels des nouvelles constructions, sur lesquelles on ne permet pas la circulation immédiate, et de plus les facteurs de sécurité sont plus grands, surtout si le bitume fluidifié est fabriqué sur place. L'utilisation des ciments asphaltiques comme liants est une alternative valable. Les proprietés des différents ciments asphaltiques provenants de sources différentes, sont très variables et de ce fait, les temperatures d'épandage par exemple, ont besoin d'être évaluées selon le produit, plutôt qu'extrapolées des tableaux du texte.

La quantité de liant bitumineux résiduel à utiliser est influencée par (a) le volume de trafic, (b) l'absorption dans l'agrégat d'épandage, et (c) la texture de la surface à enduire. La quantité de liant bitumineux total à appliquer est fonction du montant de bitume résiduel du liant bitumineux choisi (100 pour cent pour les ciments asphaltiques) et de la température d'application.

L'objectif principal d'une méthode de dimensionnement des traitements de surface adéquate, est d'avoir la réponse à chacune des six questions de base suivantes:

1. Quels genre et calibre d'agrégats d'épandage doit-on utiliser?
2. Quel poid d'agrégat doit-on utiliser par unité de mesure au carré?
3. Quelle sorte et classe de qualité de liant bitumineux doit-on choisir.
4. Quelle température d'épandage doit-on spécifier pour le liant bitumineux?
5. Quel doit être le dosage (en volume par unité de mesure au carré) d'application du liant mesuré à 15°C (60°F)?
6. Quel doit être le dosage (en utilisant les même unités de mesure) d'application du liant à la température d'épandage?

Dans ce texte on décrit les techniques de calcul utilisées pour répondre à ces questions et on donne des exemples en utilisant les principes qui en sont dérivés. On décrit aussi le matériel et les procédés utilisés pour appliquer les quantités de matériaux adéquates correctement et uniformément, sur la surface routière selon des sample calculations by using the principles derived. It also describes the construction equipment and procedures used to apply the proper quantities of materials accurately and uniformly to the road surface under suitable weather and other conditions. The text discusses how to protect the surface treatment from damage by vehicles both during construction and during the critical initial period after it is opened to traffic following construction.

The ninth text is excerpted from *Highway Maintenance Manual* (The Hashemite Kingdom of Jordan, Ministry of Public Works, Highway Department, 1972). It outlines the fundamentals of surface treatments and defines the following types of defects that commonly occur in surface treatment: (a) alligator cracking, (b) potholes, (c) raveling, (d) bleeding, (e) corrugations, and (f) stripping. The prevention, correction, or replacement of each defect is described.

The equipment used in repairing or reconstructing surface treatment is described, and checklists for each piece of equipment are provided for the maintenance foreman. Details of

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trucción y durante el período inicial, considerado crítico, cuando se lo abre al tránsito.

El noveno texto fué extraído de *Highway Maintenance Manual* (Manual de conservación vial, El Reino Hachemita de Jordania, Ministerio de Obras Públicas, Departamento Vial, 1972). Resume los principios fundamentales del tratamiento de superficie y define los siguientes tipos de defectos que comúnmente ocurren en él: (a) cuartetado, (b) baches, (c) desgaste del pavimento, (d) exudación, (e) corrugaciones, y (f) disgregación. Se describe la prevención, corrección, o reemplazo de cada defecto.

Se describe el equipo usado en la reparación o reconstrucción del tratamiento de superficie, y se suministran listas de control para cada pieza de equipo al capataz de conservación. Los detalles para la aplicación del tratamiento de superficie se presentan al nivel del supervisor de campo para conservación. Se describen los materiales de bacheo asfálticos, y se detallan el diseño y manufactura de los materiales de bacheo de mezcla en frío para la reparación de baches en el tratamiento de superficie.

Bibliografía

Al final de los textos seleccionados el lector encontrará una breve bibliografía que contiene los datos y abstractos de referencia para 20 publicaciones. Las primeras 9 referencias describen los textos seleccionados. Las otras 11 describen

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conditions météorologiques (et autres) appropriées. On discute comment assurer la protection du traitement de surface contre les dommages causés par les véhicules pendant la construction et pendant la période critique initiale de l'ouverture au trafic.

Le neuvième texte est extrait de *Highway Maintenance Manual* (Manuel d'entretien routier, Royaume Hachémite de Jordanie, Ministère des Travaux Publics, Division des Routes, 1972). On dessine les principes fondamentaux des traitements de surface, et on donne la définition des dégradations de surface suivantes: (a) peau de crocodile, ou faiençage à mailles fines; (b) nids de poules; (c) désintégration; (d) ressuage; (e) tôle ondulée; et (f) désenrobage. La prévention, la correction ou la réparation de chacunes de ces dégradations sont décrites.

Le matériel utilisé pour la réparation ou la reconstruction des traitements de surface est décrit, et des listes de contrôle pour chaque pièce d'équipement sont fournies pour le chef de secteur. L'application des traitements de surface est présentée en détail au niveau du conducteur de travaux. Les matériaux pour le reflachage sont décrits et le calcul et la fabrication de materiaux pour le reflachage à froid pour la réparation des nids de poule sont détaillés.

Le calcul du traitement superficiel utilisé en Jordanie (voir page 24 de ce texte) est décrit dans Additional Reference No. 19.

Bibliographie

Les textes choisis sont suivis d'une brève bibliographie contenant les références et les résumés applying surface treatment are presented at the maintenance field-supervisor level. Asphaltic patching materials are described, and the design and manufacture of cold-mix patching materials for repairing potholes in surface treatment are detailed.

The surface treatment design used in Jordan (see page 24 of this text) is described in Additional Reference No. 19.

Bibliography

The selected texts are followed by a brief bibliography containing reference data and abstracts for 20 publications. The first nine describe the selected texts. The other 11 describe publications related to the selected texts. Although there are many articles, reports, and books that could be listed, it is not the purpose

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publicaciones relacionadas con los textos seleccionados. Aunque existen muchos artículos, informes, y libros que podrían nombrarse, no es el propósito de esta bibliografía mencionar todas las posibles referencias que se relacionen con el tema de este compendio. Contiene únicamente aquellas publicaciones de las cuales se ha seleccionado un texto y las publicaciones básicas que se habrían seleccionado si no hubiera un límite al número de páginas en este compendio.

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de 20 publications. Les 9 premiers sont une description des textes choisis. Les autres 11 décrivent des publications apparentées au thème des textes choisis. Bien qu'il y ait beaucoup d'autres articles, rapports et livres qui pourraient être énumérés, le but de cette bibliographie n'est pas de contenir toutes les réferences possibles apparentées au thème de ce recueil. Cette bibliographie contient seulement les publications dont nous avons choisi des extraits, ou des publications de base qui auraient été choisies, s'il n'y avait de limite au nombre de pages de ce recueil.

of this bibliography to contain all possible references related to the subject of this compendium. The bibliography contains only those publications from which a text has been selected or basic publications that would have been selected had there been no page limit for this compendium.

Selected Texts

This section of the compendium contains selected pages from each text that is listed in the table of contents. Rectangular frames are used to enclose pages that have been reproduced from the original publication. Some of the original pages have been reduced in size to fit inside the frames. No other changes have been made in the original material except for the insertion of occasional explanatory notes. Thus, any errors that existed in the selected text have been reproduced in the compendium itself.

Page numbers of the original text appear inside the frames. Page numbers for the compendium are outside the frames and appear in the middle left or middle right outside margins of the pages. Page numbers that are given in the table of contents and in the index refer to the compendium page numbers.

Each text begins with one or more pages of introductory material that was contained in the original publication. This material generally includes a title page, or a table of contents, or both. Asterisks that have been added to original tables of contents have the following meanings:

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Cada texto comienza con una o más páginas de material de introducción que contenía la publicación original. Este material generalmente incluye una página título, un índice, o ambos. Los asteriscos que han sido agregados al índice original significan lo siguiente:

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Cette partie du recueil contient les sections extraites des publications indiquées à la table des matières. Les pages du texte original qui sont reproduites, sont entourées d'un encadrement rectangulaire. Certaines pages ont dû être réduites pour pouvoir être placées dans l'encadrement. Le texte original n'a pas été changé sauf pour quelques explications qui ont été insérées. Donc, si le texte original contient des erreurs, elles sont reproduites dans le recueil.

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Chaque texte commence par une ou plusieurs pages d'introduction qui étaient incluses dans le texte original. Ces pages sont généralement le titre, ou la table des matières, ou les deux. Des astériques ont été ajoutés à la table des matières d'origine, pour les raisons suivantes :

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Broken lines across any page of selected text indicate those places where original text has been omitted. In a number of places, the selected text contains explanatory notes that have been inserted by the project staff. Such notes are set off within dashed-line boxes and begin with the word NOTE.

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en el texto seleccionado, pero otras páginas (o partes de página) en esta parte de la publicación original han sido omitidas.

**Todas las páginas en esta parte del documento original también aparecen en el texto seleccionado.

Por lo tanto, los textos seleccionados únicamente incluyen aquellas partes de los documentos originales que están precedidas por asteriscos en el índice de las publicaciones respectivas.

Líneas de guiones cruzando cualquier página del texto seleccionado significan que en ese lugar se ha omitido texto original. En varios lugares el texto seleccionado contiene notas aclaradoras que han sido introducidas por el personal del proyecto. Tales notas están insertadas en recuadros de guiones y comienzan con la palabra NOTE.

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incluses dans les textes choisis, mais d'autres pages (ou portion de pages) de l'édition originale ont été omises.

**Toutes les pages dans cet extrait du document original sont incluses dans les textes choisis.

Les textes choisis, donc, incluent seulement ces extraits des documents originaux qui sont précédés d'un astérique dans les tables des matières des publications respectives.

Les lignes brisées sur les pages des textes choisis indiquent les endroits où le texte original a été omis. A certains endroits, les textes choisis contiennent des explications qui ont été insérées par notre personnel. Ces explications sont entourées d'un encadrement en pointillé, et commencent toujours par le mot NOTE.

OVERSEAS BULLETIN No. 14

Dust-laying on unsurfaced earth and gravel roads

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ROAD RESEARCH LABORATORY

DEPARTMENT of the ENVIRONMENT Reprinted 1971

DUST-LAYING ON UNSURFACED EARTH AND GRAVEL ROADS

CONTENTS

INTRODUCTION

IN MANY countries, particularly in the tropics, a high proportion of roads have gravel or earth surfaces. In the dry season such roads become dusty and often corrugate;[1] in the wet season they may become impassable. The only permanent cure for such conditions is to lay a properly constructed road with a bituminous surface. In practice, however, the initial high cost of laying a bituminous-surfaced road frequently makes this form of construction prohibitive and dust is a very real problem. This Bulletin reviews the methods that can be used to combat this problem.

N.B. This Bulletin has been reissued (1971) with the addition of metric equivalents. Names of countries, as they appeared in the original issue, have been left unchanged.

Characteristics of dust

Dust has been defined in the Encyclopaedia Britannica as "earth or other solid matter in a fine 5
state of subdivision so that particles are light enough to be easily carried as a cloud by the wind". Blacktin[2] showed that even fine sand particles clearly visible to the naked eye, when raised in a dust cloud by a moving vehicle, may be carried well clear of the highway and that really small particles may be carried distances of more than 32km (20 miles) by winds of 8km/h (5 mile/h).

Clouds of dust caused by motor vehicles are objectionable not only to the driver and his passengers but to others nearby. In villages and townships, where traffic is heaviest, the dust penetrates houses and shops. Food exposed for sale in the markets becomes covered by a layer of fine barely visible particles. Houses and plants in the vicinity of the road are slowly covered in the dust which even heavy rain fails to remove.

There is an urgent need to control dust in such places, not only because of the general nuisance but also because dust is dangerous. To the motorist a cloud of dust raised by another vehicle can cut down the visibility so that driving becomes hazardous. Fine abrasive particles greatly increase the wear on moving parts of the vehicle. Roadside plants and crops are hindered in their growth and may die if the layer of dust prevents transpiration. Man and other animals inhale dust, and particles may be retained in the body. Even if these particles are inert the purely physical effects on the body can be serious.

When a dust cloud is raised the fine constituents, clay and fine silt, are lost from an unsurfaced road. Estimates of the amount of material lost vary between 60 and 300 Mg per kilometre (100 and 500 tons per mile) of road per year. The continued loss of road material lowers the level of the road, with consequent adverse effects on the drainage. In the rainy season heaps of dry dust, which have formed near the verge, are turned to mud, making driving more difficult and impeding still further the surface-water run-off. If remedial measures
6 are delayed the road rapidly deteriorates.

Early work on dust-laying

In the earliest attempts to lay the dust on roads, fresh water was generally used although sea water was used in coastal towns[3]. Among the materials used as binders in the early experiments were heavy oils, tar and bitumen[4,5,6]. With the introduction of pressure sprayers for applying the binder [4,6] an important advance was made in the materials and methods used in dust-laying. (From these early investigations the technique of surface dressing with bitumen or tar was developed as a method of surfacing and maintaining surfaced roads.)

METHODS OF TREATMENT

The primary object in treating an unsurfaced road is to cause the finer particles which, when detached from the road, become the dust, to be bound firmly with the other constituents of the road material.

Where the road has a stable base a thin wearing course is adequate. In most cases the base is not adequately stable and, particularly on roads carrying heavy traffic, treatments are effective for varying times, and the cost of the treatment must be weighed against its life.

The principal binding agents used in dust-laying may be classified under the following headings:

(i) Water, fresh or sea

(ii) Deliquescent and hygroscopic chemicals

(iii) Other inorganic chemicals

(iv) Organic, non-bituminous binders

(v) Tar and bituminous materials.

Water, fresh or sea

Water provides only a temporary relief and the required frequency of application depends on the climate and weather; experience has shown that several light applications are better than one heavy one. A very heavy application may turn the dust to soft mud, wash away essential fines and even penetrate to the subgrade, possibly resulting in a road failure.

Seawater is generally more effective than fresh water owing to the presence of small amounts of deliquescent chemicals, principally magnesium chloride. If the atmosphere is sufficiently humid these chemicals will hold the water they absorb and the road surface will remain damp for longer than if fresh water is used.

Brine liquor, a waste product of the salt industry, which remains after most of the salt in the seawater has crystallized out by evaporation, is richer in magnesium chloride than is natural seawater. It is thus more effective than seawater as a dust palliative.

Deliquescent and hygroscopic chemicals

Several metallic salts with deliquescent or hygroscopic properties can be used as dust-laying agents. The main ones are calcium chloride and magnesium chloride, which are deliquescent, and sodium chloride (common salt), which is hygroscopic. Deliquescent substances absorb moisture from the atmosphere and liquify when the vapour pressure of their saturated solution (which is usually low) is less than that of the water in the atmosphere. With hygroscopic chemicals the quantity of water absorbed depends on the exposed surface area, more being absorbed when the substance is finely divided.

Various workers have given the relative humidity necessary for the different chemicals to be effective. Sodium chloride can absorb water only when the humidity exceeds 75 per cent,[7] and consequently is of little use in arid regions where the humidity is frequently below this value for long periods. Calcium chloride ceases to absorb moisture when the relative humidity falls below 30 or 40 per cent, depending on its purity[7]. In addition, the ability of calcium chloride to absorb water is dependent on atmospheric temperature. Figure 1 gives the lowest value of humidity and corresponding temperature at which calcium chloride will absorb moisture and completely dissolve, based on figures by Brudal[8]. In areas where the temperature and humidity are in the zone to the left of the curve calcium chloride will not absorb sufficient

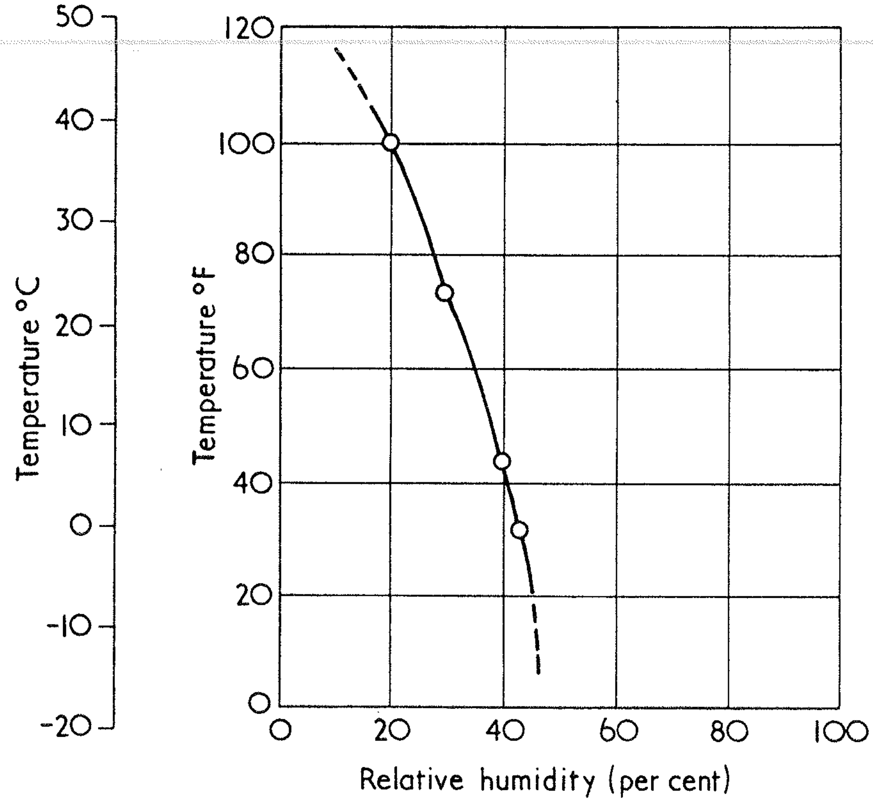

Fig.1. Relation between the lowest relative humidity of air and temperature at which calcium chloride will absorb moisture and dissolve, based on figures given by Brudal[8].

moisture for it to dissolve and thus under these conditions calcium chloride is of little value as a dust-laying agent. There would, however, be a tendency for moisture from the road to evaporate more slowly than it would if the water had not contained any chloride because it has a lower vapour pressure than water. A detailed study of the use of calcium chloride as a dust palliative has been made by Burggraf[9].

Deliquescent and hygroscopic dust-laying agents can be applied either in aqueous solution or in solid form. The latter is generally favoured, especially when heavy applications are to be made. If dust-free conditions are to be maintained, more than one treatment a year is usually necessary because these chemicals migrate downwards through the road[10].

Methods of application. The choice of method of application depends on whether only the surface of the road is to be treated or whether treatment in depth is necessary.

In the former process the calcium chloride, or other salt, is applied either in solution, preferably from power sprayers, or spread in flake form at a predetermined rate. Penetration is usually less than 12 mm ($\frac{1}{2}$ in). To ensure an adequate supply of moisture it may be necessary to spray the road before spreading the calcium chloride or other salt, in flake form.

10 In very dusty conditions where treatment in depth is to be carried out, after preliminary shaping the road is heavily scarified to a depth of 7.5 - 10 cm (3-4 in). At this stage additional soil, to improve the mechanical stability, may be added and thoroughly blended with the material already present. The next stage is to spread the calcium chloride at the appropriate rate. The soil is then thoroughly mixed to ensure an even distribution of the chemical. Shaping is carried out before final compaction to provide the correct transverse profile. All operations, other than rolling, can be done by hand or by machine. If the surface is not too wet or soft the road can be opened to traffic immediately rolling is completed.

Rates of spread. In practice it has been found that satisfactory rates of spread vary from 0.25 to 1.25 kg/m^2 ($\frac{1}{2}$ to $2\frac{1}{2}$ lb/yd^2) depending on the soil, the climatic conditions and the purpose for which the additive is being used[5,11,12,13].

<u>Advantages and disadvantages</u>. Dust-laying with calcium chloride and similar chemicals is a simple process and can be achieved without highly specialized equipment, although mechanization can lead to more rapid and uniform treatment.

Although some surface hardening may occur, the treated soil remains sufficiently workable for reshaping with a blade grader to be included in the normal maintenance routine. In temperate and cold climates there is also the advantage that soil treated with calcium chloride is less susceptible to frost.

The main disadvantage of using the deliquescent or hygroscopic chemicals is that owing to their high solubility in water they tend to be washed away. Additional treatments are thus generally necessary after periods of rain. In addition these chemicals are corrosive to most metals, particularly aluminium and its alloys. Their corrosive effects depend on the air temperature, humidity and the strength of the solution. When used as dust palliatives they do not appear to affect motor vehicles to any serious extent but their use on airfields should be approached with caution. If they become damp they are more difficult to handle and it is advisable to store the chemicals, especially calcium and magnesium chloride, under cover and away from sources of moisture.

<u>Cost</u>. Although calcium chloride is a waste product of the washing-soda industry it is not cheap in solid form or in concentrated solution. The present price in Great Britain is about £15 a Mg (£15 a ton). Magnesium chloride is slightly more expensive. The cost of calcium chloride at £15 per Mg (£15 a ton) to treat 1.6 km (1 mile) of road 6.5 m (21 ft) wide with 1 kg/m^2 (2 lb/yd^2)

would be about £165 exclusive of processing. With additional treatment at the rate of 0.25 kg/m^2 ($\frac{1}{2}$ lb/yd^2) twice a year, the total cost of calcium chloride alone over a period of 10 years would be about £1000.

Other inorganic chemicals

Other inorganic chemicals, including sodium and potassium silicates[5], may be used as dust palliatives. From solutions of metallic salts of aluminium or calcium, sodium or potassium silicates will precipitate insoluble aluminium or calcium silicates, which act as binding agents. Their use is limited because they are expensive overseas, and are often not available in large quantities there. A further disadvantage is that additional plant is required because the sodium silicate and aluminium (or calcium) salt have to be applied separately.

Organic non-bituminous binders

12 Organic non-bituminous binders may be used to lay dust on earth and gravel roads. These binders include a variety of industrial waste products, animal fats and vegetable oils. In general they are available only in small quantities or near their source of manufacture. Of the waste industrial products sulphite liquor and molasses residues are the most important.

Waste sulphite liquor

Sulphite liquor, sometimes known as sulphite lye or black or lignin liquor, is a waste product from the paper-making industry. Its composition depends on the raw materials, mainly wood-pulp, and on the chemicals used to extract the cellulose. It contains lignins, and carbohydrates in solution. The solid constituents are extracted from the waste liquor by evaporation. Proprietary dust-laying substances have been developed and it has been claimed[14] that the active constituent of one such substance is neutralized lignin sulphonic acid containing sugar. These waste products have been used successfully in Sweden,[8,15] the United States of America,[16,17] Canada[18] and French North Africa[19].

The successful use of the liquor for dust-laying depends on the grading of the earth or gravel. Experience shows that a proportion of clay must be present.[8,15,16] In Sweden it has been found advantageous to add extra clay to gravels deficient in fines.

Method of treatment. Treatment with the sulphite liquor, either in liquid form (2.5 l/m^2)(0.5 gal/yd^2) or in powder form (0.5-1 kg/m^2)(1-2 lb/yd^2), may consist of a surface application. A soil may be treated in depth with the liquor; the process then approaches one of soil stabilization. The methods of carrying out the work are identical with those described on p.6 and the equipment used is similar to that used in the process of dust-laying with hygroscopic chemicals (p.6).

Advantages and disadvantages. High outputs and more uniform results can be achieved with mechanized processing but, as with calcium chloride and other chemicals, treatment with the liquor can be carried out with the simplest equipment. The surface binding action may be reduced or completely destroyed by heavy rain because the solids content of the liquor is soluble in water. Additional treatments may therefore be necessary to maintain dust-free conditions.

There is a tendency for the soil-sulphite mixture to remain slightly plastic for some time. This permits reshaping without major reconstruction and may allow additional compaction by traffic which will give greater strength and will reduce the voids in the treated soil. Rain is then less likely to penetrate and dissolve the solids.

Sulphite and, especially, soda liquors may cause corrosion of aluminium and its alloys due to the presence of caustic compounds used in the extraction processes. For this reason the use of these liquors is not favoured on airfields. It is claimed that the corrosive effects can be diminished by the addition of a slurry of calcium carbonate to the sulphite liquor;[20] the carbonate reduces the solubility and hence prolongs the dust-laying effect.

Cost. The cost of using sulphite liquor varies according to the locality, the concentration, and whether any materials have already been recovered from it. In the United Kingdom the price is about £12 per Mg (about £12 per ton) and to treat a 6.5 m (21 ft) wide road at 2.5 l/m^2 (0.5 gal/yd^2) the liquor alone would cost about £200 per kilometre (£350 per mile). In territories remote from a suitable source of supply the cost would undoubtedly be greater.

Molasses residues

14 Molasses residues are obtained from the sugar industry. In India they have been used in a fifty per cent solution in water[21] and sprayed on the road surface which is subsequently blinded with sand. Additional treatments during the year are necessary, particularly after heavy rain as the molasses is soon dissolved out. An improvement has been obtained by adding slaked lime and charcoal to the molasses. The resultant mixture was spread over the road surface previously sprayed with a solution of molasses in water. After blinding with sand, the road was rolled to produce a hard, smooth surface. This mixture was found to be far more resistant to the action of rain than the untreated molasses residues.

Vegetable oils, animal fats and greases

These agents, which include linseed and cotton-seed oils and wool grease derivatives, are usually available only in small quantities. As dust palliatives they are not particularly satisfactory since they will only coat individual grains of soil and they have little binding power. The residue from the destructive distillation of cotton seed and wood in the form of crude tar is more effective, but the availability is so limited that it is not worth considering in detail. Such binders tend to be very liable to oxidation, and to form a brittle surface.

On many narrow roads overtaking necessitates driving on the earth shoulders and in Pakistan[22] the dust nuisance caused by this has been abated by covering the shoulders with a layer of wild grass, related botanically to sugar cane, or with reeds similar to Norfolk sedge. In India[23] coarse reeds or grass similar to Pampas grass, covered with a few inches of soil, have been used on the roads to keep down dust.

Tar and bituminous materials

The present-day production of tars (from coal) and bitumens (from crude oil) is very carefully controlled and by recombining the heavier grades of residue with the lighter fractions of distillate, products with a wide range of viscosities can be obtained. In the vicinity of oil fields, crudes containing bitumen are frequently used for dust-laying. The cost of transport prevents the use of such materials in more distant areas.

It is almost impossible to draw precise boundaries between bituminous stabilization, dust laying and bituminous construction using one or more surface dressings. For the purposes of this Bulletin, methods requiring plant mix are considered to be beyond the scope of dust-laying, and seal coats requiring blindings of crushed, graded stone are considered to be more appropriately dealt with as seal coats (surface treatments or surface dressings).

Waste oils, such as engine oils have been used as surface treatments with sands and fine-grained soils. As they supply little binding action, their effectiveness does not last long, but is extended by subsequent treatments. Ships' bunker oil gives better results.[24] The binding action of such oils can be improved by incorporating up to 25 per cent of bitumen.

Where the base of a road is adequate for the traffic, a surface treatment using a single sand-blinded dressing, or a prime followed by a sand-blinded dressing will give adequate protection. The life of such a treatment may well be short, depending on the state of the surface etc., but it may be extended by applying a seal coat. A considerable amount of work has been done on these types of treatment in New Zealand,[25] and Australia.[12,26] A somewhat cruder treatment is to use a natural gravel as the blinding material with all the fines. In this case the rate of spread of binder should be heavier as it is required to hold a thicker layer of material. No general specification can be written for such treatments, and trial runs will have to be undertaken in individual cases.

For mix-in-place treatments, the best results are given with gravel and sand gradings which are by themselves mechanically stable. Particle-size distributions have been recommended for use in America,[27,28] Scandinavia[29] and England[30]. These are in fact low-cost versions of pre-mixed surfacings rather than dust-laying procedures. Existing surfaces will usually have gradings outside the recommended limits. With such materials, trials must be made to determine whether a satisfactory mix will result. As a general rule, low viscosity binders are necessary to obtain a coating at road temperatures. Experience has shown that where the materials to be treated contain appreciable proportions of fines, particularly in the clay fraction, the fines tend to absorb the binder, while at the same time the binder tends to reduce the natural cohesion of the fines, necessitating binder contents of the order of 5 per cent or more.

For dust-laying bitumen binders will usually be applied at the ambient air temperatures and this will limit the viscosity to the range equivalent to M.C.0. or M.C.1. on the American classification (corresponding to a viscosity range of 15-150 seconds STV, 4 mm orifice). With tars, the viscosity range is normally between 5 and 15^{o} e.v.t. The rates of spread will depend on the type of material and the depth to be treated. Surface treatments will generally use applications between 0.55 and 1.35 l/m^2 (0.1 and 0.25 gal/yd^2) but with mix-in-place treatments applications may be up to 5.5 l/m^2 (1 gal/yd^2).

Use of bituminous emulsions. Bituminous emulsions have not been used for dust-laying with much success because the emulsion tends to break on contact with the dust before it has had time to penetrate into the earth or gravel. Emulsions have been used in the mix-in-place process.[31] The bitumen base of emulsions does not contain the non-volatile oils which, in a road oil, help to keep the oiled surface soft and workable for a considerable time. Up to 20 per cent of non-volatile oil, such as fuel oil, can be added to make bituminous emulsions more suitable for use. Slow breaking emulsions should be used. To obtain a satisfactory distribution of bitumen in the soil it may be necessary to dilute the emulsion with water in the proportions of about 3 parts water to 2 parts of emulsion.[32]

In an American patent[33] referring to a dust-laying emulsion it is stated that the saturated hydrocarbon components have little or no binding power; this is said to be provided by unsaturated hydrocarbons. For good adhesion and binding properties the patented emulsion should have less than 25 per cent and preferably less than 15 per cent of saturated hydrocarbons. It is stated that a highly viscous or semi-solid fraction which is resinous and liquid at higher temperatures is present in crude oils of the wax-free type (i.e. naphthenic type). This fraction is said to provide good adhesion.

Advantages and disadvantages. Bitumen and tar binders provide the most durable dust-free surfacings because of their adhesive properties and insolubility in water. Their use may be adapted to suit wide ranges of soils and gravels and traffic conditions. Good results can be achieved with simple equipment although mechanization leads to higher outputs and more uniform results. Soils treated with bituminous binders remain slightly plastic for some time and reshaping is sometimes possible after construction.

Cost. The cost of bituminous binders is high, particularly in remote districts.

EFFECT OF ENVIRONMENT ON THE COST OF DUST-LAYING

The problem of dust from roads is a world problem, not just confined to the arid tropics; it occurs in temperate climates and also in the Arctic Circle in the summer months.

The economics of the problem vary in different areas, depending on the climate, materials available and the state and rate of development of the country.

The climate has a considerable effect on the cost of road construction. For instance, where frost penetration is deep, the cost of providing an adequate depth of construction which is not susceptible to frost heave is considerable, and surfacing materials must stand up to cycles of freezing and thawing. In temperate climates, because of lower rates of evapo-transpiration especially in the winter months, water-tables are likely to be nearer the surface, giving rise to weaker subgrades. Frost action again has to be taken into account and again construction costs will be high. In the tropics and sub-tropics, frost, even where it does occur, has almost no effect, and because of the much higher evapo-transpiration rates, water-tables are further below the surface. These factors allow for a much reduced thickness of construction as compared with that in temperate and arctic climates. This means that the cost of constructing a bituminous road is generally less in the tropics and sub-tropics and that the limit of annual expenditure at which it is economically worthwhile to build a permanent road will be lower in these areas.

From the materials point of view, areas in which glaciation has occurred often have good supplies of gravels with low fines contents. These are more amenable to dust-laying treatments than the gravels and clays in the tropics, which are largely residual materials and contain appreciable amounts of plastic fines. Also the source of chemicals is nearer at hand in the temperate areas, and transport charges are less.

Finally the state of development of countries in the temperate zones is higher than in the tropics and the annual maintenance expenditure on roads is higher. In tropical countries, the rate of development is often greater than in more temperate zones, and within a very short period of time roads will require more permanent treatments than are afforded by the dust-laying techniques described.

Thus, except in special circumstances, the use of dust-laying techniques would involve higher maintenance charges than are at present budgeted for in many tropical areas. In these areas, for the level of expenditure required for dust-laying techniques, a road constructed to bituminous standards could be obtained, and is likely to be more economical in the long run.

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TECHNICAL RECOMMENDATIONS
FOR
HIGHWAYS

TRH 1

GUIDE ON PRIME COATS, TACK COATS AND TEMPORARY SURFACINGS FOR THE PROTECTION OF BASES

FEBRUARY 1970

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CONTENTS

The conversions of quantities in this Guide to f.p.s. units are given in a figure at the end of the Guide.

DEFINITIONS USED IN THIS GUIDE

Bituminous Binder

A material derived from petroleum bitumen or coal tar.

Prime Coat

A coat of suitable bituminous binder applied to a non-bituminous granular base as a preliminary treatment before the application of a bituminous surfacing to promote adhesion between the base and the surfacing, and to assist in sealing the voids and in binding the aggregate near the surface of the base.

Tack Coat

A coat of suitable bituminous binder applied to an existing surface as a preliminary treatment to promote the adhesion between the existing surface and a subsequently applied bituminous overlay or surfacing.

GUIDE ON PRIME COATS, TACK COATS AND TEMPORARY SURFACINGS FOR THE PROTECTION OF BASES

INTRODUCTION

Road engineers have sometimes asked whether prime coats and tack coats serve a useful purpose in road construction and whether they justify the extra cost and time involved in their application. This is because many roads constructed without a prime coat or a tack coat have given a satisfactory performance. On the other hand many failures that have occured have been due to their omission. It is also true that the application of a preliminary treatment which lends itself to good control reduces the risk of failure as a result of imperfections that can arise during construction and which, when they occur, can be very costly to rectify. This guide discusses some of the principles involved and makes general recommendations that can be applied to specific cases in practice.

PRIME COATS

FUNCTIONS OF A PRIME COAT

a. It assists in promoting and maintaining adhesion between a granular base and a subsequently applied bituminous surfacing (which may be a surface treatment or a premix carpet) by precoating the surface of the base and by penetrating the voids near the surface.

b. It helps to seal the surface pores in the base, thus reducing the migration of moisture and to a great extent prevents the absorption of the first spray of surfacing binder.

c. It helps to strengthen the base near its surface by binding the finer particles of aggregate.

d. It helps to stabilize cohesive soils by waterproofing the binder.

e. It provides the base with a temporary protection against the detrimental effects of weather and light traffic until the surfacing can be constructed.

REQUIREMENTS OF A PRIME

A prime must be capable of wetting and penetrating the dust film covering a granular base and coating the aggregate particles with a strongly adhering film of bituminous binder. It must also be capable of penetrating the surface of the base, normally to a depth of between 5 mm and 10 mm on dense graded bases. These requirements are met if low viscosity cut-back bitumens or tars which are solutions of bitumen or coal tar pitch in light and heavy oils are used as primes. Bituminous materials of a higher viscosity such as the type used in surfacing construction are not suitable for coating a surface when dust is present and they also penetrate most types of base to only a limited extent. Neither are bitumen emulsions suitable as they will not normally penetrate dense graded bases, since the minute bitumen droplets coalesce rapidly to form a film of bitumen on the surface.

After spraying a prime its temperature falls to that of the road surface and its viscosity increases rapidly. The prime then cures because of the loss of light oils by evaporation and, particularly in the case of tars, there is selective absorption of the heavier oils by the base. The prime must be so constituted that a thin, strong layer of bitumen or pitch is formed on the surface of the base and so that any light oils present are able to evaporate rapidly thus enabling the prime to dry within a reasonable time. A reasonable drying time for rural roads is three to four days in summer and six to eight days in winter. Where, however, access to a road has to be provided during construction, which is normally the case with city streets, then the freshly primed surface should be covered with a layer of crusher dust or sand as soon as it is necessary to open the road to traffic.

When it is necessary to delay the construction of the surfacing for several weeks or longer, and particularly when the primed base has to be opened to traffic, a type of prime must be used which is sufficiently durable to resist weathering and has good binding properties that will assist in preventing disintegration of the base by the traffic.

TYPES OF PRIME

1. Cut-back Bitumens

MC–O)
MC–1) manufactured from 'straight-run' or 'cracked' bitumen
(specified in SABS 308–1951)

2. 3/12° EVT High-temperature Coke-oven Tar Prime

(specified in SABS 748–1966)

3. Low-temperature Tar Primes

12/15° EVT
15/18° EVT
(specified in SABS 749–1966)

4. 3/12° EVT Gas-works Tar Prime

(specified in SABS 749–1966)

SELECTION OF TYPE AND GRADE OF PRIME AND RATE OF APPLICATION

GENERAL CONSIDERATIONS

The main factor that governs the selection of the type and grade of prime and its rate of application is the type of base on which it is to be used and the absorptive characteristics of the base. Weather conditions must also be taken into account, since some types of prime are slow drying in winter.

In the case of surface treatments a prime coat should always be applied to dense graded natural gravel bases (unstabilized or stabilized with a cementitious binder) and also in every case where the construction of the surfacing has to be delayed after the completion of the base. On dense graded, good-quality crushed-rock bases which can be swept to a clean, strong, stony surface free from dust, it is not essential to prime the base in order to promote adhesion of the surfacing binder. However, in an area with a predominantly wet climate it is a safeguard to prime this type of base to maintain adhesion.

Except for certain types of cement-stabilized bases, on which a bitumen emulsion tack coat is applied, it is essential to prime before applying premix surfacings. In some cases, however, it may also be necessary to apply a tack coat on the primed surface immediately before laying the premix as the adhesion of the premix to a non-bituminous base is not obtained as readily as with a surface treatment, as in the latter case the binder is in a very fluid condition when sprayed.

Ideally the viscosity and rate of application should be chosen so that the surface will absorb all it can and leave only a thin layer on the surface which dries quickly. In Australia tightly bonded surfaces are primed with a 'low viscosity' prime (10–15 centistokes at 50°C), surfaces of medium porosity with a 'medium viscosity' prime (50–150 centistokes at 50°C), and porous surfaces with a 'high viscosity' prime (150–300 centistokes at 50°C). The types of prime which are available in South Africa are given in Table 1. Experimental work on the rate of drying of different types of prime has shown that this is not determined solely by the viscosity. For example, under certain conditions high-temperature coke-oven tar prime dries more slowly than the higher viscosity low-temperature tar prime. Therefore, when considering what type of prime to use in a given case, not only must its viscosity be taken into account but also its constitution.

NORMAL PRIMING ON DENSE GRADED BASES

1. Dense Graded 'Crusher-run' Bases (Unstabilized)

Typical dense graded unstabilized 'crusher-run' bases as constructed in the Transvaal with Reef quartzite have a tightly bonded surface and a dry density greater than 2165 kg/m^3. A prime coat may be omitted on this type of base under certain conditions (see General Considerations, page 3) especially where multiple surface treatments are constructed.

If it is intended to omit the prime coat the construction of the surfacing should proceed without delay and the first spray of surfacing binder should be increased to a quantity 0.16 litre/m^2 more than that used for a primed base to allow for the absorption of binder by the base.

If, however, a prime coat is necessary, a prime of relatively low viscosity sprayed at a low rate of application should be used to avoid an excess of unabsorbed prime on the surface.

TABLE 1

*TYPES OF PRIME AND APPLICATION TEMPERATURES**

TYPE OF PRIME	CUT BACK BITUMEN		3/12° EVT HIGH-TEMPERATURE COKE-OVEN TAR PRIME	3/12° EVT GAS-WORKS TAR PRIMES	LOW-TEMPERATURE TAR PRIME	
	MC-0	MC-1			12/15° EVT	15/18° EVT
Approximate viscosity at 50°C (centistokes)	75	200	110	40–100	175	250
Minimum temperature for pumping**	5°C	20°C	30°C	To be obtained from the manufacturer	40°C	40°C
Maximum storage temperature: 15 hrs	70°C	90°C	75°C			
Maximum storage temperature: 24 hrs	50°C		65°C			
Spraying temperature range**	30°C to 70°C	50°C to 90°C	55°C to 70°C		55°C to 70°C	60°C to 75°C

Suitable types of prime to use are MC–0 cut-back bitumen, 3/12° EVT high-temperature coke-oven tar prime (preferably with a viscosity at the lower end of the range), 12/15° EVT low-temperature tar prime and 3/12° EVT gas-works tar primes. Rates of application between 0.65 and 0.76 litre/m^2 have been found suitable.

The slow rate of drying of high-temperature coke-oven tar primes on dense graded 'crusher-run' bases in winter can present a problem which can be overcome by blending in a proportion of high-temperature wood-preserving (HTWP) creosote. The creosote lowers the viscosity of the prime as shown in Table 2, increases the depth of penetration and decreases the time taken for the prime to dry. The addition of 20–30 per cent of the creosote should be satisfactory for most cases. The blending of the creosote can be carried out in the binder distributor using the circulating system to obtain good mixing. A petroleum solvent such as power paraffin must not be used for this purpose as

* Where possible application temperatures have been given *as a guide*. The range applicable to a particular product should be obtained from the manufacturer.

** Based on a viscosity of 750 centistokes for pumping and on a viscosity range of 40–100 centistokes for spraying.

the incompatibility of the materials causes coagulation which results in the formation of lumps of fibrous matter which block the pump and spray nozzles.

TABLE 2

APPLICATION TEMPERATURES FOR A HIGH-TEMPERATURE COKE-OVEN TAR PRIME CUT BACK WITH VARIOUS PRECENTAGES OF HTWP CREOSOTE

TYPE OF PRIME	TYPE OF CUTTING BACK MATERIAL	PERCENTAGE OF CUTTING BACK MATERIAL	APPROXIMATE VISCOSITY AT 50°C (centistokes)	SPRAYING TEMPERATURE RANGE °C (25–50 sec Saybolt-Furol viscosity)
High temperature coke-oven tar prime (Pretoria)	–	–	110	55–65
	HTWP creosote	10	75	45–55
		20	50	40–50
		30	35	35–45
		50	10	25–30

2. Dense Graded Natural Gravel Bases (Unstabilized or Stabilized with a Cementitious Binder)

A layer of dust is usually present on the surface of these bases which can only be partly removed by sweeping. They usually have higher absorptive properties than the 'crusher-run' bases described above and usually a lower dry density (typical range 1920–2165 kg/m^3).

All the types of prime given in Table 1 can be used. Rates of application between 0.87 and 1.09 litre/m^2 have been found suitable on typical gravel bases in the Transvaal. Some authorities have found that in the case of cement-stabilized bases, the setting of the cement seems to be retarded or otherwise affected by the penetration of the organic priming material. Instead they prefer to use a bitumen emulsion tack coat as they consider this provides a more efficient curing membrane than a prime coat since a thicker film of bitumen is formed on the surface.

SPECIAL CASES

1. Opening the Primed Base to Traffic before Constructing the Surfacing

It is the normal practice to construct the surfacing soon after the prime coat has dried. Although it is permissible to open an ordinary primed base to construction and light traffic for a short period, there are times when it is necessary to open a base to traffic for relatively long periods before constructing the surfacing. In these cases a temporary surfacing should be constructed as described below. The condition of the primed base, however, must be carefully watched and not allowed to deteriorate unduly. Speed control notices should be posted to limit the destructive effect of traffic and any damaged areas repaired before the surfacing is constructed.

With dense graded 'crusher-run' bases the type of prime used is not critical and all the types of prime given above for normal application with this type of base are suitable, except that the rate of application should be increased up to 0.87 litre/m^2, depending on the length of time the base is likely to be open to traffic.

On natural gravel bases (unstabilized or stabilized) the disintegrating effect of traffic is influenced by the type of prime used, its viscosity and its rate of application. The following types of prime are suitable on natural gravel bases : MC–1 cut-back bitumen, 3/12^{O} EVT high-temperature coke-oven tar prime and 15/18^{O} EVT low-temperature tar prime and on these, too, the rate of application should be increased up to 1.36 litre/m^2 depending on the length of time the base is likely to be open to traffic. Usually traffic should not be permitted on this type of base for longer than one month.

2. Base Materials Containing Soluble Salts

The adhesion of bituminous materials to aggregates can be adversely affected by the presence of soluble salts, such as sulphates and chlorides, in the underlying layers. It has been found that the dissolved salt is transported by the moisture moving through the subgrade soil and the foundation layers and is deposited in the hydrated form where the migration ceases, i.e. near the surface of the road. In some particular cases this problem arises soon after a prime coat has dried, the failure manifesting itself in the form of small patches of eruptions or blisters on the primed surface, which leave the surface in a loose and powdery condition. This is due to the deposition of salts in localized areas immediately beneath the primed surface which causes loss of adhesion; then owing to sudden changes in temperature vapour pressure builds up under the bituminous layer causing the blisters to form. In dealing with this condition a higher viscosity prime is more satisfactory than one of lower viscosity, and also a higher rate of application of the prime is often beneficial. It has been suggested that in these cases a bitumen emulsion tack coat might give more satisfactory results than a prime coat.

The surfacing should be constructed as soon as possible after the prime has dried. Because of its strength and weight a heavy type of surfacing will resist the eruptive action of salts, and a dense surfacing with a low permeability will restrict the migration of moisture through the surfacing and the hydration of salts will thus not take place at the final wearing surface.

A GUIDE TO THE PRIMING PROCESS

When to Prime

Cement-stabilized bases should be primed or sprayed with a tack coat of bitumen emulsion preferably within 16 hours of the completion of the base. With other types of base, priming should generally be carried out as soon as possible after completion unless the base is very moist, when priming must be delayed until the top 10mm to 25mm has dried out to some extent. With lime-stabilized bases some authorities consider it desirable to delay priming for seven days during which time the surface is kept in a moist condition to allow carbonation of the lime to take place. These authorities have reported that when lime-stabilized bases are primed soon after completion, the top 10mm of the base remains relatively soft, so that when a surface treatment is constructed the first layer of stone embeds into it, resulting in a lower void content in the surfacing and the possibility of 'bleeding'.

Preparation of the Base

The surface of the base should be well swept with a mechanical broom. Moistening the surface immediately prior to priming, particularly in the case of gravel bases, assists the prime to wet the surface uniformly and facilitates its penetration into the base. Care should be taken, however, not to apply an excess of water, since voids that are filled with water cannot be filled with prime. For the prime to be readily absorbed the base should be just damp to a depth of about 10mm, and beginning to dry out.

Weather Conditions

Priming should not be carried out when the road surface temperature is lower than 10°C, nor when the spraying performance of the distributor could be affected by wind, nor when rain is threatening. Should rain fall within 4 5 hours of priming, the drying of the prime will be delayed, although its performance will most probably not be otherwise affected.

Type of Prime and Rate of Application

The type of prime can be selected according to the purpose required as recommended above. The initial rate of application should preferably be near the lower end of the range recommended – if it becomes necessary, the rate of application can be increased as the job proceeds. In this way the maximum penetration of the prime, consistent with a reasonable drying time, will be obtained (see 'Requirements of a prime' above).

Spraying the Prime

The prime should be sprayed with a binder distributor calibrated to give an accurate rate of application and tested for satisfactory transverse distribution. A guide to pumping, storage and spraying temperatures for the different types of prime available is given in Table 1. To prevent the undue evaporation of volatiles which will result in the hardening of the material, the prime should not be heated to more than 10°C above the highest temperature of the range given. Where the prime has to be heated from the cold state it should be heated slowly even when it is in a viscous condition, to avoid overheating that part of the prime that is in close proximity to the source of heat.

Curing

Traffic barriers should be erected to keep traffic off the road as the primed surface must be left undisturbed until the prime has dried or at least until it is no longer picked up on the tyres of vehicles. Where an alternative route can not be provided and it is necessary to allow traffic to use the road before the prime has dried, the primed surface should be covered with crusher dust or sand. However, before proceeding further with the construction, care must be taken to remove any loose aggregate from the surface by sweeping.

TACK COATS

FUNCTIONS OF A TACK COAT

A tack coat assists in achieving adhesion between an existing surface and a new bituminous overlay or surfacing. A tack coat of bitumen emulsion is often used as a curing membrane for cement-stabilized bases.

USE OF TACK COATS WITH PREMIX SURFACINGS OR OVERLAYS

For the layered road structure to develop the full strength of which it is capable it is necessary for adjacent layers to become bonded to one another. This is particularly necessary near the surface of a road where the highest horizontal shearing stresses occur and where the lack of an adequate bond can result in stress concentrations which are capable of causing the surfacing to slide over the underlying layer.

A tack coat is necessary in every case where doubt exists as to whether adequate adhesion can be obtained between a newly applied bituminous layer and an underlying layer. This usually applies in the following cases:

a. when a premix surfacing is constructed over a concrete road or concrete bridge deck;

b. when a premix surfacing is laid on a previously primed surface that has become excessively dusty or has dried out excessively;

c. when a premix surfacing is laid on an existing bituminous surface that is smooth or deficient in bitumen, (this can apply when the existing surface is an old bituminous road and also when a newly laid levelling course has a very smooth texture);

d. when a thin premix surfacing up to 40mm thick is laid;

e. in areas where exceptionally high shearing stresses are induced, such as on steep gradients, on sharp bends and at street intersections with traffic lights;

f. during periods of cold or moist weather or when the site of the work is in a shaded area;

g. when a tar-bound overlay is laid on an existing bitumen surface – in this case the temperature at which the tar-bound overlay is laid is often too low to cause good bonding to the existing surface, particularly if the bitumen in this surface has hardened through aging.

A tack coat is not necessary when a premix surfacing is laid on an existing surface rich in bitumen during warm weather, or on a newly constructed bituminous-bound base that has a coarse texture.

Prime Coats and Tack Coats
TRH 1, Pretoria, South Africa, 1969

BINDERS USED AND RATES OF APPLICATION

The Country Roads Board, Victoria, Australia, specifies MC–2 cut-back bitumen to be used for tack coats at the following rates of application:

- **a.** very smooth bituminous surface or concrete : *0.27 litre/m^2
- **b.** smooth bituminous surface : *0.41 litre/m^2
- **c.** 'hungry', rough or badly cracked bituminous surface : 0.54 litre/m^2
- **d.** very open bituminous surface : 0.68 litre/m^2

Heavy applications must be avoided as any excess of tack coat binder will be absorbed into the surfacing; this will increase the binder content and may cause bleeding.

It is usually more convenient to use bitumen emulsions for spraying purposes since they are either sprayed at ambient temperatures or in some cases after heating to approximately 45°C. As the emulsion can be diluted with water a very thin film of bitumen can be achieved at a convenient rate of application from the distributor. To avoid premature breaking of the emulsion it must be ensured that the water is not excessively alkaline. High rates of application of bitumen emulsion or diluted bitumen emulsion should be avoided on existing roads as this could cause a concentration of the emulsion in depressions which could result in subsequent compaction problems or fatty areas. To obtain satisfactory results on existing bituminous surfaces of average textures, an undiluted spray-grade anionic bitumen emulsion (bitumen content 55 per cent) should be applied at a rate of between 0.54 and 0.76 litre/m^2. A special cationic bitumen emulsion with a bitumen content of 45 cent applied at a rate of 0.76 litre/m^2 has been found to be suitable for the decks of concrete bridges.

CONSTRUCTION OF TACK COATS

It is essential that no traffic should be allowed to ride on a tack coat; this means that when carrying out work on existing trafficked roads only a limited length of the surface can be sprayed ahead of paving operations. It is also undesirable for rain to fall on an uncovered tack coat. Under these conditions the most convenient method is to use a small bitumen distributor that is always available for the purpose. Hand spraying, although permissible, is not as accurate as application with a binder distribution and if this is resorted to, care must be taken not to over-apply the material as it can cause fatty areas in the surfacing. Hand application methods such as by watering can result in a non-uniform distribution of the material, and must not be allowed under any circumstances.

* With the normal types of bitumen distributor it would be very difficult to achieve these low rates of application.

TEMPORARY SURFACINGS FOR THE PROTECTION OF BASES

FUNCTION

The main function of this type of treatment is to protect the base for longer periods than can be provided by an ordinary prime coat, especially against the destructive effects of traffic.

USE OF TEMPORARY SURFACINGS FOR THE PROTECTION OF BASES

Temporary surfacings are used for protecting bases in the following instances:

a. where it is the policy to construct the surfacing in long lengths and to eliminate deviations as quickly as possible by letting traffic use the new road as soon as portions of the base have been completed;

b. where it is desired to improve the density of a road by means of traffic compaction before the construction of the final surfacing, and

c. where it is necessary to carry out the final surfacing while weather conditions are most suitable.

PRACTICE IN AUSTRALIA

In Australia this type of temporary surfacing is known as a 'Primerseal'. It consists of either one coat on tightly bonded bases or of two coats on other types of base; it may be a light treatment which will last up to six months or a heavier treatment which will last up to twelve months. One-coat work consists of a prime coat followed by the immediate application of a layer of small aggregate. Two-coat work consists of a prime coat which is allowed to cure followed by a second coat to which the aggregate cover is applied. It is essential that the aggregate cover be a graded material and not single-sized and, since it is the intention to build up a thin wearing course, that the aggregate be applied immediately after spraying the binder. This means that in the case of single coat work the prime will not have an opportunity to penetrate fully into the base.

RECOMMENDATIONS FOR SOUTH AFRICAN CONDITIONS

The following recommendations based on Australian practice are made for treatments to protect granular bases to last up to six months under South African conditions.

Dense Graded 'Crusher-run' Bases

MC–1 cut-back bitumen or 3/12^{O} EVT high-temperature coke-oven tar prime sprayed at 1.09 litre/m^2 and covered with 5mm nominal size graded crushed aggregate or sand spread at 5.7 x 10^{-3} m^3/m^2.

Dense Graded Natural Gravel Bases

First Coat:

MC–1 cut-back bitumen or 3/12^{O} EVT high-temperature coke-oven tar prime sprayed at 0.82 litre/m^2 which is allowed to cure.

Second coat:

MC–1 cut-back bitumen or 3/12^{O} EVT high-temperature coke-oven tar prime sprayed at 0.82 litre/m^2 and covered with 5mm nominal size graded crushed aggregate or sand spread at 5.7 x 10^{-3} m^3/m^2.

WORKING GUIDE

PRIME COATS

The following key will be useful in deciding when a prime coat should be used on dense graded crusher-run or natural gravel bases:

DENSE GRADED, GOOD QUALITY, CRUSHED ROCK THAT CAN BE SWEPT TO A CLEAN STONY SURFACE FREE OF DUST

1. Dry Climate

Prime not essential:

Construct surfacing without delay, increasing application rate of surfacing binder in 'first' layer to 0.16 litre/m^2 more than for a primed base.

2. Wet Climate or Where it is the Policy to Prime this Type of Base

Apply prime coat as a safeguard to maintain adhesion using a prime of low viscosity at a low rate of application. Choose one of the following:-

a. MC–0 cut-back bitumen

b. 3/12° EVT high-temperature coke-oven tar prime with viscosity preferably at lower end of range

c. 12/15° EVT low-temperature tar prime

d. 3/12° EVT gas-works tar prime.

Rate of application between 0.65 and 0.76 litre/m^2. For winter application of high-temperature coke-oven tar prime it may be necessary to blend in 20–30 per cent high-temperature wood preserving (HTWP) creosote in the binder distributor (see Table 2). *Do not use a petroleum solvent for this purpose.* 39

DENSE GRADED NATURAL GRAVEL BASE EITHER STABILIZED WITH CEMENTITIOUS BINDER OR UNSTABILIZED

Prime necessary:

All types given in Table 1, p5 are suitable. Rate of application 0.87 to 1.09 litre/m^2. In the case of a cement-stabilized base if the setting of the cement is retarded by the penetration of the organic priming material a bitumen emulsion tack coat can be used instead.

Note: Construct the surfacing as soon as possible after the prime coat is dry.

SPECIAL CASES

1. Where the base has to be opened to traffic before the construction of the surfacing. If this is for a relatively long period use a temporary surfacing. For a shorter period the rate of application of prime should be increased up to 0.87 litre/m^2 on *dense graded crusher-run bases* and up to 1.36 litre/m^2 on *natural gravel bases*.

With dense graded crusher-run bases the type of prime is not very critical. The following types of prime are suitable for the natural gravel bases:

a. MC–1 cut-back bitumen
b. 3/12^O EVT high-temperature coke-oven tar prime
c. 15/18^O EVT low temperature tar prime.

Post notices to control the speed of traffic and repair any damaged areas before constructing the surfacing.

2. Where the presence of soluble salts in the base material adversely affects the adhesion of the bituminous material to the aggregate, use a prime of higher viscosity at a higher rate of application and construct the surfacing as soon as possible.

Note: A guide to the priming process will be found on pages 8–9.

TACK COATS

A tack coat assists in obtaining adhesion between an existing surface and a new bituminous surfacing or overlay and acts as a curing membrane for cement-stabilized bases. Bitumen emulsion is usually used. Heavy applications must be avoided. A tack coat would probably be used in the situations listed on page 10 **a.** to **g.**

Use undiluted spray-grade anionic bitumen emulsion (bitumen content 55 per cent) at a rate between 0.54 and 0.76 litre/m^2 on existing bituminous surfaces. Use a cationic bitumen emulsion (bitumen content 45 per cent) at a rate of 0.76 litre/m^2 for the decks of concrete bridges. (For details of construction see p 11).

TEMPORARY SURFACINGS

(primarily for protecting the base if it is to be open to traffic for longer periods than 1 month).

Use a temporary surfacing in the following cases:

a. When it is intended to construct the road in long lengths so that traffic can use the road as portions of the base are constructed thus avoiding the necessity for deviations.

b. When it is necessary to improve the density of the road by traffic compaction.

c. When it is necessary to wait for favourable weather conditions before constructing the final surfacing.

On dense graded 'crusher-run' bases use MC–1 cut-back bitumen or 3/12^{O} EVT high-temperature coke-oven tar prime sprayed at 1.09 litre/m^2 and covered with 5mm nominal size graded crushed aggregate or sand spread at 5.7 x 10^{-3} m^3/m^2.

On dense graded natural gravel bases use:-

First Coat:

MC–1 cut-back bitumen or 3/12^{O} EVT high-temperature coke-oven tar prime sprayed at 0.82 litre/m^2 which is allowed to cure.

Second Coat:

MC–1 cut-back bitumen or 3/12^{O} EVT high-temperature coke-oven tar prime sprayed at 0.82 litre/m^2 and covered with 5mm nominal size graded crushed aggregate or sand spread at 5.7 x 10^{-3} m^3/m^2.

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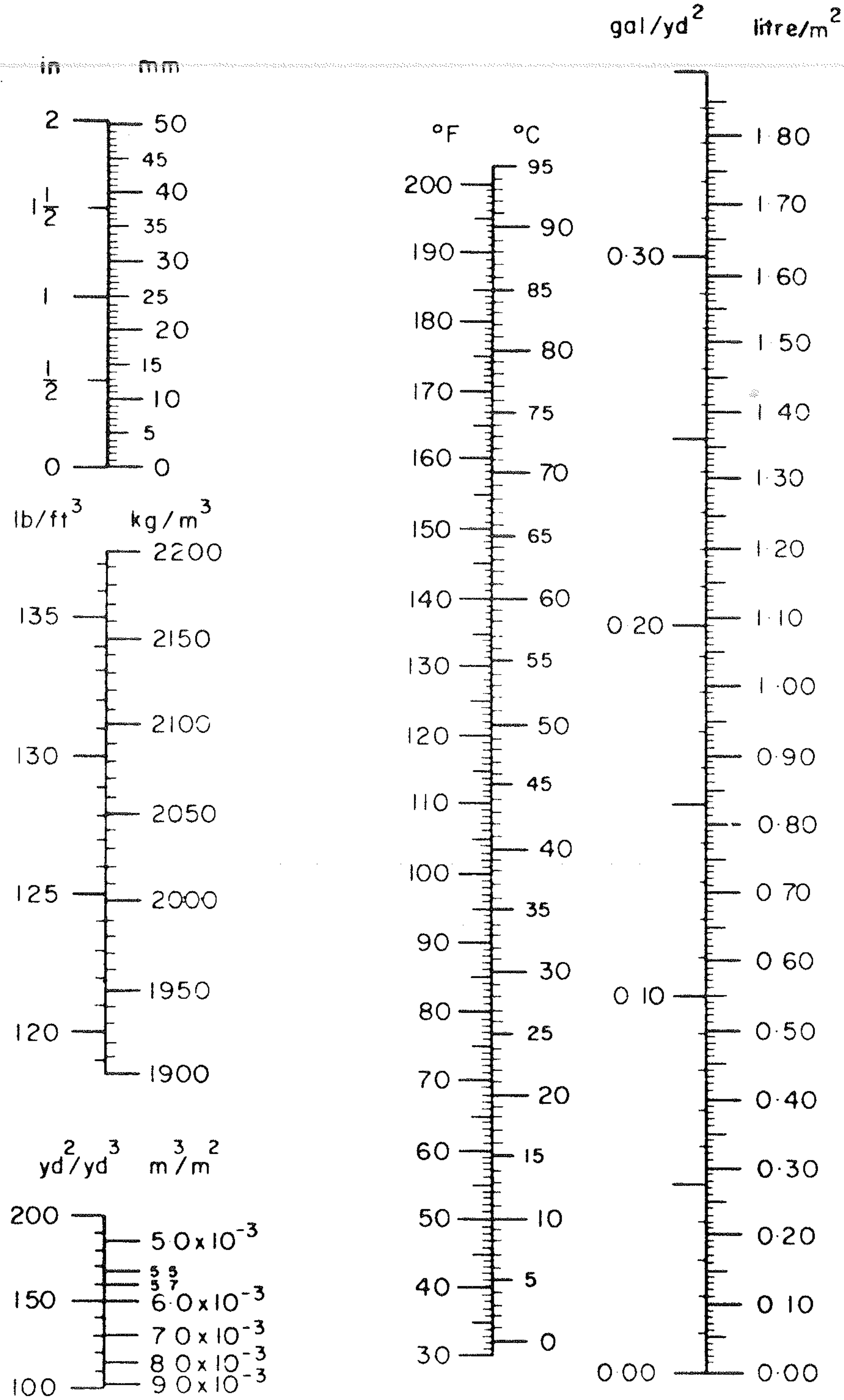

in mm
2 50 45 40 1½ 35 30 1 25 20 15 ½ 10 5 0 0
lb/ft3 kg/m3
2200 135 2150 2100 130 2050 125 2000 1950 120 1900
yd2/yd3 m3/m2
200 5·0x10-3 5·5 5·7 150 6·0x10-3 7·0x10-3 8·0x10-3 100 9·0x10-3
°F °C
200 95 90 190 85 180 80 170 75 160 70 150 65 140 60 130 55 120 50 110 45 40 100 35 90 30 80 25 70 20 60 15 50 10 40 5 30 0
gal/yd2 litre/m2
1·80 1·70 0·30 1·60 1·50 1·40 1·30 1·20 0·20 1·10 1·00 0·90 0·80 0·70 0·60 0·10 0·50 0·40 0·30 0·20 0·10 0·00 0·00

NATIONAL ASSOCIATION
OF
AUSTRALIAN STATE ROAD AUTHORITIES

SPECIFICATION FOR PERFORMANCE REQUIREMENTS FOR MECHANICAL SPRAYERS OF BITUMINOUS MATERIALS

SECOND EDITION
1969

CONTENTS

SPECIFICATION
FOR
PERFORMANCE REQUIREMENTS FOR MECHANICAL SPRAYERS OF BITUMINOUS MATERIALS

1. Scope

The requirements of this specification apply to sprayers to be used for the distribution of hot and/or cold bituminous materials in sprayed bituminous surfacing, but do not apply to spraying equipment used exclusively for hand sprayed work.

Methods of testing mechanical sprayers of bituminous materials are shown in the Appendix.

2. Types of Sprayers

The types of sprayers for which the State Road Authority will consider the issue of certificates are:

(i) Constant pressure with or without by-pass when spraying.

(ii) Pressure varying with road speed (single engine for propulsion and spraying — with adjustable ratio drive between engine and pump).

(iii) Air pressure (for spraying cold bituminous materials only).

In special circumstances the Authority may consider the issue of certificates for sprayers of other types.

3. Legal Requirements

It is the responsibility of the owner of the sprayer to ensure compliance at all times with all legal requirements covering the vehicle and its equipment, e.g. the Motor Traffic Act and Regulations, regulations governing load limitations, the Boiler and Pressure Vessel Regulations under the Factories and Shops Act, the Inflammable Liquids Act.

4. Certificates

(a) Applications for the issue, renewal, restoration or replacement of sprayer certificates should be made to the appropriate State Road Authority. Tentative arrangements for testing should be made at least one month in advance of the desired date.

(b) The following items will be required either before or at the time the sprayer is presented to the Authority for inspection and/or tests:

(i) The completed application for a certificate on the appropriate form used by the Authority.

(ii) Calibration certificate for the sprayer tank acceptable to the Weights and Measures Department (where applicable) in the State in which the machine will be tested, indicating depths and corresponding quantities in Imperial gallons as set out hereafter.

(Note — This item will be required for a first certificate only, unless otherwise directed by the Authority.)

(iii) Calibrated dipstick for checking by the Testing Officer.

(c) Before issuing a certificate the State Road Authority will arrange for such inspections and/or tests (See Appendix) as it considers necessary to ascertain that the sprayer and its equipment and the vehicle conform to the performance requirements set out in Clauses 6-13. The tests performed will be shown on the certificate.
The sprayer for which a certificate is required shall be mounted on the vehicle on which it will be operated, and shall be completely equipped, in satisfactory operating condition, and thoroughly clean when presented for testing. Failure to meet these requirements may cause a delay in testing, also extra cost to the applicant.

(d) The owner shall arrange for an experienced driver and operator to be present with the sprayer during testing to assist with examinations or tests as required by the Testing Officer.

(e) Sprayer certificates will normally be issued for a period of one year, and may be subject to such conditions as the State Road Authority may determine.
The certificate shall be mounted or retained on the sprayer, protected against damage, and shall be available for inspection at all times.

(f) Certificates may be suspended or withdrawn at any time should the sprayer or its equipment, or the vehicle, be unsatisfactory, or should defects develop, or any adjustments or alterations be made which may affect the accuracy of the operation of the sprayer. Any sprayer certificate which may be current is automatically suspended should there be any change in the sprayer and/or its equipment without the prior approval of the State Road Authority.

(g) Sprayers may be inspected at any time during the currency of Sprayer Certificates. If a serious defect is detected, the Testing Officer may mark the sprayer certificate "Cancelled" and he will then supply the owner's representative with a Defect Notice. Further tests will then be required before a fresh Sprayer Certificate is issued.

5. Spraying Table

For the guidance of the owner of the sprayer the State Road Authority will issue a spraying table indicating appropriate operating data for certain application rates and widths of spray which shall be retained on the sprayer, protected against damage and available for inspection at all times. From this information the owner may prepare more detailed spraying tables to suit his requirements. In service these tables may require adjustment because of wear in the sprayer, and it will be the owner's responsibility to effect the necessary adjustments to ensure that the rates of application achieved are correct.

6. Sprayer Vehicle

Sprayers shall be self propelled. Sprayers shall be mounted on a chassis of adequate load carrying capacity equipped with pneumatic tyres. The tyres on the wheels nearest to the spray bar shall be of adequate load carrying capacity and have equal diameters. Sprayers shall be adequately powered and braked, and be capable of maintaining steady speeds required for the rates of application stated in Clause 11, on an ascending grade of 10 per cent (1 in 10) while fully laden.

The exhaust of the vehicle on which the sprayer is mounted should be so directed that fumes from the exhaust do not reach the driver or operator, and there is no danger of sparks coming in contact with fumes or material from the overflow pipe, or any other inflammable material.

7. Sprayer Tank

(*a*) *Construction*

The sprayer tank shall be structurally sound, and the whole of the sprayer equipment shall be securely attached to the vehicle on which the sprayer is mounted. In cases where the tank and spraying equipment are not permanently fixed to the vehicle, positive means shall be provided for re-locating the tank and equipment in the correct positions.

(*b*) *Insulation*

Except in sprayers to be used solely for spraying cold bituminous materials, the sprayer tank shall be covered with suitable non-combustible insulation of adequate thickness. The insulating material shall be retained in position by suitable lugs and sheathing to ensure that it does not move in use and is completely protected from the entry of water. The insulation shall be such that the temperature drop of a full load of bituminous material at a temperature of 150°C (300°F) shall not exceed 11°C (20°F) in any one hour with the tank at rest, the load circulating, and the heating equipment not in use.

(*c*) *Manhole*

A manhole with readily removable cover shall be mounted on top of the tank, preferably at or near the mid-length of the tank.

(*d*) *Overflow Pipe*

Except in the case of air pressure type sprayers, an overflow pipe, capable of discharging overflow from the tank, and readily accessible for cleaning, shall be mounted inside the tank at or near the mid-length of the tank. The pipe should be not less than 3 in internal diameter. The opening at the upper end of the overflow pipe shall be slightly above the level of the top of the tank and below the level of the manhole opening. The lower end of the overflow pipe shall be extended through the underside of the tank and insulation, and effective means shall be provided to prevent any dribble from the overflow pipe reaching the ground.

(*e*) *Baffles*

Baffles shall be so fitted in the tank, and the draw-off from the tank so arranged, that surging of the material in the tank towards the end of each run of the sprayer will not cause entrainment of air in the spraying gear. The tank baffles shall be arranged so that they do not impede thorough mixing of materials in the tank when circulated by the pump. Provision shall be made in the baffles for access to all compartments so that inspection and repairs can be carried out.

(*f*) *Sump*

A sump shall be provided in the tank at the draw-off to the spraying gear, or the tank shall be raised at the end opposite the draw-off. The tank shall be capable of being completely emptied when the sprayer is standing on a level surface.

(*g*) *Circulatory System*

Except in sprayers to be used solely for spraying cold bituminous materials, a system capable of circulating and thoroughly mixing the contents over the full length of the sprayer tank shall be provided. See also Clause 9(b).

(*h*) *Heating Tubes*

Except in sprayers to be used solely for spraying cold bituminous materials, and except as otherwise provided in Clause 8, the tank shall be provided with sufficient heating tubes, symmetrically arranged, for the heating of the contents of the tank by adjustable burners. The heating tubes should have a slight downward slope to the rear of the tank, and the burners and controls should be so arranged as to avoid the need for the operator to be directly behind the flues when operating the burners. See Clause 8 for heating equipment.

(*i*) *Safety Valve*

In the case of air pressure type sprayers, the tank shall be fitted with an approved type of safety valve, capable of being set to release at slightly above normal operating pressure in the tank.

(*j*) *Dipstick and Guide*

The tank shall be calibrated as to its capacity and shall be provided with a dipstick graduated in Imperial gallons to indicate accurately the quantity of material in the tank. The dipstick shall be of rigid construction, mounted at about the centre of the tank in a suitable guide, so constructed as to maintain the dipstick in a vertical position, and prevent the scraping of material from the dipstick as it is withdrawn and the welling up of material as the dipstick is being lowered into the tank. A suitable seating for the dipstick shall be provided at the top of the tank to ensure that it measures at all times from a fixed point, and the bottom end of the dipstick shall be free from contact with any part of the bottom of the tank. The dipstick shall be marked to indicate increments of 100 gal on one face, and, on an adjacent face, increments of not more than 20 gal for tanks over 600 gal capacity, and increments of 10 gal for tanks of lesser capacity. The dipstick shall also be marked clearly at the level below which burners are not to be used (generally about 4 in above the highest level of the heating tubes).

Calibration of the tank shall be undertaken whilst the vehicle is standing on a level surface with the tyres correctly inflated.

8. Heating Equipment

(*a*) *Burners*

An adjustable burner of a type approved by the Authority shall be provided for each heating tube. Alternatively, consideration will be given to approving other methods of heating, with or without heating tubes. The burners shall be shrouded to facilitate operation in a gusty wind, and shall be capable of maintaining the material in the tank at a steady temperature, or raising it from 135° to 175°C (275° to 350°F) in not more than one and a half hours when the tank is fully loaded.

A portable adjustable heater with an adequate length of flexible hose shall be provided for heating the pump, spray bars, etc., if bituminous material should solidify in the system. One of the main burners, if readily detachable, may be used as a portable heater in lieu of the separate portable unit. All heater fuel tanks shall be clearly marked with the type of fuel which they are intended to use.

Outlet flues of burners shall be fitted with spark arrestors.

(*b*) *Thermometers*

A mercury-in-steel or other approved type of dial thermometer shall be fitted to the tank. The element shall be located at about mid-height and mid-length of the tank and the dial shall be readily readable by the operator. The dial of the thermometer shall read in increments of not more than 2°C (or 5°F), and shall include the range of 10° to 230°C (50° to 450°F) over a scale distance of not less than 6 in. The thermometer shall be accurate to within ± 2½ per cent over the full operating range when tested in accordance with Clause A.10 of the Appendix. Dial thermometers shall give steady readings, free from flutter or oscillation. Where the thermometer assembly cannot be conveniently removed for checking, a built-in checking tube shall be provided adjacent to the element of the main thermometer for checking accuracy of the temperature indicated. The sprayer shall be provided with a thermometer of a type approved by the Authority for the purpose of checking the accuracy of the main thermometer.

(Note — This clause is not applicable to sprayers used solely for spraying cold bituminous materials.)

9. Pumping Equipment

(*a*) *Pump*

The pump shall have a non-pulsating discharge and, at its maximum permissible speed, shall have a discharge 10 per cent greater than that required for the maximum rate of spray stated hereafter, up to the full width of spray for which the machine is to be used.

In the case of sprayers referred to in Clause 2(ii) (single engine for propulsion and spraying), the transmission between the engine and the pump shall be capable of being adjusted to different ratios. At any selected coupling ratio, the pump output shall vary with the road speed in such a manner that for an increase of 20 per cent above a selected road speed, the pump output will be between 16 and 24 per cent greater than the output at the selected speed. In like manner, for a decrease of 20 per cent in road speed, the pump output shall be between 16 and 24 per cent less than the output at the selected speed. See also Clause A.7 of the Appendix.

The pump drive shaft shall be provided with a shear pin or other adequate device to prevent damage to the pump or drive shaft in the event of overload due to material solidifying in the system, or any other cause. Except in sprayers to be used solely for spraying cold bituminous materials, provision shall be made for flushing the pump and spraying system with light oil without the oil entering the tank (see also Clause 10(c).

(*b*) *Loading and Mixing*

The pumping system shall be capable of loading and unloading bituminous materials. In the case of sprayers which will be used for spraying hot bituminous materials, the pumping system shall be capable of mixing by circulation, and should also be able to transfer material from one external container to another, while the sprayer is loaded. Mixing efficiency shall be such that when 20 per cent of a suitable cutter oil (e.g. power kerosene) and 80 per cent R90 bitumen are added separately, to the tank, and circulation is undertaken for 20 minutes with the pump operating at not more than 75 per cent of its maximum output, the percentage of cutter oil in the mixture shall be within the limits of 18 and 22 per cent at any point in the tank. See Clause A.11 of the Appendix.

In the case of air pressure type sprayers the system shall be capable of discharging bituminous material at a pressure 10 per cent above that required for satisfactory operation at the maximum rate of application stated in Clause 10, and maximum width of spray in Clause 11. Provision shall be made in air pressure type sprayers for loading and unloading bituminous material at a rate of not less than 40 gal/min.

All controls and settings of the system shall be clearly marked and adequate instruments for the control of the spray shall be provided.

(*c*) *Flexible Hoses*

Except in the case of air pressure type sprayers, all flexible hoses carrying bituminous materials shall be of the metallic type and together with couplings shall be suitable for operation at about 90 lb/sq in but capable of withstanding a minimum test pressure of 300 lb/sq in and temperature of 205°C (400°F). The internal diameter of the hoses shall be such that the discharge of the pump is not adversely affected.

(*d*) *Strainers*

Provision shall be made for straining bituminous material, either by an external strainer, or a removable strainer in the suction pipe or hoses. Such strainers shall have clear openings not greater than $\frac{1}{8}$ in. The total area of the strainer orifices shall not be less than seven times greater than the cross sectional area of the pipe or hose to which the strainer is fitted.

(*e*) *Pumping Engine*

The engine driving the sprayer pump (or air compressor in the case of air pressure sprayers) shall be capable of driving the equipment without appreciable pulsation or vibration, and of providing a maximum spray rate 10 per cent in excess of that specified in Clause 11 (a), Rates of Application.

Where a separate engine drives the pump, the engine shall be fitted with an efficient governor capable of maintaining the engine at a steady speed without "hunting", and shall be capable of controlling the spray pump shaft revolutions within the $\pm$ $2\frac{1}{2}$ per cent of the predetermined spraying speed within the full operating range — See Clause 11 (a). Alternatively to the governor, a smoothly adjustable throttle control may be considered, provided that the engine speed variations are within the limits stated above. In the case of air pressure sprayers, the air pressure in the tank shall be maintained at the required amount by a smoothly operating throttle control on the engine driving the air compressor, or by other means approved by the Authority.

The exhaust pipe of the pumping engine should be so directed that fumes from the exhaust do not reach the driver or the operator and there is no danger of sparks coming in contact with fumes or any other inflammable material. The pipe shall be fitted with a spark arrestor.

(*f*) *Relief Valves*

Relief valves, if fitted, shall be of the enclosed spring type with closed outlet and shall be set at least 20 lb/sq in above the maximum spraying pressure required for the maximum length of spray bar. Provision shall be made for the checking of opening pressures.

10. Spraying Equipment

The spraying gear shall be such that, in conjunction with adjustment of the road speed of the sprayer, any predetermined amount of bituminous material within the limits stated hereinafter can be applied uniformly and accurately to the road surface for any width of spray for which the machine is to be used.

(*a*) *Revolution Counter*

A revolutions-per-minute counter of an industrial type approved by the Authority shall be fitted to show the speed of the pump shaft, or, in the case of air pressure sprayers, the speed of the air compressor. The instrument shall be calibrated in increments of not more than 10 revolutions per minute or 50 revolutions per minute in the case of air pressure machines over the full operating range, which shall occupy a scale distance of not less than 6 in. The instrument shall be accurate over that range to within ± 2½ per cent.

(*b*) *Pressure Gauge*

A pressure gauge of the diaphragm type which complies with BS 1780, Bourdon Tube Pressure and Vacuum Gauges, and amendments or other type approved by the Authority shall be fitted to show the pressure of the discharge from the pump, or in the case of air pressure type sprayers, the pressure in the sprayer tank. (In order to minimise the risk of bitumen solidifying at the diaphragm, the latter should be mounted immediately above the discharge pipe from the pump.)

Where the pressure is controlled by varying the pump revolutions, the pressure gauge shall be fitted to the discharge pipe system. The pressure gauge shall be calibrated in increments of not more than 2 lb/sq in over the full operating range within a scale distance of not less than 6 in. The pressure gauge shall be accurate over that range within ± 2½ per cent. Where the pressure is regulated by a by-pass valve, the pressure gauge shall measure the operating pressure in the spray bar, and shall be graduated in increments of ½ lb/sq in to include the range 0 to 25 lb/sq in over a scale distance not less than 10 in. The gauge shall be accurate to within ± 2½ per cent.

In sprayers where the discharge to the spray bar is controlled by air pressure in the sprayer tank, the pressure gauge indicating the pressure in the sprayer tank shall be graduated in increments of not more than 1 lb/sq in from 0 to 30 lb/sq in over a scale distance of not less than 6 in, and shall be accurate over that range to within ± 2½ per cent. In air pressure sprayers which use a partial vacuum for loading purposes, the gauge shall be of the compound type, indicating either pressure or vacuum as required. The pressure portion of the gauge shall conform with the above requirements relating to calibration and accuracy.

All pressure gauges and revolution counters shall give steady readings, free from flutter and oscillation.

Where a by-pass valve is used for controlling the pressure and the discharge from the sprayer, it shall be of a type approved by the Authority, capable of smoothly and uniformly varying the quantity of material by-passed in order to maintain the required pressure in the spray bar. It shall be capable of by-passing not less than 25 per cent of the maximum output of the pump. The by-pass valve control shall be suitably marked so that any predetermined setting can be obtained.

(*c*) *Spray Bar*

Subject to the approval of the relevant Authority the spray bar shall be one of the following types:

(i) Fully-circulating type, in which the bituminous material is pumped from the tank through the full length of the spray bar in use, and returned to the tank while the valves controlling the individual spray nozzles are closed. The spray nozzles in the bar shall be controlled by a linkage or other means which shall open or close the check valves of all nozzles equally, simultaneously, and fully. Two spray nozzles may be controlled from a single check valve if desired. The check valve shall be of adequate capacity to allow the nozzles to discharge at the required rate. Provision shall be made for manually cutting off each nozzle or pair of nozzles to permit ready adjustment of the width of spray. The spray bar shall be capable of being extended to beyond 8 ft with suitable extensions to the width required.

(ii) Non-circulating type, in which the spray bar is easily removed immediately spraying ceases, and is placed with nozzles uppermost in a suitable rack on the side of the sprayer, so that any bituminous material will drain from the spray bar and nozzles into suitable containers. Any devices for connecting the spray bar to the delivery pipes of the sprayer shall be rapid and positive in operation. Provision shall be made for instantaneous sucking back from the spray bar at the same time as the delivery to the spray bar is stopped.

(iii) Any other type of spray bar which is acceptable to the relevant Authority.

Spray bars shall be constructed to meet the transverse distribution requirements of Clause 12(a). In the case of fully circulating bar this shall be achieved without the use of restriction washers in the spray bar or fittings. The use of restriction washers which are fitted to existing machines will only be accepted until 1st January, 1973.

Except as may be otherwise approved, spray bars shall be capable of applying bituminous material at all rates of application specified in Clause 11(a).

Spray bars exceeding a length of 12 ft shall be capable of being adjusted to conform to the crossfall of the road pavement.

The spray bar may be provided with means for moving it transversely while spraying, such movement being readily controlled by the operator. The spray bar shall be fitted to the sprayer in such a manner that the lower faces of the spray nozzles are maintained between 10 and 12 in above the road surface under operating conditions, irrespective of the loading of the sprayer. Adequate provision shall be made for clearing all material from the spray bar, valves, ports, nozzles, etc., when not spraying, and for flushing out the spray bar with light oil when necessary.

(*d*) *Spray Nozzles*

Spray nozzles shall be of a slot type approved by the Authority, and apart from any special end nozzles, shall be of similar construction and interchangeable. Nozzles shall be set vertically at the correct horizontal spacing, and with the slots in the nozzles at the correct horizontal angle for all portions of the road surface being sprayed to receive an even application of material. A means of providing quick adjustment of the nozzles to the correct horizontal angle will be required. At least 10 spare nozzles, in good condition, shall be carried on the sprayer.

(*e*) *Cut-in and Cut-off Distances*

Within the ranges of rates of application stated in Clause 11(a), the full intensity of spray application shall be reached or cut-off within a length of travel of the sprayer not exceeding 2 ft in the case of a fully circulating spray bar, or a distance equal to one-third of the effective width of spray in the case of other types.

(*f*) *Hand Spray Equipment*

Hand spray equipment approved by the Authority and capable of being operated independently of the main spray bar, shall be provided. This equipment shall be suitable for operation of 90 lb/sq in but must be capable of withstanding a minimum test pressure of 300 lb/sq in and a temperature of 205°C (400°F).

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11. Operation of Sprayer

(*a*) *Rates of Application*

Sprayers shall be capable of applying bituminous material evenly and uniformly to the surface on which the material is to be applied, at any required temperature not exceeding 190°C (375°F) and at any rate of application required within the range 0.05-0.50 gal/sq yd.

The sprayer shall be capable of achieving the above-mentioned spraying rates at speeds not exceeding 1500 ft/min (or 17 miles per hour). For lower rates of application, special nozzles may be required to keep below this speed limit.

(*b*) *Road Speed Indicator*

The sprayer shall be provided with a dial type road speed indicator reading in feet per minute, operated from a separate wheel attached to the sprayer, and capable of being lifted from the road when not required. The dial of the indicator shall be mounted so as to be easily read without parallax error by the sprayer driver, or the person who is in control of the forward speed of the sprayer when spraying is in progress. The dial scale of the indicator shall include the range 0-1500 ft/min, shall be graduated in increments of not more than 20 ft/min, and shall be so constructed that the scale distance for each 100 ft/min of sprayer speed is not less than $\frac{3}{4}$ in. The dial indicator needle shall be reasonably stable over the full spraying range, and any fluctuations in speed shall be recorded without lag, sticking, or oscillation of the needle. The road speed indicator shall be of such accuracy that the reading error shall not exceed $\pm 2\frac{1}{2}$ per cent throughout the full spraying range. If required by the Authority, the dial speed indicator shall include an odometer to record the distance travelled in feet.

(*c*) *Guide Arm*

A guide arm with suitable pointer and chain shall be provided to assist the sprayer driver in following the correct line. The guide arm shall be mounted on the driver's side of the vehicle, forward of, and in full view of the driver.

(*d*) *Instruments and Controls*

Instruments and controls shall be convenient to the driver or operator, as the case may be. The operator's normal position shall be such that he has a clear view of the ends of the spray bar, and preferably a view of all spray nozzles. Convenient access shall be provided to the manhole, dipstick, instruments and controls.

April 1976

NATIONAL ASSOCIATION

OF

AUSTRALIAN STATE ROAD AUTHORITIES

Amendment 1

TO

Specification for Performance Requirements for Mechanical Sprayers of Bituminous Materials, 1969
(ISBN 0 85588 023 6)

Page 12, Clause 11(c), Guide Arm

Delete the clause and substitute:

(c) Guide Arm

A guide arm with suitable pointer and chain shall be provided to assist the sprayer driver in following the correct line. The guide arm shall be mounted on the driver's side of the vehicle, forward of, and in full view of the driver, and shall be marked and numbered relative to the spray bar nozzles.

(*e*) *Signal System*

An adequate signal system shall be provided between operator and driver.

12. Uniformity of Distribution

(*a*) *Transverse Distribution*

The uniformity of the spray distribution transversely across the surface on which the bituminous material is applied shall comply with the following requirements at all specified rates of application and for any width of spray up to the maximum for which the machine is to be used. The uniformity of the transverse distribution shall be determined from the average application of bituminous material over all 2 in widths sprayed. A strip of up to 6 in wide along each side of the width sprayed may be disregarded when determining the average rate of spray application. The following requirements shall be adhered to:

(i) The material applied on any width of 2 in shall not differ by more than 20 per cent from the average application on all 2 in widths.

(ii) Not more than two of any consecutive ten widths of 2 in shall differ by more than 15 per cent from the average application on all 2 in widths.

(iii) Not more than four of any consecutive seven widths of 2 in shall differ by more than 10 per cent from the average application on all 2 in widths.

(*b*) *Effective Widths of Spray*

The effective width of spray shall be the width within which the spray application of the bituminous material complies with the foregoing requirements.

(*c*) *Consistency of Sprayer Output*

The rate of output shall not vary from the mean by more than ± 2½ per cent during the discharge of the full sprayer load.

13. Fire Extinguishers

Fire extinguishers shall be mounted on the sprayer in a readily accessible position using quick release brackets. The number and capacity of the extinguishers shall be as required by the Authority.

APPENDIX

METHODS OF TESTING MECHANICAL SPRAYERS

A.1 Sprayer Inspection

The sprayer is first inspected to determine whether it incorporates the mechanical features required by the Specification. Before the main tests are put in hand, the sprayer should be operated with testing oil of a viscosity determined by the Authority but within the range 30-70 centistokes in all phases, such as filling, tank circulating, spray bar circulating, and spraying, so as to ensure that the engine, pump, valves, controls, spray bar, etc., are all functioning and the relief valve, if fitted, is set at the correct opening pressure. The bitumen pump (if fitted) should be checked for rate of delivery and wear, and the whole system closely examined for leaks. In pump type sprayers the pumping engine should be checked for speed variations.

A.2 Road Speed Indicator

The road speed indicator is tested by driving the sprayer at a series of uniform speeds on a test section of road, or by the use of test apparatus in which the wheel of the road speed indicator is rotated by a roller driven at controlled and predetermined speeds. Each test is performed twice and, if the readings are not in close agreement, is repeated until the reasons for varying results are determined.

A graph is plotted showing indicated road speeds against actual road speeds. Indicated road speeds are shown in the spraying table, while actual speeds are used in calculating the spraying rates. 59

Note: Some road speed indicators may be damaged by operating in reverse. In such cases the separate wheel driving the indicator should be lifted from the road before the sprayer is reversed.

A.3 Pump Tachometer

The pump tachometer is checked over the full working range either while still in position on the sprayer or on a test bench after being removed from the sprayer.

A.4 Pressure Gauge

The gauge is tested in position over the full working range, with a boiler inspector's pressure gauge testing kit or is removed from the sprayer and connected to a cylinder containing a suitable fluid such as glycerine. The cylinder is fitted with an oil-tight piston which is progressively loaded with weights in increments of 5 lb. The gauge reading at each weight is recorded. Check readings are taken as the load is removed in similar increments.

A.5 Tank Calibration

With the sprayer standing on a level surface, water, oil, or other suitable liquid, is added to the tank in accurately measured increments of 20 gal (or 10 gal in the case of sprayers of less than 600 gal capacity). The depth of liquid in the tank is recorded at each increment, and the dipstick marked accordingly. Any tendency for the fluid to well up in the dipping tube should be noted, as this may give false readings.

Markings and figures in accordance with Clause 7(j) of the Specification should be stamped clearly and permanently on the dipstick. Calibrations obtained from this test may be required to be checked and certified by the Weights and Measures Department.

A.6 Pump Output

With the spray nozzles correctly fitted, and the sprayer controls set to provide a spray bar pressure, which will give the rated discharge of the nozzles, testing oil as in Clause A.1 of this Appendix, is sprayed into a trough for about 45 seconds, or other suitable period. The quantity sprayed is determined from the dipstick readings before and after spraying, and a record is made of the spray bar pressure, the pump output pressure, the pump speed in revolutions per minute, and the pump output in gallons per minute. This test is repeated several times for each length of spray bar to be shown in the application rate chart. Pump output tests may be undertaken in conjunction with output consistency and transverse distribution tests (Clauses A.7 and A.9 respectively).

Following these tests a spraying rate table will be prepared showing operating data for certain widths of spray. The owner of the sprayer may require a more detailed table to suit his requirements, and this may be prepared by interpolating pump outputs and pump revolutions per minute for spray widths between those given by the Road Authority.

In the case of pump type sprayers, the spraying tables show the appropriate indicated road speeds, pump revolutions per minute (circulating), pump revolutions per minute (spraying), pump output pressures, and the pump engine gear (if applicable), for all specified spray bar widths and rates of application.

In the case of air pressure sprayers, the spraying tables show the appropriate indicated road speeds, tank pressures, and the required revolutions per minute for the compressor to maintain that pressure, for all specified spray bar widths and rates of application.

A.7 Consistency of Sprayer Output

The object of this test is to determine the ability of the sprayer to maintain a consistent rate of output while the level of material in the tank varies and to repeat the same rate of output after the operating controls have been varied and re-set.

The sprayer tank is filled to its maximum calibrated capacity with the testing oil, and the sprayer is operated with the controls correctly set for the number of spray nozzles fitted. Oil is sprayed for approximately 60 seconds, then the engine is stopped and the setting of all controls varied. Dipstick readings before and after spraying and the actual time of spraying are recorded.

The procedure is repeated with the initial levels in the tank adjusted to:

(i) Approximately 60 per cent capacity,

(ii) Approximately 25 per cent capacity, or sufficient quantity to avoid the entrainment of air towards the end of spraying.

The rate of output for each of the three spraying periods is determined from the dipstick readings and the actual times of spraying.

In the case of sprayers referred to in Clause 2(ii) of the Specification (single engine for propulsion and spraying), the pump output is also determined with the sprayer tank approximately three-quarters full of testing oil. Controls are set in the "tank circulate" position, and while circulating, the sprayer is driven at a corrected road speed of 500 ft/min. The established pump speed for a 20 ft spray bar is synchronised and the controls locked.

The road speed is then increased and decreased by 100 ft/min and corresponding pump speeds recorded. Pump outputs are established for the recorded speeds and compared with the performance required by Clause 9(a) of the Specification.

A.8 Transverse Distribution

When the sprayer is known to be in working order, this test may be performed in the field, using an absorbent plastic material such as "Innerbond" to collect a small sample of the material sprayed in a trial run. Where the sprayer is new, or has been extensively modified, it shall be tested in accordance with the trough test.

(*a*) *Trough Test*

A trough, about 28 ft long and 2 ft wide, divided into segments 2 in wide by a series of transverse vanes and so arranged that testing oil sprayed into each segment will drain into its own measuring container (approximately 21 in deep by 6 in diameter) is used in the test.

The sprayer is loaded with testing oil and placed on a level platform, and with the spray bar extended to its maximum operating width, the spray nozzles are set 10 in above the trough.

Oil is then sprayed into the tray using the appropriate pump output referred to in Clause A.6 for about 45 seconds, or such other period as is necessary to fill the measuring containers to about 75 per cent of their capacity. The quantity of oil in each container is measured, and the results plotted as a graph to show the variations in transverse distribution. If local variations in distribution occur outside the limits given in Clause 12(a) of the Specification, the spray nozzles and control cocks (if any) should be examined for partial blockage or mechanical fault. Any marked reduction in output towards the end of the spray bar may indicate faulty design.

The test is repeated for various spray bar widths.

(*b*) *Field Test*

A strip of "Innerbond" (or equivalent material) at least 2 ft wide, and of length about 4 ft greater than the spray bar to be tested, is placed on a strip of Sisalkraft (or equivalent material) 3 ft wide on a level area which should be clear of all debris. A light timber template 22 in wide is placed over the "Innerbond", and a strip of cellulose tape 1 in wide is placed on each of the long edges of the "Innerbond" adjacent to the template, which is removed later.

Strips of heavy paper, each 3 ft wide, are then placed against the cellulose tapes and joined to them with masking tape 2 in wide. If required, the prepared mat may be rolled on a wire mesh cylinder for handling and transport. The material should be unrolled within a few hours.

The test may be undertaken on any smooth level area, or at the end of a section of road which is to be sprayed. The "Innerbond" mat is placed in a straight line across the test area and the outer edges of the paper strips are attached by masking tape to pieces of cord stretched taut across them. The mat is then fastened to the road by roofing nails or other suitable means.

Two strips of Sisalkraft, each 3 ft wide and about 3 ft long, are placed over the "Innerbond" in such a position that they will be traversed by the sprayer wheels. These strips are attached to a light steel frame, so arranged that it is picked up by the sprayer immediately after the rear wheels have passed, thus exposing the "Innerbond" to the spray.

After spraying is completed, the brown paper is removed from the edges of the "Innerbond", which is then covered with fresh brown paper, and rolled onto the wire mesh cylinder. The "Innerbond" is subsequently cut (in the direction of the spray) into strips 2 in wide. The strips are weighed to the nearest 0.1 g, and after deducting the tare weights of the "Innerbond" the weights of the sprayed material are plotted to show the transverse distribution.

Note: Bituminous materials having a minimum viscosity of about 3,000 stokes at the road temperature at the time of test are suitable for use with "Innerbond". Materials of lower viscosity are likely to soak through the mat and give inaccurate results.

A.9 Power

The sprayer must be capable of ascending a 10 per cent (1 in 10) grade with the sprayer tank filled to its maximum calibrated capacity.

In the case of sprayers referred to in Clause 2 (ii) (single engine for propulsion and spraying), the test is conducted as follows:

Controls are set in the "tank circulate" position, and while circulating, the sprayer is driven at a corrected road speed of 200 ft/min, on a level site. The established pump speed for the maximum spray bar length is synchronised and controls locked. The sprayer is then driven on a 10 per cent ascending grade and any variations in road speed, pump speed or pump pressure are noted.

The test is repeated for the "bar circulate" position.

Similar tests are also carried out at a corrected road speed of 600 ft/min with the controls set in the "tank circulate" and "bar circulate" positions.

While ascending the grade, it is only necessary to operate the pump in the "bar circulate" position for approximately five seconds.

A.10 Thermometer

Thermometers can be checked during the thermal test described in Clause A.12. A thermometer of known accuracy is inserted in the checking tube, and is withdrawn and read at intervals of about 14°C (25°F) whilst the contents of the tank are being heated to about 175°C (350°F). Simultaneous readings of the dial thermometer are taken and recorded.

Alternatively, the dial thermometer and element is removed, and the element placed beside a master thermometer in a container of oil which can be heated to about 205°C (400°F) at a rate of 1°C (2°F) per minute. Contact with the bottom or sides of the container must be avoided. Whilst the oil is being heated and stirred, the master thermometer is read at increments of about 14°C (25°F), and simultaneous readings of the thermometer under test are taken and recorded.

A.11 Mixing and Circulation

(*a*) *By Viscosity Measurements*

In this test 20 parts by volume of power kerosene are added slowly to 80 parts by volume of R90 Bitumen (at about 190°C (380°F)) in the sprayer. Circulation is then commenced, and stopped ten minutes later. The viscosities of 10 samples of the mixture, taken at widely spaced points in the tank, are determined and compared with that of a thoroughly mixed laboratory sample of the original ingredients. Further groups of samples are then taken after total mixing times of 20 and 30 minutes, and compared with the laboratory sample. Mixing is considered complete when all samples in one group show cutter oil contents (as determined from viscosity variations) within the limits of 18 and 22 per cent in different parts of the tank.

Note: (1) The sampling points in the tank shall include those at which the minimum movement of material during circulation would be expected.

(2) In order to obtain satisfactory mixing, it may be necessary to operate the pump at about 75 per cent of its maximum output.

(*b*) *By Temperature Measurements*

In this test two quantities of bitumen (each about one-third of a sprayer load) at respective temperatures of about 140°C (280°F) and 205°C (400°F) are added separately to the sprayer in the order indicated. Temperatures are then taken at 10 widely spaced points in the tank, preferably by means of accurate electric measuring equipment. Circulation is commenced, and stopped 5 minutes later. Further temperature recordings are made at all points after total circulation times of 10, 15, 20 and 30 minutes. Mixing is complete when the temperature throughout the tank is substantially uniform.

This test, although simpler and speedier than that given in (a) above, requires correlation with variations in cutter content before permissible temperature variations can be fixed.

A.12 Thermal Test

The sprayer tank is filled with bitumen at approximately 150°C (300°F) and allowed to cool to approximately 135°C (275°F), the load being circulated continuously. The burners are then started, and adjusted so as to raise the temperature of the bitumen at a rate of approximately 0.4°C (0.8°F) per minute or 28°C (50°F) per hour, circulation still proceeding. The burners are extinguished when the temperature reaches about 175°C (350°F).

The tank thermometers are read at intervals of 10 minutes during cooling and heating, but the readings taken during the first half hour of cooling shall be disregarded, as some time is required for the sprayer to absorb heat from the bitumen.

A.13 Spray Nozzle

Testing oil is pumped from a tank through a pipe manifold and returned to the tank. The apparatus is arranged so that the test nozzle can be readily inserted in the manifold, and supplied with testing oil at a pressure which will give the design discharge of the nozzle. Provision is made for quickly cutting off the supply of oil to the nozzle, and also collecting the output of the nozzle in a measuring tank. The number of gallons sprayed by the nozzle in 60 seconds at this pressure is recorded. The nozzle shall be rejected if the discharge varies by more than ± 5 per cent from the design discharge.

A.14 Spray Commencement and Cut-off

A level area about 30 ft long, and 4 ft wider than the maximum width of spray bar, is covered with heavy brown paper. Strips of "Innerbond" each 2 ft wide and 30 ft long are attached longitudinally to the paper in the same manner as in Clause A.8(b). One strip is placed at or near the centre of the spray (but avoiding the sprayer wheels), and the other two are respectively about 2 ft from the edges of the spray.

Bituminous material, as described in the note at the foot of Clause A.8(b) is then sprayed at a rate of about 0.25 gal/sq yd in such a way that spray starts and finishes within the limits of the "Innerbond" mats. The mats are removed and cut transversely into segments 2 in wide, which are then weighed. The net weights of bitumen on successive segments are plotted so as to give longitudinal distribution curves at start and finish of spraying.

September, 1973

METRIC ADDENDUM TO SPECIFICATION FOR PERFORMANCE REQUIREMENTS FOR MECHANICAL SPRAYERS OF BITUMINOUS MATERIALS — 1969

General
Delete all reference to temperature in degrees Fahrenheit.

Page 2, Clause 4(b) (ii)
In line 5 *substitute* litres *for* Imperial gallons.

Page 4, Clause 7(d)
In line 5 *substitute* 75 mm *for* 3 in.

Page 5, Clause 7(j)
In line 2 *substitute* litres *for* Imperial gallons.
In line 14 *substitute* 500 litres *for* 100 gal.
In line 15 *substitute* 100 litres *for* 20 gal; and 3 kilolitres *for* 600 gal.
In line 16 *substitute* 50 litres *for* 10 gal.
In line 18 *substitute* 100 mm *for* 4 in.

Page 6, Clause 8(b)
In line 8 *substitute* 150 mm *for* 6 in.

Page 7, Clause 9(b)
In line 21 *substitute* 180 litres/min *for* 40 gal/min.

Page 7, Clause 9(c)
In line 4 *substitute* 600 kPa *for* 90 lb/sq in.
In line 5 *substitute* 2 MPa *for* 300 lb/sq in.

Page 8, Clause 9(d)
In line 4 *substitute* 3 mm *for* $\frac{1}{8}$ in.

Page 8, Clause 9(f)
In line 2 *substitute* 150 kPa *for* 20 lb/sq in.

Page 9, Clause 10(a)
In line 8 *substitute* 150 mm *for* 6 in.

Page 9, Clause 10(b)
In line 12 *substitute* 10 kPa *for* 2 lb/sq in.
In line 13 *substitute* 150 mm *for* 6 in.
In line 17 *substitute* 2 kPa *for* ¼ lb/sq in.
In line 18 *substitute* 200 kPa *for* 25 lb/sq in.
In line 19 *substitute* 250 mm *for* 10 in.
In line 24 *substitute* 5 kPa *for* 1 lb/sq in; and 200 kPa *for* 30 lb/sq in.
In line 25 *substitute* 150 mm *for* 6 in.

Page 10, Clause 10(c) (i)
After the second sentence insert the following, "Should the spray nozzle valve be power operated a manual control for the valve should be provided".
In line 15 *substitute* 2·5 m *for* 8 ft.

Page 11, Clause 10(c)
In line 6 *substitute* 3·7 m *for* 12 ft.
In line 13 *substitute* "230 mm and 280 mm" *for* "10 and 12 in", respectively.

Page 11, Clause 10(e)
In line 4 *substitute* 600 mm *for* 2 ft.

Page 11, Clause 10(f)
In line 4 *substitute* "at 600 kPa" *for* "of 90 lb/sq in."
In line 5 *substitute* 2 MPa *for* 300 lb/sq in.

Page 12, Clause 11(a)
In line 5 *substitute* 0·3-3·0 l/m^2 *for* 0·05-0·50 gal/sq yd.
In line 7 *substitute* "450 m/min (or 27 km/h)" *for* "1500 ft/min (or 17 miles per hour)".

Page 12, Clause 11(b)
In line 2 *substitute* "metres per minute" *for* "feet per minute".
In line 9 *substitute* 0-450 m/min *for* 0-1500 ft/min.
In line 10 *substitute* 5m/min *for* 20 ft/min.
In line 11 *substitute* 50 m/min *for* 100 ft/min.
In line 12 *substitute* 30 mm *for* ¼ in.
In line 19 *substitute* metres *for* feet.

Page 13, Clause 12(a)

In line 7 *substitute* 50 mm *for* 2 in.

In line 8 *substitute* 150 mm *for* 6 in.

Page 13, Clause 12(a) (i)

In lines 1 and 3 *substitute* 50 mm *for* 2 in.

Page 13, Clause 12(a) (ii)

In lines 2 and 3 *substitute* 50 mm *for* 2 in.

Page 13, Clause 12(a) (iii)

In lines 2 and 3 *substitute* 50 mm *for* 2 in.

Page 14, Appendix, Clause A.1

In line 4 *substitute* "(see Clause A15 of this Appendix)" *for* "... of a viscosity determined by the Authority but within the range 30-70 centistokes".

Page 14, Clause A.4

In line 5 *substitute* "in appropriate increments" *for* "with weights in increments of 5 lb."

In line 6 *substitute* mass *for* weight.

Page 15, Clause A.5

In line 3 *substitute* "100 litres or 50 litres *for* sprayers less than 3 kl capacity" *for* "20 gal (or 10 gal in the case of sprayers of less than 600 gal capacity)".

Page 15, Clause A.6

In line 3 *substitute* Clause A.15 *for* Clause A.1.

In line 8 *substitute* litres per minute *for* gallons per minute.

Page 16, Clause A.7

In line 24 *substitute* 150 m/min *for* 500 ft/min.

In line 24 *substitute* 6 m *for* 20 ft.

In line 26 *substitute* 30 m/min *for* 100 ft/min.

Page 16, Clause A.8

In line 2 *substitute* "suitable" *for* "absorbent plastic".

Page 16, Clause A.8(a)

In line 1 *substitute* "about 8·5 m long and 600 mm wide" *for* "about 28 ft long and 2 ft wide".
In line 2 *substitute* approximately 50 mm *for* 2 in.
In line 4 *substitute* "approximately 500 mm deep by 150 mm diameter" *for* "approximately 21 in deep by 6 in diameter".
In line 8 *substitute* 250 mm *for* 10 in.

Page 17, Clause A.8(b)

In line 2 *substitute* 600 mm *for* 2 ft; and 1·2 m *for* 4 ft.
In line 4 *substitute* about 1m *for* 3 ft.
In line 5 *substitute* 550 mm *for* 22 in.
In line 7 *substitute* 25 mm *for* 1 in.
In line 10 *substitute* about 1 m *for* 3 ft.
In line 12 *substitute* 50 mm *for* 2 in.
In line 22 *substitute* "about 1 m^2" *for* "3 ft wide and about 3 ft long".

Page 18, Clause A.8(b)

In line 32 *substitute* 50 mm *for* 2 in
In line 33 *substitute* "... and after allowing for the mass of the Innerbond the quantities ..." *for* "... and after deducting the tare weights of the 'Innerbond' the weights ...".

Page 18, Clause A.9

In line 7 *substitute* 60 m/min *for* 200 ft/min.
In line 14 *substitute* 180 m/min *for* 600 ft/min.

Page 18, Clause A.10

In line 3 *substitute* 15°C *for* 14°C.
In line 12 *substitute* 15°C *for* 14°C.

Page 19, Clause A.12

In line 5 *substitute* "0·5°C/min or 30°C/h" *for* "0·4°C (0·8°F) per minute or 28°C (50°F) per hour".

Page 20, Clause A.13

In line 7 *substitute* litres *for* gallons.

Page 20, Clause A.14

In line 1 *substitute* "about 10 m long and 1·2 m wider" *for* "about 30 ft long, and 4 ft wider".
In line 3 *substitute* "600 mm wide and 10 m long" *for* "2 ft wide and 30 ft long".
In line 6 *substitute* 600 mm *for* 2ft.
In line 9 *substitute* 1·5 l/m^2 *for* 0·25 gal/sq yd.
In line 12 *substitute* 50 mm *for* 2 in.
In line 12 *substitute* quantities *for* net weights.

Page 21, Add the following new clause:

A.15 FLUID FOR TESTING AND CALIBRATING BITUMEN SPRAYERS

The testing fluid shall have similar characteristics to that of bitumen at its best spraying temperature.

The viscosity of the fluid shall be within the range of 65-95 centistokes at a temperature to suit the ambient temperature normally experienced at the testing site. Both the viscosity and temperature to be used in the test shall be nominated by the state road authority.

The density of the fluid shall be between 0·86 and 0·94 g/ml and the surface tension between fluid and air shall be between 24×10^{-6}N/mm and 33×10^{-6}N/mm at the nominated temperature.

The temperature at which the testing fluid is used shall be within 8°C of the nominated temperature mentioned above.

NOTE: Suitable methods for testing the fluid are specified in:

Viscosity	ASTM D445
Density	ASTM D1298
Surface Tension	Either Nellesteyn's Method or ASTM D971-50

ASPHALT SURFACE TREATMENTS

AND

ASPHALT PENETRATION MACADAM

THE ASPHALT INSTITUTE

Second Edition *November 1969*

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MANUAL SERIES NO. 13 (MS-13)

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CONTENTS

Chapter I

INTRODUCTION

1.01 ASPHALT SURFACE TREATMENTS.— Asphalt surface treatment is a broad term embracing several types of asphalt and asphalt-aggregate applications, usually less than one inch thick, to any kind of road surface.

Properly constructed, asphalt surface treatments are economical, easy to place and long lasting. By waterproofing the base they maintain adequate foundation support but of themselves they add little structural strength to pavements.

The types of surface treatment range from single, light applications of liquid asphalt to multiple surface courses made up of alternate applications of asphalt and aggregate. They all seal and add life to road surfaces but each type has one or more special purposes.

This manual is a guide to the proper design and construction of surface treatments. As such, it describes the materials and equipment and explains the surface treatment processes. The appendices contain design methods, suggested specifications, and other useful information pertaining to asphalt surface treatments.

1.02. TYPES OF ASPHALT SURFACE TREATMENTS.—

(1) **Single Surface Treatments.** A single application of asphalt to any kind of road surface followed immediately by a single layer of aggregate of as uniform size as practicable. The thickness of the treatment is about the same as the nominal maximum size aggregate particles. A single surface treatment is used as a wearing and waterproofing course.

(2) **Multiple Surface Treatment.** Two or more surface treatments placed one on the other. The aggregate maximum size of each successive treatment is usually one-half that of the previous one, and the total

thickness is about the same as the nominal maximum size aggregate particles of the first course. Or, a multiple surface treatment may be a series of single treatments that produces a pavement course up to one inch or more. A multiple surface treatment is a denser wearing and waterproofing course than a single surface treatment, and it adds *some* strength.

(3) **Seal Coat.** A thin surface treatment used to improve the texture of and waterproof an asphalt surface. Depending on the purpose, seal coats may or may not be covered with aggregate. The main types of seal coats are aggregate seals, fog seals, emulsion slurry seals, and sand seals.

a. *Aggregate Seal.* Usually the same as single surface treatment—(1) above.

b. *Fog Seal.* A light application of slow-setting asphalt emulsion diluted with water. It is used to renew old asphalt surfaces and seal small cracks and surface voids. The emulsion is diluted with an equal amount of water and sprayed at the rate of 0.1 to 0.2 gallon (of diluted material) per square yard, depending on the texture and dryness of the old pavement.

c. *Emulsion Slurry Seal.* A mixture of slow-setting asphalt emulsion, fine aggregate, mineral filler, and water. It is used to fill cracks and scaled areas of old pavements to restore a uniform surface texture and to seal the surface to prevent moisture and air intrusion into the pavement.

d. *Sand Seal.* An application of asphaltic material covered with fine aggregate. It may be used to improve the skid resistance of slippery pavements and to seal against air and water intrusion.

(4) **Prime Coat.** An application of low viscosity liquid asphalt to an absorbent surface. It is used to prepare an untreated base for an asphalt surface. The prime penetrates into the base and plugs the voids, hardens the top and helps bind it to the overlying asphalt course.

(5) **Tack Coat.** A very light application of liquid asphalt, usually asphalt emulsion diluted with water. It is used to insure a bond between the surface being paved and the overlying course.

(6) **Dust Laying.** Liquid asphalt usually SC-70, MC-30, MC-70 or diluted slow-setting emulsion, sprayed on an untreated surface to prevent dust. The asphalt and its diluent penetrate and coat the fine particles to relieve the dust nuisance temporarily. This treatment also is called dust palliative.

(7) **Road Oiling.** Similar to dust laying except that usually it is done as a part of a planned build-up of low-cost road surfaces over several years. Each application of asphalt may be mechanically mixed with the material being treated or it may be allowed to penetrate.

(8) **Mixed-in-Place Surface Treatment.** A course produced by mixing mineral aggregate and liquid asphalt with travel plants, blade graders, drags or special road mixing equipment. The principal advantage of mixing-in-place is that it utilizes aggregate already on the roadbed, or which is available from nearby sources. For more information about mixed-in-place surface treatments see *Asphalt Mixed-in-Place (Road-Mix) Manual* (MS-14), The Asphalt Institute.

(9) **Plant-Mixed Surface Treatments.** A layer, less than one inch thick, of aggregate that is coated with asphalt in a plant. Plant-mixed surface treatments are used extensively for providing skid-resistant surfaces. For additional information refer to *The Asphalt Handbook* (MS-4), *Construction Specifications for Asphalt Concrete and Other Plant-Mix Types* (SS-1), the *Asphalt Plant Manual* (MS-3), and *Thin Hot-Mix Wearing Courses* (MISC-68-3), The Asphalt Institute.

1.03 USES OF SURFACE TREATMENTS.—Surface treatments are used to:

(1) **Provide a Low-Cost, All-Weather Surface.** For traffic volume in the light and medium category,

a surface treatment on a granular base will provide a long-lasting, economical surface.

(2) **Waterproof.** To give its best service, a pavement should prevent surface water from penetrating into the foundation courses. Surface treatments are widely used to prevent surface water from penetrating granular bases and old pavements that have become weathered or cracked.

(3) **Bind the Base to the Overlying Course.** Granular bases should be treated with prime coats to insure adherence to the overlying asphalt courses by plugging voids, coating and bonding loose mineral particles, and hardening the surface.

(4) **Provide a Skid-Resistant Surface.** Pavements that have become slippery because of wear and polishing of surface aggregates may be surface treated with sharp, hard aggregate to restore skid resistance.

(5) **Give New Life to Dry, Weathered Surfaces.** A pavement that has weathered to a point where raveling might occur can be restored to useful service by application of a fog seal or an asphalt-aggregate surface treatment.

(6) **Provide a Temporary Cover for a New Base.** Sometimes it is desirable to have a new base course go through a winter so that any weak spots will show up and be corrected before the final surface is placed. A surface treatment makes a fine temporary cover. Also, in planned stage construction a surface treatment often is used until the final asphalt courses are placed.

(7) **Reinforce Pavement.** Older pavements which need some strengthening because of increased traffic conditions often can be salvaged by preventing disintegration with multiple surface treatments.

(8) **Control Dust.** Dust from untreated road surfaces can be controlled effectively with light liquid asphalts or diluted slow-setting asphalt emulsions.

(9) **Guide Traffic.** Surface treatments with aggregate of different color than the main pavement provide demarcation between shoulder sections and traffic lanes.

(10) **Improve Night Visibility.** Where proper lane markings are not provided, surface treatments with light reflecting aggregate may be used to improve visibility at night.

1.04 ASPHALT PENETRATION MACADAM.—Asphalt penetration macadams are not surface treatments. The construction procedures for the two are so similar, however, that specifications for both are included in Appendix D. The general information in this publication covering materials, equipment, survey of the project, repair of defects, and preparation for construction applies also to penetration macadam. And much of the information in the section on surface treatment operation is applicable to penetration operation—priming, transverse and longitudinal joints, removing excess aggregate, and traffic control.

Chapter II

MATERIALS AND EQUIPMENT

2.01. INTRODUCTION.—The proper materials and equipment, correctly used, will combine to make good surface treatments. The exact amount and grade of asphalt coupled with the correct quantity and type of mineral aggregates will perform the functions discussed in Chapter I. The pavement structure, however, must have adequate load-supporting capacity and the proper equipment and construction methods must be used in the work.

A. Materials

2.02. ASPHALT.—To select the proper grade of asphalt for a surface treatment, consideration should be given to:

(1) Temperature of the surface to which asphalt will be applied
(2) Air temperatures
(3) Humidity and wind
(4) Condition of the surface
(5) Type and condition of the aggregate to be applied
(6) Equipment to be used

The correct grade of asphalt for the surface treatment will:

(1) When applied, be fluid enough to spray properly and cover the surface uniformly
(2) After application, retain the proper consistency to wet the applied aggregate
(3) Cure and develop adhesion quickly
(4) After rolling and curing, hold the aggregate tightly to the road surface to prevent dislodgment by traffic
(5) When applied in the right amount, not bleed or strip with changing weather conditions.

The proper grade of liquid asphalts, including asphalt emulsions, will satisfy these requirements. In hot, dry weather, the softer grades of asphalt cement are quite satisfactory when dry aggregate is placed immediately after spraying. More specifically, rapid-curing liquid asphalts, rapid-setting emulsions, and the 120 to 150 and 200 to 300 penetration asphalt cements are usually best suited for most surface treatments.

NOTE

In some areas persistent difficulty in retaining aggregate has been experienced with 200-300 penetration asphalt cements. Where this has occurred, the use of 200-300 penetration asphalt cements is not recommended.

Medium-curing liquid asphalts can be used successfully provided sufficient curing time is permitted before traffic is allowed on the treatment. Quite often in hot, arid climates where the kerosene-type cutter stock will evaporate rapidly, or in special applications such as priming of granular bases, medium-curing liquid asphalt may be quite useful.

Slow-setting asphalt emulsions are used in the slurry seal type of treatment.

Table II-1 suggests types of asphalt for use in various surface treatments.

2.03 CONTROL OF ASPHALT SPRAYING TEMPERATURES.—Asphalt is a thermoplastic material that becomes more liquid (decreases in viscosity) with increasing temperatures. The spraying temperature then should be selected carefully because the ability to spray at a certain temperature (temperature-viscosity relationship) is not always the same for different types and

TABLE II-1—TYPES OF ASPHALT FOR SURFACE TREATMENTS

Types of Construction	Asphalt Cements		Liquid Asphalts																							
			Rapid Curing (RC)				*Medium Curing (MC)*					*Slow Curing (SC)*				*Emulsified (Anionic)*					*Emulsified (Cationic)*					
	120/150	200/300	70	250	800	3000	30	70	250	800	3000	70	250	800	3000	RS-1	RS-2	MS-2	SS-1	SS-1h	CRS-1	CRS-2	CMS-2s	CMS-2	CSS-1	CSS-1h
Surface Treatments With Cover Aggregates	X	X	X	X	X	X			X	X	X			X	X	X	X				X	X				
Seal Coats	X	X	X	X	X	X		X	X	X	X					X	X		X[1]	X[1]	X	X			X[1]	X[1]
Slurry Seal																			X	X					X	X
Fog Seal																				X[2]						X[2]
Tack Coat			X													X[2]			X[2]	X[2]	X[2]				X[2]	X[2]
Prime			X	X			X	X	X			X	X													
Dust Laying							X	X				X							X[2]						X[2]	

[1] *SS grades can be used when sand is used for cover.*
[2] *Water diluted.*

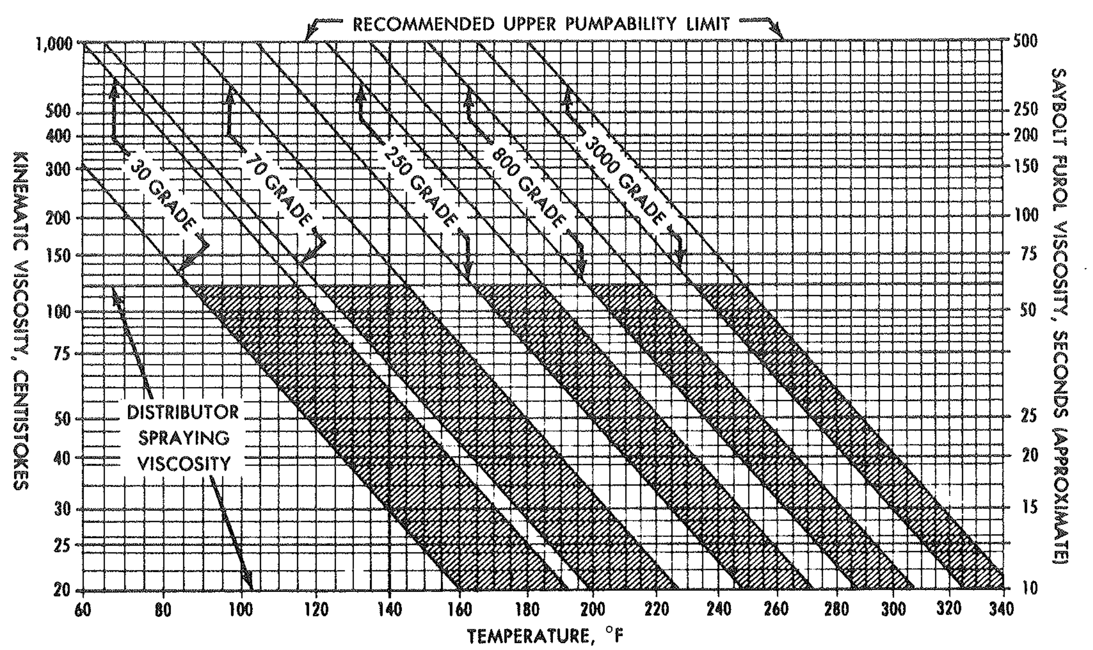

Figure II-1—Temperature-Viscosity for Handling Liquid Asphalts

grades, or for asphalts of the same grade from different sources. The recommended viscosity range for spraying is 20-120 centistokes, kinematic (approximately 10-60 seconds, Saybolt Furol), however, there is no recommended lower limit for prime or tack coating applications. In any case, the lowest viscosity used should be that at which no fogging occurs. The temperatures needed to produce this range of viscosities vary widely. Table II-2 and Figure II-1 show that correct spraying temperature can range from 75°F. to 395°F., depending upon the material used and the recommended limits.

A temperature-viscosity chart is the best method of selecting the temperature that gives the most effective viscosity for spraying. An example is shown in Figure II-3. The correct spraying temperature for the asphalt plotted on the chart is 198°F. ± 34°F.

If, for some reason, a temperature-viscosity chart for the asphalt is not available, Figure II-1 or Table II-2 can be used as a guide to find the range that encompasses the correct spraying temperature.

Refer to *The Asphalt Handbook* (MS-4), The Asphalt Institute, for additional information on asphalts and spraying temperatures. Appendix C of this manual discusses the selection of the proper type and grade of asphalt for the job at hand.

2.04 ASPHALT QUANTITIES REQUIRED.—After a surface treatment has been subjected to traffic for some time the aggregate particles will have oriented into their densest positions. The particles will be lying on their flattest sides and voids between them will usually be about 20 percent of the total volume. The asphalt used for the treatment should fill 60 to 70 percent of this void space. Appendix C of this manual provides a method for finding the quantity of asphalt to use.

2.05. AGGREGATE.—Most hard aggregate such as sand, gravel, crushed stone, and crushed slag can be used successfully for surface treatments. The aggregate selected, however, must meet certain requirements of size, shape, cleanliness, and surface properties.

TABLE II-2—SUGGESTED DISTRIBUTOR SPRAYING TEMPERATURES FOR VARIOUS GRADES OF ASPHALT

Asphalt Cements	275-400°F
Asphalt-Emulsions	
Anionic:	
RS-1	75–130°F
RS-2	110–160°F
MS-2	100–160°F
SS-1	75–130°F
SS-1h	75–130°F
Cationic:	
CRS-1	75–130°F
CRS-2	110–160°F
CMS-2S	100–160°F
CMS-2	100–160°F
CSS-1	75–130°F
CSS-1h	75–130°F

CAUTION

The purpose of Table II-2 and Figure II-1 is to indicate temperature ranges necessary to provide proper asphalt viscosity for spraying applications for the grades of asphalt shown. It *must* be recognized, however, that temperature ranges indicated in Figure II-1 generally are above the minimum flash point for the RC, MC, and SC liquid asphaltic materials as specified by The Asphalt Institute and other agencies. In fact, some of these liquid asphalts will "flash" at temperatures below these indi-

cated ranges. Accordingly, suitable safety precautions are mandatory at all times when handling these liquid asphalts. These safety precautions include, but are not limited to, the following:

(1) Do not permit open flames or sparks of any kind close to these materials except in heating kettles, mixers, distributors, or other equipment designed and approved for handling and applying them.

(2) Do not use an open flame to inspect or examine drums, tank cars or other containers in which these materials have been stored.

(3) Properly vent all vehicles transporting these materials.

(4) Permit only experienced personnel to supervise the handling of these materials.

(5) Comply with all applicable intra- and interstate commerce requirements.

2.06. SIZE OF THE AGGREGATE.—The aggregate should be as close to uniform size as is economically practical so the surface treatment will have only one layer of aggregate. If there is much difference between the largest and the smallest size particles, the asphalt film may completely cover the smaller sizes and prevent proper embedding of the larger particles. If this happens, the courser ones may be whipped off easily by high speed traffic.

Generally, the largest size for a surface treatment aggregate should be no more than twice the smallest size, with a reasonable tolerance for oversize and undersize to allow for economical production.

The maximum size of the aggregate used also will determine the smoothness and quietness of the riding surface. It has been found that aggregates smaller than one-half inch diameter are best for these criteria.

The aggregate for slurry seals is the exception to the

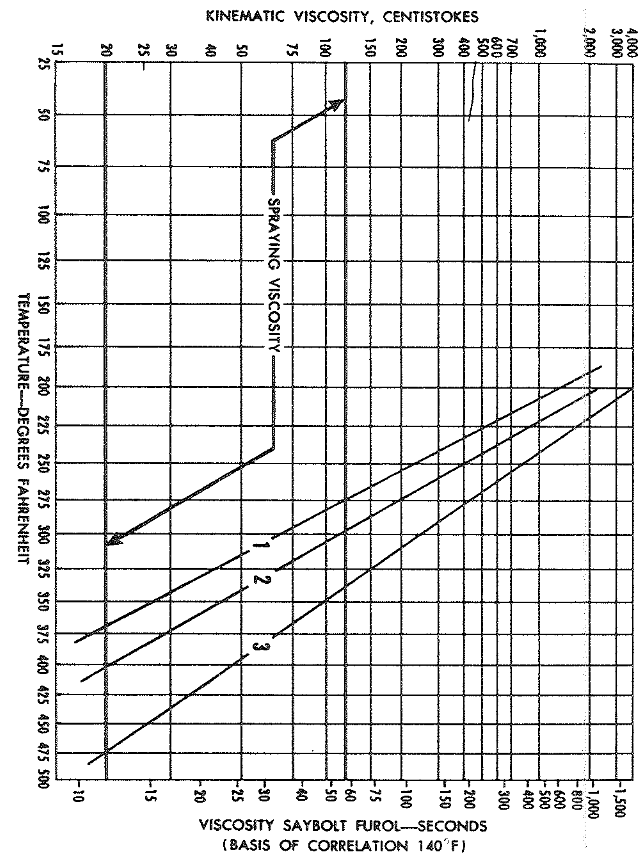

Figure II-2—Representative Temperature Viscosity Curve for 200-300 pen. Asphalt Cements

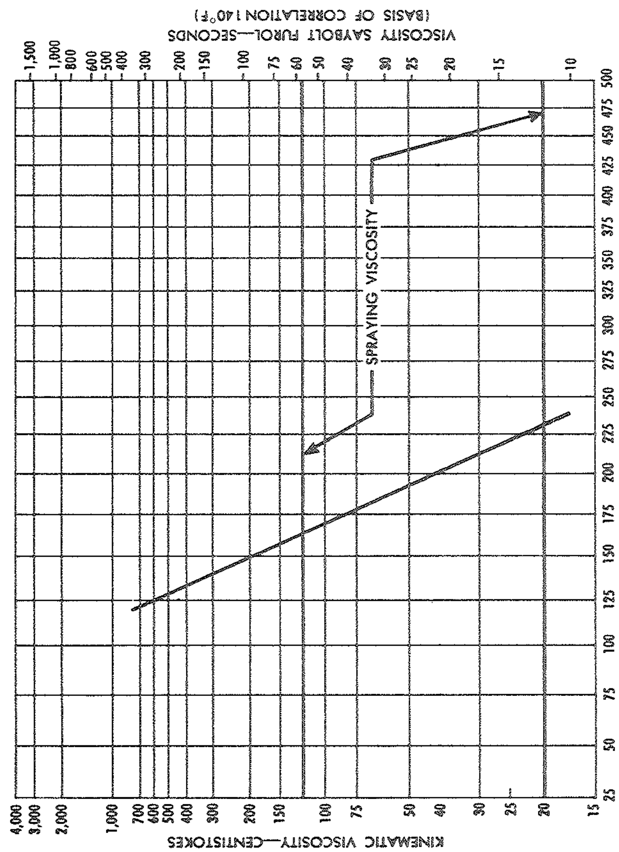

Figure II-3—Temperature-Viscosity Curve for RC-250

one-size principle and the minimum-size limitation. This should be a fine-graded aggregate with a top size of about 0.10 inch (No. 8 sieve) and with up to 15 percent smaller than 0.03 inch (No. 200 sieve) (refer to Appendix D).

2.07 SHAPE OF THE AGGREGATE.—Shape of the particles is important in aggregates for surface treatments—the ideal shape being cubical or pyramidal. A large amount of flat and elongated particles is undesirable because they may be completely covered if enough asphalt is used to hold the cubical particles (see Figure II-4). If all particles are flat and elongated it takes so little asphalt to hold them that control becomes difficult. Figure II-5 illustrates this.

2.08 CLEANLINESS OF THE AGGREGATE.—Clean aggregate is extremely important. If the particles are dusty or coated with silt or clay, the asphalt may not stick as the dust produces a film which will prevent adhesion to the aggregate. Good results cannot be assured with dusty or dirty aggregate.

2.09 ADHESION.—Good adhesion between the aggregate and the asphalt and the ability to retain it are essential to a successful surface treatment. Adhesion, however, is influenced by the many variables described in the preceding sections of this chapter and often there are jobs where ideal conditions cannot be obtained.

For example, wet clean aggregates do not adhere as well as dry clean ones and the best adhesion is obtained when they are hot and dry. Field conditions are such

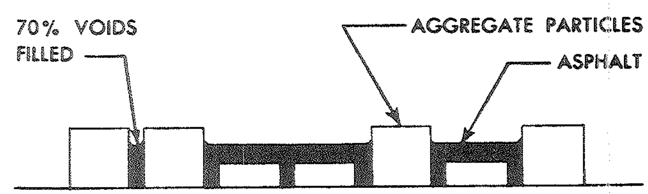

Figure II-4—Flat Particles Are Covered When Enough Asphalt is Used to Hold Cubical Particles

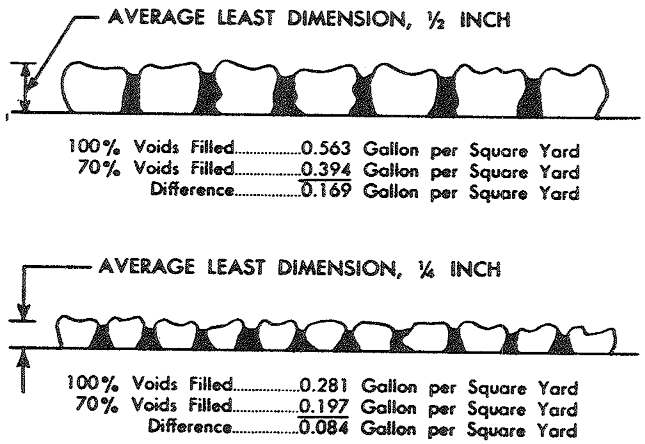

Figure II-5—Surface Treatments With Larger Aggregates are Less Sensitive to Small Variations in Asphalt Application Than When Smaller Aggregates Are Used

that clean cover aggregates will often contain some moisture and must be used this way. This presents no serious field problem when the work is done in warm, dry weather which promotes rapid drying. However, aggregate having free water will seldom provide a satisfactory treatment.

There is some evidence that dusty aggregates give better results when damp. For this reason, dusty aggregates often are moistened when they must be used.

Adhesion between asphalt and aggregate often can be helped by a thin coating of kerosene on the aggregate applied by misting at the rate of one-half to one gallon of kerosene per ton of aggregate while it is being loaded into the trucks by a belt conveyor or from a bin at the plant.

Precoating the aggregate with a very thin film of asphalt usually will solve the dust problem and provide good adhesion of the asphalt to the aggregate. The aggregate is run through an asphalt mixing plant dryer,

cooled to under 200°F., then mixed in the pugmill with about one percent MC-70 to coat each particle thoroughly. The small amount of asphalt does not change the aggregate from a free flowing material which can still be applied with aggregate spreaders. The precoating adds to the cost of the aggregate but the additional cost is often justified by the better results obtained.

2.10 COARSE AGGREGATE.—Coarse aggregate is defined as all mineral material retained on a No. 8 sieve (approximately 0.10 inch). Many agencies are now using the standard sizes of coarse aggregates commonly known as Simplified Practice gradations. These are specified in AASHO Designation: M43 (refer to Appendix D). One-size aggregate requirements, also, are specified in Appendix D.

2.11 FINE AGGREGATE.—Fine aggregate is defined as all mineral matter passing a No. 8 sieve. It may consist of natural or manufactured material.

2.12 AGGREGATE QUANTITIES REQUIRED.—Studies have shown that except under unusual conditions, only one layer of aggregate will stick when it is spread over sprayed asphalt—any amount over that will be wasted. It is, therefore, essential for economy that the quantity of aggregate needed be determined carefully. Methods for selecting the correct amount are explained in Appendix C.

B. Equipment

2.13 GENERAL.—Successful surface treatments depend to a large extent on the equipment used, its condition, and the way it is handled. This is why specifications generally require that the equipment be in good mechanical condition, properly adjusted and free from wear which would impair the quality of the work. But, whether required or not, it is always good practice to make a careful inspection before operations begin to be sure all pieces are clean, calibrated, and in top operating form.

2.14 ASPHALT DISTRIBUTOR.—The most important piece of equipment on a surface treatment is the asphalt distributor. It is made specifically to apply the asphalt product uniformly to a surface in proper quantities and to maintain the specified rate for the entire load, regardless of change in grade or direction.

The asphalt distributor consists of a truck (or trailer) on which is mounted an insulated tank with a heating system, usually oil burning, with heat from the flue passing through the tank. An armored thermometer, located in a well in the side of the tank, is provided for checking the temperature of the asphalt. The distributor also has a power-driven pump which will handle products ranging from light, cold application liquid asphalt to heavy asphalt cements heated to spraying viscosity. At the back end of the tank is a system of spray bars and nozzles through which the asphalt is forced under pressure onto the surface of the road. These spray bars will cover widths from six feet to thirty feet in one pass, depending on the pump capacity.

2.15 NOMENCLATURE.—The major parts of the asphalt distributor, excluding the truck or tractor, are as follows:

(1) **Tank.** The tank, ranging from 800 gallons to 5,500 gallons capacity, is an insulated shell with flues, a thermometer, baffle or surge plates, a manhole and an overflow pipe.

(2) **Burners.** One or two burners are included with a distributor. Each burner throws a direct flame into a heating flue which, in turn, transfers the heat to the asphalt.

(3) **Circulating System.** The circulating system has an engine-driven pump which:

a. Fills the distributor tank

b. Circulates material in the bar and tank

c. Sprays material through the bar or hand spray

d. Draws material back to the tank from the bar or hand spray

e. Pumps material from the tank to outside storage

f. Transfers material from one storage tank to another

(4) **Spray Bar.** Most new distributors are equipped with full circulating spray bars that prevent clogging by keeping asphalt flowing when not spraying. These are two compartment bars, bars with an inner tube, or bars consisting of two pipes. The spray bar has nozzles, usually mounted four inches apart, through which the material is applied to the road surface.

(5) **Controls.** The controls include a valve system which governs the flow of material, a pump tachometer or a pressure gauge which registers pump output, and a bitumeter with an odometer which indicates the number of feet per minute and total distance traveled. Figure II-6 is a cutaway drawing of a typical asphalt distributor showing the interior of the tank, the burners, the pumping system, the spray bar, and the controls.

Table II-3 gives spray nozzle and application data for eight makes of asphalt distributors.

2.16 CALIBRATING THE TANK.—All new distributors have float-type gauges and measuring sticks for indicating the contents of the tank. Most sticks furnished by manufacturers are calibrated in 25 to 50 gallon increments, depending upon tank size, but it often is necessary to check the contents of the tank quite closely. Therefore, a calibration curve should be prepared by the engineer from measurements on the gauge stick so that tank contents can be determined to the nearest five or ten gallons. See Figure II-7 for an example of a calibration curve.

NOTE

The volume of asphalt varies with temperature so most specifications have set 60°F. as the standard for volume measurement of asphaltic material. Appendix G details a method of correcting to the volume at 60°F. from any volume measurement temperature.

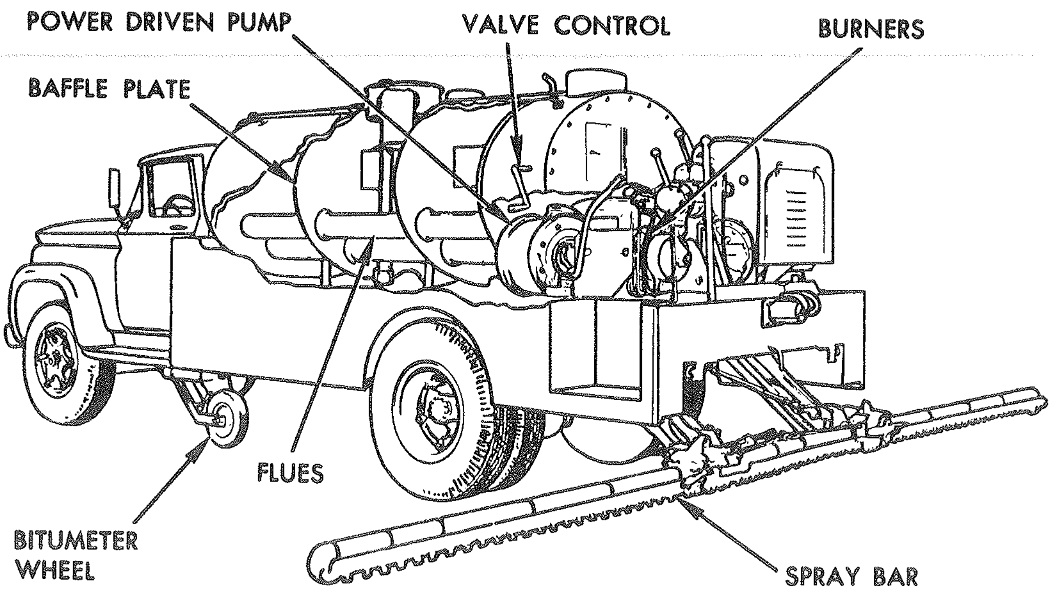

Figure II-6—Distributor

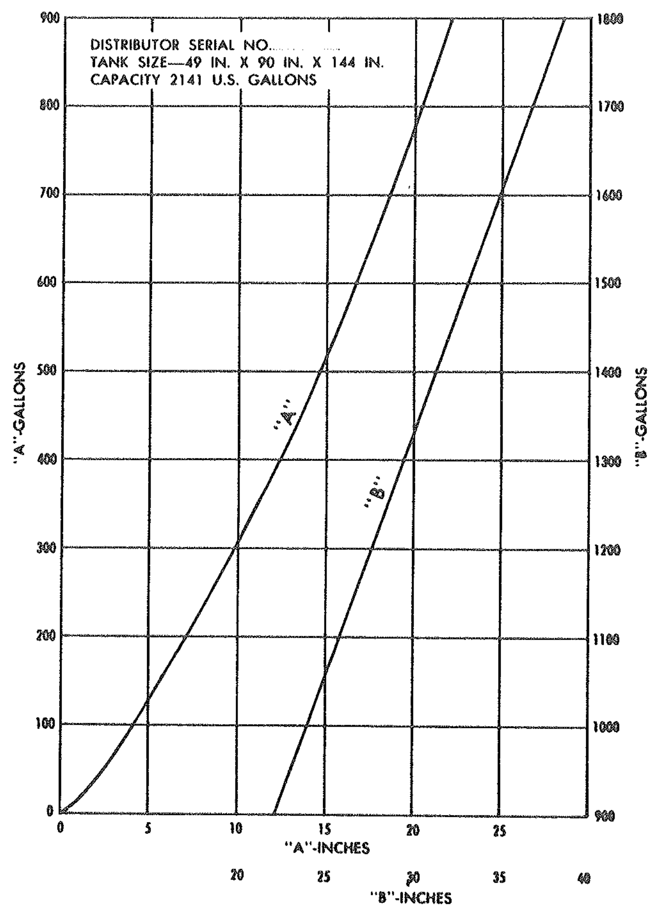

Figure II-7—Tank Calibration Measured from Top of Manhole to Surface of Material

TABLE II-3—ASPHALT DISTRIBUTOR DATA*

Distributor	Nozzle Size	Nozzle Spacing	Nozzle Slot Angle	Nozzle Height Above Road	Pump Discharge—Gals. per Min.—or Pump Speed	Pump Pressure	Application Rate Gal. per Sq. Yd.	Coverage
CHAUSSE	1/16 in.	4 in. 6 in.	45° with Spray Bar	6 in. to 15 in.	95 gals. per min. at 420 RPM	5 to 15 lbs. per sq. in.	Varies with size of Bar and speed of truck	4 in. Center—Triple Lap 6 in. Center—Double Lap
	1/8 in.	4 in. 6 in.	45° with Spray Bar	6 in. to 15 in.	95 gals. per min. at 420 RPM	5 to 15 lbs. per sq. in.	Varies with size of Bar and speed of truck	4 in. Center—Triple Lap 6 in. Center—Double Lap
	5/32 in.	4 in. 6 in.	45° with Spray Bar	6 in. to 15 in.	45 gals. per min. at 420 RPM	5 to 15 lbs. per sq. in.	Varies with size of Bar and speed of truck	4 in. Center—Triple Lap 6 in. Center—Double Lap
	3/16 in.	4 in. 6 in.	45° with Spray Bar	6 in. to 15 in.	45 gals. per min. at 420 RPM	5 to 15 lbs. per sq. in.	Varies with size of Bar and speed of truck	4 in. Center—Triple Lap 6 in. Center—Double Lap
ETNYRE	1/16 in.	4 in.	30° with Spray Bar	12 in.	5 to 7 gals. per ft. of Spray Bar	—	0.03 gal. to 3.0 gals.	Triple Lap
	5/32 in.	4 in.	30° with Spray Bar	12 in.	7 to 10 gals. per ft. of Spray Bar	—	0.03 gal. to 3.0 gals.	Triple Lap
	1/8 in.	4 in.	30° with Spray Bar	12 in.	10 to 15 gals. per ft. of Spray Bar	—	0.03 gal. ot 3.0 gals.	Triple Lap
	3/16 in.	4 in.	30° with Spray Bar	12 in.	12 to 20 gals. per ft. of Spray Bar	—	0.03 gal. to 3.0 gals.	Triple Lap
	S36-5	4 in.	30° with Spray Bar	12 in.	10 to 15 gals. per ft. of Spray Bar	—	0.06 gal. to 3.0 gals.	Quadruple Lap
GRACE—200 Series	1/16 in.	6 in.	60° with Spray Bar	11 in.	100 gals. per min.	35 lbs. per sq. in.	0.05 gal. to 1.0 gal.	Double Lap
	5/32 in.	6 in.	60° with Spray Bar	11 in.	100 gals. per min.	35 lbs. per sq. in.	0.05 gal. to 1.0 gal.	Double Lap
300 Series	1/8 in.	4 in.	60° with Spray Bar	9 in.	325 gals. per min.	35 lbs. per sq. in.	0.05 gal. to 1.0 gal.	Triple Lap
	3/16 in.	4 in.	60° with Spray Bar	9 in.	325 gals. per min.	35 lbs. per sq. in.	0.05 gal. to 1.0 gal.	Triple Lap
LITTLEFORD	1/8 in. Square Slot	4 in.	15° with Spray Bar	10 in. min. 12 in. max.	12½ gals. per ft. of Spray Bar	—	0.05 gal to 3.3 gals.	Triple Lap
	1/8 in. "V" Slot	4 in.	15° with Spray Bar	10 in. min. 12 in. max.	12½ gals. per ft. of Spray Bar	—	0.05 gal. to 3.3 gals.	Triple Lap
ROSCO	No. 0	4 in.	25° with Spray Bar	10 in.	—	10 to 50 lbs. per sq. in.	0.05 gal. to 2.0 gals.	Triple Lap
	No. 1	4 in.	25° with Spray Bar	10 in.	—	10 to 50 lbs. per sq. in.	0.05 gal. to 2.0 gals.	Triple Lap
	No. 2	4 in.	25° with Spray Bar	10 in.	—	10 to 50 lbs. per sq. in.	0.05 gal. to 2.0 gals.	Triple Lap
SEAMAN-GUNNISON	1/8 in.	4 in.	15° with Spray Bar	9 in.	375 gals. per min. at 375 RPM	—	0.1 gal. to 3.0 gals.	Triple Lap
	3/16 in.	4 in.	15° with Spray Bar	9 in.	375 gals. per min. at 375 RPM	—	0.1 gal. to 3.0 gals.	Triple Lap
SOUTH BEND (Municipal)	1/16 in.	4 in. 6 in.	22° with Spray Bar	9 in. min. 11 in. max.	90 gals. to 375 gals. per min.	20 to 40 lbs. per sq. in.	0.1 gal. to 3.0 gals.	Triple Lap
	1/8 in.	4 in. 6 in.	22° with Spray Bar	9 in. min. 11 in. max.	90 gals. to 375 gals. per min.	20 to 40 lbs. per sq. in.	0.1 gal. to 3.0 gals.	Triple Lap
	3/16 in.	4 in. 6 in.	22° with Spray Bar	9 in. min. 11 in. max.	90 gals. to 375 gals. per min.	20 to 40 lbs. per sq. in.	0.1 gal. to 3.0 gals.	Triple Lap
STANDARD	1/16 in.	4 in.	45° with Spray Bar	9 in.	375 gals. per min. at 675 RPM	50 lbs. per sq. in.	0.1 gal. to 1.0 gal.	Triple Lap
	5/32 in.	4 in.	45° with Spray Bar	9 in.	375 gals. per min. at 675 RPM	50 lbs. per sq. in.	0.1 gal. to 1.0 gal.	Triple Lap

* Furnished by the manufacturers.

An opening and guide for the gauge stick must be provided in the top center of the tank to minimize errors due to tilting. A capped 1½ inch pipe, six or eight inches long, passing through the insulated roof serves very well. If the dome of the tank is in the center, a template or guide for the gauge stick which fits across the manhole opening may be used. Or the stick can be held vertically against the side of the manhole, using the top of the rim as a reference.

If a gauge stick is not available for the distributor, one can be made of brass (1 inch × 3/16 inch) and calibrated in the following manner:

(1) The distributor is emptied completely.

(2) A container is calibrated to measure exactly ten gallons.

(3) The distributor is leveled, both longitudinally and transversely, using a spirit level.

(4) The tank is filled with water in ten-gallon increments. After each increment is added, the water in the tank must be allowed to settle to a quiet surface. Then the gauge stick is carefully lowered, centered and plumb, to just touch the surface of the liquid. The stick is then marked at a reference line on the guide.

(5) When the calibration has been completed all water is drained from the distributor.

CAUTION

Although the distributor is completely drained, some water may remain trapped in a valve or pipe. This is not hazardous when liquid asphalt is to be used immediately, but if the distributor is to be used for applying asphalt cement, even a small amount of water is a serious hazard as the hot asphalt will cause it to boil with near explosive force. It is advisable to flush the distributor with oil or cutback following calibration.

2.17 ALTERNATE METHODS OF CALIBRATION.—If it is more convenient, the calibration procedure can be reversed. The tank is completely filled with water, and the gauge stick is marked as described above as the water is drawn out in 25 gallon increments. By this method the total quantity (and hence the quantities at each mark on the stick) will be known only when the tank is again empty.

A calibration chart, prepared from the measurements on the stick, is then used to calibrate the gauge stick to ten-gallon increments.

Another method of calibration can be used if an accurate flow meter is available. The tank is filled in increments of one-half inch or one inch, the flow stopped and the meter reading recorded at each increment. The recorded figures are used as the basis for the calibration chart.

2.18 SELECTING NOZZLE SIZE.—One of the most important parts of the distributor is the spray bar, for through the spray nozzles the proper quantity of asphalt must be spread uniformly on the road surface. To achieve good results then, correctly sized nozzles for job conditions must be selected. For example, if nozzles are too large for the desired application, pulsation of the spray may occur. This results in uneven longitudinal spreading of the asphalt.

Each distributor manufacturer has specific recommendations for the size of spray nozzles to use for different applications. The manufacturer's recommendation should be used in choosing the correct nozzle size.

All nozzles selected for use at any one time should have the same size opening.

2.19 PROPER PRESSURE.—The spray bar must have a constant, uniform pressure along its entire length for equal output from all nozzles.

Although several methods may be used to maintain pressure, all distributors use gear-type pumps to deliver asphalt to the spray bar. On some distributors pressure is governed by variable pump speed and on others by constant pump speed and a pressure relief valve. Each application should be checked, using the method recommended by the manufacturer.

The correct pump speed or pressure will neither atomize the asphalt nor distort the spray fan. Too low a pressure will result in streaking from a non-uniform discharge of material from the individual nozzles. Too high a pressure, in addition to atomizing the asphalt, will distort the spray fan.

When a metering system is used, the manufacturer supplies the distributor with charts for finding the proper pump speed for each application rate.

When a pressure relief valve is used, the pump runs at a constant speed and the pressure is automatically held in the spray bar. The manufacturer supplies charts for determining the discharge in gallons per minute for each size nozzle, the proper truck speeds for various application rates and the corrections for temperature-viscosity variations.

2.20 SPRAY BAR HEIGHT.—Probably the most important adjustment to assure uniformity of spread of asphalt is the height of the spray bar above the pavement surface. It is important, too, to maintain the correct height during the entire application.

If the spray bar is too low or too high, streaking will result.

The best results with four-inch nozzle spacing will come from an exact triple lap of the spray fans. But with six-inch nozzle spacing, the height of bar necessary to give a triple lap will frequently cause wind distortion of the spray fans, resulting in non-uniform application; a double lap is therefore recommended for six-inch nozzle spacing.

A simple test procedure has been devised which will assure the proper height setting of a spray bar with four-inch nozzle spacing. It is based on the fact that, by visual inspection, one can determine whether or not an exact single lap, or single film, of asphalt is being applied.

To begin, the second and third, fifth and sixth, eighth and ninth, etc., nozzles are closed, using the center sec-

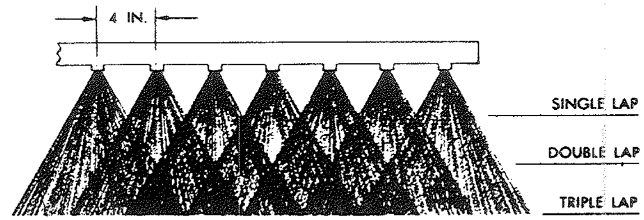

Figure II-8—Perfect Triple Lap

tion of the bar only. The distributor is then operated at the correct pump speed or pressure with the spray bar height changed not more than one-half inch at a time. When an even single film of asphalt, heated to the proper spraying viscosity, is applied to the surface, it will give a uniform triple lap with all nozzles operating.

Double lap coverage involves the same procedure as above except that every other nozzle is left open; the remaining ones are shut off. If the distributor has already been checked for double lap coverage, increasing the spray bar height by 50 percent will give triple lap coverage.

2.21 MAINTAINING PROPER SPRAY BAR HEIGHT.—For best results, the height of the spray bar above the pavement surface should not vary more than one-half inch. The bar will not stay within this tolerance, however, unless the manufacturer or the contractor takes special steps to assure it. As the asphalt leaves the spray bar, the load lightens and the springs raise the distributor. If there is an appreciable amount of deflection in the springs, the spray bar can rise as much as four inches, resulting in an uneven application.

Excess vertical movement of the spray bar can be corrected in several ways. After the bar height is adjusted with a full load in the tank, the frame of the distributor can be tied down to the axle during the spreading runs. If it is a truck-mounted distributor and has an adjustable-type spray bar, mechanical controls can be supplied by the manufacturer to maintain the proper height, regardless of the deflection in the springs. On trailer-mounted distributors, bar height control is not necessary because of the small deflection of trailer springs. In any event, the height of the bar should be checked after each run and any necessary adjustment made at that time.

2.22 PROPER NOZZLE ANGLE.—The angle of the long axis of the nozzle openings must be adjusted so that the spray fans will not interfere with each other. The nozzle angle will vary according to the make of distributor. The angle recommended by The Asphalt Institute, measured from the spray bar axis, is from 15 degrees to 30 degrees. Figure II-9 illustrates nozzle angle setting.

The various manufacturers usually furnish special wrenches for setting the angle of the nozzles. The use of these wrenches is recommended as it is extremely difficult to obtain a uniform spread with visually set nozzles.

NOTE

The end nozzles are often set at a different angle (60 degrees to 90 degrees with respect to the spray bar) from the other nozzles to get a good edge. *This practice should not be permitted as it will produce a fat streak on the edge and rob the adjacent spray fan of the lap from this nozzle.* A curtain on the end of the bar or a special end nozzle with all nozzles set at the same angle will provide more uniform coverage and make a better edge.

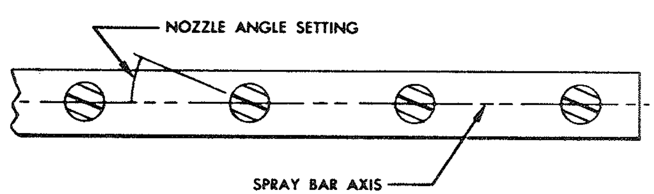

Figure II-9—Proper Nozzle Angle Setting

At the time the angle of the nozzles is set, the edges of the nozzle openings should be inspected to see that they are not damaged. A nicked or otherwise damaged edge will produce a distorted fan of asphalt.

2.23 CHECKING THE BITUMETER.—A Bitumeter consists of a rubber-tired wheel, mounted on a retractable frame, with a cable leading to a circular dial in the cab of the vehicle. (See Figure II-10.) The dial registers the rate of travel in feet per minute and trip and total distance in feet. At least one manufacturer furnishes a dial that registers the application rate in gallons per square yard in addition to travel in feet per minute.

The bitumeter should be checked at regular intervals to insure accurate registering of speeds when the distributor is spraying asphalt. To check the bitumeter, a distance of 500 feet to 1,000 feet is marked off accurately on a straight and level length of road. The distributor is driven at constant speed over this length and the trip is timed with a stopwatch. Then the speed in feet per minute is calculated and compared with the bitumeter dial reading recorded during the run. This procedure is repeated for a number of other speeds, bracketing the speed to be used for spraying.

The errors found at the various speeds are tabulated or plotted on a graph so that they can be readily applied when using the distributor.

The bitumeter wheel must be kept clean to insure accurate registering of the truck speed. A build-up of asphalt on the wheel will produce an error.

Appendix A shows how to find the distributor speed needed for any rate of application.

2.24 CHECKING TRANSVERSE SPREAD.—Transverse spread should be allowed to vary no more than 15 percent for asphalt emulsions and no more than 10 percent for asphalt cements or heavier grades of liquid asphalts. To assure the correct application, the distributor must be calibrated before it is used and a maximum variation set by the engineer. Then, the trans-

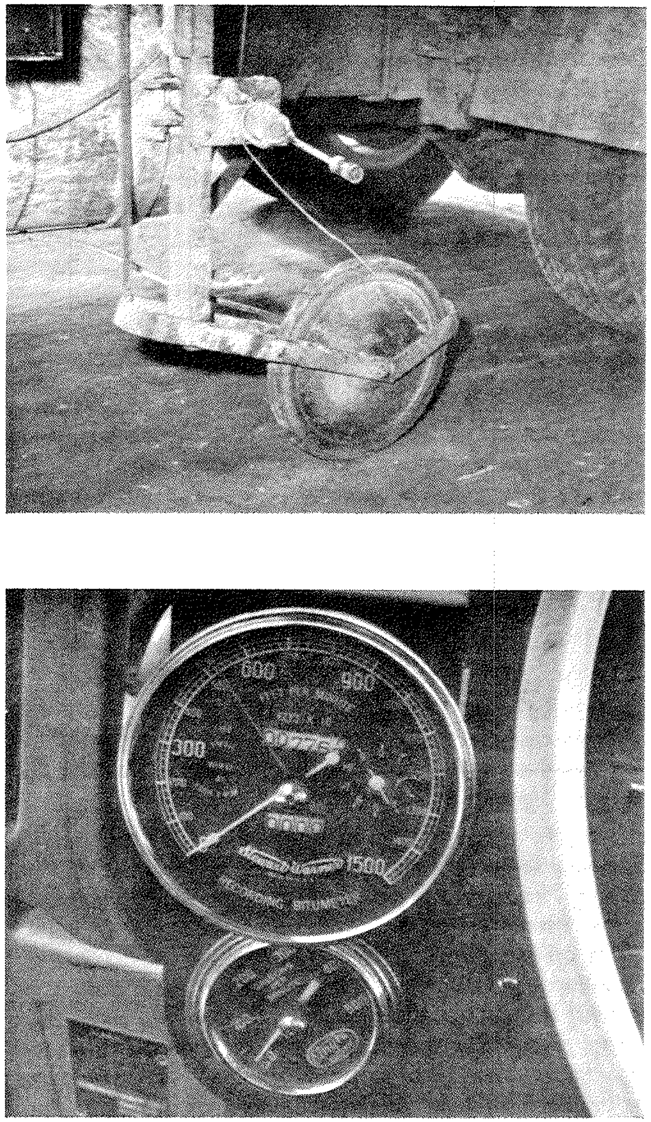

Figure II-10—Bitumeter Wheel and Bitumeter Dial

verse spread should be checked periodically to determine if the distributor is operating within these limits.

A procedure for checking transverse spread in the field with a minimum of testing equipment and asphalt was developed by the California Division of Highways.* This procedure, resembling a method developed in South Africa, has been used on a number of jobs and has been found to be quite accurate. It can be performed during surface treatment operations with little interference to the work. The transverse spread is determined from samples caught on four-inch by eight-inch cotton pads** (or two-inch by eight-inch if greater accuracy is desired) glued to sheets of paper which, in turn, are attached to strips of sheet metal and placed across the pavement. The cotton fibers prevent the asphalt from flowing. The pads with the attached sheets of paper are weighed before placing on the road and are removed after passage of the distributor and weighed again to determine quantities. The pads then can be discarded. Figure II-11 shows the results of a typical transverse spread check. Appendix E contains a tentative method for determining distributor spread rate.

2.25 CHECKING LONGITUDINAL SPREAD.—The longitudinal spread should not vary more than 10 percent for any type of asphalt binder and the distributor's longitudinal application rate should also be checked. This can be done by taking samples in 12-inch by 12-inch shallow metal pans placed at 100 to 150-foot intervals along the road. The pans are lined with heavy wrapping paper. A ¼-inch lip around the edge of the pan helps to hold the paper liner in place and also prevents the collected asphalt from running out. Quantities are determined by weighing the pans with paper liners before and after the pass of the distributor. Figure II-12 shows the results of a typical longitudinal spread check.

* *"Seal Coats: Laboratory Contributions Toward Better Performance," by Ernest Zube, Bulletin 215, Highway Research Board, 1959.*

** *Multigraph machine cleaning pads.*

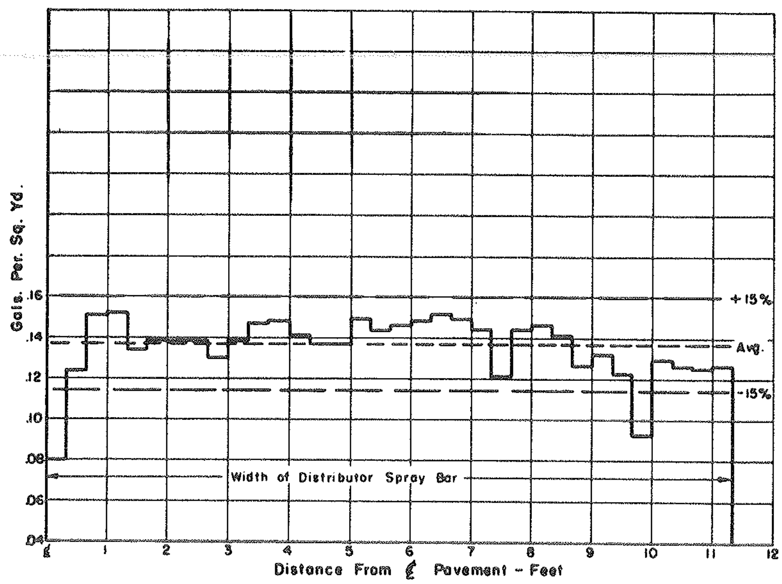

Figure II-11—Transverse Variation in Spread Rate of Asphalt Binder
—Courtesy California Division of Highways

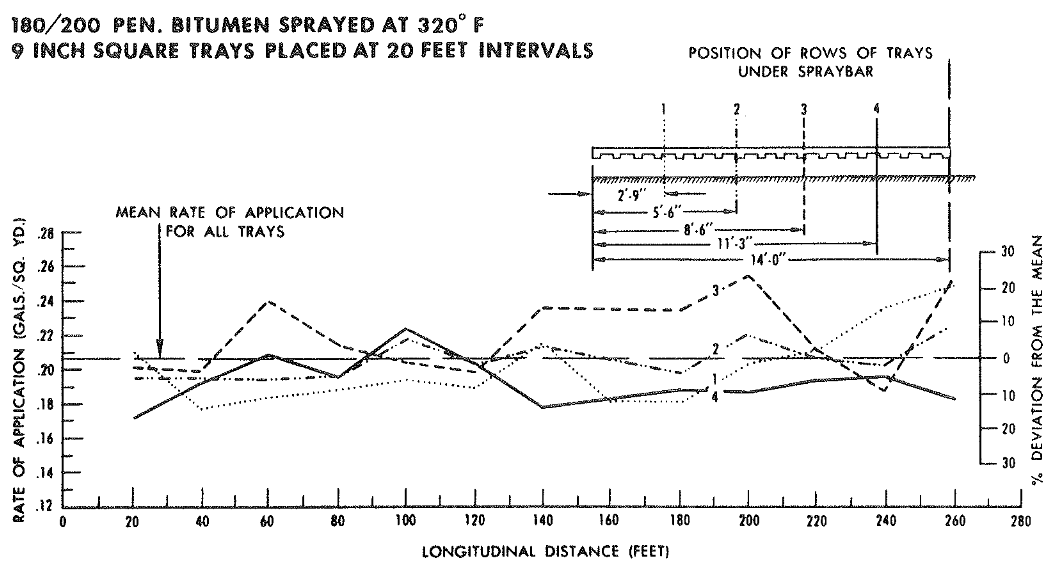

Figure II-12—Longitudinal Variation in Spread Rate of Asphalt Binder
—Courtesy South African Council for Scientific and Industrial Research

2.26 LENGTH OF SPREAD FOR A DISTRIBUTOR LOAD.—In planning operations it is necessary to know how far the asphalt in the tank will go. Appendix A contains a formula for calculating the length of spread.

2.27 MAINTENANCE OF DISTRIBUTOR.—Clean, smoothly operating équipment is a source of pride to all concerned with a surface treatment job. This applies especially to the distributor. A few things that should be done to keep it in clean tip-top condition are:

(1) At the end of each day's operation, clean the circulating system, spray bar, valves, and nozzles using a flushing agent that is compatible with the asphaltic material used.*

(2) Each morning, check the nozzles to be sure that they are clean and that they spray properly.

(3) At the start of each day, lubricate the distributor in accordance with the manufacturer's recommendations.

(4) At least once a day, check the nozzle angle setting.

(5) At the beginning and end of each spread, check the spray bar height to make sure that the correct height is being held.

(6) While spraying, maintain the spraying pressure high enough to give constant straight edged spray fans at each nozzle.

Asphalt Distributor Checklist

(1) Does the asphalt distributor comply with specifications?

(2) Are the heaters and the pump in good working condition?

(3) Have all gauges and measuring devices such as the pump tachometer, measuring stick, thermometers, and bitumeter been calibrated?

(4) Are spray bars and nozzles clean and set for proper application of asphalt?

(5) Are the nozzles free of burrs that will distort the spray?

(6) Is the height of the bar set to give a uniform application?

(7) Have transverse and longitudinal spreads been checked?

* *The flushing agent must have a higher flash point than the temperature of the asphaltic material remaining in the system.*

2.28 AGGREGATE SPREADERS.—The piece of equipment next in importance to the asphalt distributor is the aggregate spreader. A good spreader, operated properly, will conserve aggregate and produce a uniform spread. Spreaders range from the simple vane type attached to a truck tail gate to the highly efficient self-propelled type.

2.29 TAIL GATE SPREADERS.—There are several types of tail gate spreaders. The simplest is the vane spreader. (See Figure II-13.) It consists of a steel plate with a series of vanes which spread the aggregate for the desired width on the road surface. There are tail gate spreaders that consist of a hopper with a feed roller which is activated by small wheels that contact the truck wheels. (See Figure II-14.) And there are the ones that spread the aggregate from a whirling disc. (See Figure II-15.)

2.30 MECHANICAL SPREADERS.—Mechanical spreaders (see Figures II-16, II-17 and II-18) are hoppers on wheels which are hooked onto and are propelled by backing aggregate trucks. Hoppers, which come in widths of from eight to twelve feet and in capacities of from less than one cubic yard to about two cubic yards, usually contain augers to distribute the aggregate the full width of the box. The wheels, which support the spreader and operate the auger, also turn a scored or roughened spread roll in the bottom of the hopper. The roll insures a positive feed of material onto the road surface. There

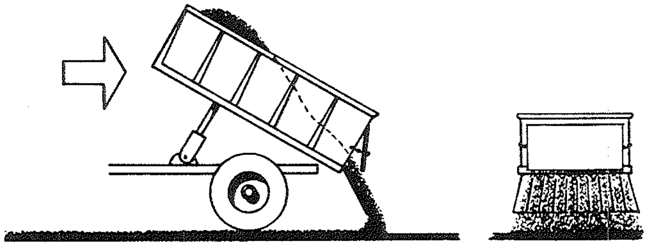

Figure II-13—Vane Spreader

is an adjustable hitch on the front of the spreader by which it is attached to the aggregate truck. Mechanical spreaders also have controls to regulate the feed gates, the feed roll, the auger, and the truck hitch.

2.31 SELF-PROPELLED SPREADERS.—A self-propelled spreader is illustrated in Figure II-19. This machine not only makes very uniform and continuous application of cover aggregate possible but it also is able to keep up with the asphalt distributor, thus producing an immediate application of aggregate to the asphalt while it is still in a fluid condition.

Figure II-14—Hopper-Type Tail Gate Spreader

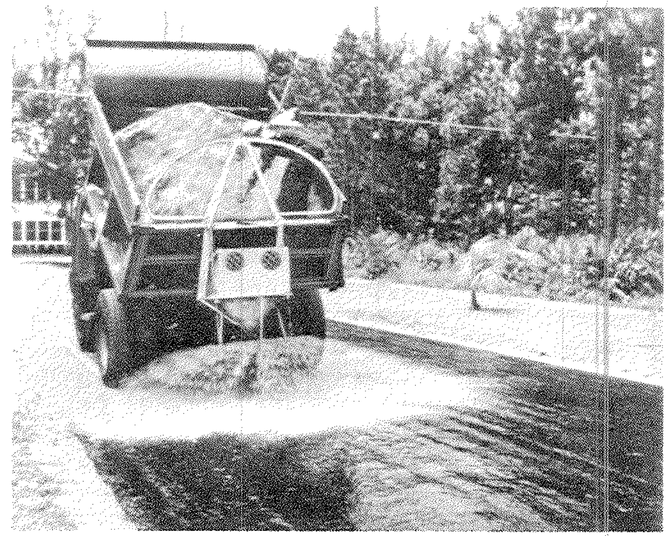

Figure II-15—Whirl-Type Tail Gate Spreader

Figure II-16—Mechanical Spreader

The spreader is a self-powered machine on four wheels with a receiving hopper in the rear where aggregate trucks hitch to dump their loads. The spreader pulls the truck instead of the truck pushing the spreader. Belt conveyors carry the aggregate to the front of the machine where it is dropped through a scalping screen into the spreading hopper. Cut-off gates control the width of spread and an auger assures full-width distribution of aggregate in the hopper. The aggregate flows over the spread roll onto a screen which first places the larger particles on the asphalt and then drops the fine aggregate on top. This operation insures that the larger sizes have enough asphalt to hold them properly in place. Figure II-20 is a flow diagram showing how the spreader works.

2.32 CALIBRATION AND ADJUSTMENTS.—Calibration and adjustments for all types of aggregate spreaders should be made according to the manufacturers' instruction and operating manuals.

There are also some additional checks that can be made to help insure good results:

(1) A tachometer used as an aid in maintaining uniform spreader box speed has proved to be highly successful.

(2) Distribution rates are closely controlled by laying off the length which each truck load of aggregate should cover.

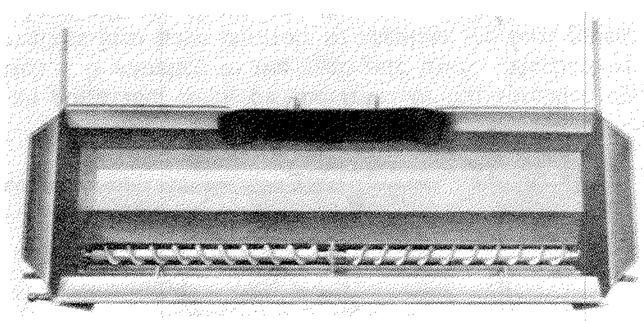

Figure II-17—Top View of One Make of Mechanical Aggregate Spreader

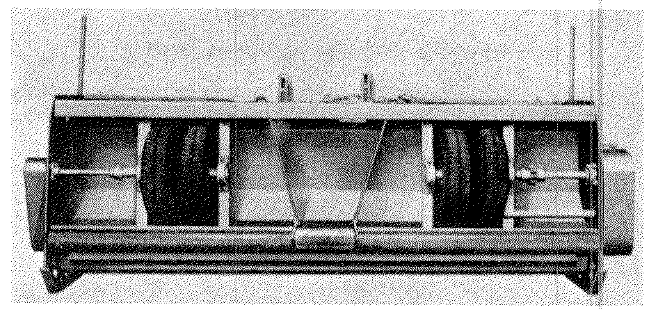

Figure II-18—Bottom View of One Make of Mechanical Aggregate Spreader

(3) A quick check on the rate of application of aggregate can be made by laying a one-square-yard section of cloth or building paper on the pavement (or by supporting a shallow one-square-yard box above the asphalt with nails or screws) and by passing over it with the spreader. The cloth, paper or box is then carefully lifted and the aggregate on it is weighed. This will give the weight per square yard of aggregate being spread.

Aggregate Spreaders Checklist

(1) Does the spreader comply with specifications?

(2) Has the aggregate spreader been checked for proper operation?

(3) Have all adjustments been made according to the manufacturer's operating manual?

(4) Have the hitches on all trucks been checked to make sure they may be connected quickly and positively to the spreader?

(5) Has the rate of application of the spreader been checked?

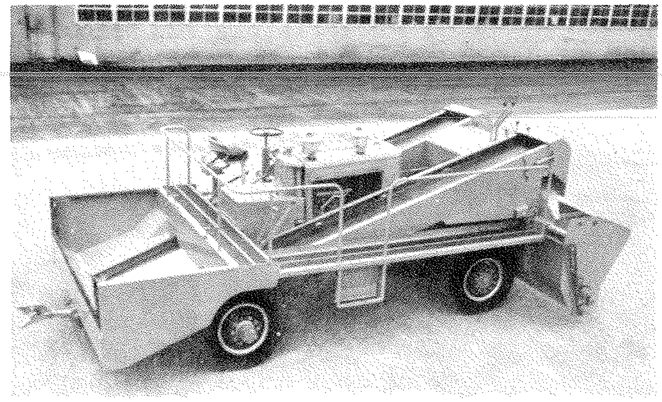

Figure II-19—Self-Propelled Aggregate Spreader

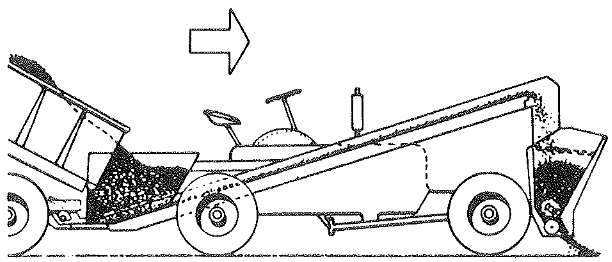

Figure II-20—Flow of Aggregate
Through a Self-Propelled Spreader

Ruslan Diwiryo, Director, Directorate of City and Regional Planning, Department of Public Works, Indonesia.
(Project Correspondent)

Specifications
for
ASPHALT CEMENTS
and
LIQUID ASPHALTS

(As of December 5, 1963)

THE ASPHALT INSTITUTE

Sixth Edition—January 1964

Specification Series No. 2 (SS-2)

FOREWORD

This publication contains two sets of specifications for Rapid Curing (RC), Medium Curing (MC) and Slow Curing (SC) liquid asphalts. Current Asphalt Institute specifications for these materials, adopted by The Asphalt Institute on December 6, 1961, are shown on pages 6, 7, and 8. Former Asphalt Institute specifications for these materials are shown on pages 12, 13, and 14 (see colored insert).

In the current grade designations, note that the number in the grade designation signifies the lower limit of the kinematic viscosity for the grade. The upper viscosity limit is twice the lower limit. For example, MC-70 indicates a Medium Curing liquid asphalt having a kinematic viscosity within the range of 70-140 centistokes at 140° F.

This publication also contains a complete set of specifications for cationic emulsified asphalts adopted by The Asphalt Institute on June 26, 1963 and specifications for an MC-30 grade of Medium Curing liquid asphalt adopted on December 5, 1963.

THE ASPHALT INSTITUTE
ASPHALT INSTITUTE BUILDING
COLLEGE PARK, MARYLAND

JANUARY 1964

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SPECIFICATIONS FOR ASPHALT CEMENTS

Characteristics	AASHO Test Method	ASTM Test Method	GRADES				
			40-50**	60-70	85-100	120-150	200-300
Penetration, 77° F., 100 g., 5 sec.	T 49	D 5	40-50**	60-70	85-100	120-150	200-300
Viscosity at 275° F.							
Saybolt Furol, SSF	....	E 102	120+	100+	85+	70+	50+
Kinematic, Centistokes	....	D 2170	240+	200+	170+	140+	100+
Flash Point (Cleveland Open Cup), °F.	T 48	D 92	450+	450+	450+	425+	350+
Thin Film Oven Test	T 179	....	....	....	....	....	....
Penetration After test, 77° F., 100 g., 5 sec., % of Original	T 49	D 5	55+	52+	47+	42+	37+
Ductility:							
At 77° F., cms.	T 51	D 113	100+	100+	100+	60+	....
At 60° F., cms.			....	....	....	....	60+
Solubility in Carbon Tetrachloride, %	T 44*	D 4*	99.5+	99.5+	99.5+	99.5+	99.5+
General Requirements			The asphalt shall be prepared by the refining of petroleum. It shall be uniform in character and shall not foam when heated to 350° F.				

* Except that carbon tetrachloride is used instead of carbon disulphide as solvent, Method No. 1 in AASHO Method T 44 or Procedure No. 1 in ASTM Method D 4.

** Also special and Industrial uses.

SPECIFICATIONS FOR RAPID-CURING (RC) LIQUID ASPHALTS

(These specifications supersede those shown on page 12)

Characteristics	AASHO Test Method	ASTM Test Method	GRADES			
			RC-70	RC-250	RC-800	RC-3000
Kinematic Viscosity at 140°F., cs.[1]	....	D 2170	70-140	250-500	800-1600	3000-6000
Flash Point (Open Tag.), °F.	T 79	D 1310	....	80+	80+	80+
Distillation—						
Distillate (per cent of total distillate to 680°F.):						
to 374°F.	T 78	D 402	10+	....	....	....
to 437°F.			50+	35+	15+	....
to 500°F.			70+	60+	45+	25+
to 600°F.			85+	80+	75+	70+
Residue from distillation to 680°F., per cent by volume.			55+	65+	75+	80+
Tests on Residue from Distillation:						
Penetration, 77°F., 100 g., 5 sec.	T 49	D 5	80-120	80-120	80-120	80-120
Ductility, 77°F., cms.	T 51	D 113	100+	100+	100+	100+
Solubility in Carbon Tetrachloride, %	T 44[2]	D 4[2]	99.5+	99.5+	99.5+	99.5+
Water, %	T 55	D 95	0.2−	0.2−	0.2−	0.2−

General Requirement—The material shall not foam when heated to application temperature recommended by The Asphalt Institute.

Note: When the Heptane-Xylene Equivalent Test is specified by the consumer, a negative test with 35 per cent xylene after 1 hour will be required, AASHO Method T 102.

[1] As an alternate, Saybolt Furol Viscosities may be specified as shown on page 11.

[2] Except that carbon tetrachloride or trichloroethylene is used instead of carbon disulphide as solvent, Method No. 1 in AASHO Method T 44 or Procedure No. 1 in ASTM Method D 4.

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SPECIFICATIONS FOR MEDIUM-CURING (MC) LIQUID ASPHALTS

(These specifications supersede those shown on page 13)

Characteristics	AASHO Test Method	ASTM Test Method	GRADES				
			MC-30	MC-70	MC-250	MC-800	MC-3000
Kinematic Viscosity at 140°F., cs.[2]	....	D 2170	30-60	70-140	250-500	800-1600	3000-6000
Flash Point (Open Tag.), °F.[1]	T 79	D 1310	100+	100+	150+	150+	150+
Distillation—							
Distillate (per cent of total distillate to 680°F.):							
To 437°F.	T 78	D 402	25−	20−	0-10	....	....
To 500°F.			40-70	20-60	15-55	35−	15−
To 600°F.			75-93	65-90	60-87	45-80	15-75
Residue from distillation to 680°F., per cent by volume.			50+	55+	67+	75+	80+
Tests on Residue from Distillation:							
Penetration, 77°F., 100 g., 5 sec.	T 49	D 5	120-250	120-250	120-250	120-250	120-250
Ductility, 77°F., cms.[3]	T 51	D 113	100+	100+	100+	100+	100+
Solubility in Carbon Tetrachloride, %	T 44[4]	D 4[4]	99.5+	99.5+	99.5+	99.5+	99.5+
Water, %	T 55	D 95	0.2−	0.2−	0.2−	0.2−	0.2−

General Requirement—The material shall not foam when heated to application temperature recommended by The Asphalt Institute.

Note: When the Heptane-Xylene Equivalent Test is specified by the consumer, a negative test with 35 per cent xylene after 1 hour will be required, AASHO Method T 102.

[1] Flash Point by Cleveland Open Cup may be used for products having a flash point greater than 175°F.

[2] As an alternate, Saybolt Furol Viscosities may be specified as shown on page 11.

[3] If penetration of residue is more than 200 and its ductility at 77°F. is less than 100, the material will be acceptable if its ductility at 60°F. is 100+.

[4] Except that carbon tetrachloride or trichloroethylene is used instead of carbon disulphide as solvent, Method No. 1 in AASHO Method T 44 or Procedure No. 1 in ASTM Method D 4.

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SPECIFICATIONS FOR SLOW-CURING (SC) LIQUID ASPHALTS

(These specifications supersede those shown on page 14)

Characteristics	AASHO Test Method	ASTM Test Method	GRADES SC-70	SC-250	SC-800	SC-3000
Kinematic Viscosity at 140°F., cs.[1]	....	D 2170	70-140	250-500	800-1600	3000-6000
Flash Point (Cleveland Open Cup), °F.	T 48	D 92	150+	175+	200+	225+
Distillation:						
Total Distillate to 680°F., % by volume	T 78	D 402	10-30	4-20	2-12	5—
Float Test on Distillation Residue at 122°F., sec.	T 50	D 139	20-100	25-110	50-140	75-200
Asphalt Residue of 100 Penetration, %	T 56	D 243	50+	60+	70+	80+
Ductility of 100 Penetration Asphalt Residue at 77°F., cms.	T 51	D 113	100+	100+	100+	100+
Solubility in Carbon Tetrachloride, %	T 44[2]	D 4[2]	99.5+	99.5+	99.5+	99.5+
Water, %	T 55	D 95	0.5—	0.5—	0.5—	0.5—

General Requirement—The material shall not foam when heated to application temperature recommended by The Asphalt Institute.

Note: When the Heptane-Xylene Equivalent Test is specified by the consumer, a negative test with 35 per cent xylene after 1 hour will be required, AASHO Method T 102.

[1] As an alternate, Saybolt Furol Viscosities may be specified as shown on page 11.

[2] Except that carbon tetrachloride or trichloroethylene is used instead of carbon disulphide as solvent, Method No. 1 in AASHO Method T 44 or Procedure No. 1 in ASTM Method D 4.

SPECIFICATIONS FOR ANIONIC EMULSIFIED ASPHALTS

Characteristics	AASHO Test Method	ASTM Test Method	GRADES Rapid Setting RS-1	Rapid Setting RS-2	Medium Setting MS-2	Slow Setting SS-1	Slow Setting SS-1h
TESTS ON EMULSION							
Furol Viscosity at 77°F., sec.	T59	D244	20-100	....	100+	20-100	20-100
Furol Viscosity at 122°F., sec.			....	75-400	....	....	....
Residue from Distillation, % by weight			57+	62+	62+	57+	57+
Settlement, 5 days, % difference			3—	3—	3—	3—	3—
Demulsibility:							
35 ml. of 0.02 N $CaCl_2$, %			60+	50+	....	....	....
50 ml. of 0.10 N $CaCl_2$, %			....	....	30—	....	....
Sieve Test (Retained on No. 20), %			0.10—	0.10—	0.10—	0.10—	0.10—
Cement Mixing Test, %			....	....	....	2.0—	2.0—
TESTS ON RESIDUE							
Penetration, 77°F., 100g., 5 sec.	T49	D5	100-200	100-200	100-200	100-200	40-90
Solubility in Carbon Tetrachloride, %	T44[1]	D4[1]	97.5+	97.5+	97.5+	97.5+	97.5+
Ductility, 77°F., cms.	T51	D113	40+	40+	40+	40+	40+

[1] Except that carbon tetrachloride is used instead of carbon disulphide as solvent. Method No. 1 in AASHO Method T44 or Procedure No. 1 in ASTM Method D4.

SPECIFICATIONS FOR CATIONIC EMULSIFIED ASPHALTS

Characteristics	AASHO Test Method	ASTM Test Method	GRADES					
			Rapid Setting		Medium Setting		Slow Setting	
			RS-2K	RS-3K	SM-K	CM-K	SS-K	SS-Kh
TESTS ON EMULSION								
Furol Viscosity at 77°F., sec.	T 59	D 244	....	....	....	....	20—100	20—100
Furol Viscosity at 122°F., sec.	T 59	D 244	20—100	100—400	50—500	50—500	....	....
Residue from Distillation, % by weight	T 59	D 244	60+	65+	60+	65+	57+	57+
Settlement, 7 days, % difference	T 59	D 244	3—	3—	3—	3—	3—	3—
Sieve Test (Retained on No. 20), %	T 59[1]	D 244[1]	0.10—	0.10—	0.10—	0.10—	0.10—	0.10—
Aggregate Coating-Water Resistance Test	....	D 244						
Dry Aggregate (Job), % Coated			....	....	80+	80+	....	....
Wet Aggregate (Job), % Coated			....	....	60+	60+	....	....
Cement Mixing Test, %	T 59	D 244	....	....	....	....	2—	2—
Particle Charge Test[2]	....	....	Positive	Positive	Positive	Positive	....	....
pH	....	E 70	....	....	....	....	6.7—	6.7—
Oil Distillate, % by Volume	T 59	D 244	5—	5—	20—	12—	....	....
TESTS ON RESIDUE								
Penetration, 77°F., 100 g., 5 sec.	T 49	D 5	100—250	100—250	100—250	100—250	100—200	40—90
Solubility in Carbon Tetrachloride, %	T 44[3]	D 4[3]	97.0+	97.0+	97.0+	97.0+	97.0+	97.0+
Ductility, 77°F., cm.	T 51	D 113	40+	40+	40+	40+	40+	40+

1 Except that distilled water is used instead of sodium oleate solution.

2 Tested in accordance with paragraph 4.4.4., *Particle Charge Test*, Interim Federal Specification SS-A-00674C (GSA-FSS) dated August 20, 1962.

3 Except that carbon tetrachloride is used instead of carbon disulphide as solvent, Method No. 1 in AASHO Method T 44 or Procedure No. 1 in ASTM Method D 4.

Note: a) "K" in grade designations signifies cationic type
b) In Medium Setting Grades—
"SM" indicates sand mixing grade
"CM" indicates coarse aggregate mixing grade

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ALTERNATE VISCOSITY SPECIFICATIONS FOR LIQUID ASPHALTS[1]

Characteristics	AASHO Test Method	ASTM Test Method	GRADES				
			MC-30	RC-, MC- or SC-70	RC-, MC- or SC-250	RC-, MC- or SC-800	RC-, MC- or SC-3000
Furol Viscosity at 140°F., sec.	T 72	D 88	-------	35-70	125-250	400-800	1500-3000
Or							
Furol Viscosity at 77°F., sec.			75-150				
Furol Viscosity at 122°F., sec.			....	60-120	....	....	....
Furol Viscosity at 140°F., sec.	T 72	D 88	....	....	125-250	....	....
Furol Viscosity at 180°F., sec.			....	....	....	100-200	300-600

1 As an alternate for kinematic viscosity limits included in specifications on pages 6, 7, and 8 Furol Viscosity limits may be used. These Furol Viscosity limits may be specified, as shown above, either at a constant temperature (140° F.) or at four temperatures. This alternate is provided in recognition of the transition period required in changing from the Saybolt Furol test to the more fundamental kinematic viscosity test.

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FORMER SPECIFICATIONS FOR RAPID-CURING (RC) LIQUID ASPHALTS

(Superseded by specifications shown on page 6)

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Characteristics	AASHO Test Method	ASTM Test Method	RC-0	RC-1	RC-2	RC-3	RC-4	RC-5
Flash Point (Open Tag.), °F.	T79	D1310	....	....	80+	80+	80+	80+
Furol Viscosity at 77°F., sec.			75–150	....	....	....	....	....
Furol Viscosity at 122°F., sec.			....	75–150	....	....	....	....
Furol Viscosity at 140°F., sec.	T72	D88	....	....	100–200	250–500	....	....
Furol Viscosity at 180°F., sec.			....	....	....	....	125–250	300–600
Distillation—								
Distillate (per cent of total distillate to 680°F.):								
To 374°F.			15+	10+	....	....	....	....
To 437°F.			55+	50+	40+	25+	8+	....
To 500°F.	T78	D402	75+	70+	65+	55+	40+	25+
To 600°F.			90+	88+	87+	83+	80+	70+
Residue from distillation to 680°F., volume per cent by difference			50+	60+	67+	73+	78+	82+
Tests on Residue from Distillation:								
Penetration, 77°F., 100g., 5 sec.	T49	D5	80–120	80–120	80–120	80–120	80–120	80–120
Ductility, 77°F., cms.	T51	D113	100+	100+	100+	100+	100+	100+
Solubility in Carbon Tetrachloride, %	T44 [1]	D4 [1]	99.5+	99.5+	99.5+	99.5+	99.5+	99.5+
General Requirements			The material shall be free from water.					

[1] Except that carbon tetrachloride is used instead of carbon disulphide as solvent, Method No. 1 in AASHO Method T44 or Procedure No. 1 in ASTM Method D4.

FORMER SPECIFICATIONS FOR MEDIUM-CURING (MC) LIQUID ASPHALTS

(Superseded by specifications shown on page 7)

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Characteristics	AASHO Test Method	ASTM Test Method	MC-0	MC-1	MC-2	MC-3	MC-4	MC-5
Flash Point (Open Tag.), °F.	T79	D1310	100+	100+	150+	150+	150+	150+
Furol Viscosity at 77°F., sec.			75–150	....	....	....	....	....
Furol Viscosity at 122°F., sec.			....	75–150	....	....	....	....
Furol Viscosity at 140°F., sec.	T72	D88	....	....	100–200	250–500	....	....
Furol Viscosity at 180°F., sec.			....	....	....	....	125–250	300–600
Distillation—								
Distillate (per cent of total distillate to 680°F.):								
To 437°F.			25—	20—	10—	5—	0	0
To 500°F.	T78	D402	40–70	25–65	15–55	5–40	30—	20—
To 600°F.			75–93	70–90	60–87	55–85	40–80	20–75
Residue from distillation to 680°F., volume per cent by difference			50+	60+	67+	73+	78+	82+
Tests on Residue from Distillation:								
Penetration, 77°F., 100g., 5 sec.	T49	D5	120–300	120–300	120–300	120-300	120-300	120-300
Ductility, 77°F., cms. [1]	T51	D113	100+	100+	100+	100+	100+	100+
Solubility in Carbon Tetrachloride, %	T44 [2]	D4 [2]	99.5+	99.5+	99.5+	99.5+	99.5+	99.5+
General Requirements			The material shall be free from water.					

[1] If penetration of residue is more than 200 and its ductility at 77°F. is less than 100, the material will be acceptable if its ductility at 60°F. is 100+.

[2] Except that carbon tetrachloride is used instead of carbon disulphide as solvent, Method No. 1 in AASHO Method T44 or Procedure No. 1 in ASTM Method D4.

FORMER SPECIFICATIONS FOR SLOW-CURING (SC) LIQUID ASPHALTS

(Superseded by specifications shown on page 8)

Characteristics	AASHO Test Method	ASTM Test Method	GRADES SC-0	SC-1	SC-2	SC-3	SC-4	SC-5
Flash Point (Cleveland Open Cup), °F.	T48	D92	150+	150+	175+	200+	225+	250+
Furol Viscosity at 77°F., sec.			75–150	....	....	....	....	....
Furol Viscosity at 122°F., sec.			....	75–150	....	....	....	....
Furol Viscosity at 140°F., sec.	T72	D88	....	....	100–200	250–500	....	....
Furol Viscosity at 180°F., sec.			....	....	....	....	125–250	300–600
Water, %	T55	D95	0.5—	0.5—	0.0	0.0	0.0	0.0
Distillation:								
Total Distillate to 680°F.	T78	D402	15–40	10–30	5–25	2–15	10—	5—
Float Test on Distillation Residue at 122°F., sec.	T50	D139	15–100	20–100	25–100	50–125	60–150	75–200
Asphalt Residue of 100 Penetration, %	T56	D243	40+	50+	60+	70+	75+	80+
Ductility of 100 Penetration Asphalt Residue at 77°F., cms.	T51	D113	100+	100+	100+	100+	100+	100+
Solubility in Carbon Tetrachloride, %	T44 [1]	D4 [1]	99.5+	99.5+	99.5+	99.5+	99.5+	99.5+

[1] Except that carbon tetrachloride is used instead of carbon disulphide as solvent, Method No. 1 AASHO Method T44 or Procedure No. 1 in ASTM Method D4. If the material fails to meet the requirement for solubility it will be acceptable if its solubility in carbon disulphide is 99%+, and proportion of bitumen (material soluble in carbon disulphide) soluble in carbon tetrachloride is 99.65%+.

A BASIC ASPHALT EMULSION MANUAL

THE ASPHALT INSTITUTE

MANUAL SERIES NO. 19 (MS-19)
MARCH 1979

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CHAPTER II

THE CHEMISTRY OF ASPHALT EMULSIONS

A. GENERAL

2.01 EMULSIONS

There are many types of emulsion products that we use in our daily lives. Some of the more common are mayonnaise, paints, hair dyes, and ice cream. In each case, certain mechanical and chemical processes are involved that permit the combining of two or more materials that, under normal conditions, will not mix. An entire scientific field is devoted to the study of emulsification. You don't have to understand how an internal combustion engine works to operate an automobile. Neither do you have to understand complex emulsion chemistry to obtain high quality results with asphalt emulsion. The key is to select the right emulsion for the aggregate and construction system involved. Throughout this text when the term "emulsion" is used it is intended to mean "asphalt emulsion."

2.02 COMPOSITION OF ASPHALT EMULSIONS

An asphalt emulsion consists of three basic ingredients: asphalt, water, and an emulsifying agent. On some occasions the emulsifying agent may contain a stabilizer.

It is well known that water and asphalt will not mix, except under carefully controlled conditions using highly specialized equipment and chemical additives. The blending of asphalt cement and water is somewhat akin to an auto mechanic trying to wash grease from his hands with water only. It is not until a detergent or soapy agent of some type is used that grease can be successfully removed. The soap particles surround the globules of grease, break the surface tension that holds them, and allow them to be washed away. Some of the same physical and chemical principles apply in the formulation, production, and use of asphalt emulsion.

The object is to make a dispersion of the asphalt cement in water, stable enough for pumping, prolonged storage, and mixing. Furthermore, the emulsion should break down quickly after contact with aggregate in a mixer, or after spraying on the roadbed. Upon curing, the residual asphalt retains all of the adhesive, durability, and water-resistant properties of the asphalt cement from which it was produced.

2.03 CLASSIFICATION

Asphalt emulsions are divided into three categories: anionic, cationic, and nonionic. In practice, the first two types are ordinarily used in roadway construction and maintenance. Nonionics, however, may be more widely used as emulsion technology advances. The anionic and cationic classes refer to the electrical charges surrounding the asphalt particles. This identification system stems from one of the basic laws of electricity — like charges repel one another and unlike charges attract. When two poles (an anode and a cathode) are immersed in a liquid and an electric current is passed through, the anode becomes positively charged and the cathode becomes negatively charged. If a current is passed through an emulsion containing negatively charged particles of asphalt they will migrate to the anode. Hence, the emulsion is referred to as anionic. Conversely, positively charged asphalt particles will move to the cathode and the emulsion is known as cationic. With nonionic emulsions, the asphalt particles are neutral and, therefore, do not migrate to either pole.

Emulsions are further classified on the basis of how quickly the asphalt will coalesce; i.e., revert to asphalt cement. The terms RS, MS, and SS have been adopted to simplify and standardize this classification. They are relative terms only and mean rapid-setting, medium-setting, and slow-setting. The tendency to coalesce is closely related to the mixing of an emulsion. An RS emulsion has little or no ability to mix with an aggregate, an MS emulsion is expected to mix with coarse but not fine aggregate, and an SS emulsion is designed to mix with fine aggregate.

The emulsions are further subdivided by a series of numbers related to viscosity of the emulsions and hardness of the base asphalt cements. The letter "C" in front of the emulsion type denotes cationic. The absence of the "C" denotes anionic or nonionic. For example, RS-1 is anionic or nonionic and CRS-1 is cationic.

Three grades of high-float medium-setting anionic emulsions, designated HFMS, have been added to standard ASTM specifications. These grades are used primarily in cold and hot plant mixes, coarse aggregate seal coats, and road mixes. High float emulsions have a specific quality that permits a thicker film coating without danger of runoff.

A quick-set type of emulsion (QS) has been developed for slurry seals. Its use is rapidly increasing as the unique quick-setting property solves one of the major problems associated with the use of slurry seals.

Standard specifications for quick-set emulsions are under development. Additionally, some emulsions are made with the water dispersed in asphalt, usually a cutback. As these so-called "inverted emulsions" are seldom used, they are not discussed at all.

2.04 SPECIFICATIONS

AASHTO and ASTM have developed standard specifications for the following grades of emulsions:

EMULSIFIED ASPHALT	CATIONIC EMULSIFIED ASPHALT
RS-1	CRS-1
RS-2	CRS-2
MS-1	—
MS-2	CMS-2
MS-2h	CMS-2h
HFMS-1	—
HFMS-2	—
HFMS-2h	—
SS-1	CSS-1
SS-1h	CSS-1h

The "h" that follows certain grades simply means that a harder base asphalt is used. The "HF" preceding some of the MS grades indicates high-float, as measured by the Float Test (AASHTO T 50 or ASTM D 139). High-float emulsions have a quality, imparted by the addition of certain chemicals, that permits a thicker asphalt film on the aggregate particles with minimum probability of drainage. Some user agencies specify an additional cationic sand-mixing grade designated CMS-2s, which contains more solvent than other cationic grades. All grades in this lengthy list of emulsions cannot be stocked by most producers. Communication and planning between user and producer helps facilitate service and supply of a given grade.

The specifications for emulsified asphalts (AASHTO M 140 and ASTM D 977) make no mention of a solvent in the emulsion. CRS- and CMS- cationic emulsion specifications (AASHTO M 208, ASTM D 2397), on the other hand, permit solvent but restrict the amount.

General guidelines for use as contained in "Standard Practice for Selection and Use of Emulsified Asphalts," ASTM D 3628, are given in Table V-1, Chapter V. Standard specifications for emulsified asphalts carry AASHTO Designations M 140 and M 208 and ASTM Designations D 977 and D 2397. For convenience, the basic requirements of these specifications are given in Tables II-1 and II-2.

2.05 VARIABLES AFFECTING ASPHALT EMULSION

There are many factors that affect the production, storage, use, and performance of an asphalt emulsion. It would be hard to single out any one as being most significant. But, among the variables having a significant effect are:

- Chemical properties of the base asphalt cement
- Hardness and quantity of the base asphalt cement
- Asphalt particle size in the emulsion
- Type and concentration of the emulsifying agent
- Manufacturing conditions such as temperatures, pressures, and shear
- The ionic charge on the emulsion particles
- The order of addition of the ingredients
- The type of equipment used in manufacturing the emulsion
- The property of the emulsifying agent
- The addition of chemical modifiers.

The above factors can be varied to suit the available aggregates or to suit construction conditions. It is always advisable to consult the emulsion supplier with respect to a particular asphalt-aggregate combination as there are few absolute rules that will work the same under all conditions. Therefore, making asphalt emulsions appears to be a combination of art and science.

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An examination of the three main constituents—asphalt, water, and emulsifier—is essential to an understanding of why asphalt emulsions work as they do.

B. EMULSION INGREDIENTS

2.06 ASPHALT

Asphalt cement is the basic ingredient of asphalt emulsion and, in most cases, it makes up from 55 to 70 percent of the emulsion. Tables II-1 and II-2 show the asphalt content specified for various types of emulsions.

Because asphalt cement is such a complex material, only those properties that significantly affect emulsions are discussed. There is not an exact correlation, however, between the properties and the ease with which the asphalt can be emulsified. Although hardness of base asphalt cements may be varied as desired, most emulsions are made with asphalts in the 100—250 penetration range. On occasion, climatic conditions may dictate that a harder or softer base asphalt be used. In any case, compatibility of the emulsifying agent with the asphalt cement is essential for production of a stable emulsion.

Asphalt is a colloid composed of several fractions, the major ones being asphaltenes and maltenes. The colloidal make-up of the asphalt depends on the chemical nature and percentage of these fractions and their relationship to each other.

TABLE II-1 REQUIREMENTS AND TYPICAL APPLICATIONS FOR EMULSIFIED ASPHALT

D 977

Type	Rapid-Setting				Medium-Setting						Medium-Setting						Slow-Setting			
	RS-1		RS-2		MS-1		MS-2		MS-2h		HFMS-1		HFMS-2		HFMS-2h		SS-1		SS-1h	
Grade	min	max	min	max	min	max	min	max	min	max	min	max	min	max	min	max	min	max	min	max
Tests on emulsions:																				
Viscosity, Saybolt Furol at 77°F (25°C), s	20	100			20	100	100		100		20	100	100		100		20	100	20	100
Viscosity, Saybolt Furol at 122°F (50°C), s			75	400																
Settlement,[a] 5-day, %		5		5		5		5		5		5		5		5		5		5
Storage stability test,[b] 24-h, %		1		1		1		1		1		1		1		1		1		1
Demulsibility,[c] 35 ml, 0.02 N $CaCl_2$, %	60		60																	
Coating ability and water resistance:																				
Coating, dry aggregate					good		good		good		good		good		good					
Coating, after spraying					fair		fair		fair		fair		fair		fair					
Coating, wet aggregate					fair		fair		fair		fair		fair		fair					
Coating, after spraying					fair		fair		fair		fair		fair		fair					
Cement mixing test, %																		2.0		2.0
Sieve test, %		0.10		0.10		0.10		0.10		0.10		0.10		0.10		0.10		0.10		0.10
Residue by distillation, %	55		63		55		65		65		55		65		65		57		57	
Tests on residue from distillation test:																				
Penetration, 77°F (25°C), 100 g, 5 s	100	200	100	200	100	200	100	200	40	90	100	200	100	200	40	90	100	200	40	90
Ductility, 77°F, (25°C), 5 cm/min, cm	40		40		40		40		40		40		40		40		40		40	
Solubility in trichloroethylene, %	97.5		97.5		97.5		97.5		97.5		97.5		97.5		97.5		97.5		97.5	
Float test, 140°F (60°C), s											1200		1200		1200					
Typical applications[d]	surface treatment, penetration macadam, sand seal coat, tack coat, mulch		surface treatment, penetration macadam, coarse aggregate seal coat (single and multiple)		cold plant mix, road mix, sand seal coat, crack treatment, tack coat		cold plant mix, coarse aggregate seal coat (single and multiple), crack treatment, road mix, tack coat, sand seal coat		cold plant mix, hot plant mix, coarse aggregate seal coat (single and multiple), crack treatment, road mix, tack coat		cold plant mix, road mix, sand seal coat, crack treatment, tack coat		cold plant mix, coarse aggregate seal coat (single and multiple), crack treatment road mix, tack coat, and seal		cold plant mix, hot plant mix, coarse aggregate seal coat (single and multiple). crack treatment road mix, tack coat		cold plant mix, road mix, slurry seal coat, tack coat, fog seal, dust layer, mulch			

[a] The test requirement for settlement may be waived when the emulsified asphalt is used in less than 5 days time; or the purchaser may require that the settlement test be run from the time the sample is received until the emulsified asphalt is used, if the elapsed time is less than 5 days.

[b] The 24-h storage stability test may be used instead of the 5-day settlement test.

[c] The demulsibility test shall be made within 30 days from date of shipment.

[d] These typical applications are for use only as a guide for selecting and using the emulsion for pavement construction and maintenance.

TABLE II-2 REQUIREMENTS AND TYPICAL APPLICATIONS FOR CATIONIC EMULSIFIED ASPHALT

ASTM D 2397

Type	Rapid-Setting				Medium-Setting				Slow-Setting			
Grade	CRS-1		CRS-2		CMS-2		CMS-2h		CSS-1		CSS-1h	
	min	max	min	max	min	max	min	max	min	max	min	max
Test on emulsions:												
Viscosity, Saybolt Furol at 77°F (25°C), s									20	100	20	100
Viscosity, Saybolt Furol at 122°F (50°C), s	20	100	100	400	50	450	50	450				
Settlement,[a] 5-day, %		5		5		5		5		5		5
Storage stability test,[b] 24-h, %		1		1		1		1		1		1
Classification test[c]	passes		passes									
or												
Demulsibility,[d] 35 ml 0.8 % sodium dioctylsulfosuccinate, %	40		40									
Coating, ability and water resistance:												
Coating, dry aggregate					good		good					
Coating, after spraying					fair		fair					
Coating, wet aggregate					fair		fair					
Coating, after spraying					fair		fair					
Particle charge test	positive		positive		positive		positive		positive		positive	
Sieve test, %		0.10		0.10		0.10		0.10		0.10		0.10
Cement mixing test, %										2.0		2.0
Distillation:												
Oil distillate, by volume of emulsion, %		3		3		12		12				
Residue, %	60		65		65		65		57		57	
Tests on residue from distillation test:												
Penetration, 77°F (25°C), 100 g, 5 s	100	250	100	250	100	250	40	90	100	250	40	90
Ductility, 77°F (25°C), 5 cm/min, cm	40		40		40		40		40		40	
Solubility in trichloroethylene, %	97.5		97.5		97.5		97.5		97.5		97.5	
Typical applications[e]	surface treatment, penetration macadam, sand seal coat, tack coat, mulch		surface treatment, penetration macadam, coarse aggregate seal coat (single and multiple)		cold plant mix, coarse aggregate seal coat (single and multiple), crack treatment, road mix, tack coat, sand seal coat		cold plant mix, hot plant mix, coarse aggregate seal coat (single and multiple), crack treatment, road mix, tack coat		cold plant mix, road mix, slurry seal coat, tack coat, fog seal, dust layer, mulch			

[a] The test requirement for settlement may be waived when the emulsified asphalt is used in less than 5 days time; or the purchaser may require that the settlement test be run from the time the sample is received until the emulsified asphalt is used, if the elapsed time is less than 5 days.

[b] The 24-h storage stability test may be used instead of the 5-day settlement test.

[c] Material failing the classification test will be considered acceptable if it passes the demulsibility test.

[d] The demulsibility test shall be made within 30 days from date of shipment.

[e] These typical applications are for use only as a guide for selecting and using the emulsion for pavement construction and maintenance.

The asphaltenes are the dispersed phase in the asphalt whereas the maltenes are the continuous phase. The asphaltenes are thought to furnish hardness while the maltenes are believed to provide the adhesive and ductile properties of the asphalt. The maltenes present have an influence on the viscosity, or flow properties, of the asphalt. The complex interaction of the different fractions makes it almost impossible to predict accurately the behavior of an asphalt to be emulsified. For this reason, constant quality control is maintained on emulsion production to detect and correct any tendency of the asphalt to affect adversely the performance of the resulting emulsion.

Several systems of asphalt analysis are in use today to separate and evaluate the fractions. There is no absolute agreement among technologists as to how each fraction affects field performance. Nor is there total agreement about the ease with which an asphalt cement can be emulsified.

Each emulsion manufacturer has his own formulations and production techniques. They have been developed to achieve optimum results with the asphalt cement and emulsifying chemicals that he uses.

2.07 WATER

The second largest ingredient in an asphalt emulsion is water. Its contribution to the desired properties of the finished product cannot be minimized. Water wets and dissolves; it adheres to other substances; and, it moderates chemical reactions. These are all important factors that can be favorable to the production of a satisfactory emulsion. On the other hand, water may contain minerals or other matter that affect the production of stable asphalt emulsions.

Water found in nature may be unfit because of impurities, either in solution or colloidal suspension. Of particular concern is the presence of calcium and magnesium ions, which can affect the properties of the emulsion.

Water containing foreign matter should not be used in emulsion production. It may result in an imbalance of the emulsion components that can adversely affect performance or cause premature breaking.

In summary, water used to produce asphalt emulsions should be reasonably pure and free from foreign matter and should be considered an important item.

2.08 EMULSIFYING AGENTS

Properties of an asphalt emulsion depend greatly upon the chemical used as the emulsifier. That chemical is a surface-active agent, commonly called surfactant, that determines whether the emulsion will be classified as anionic, cationic, or nonionic. The emulsifier also keeps the asphalt droplets in stable suspension and permits breaking at the proper time. The surfactant changes the surface tension at the interface, i.e., the area of contact between the asphalt droplets and the water. A great many chemical emulsifiers are available. Each must be appraised for compatibility with the asphalt cement being used.

In the early days of asphalt emulsion production, such materials as ox-blood, clays, and soaps were used as emulsifying agents. As the demand for emulsions increased, new and more efficient emulsifying agents were found. Several chemical emulsifiers now are commercially available.

The most often used anionic emulsifiers are fatty acids, which are wood-product derivatives such as tall oils, rosins, and lignins. Anionic emulsifiers are saponified (turned into soap) by reacting with sodium hydroxide or potassium hydroxide.

Most cationic emulsifiers are fatty amines (diamines, imidazolines, amidoamines, to name three). The amines are converted into soap by reacting with acid, usually hydrochloric. Another type of emulsifying agent, fatty quarternary ammonium salts, is used to produce cationic emulsions. They are water-soluble salts as produced and do not require the addition of acid to make them water-soluble. They are stable, effective cationic (positively charged) emulsifiers.

It is important to remember that the pH value of the asphalt emulsion is unrelated to its identification as cationic or anionic. Acidity or alkalinity does not determine the sign of the charge. This sign is determined only by the type of emulsifier.

Each manufacturer has his own procedure for using his agent in asphalt emulsion production. In most cases, the agent is combined with the water before introduction into the colloid mill. In other cases, however, it may be combined with the asphalt cement just before it goes into the colloid mill.

C. PRODUCING THE EMULSION

2.09 EMULSIFYING EQUIPMENT

Basic equipment to prepare an emulsion includes a high-speed, high-shear mechanical device (usually a colloid mill) to divide the asphalt into tiny droplets. Also needed are an emulsifier solution tank, heated asphalt tank, pumps, and flow-metering gauges. The colloid mill has a high-speed rotor that revolves at 1,000–6,000 rpm (17—100 Hz) with mill-clearance settings in the range of about 0.01 to 0.02 in. (0.25 to 0.50 mm). Such settings yield emulsions with asphalt droplet sizes smaller than the diameter of a human hair [about 0.001 to 0.005 in. (0.025 to 0.125 mm)]. There is a slight variation in mill clearance settings and, thus, asphalt droplet sizes depend upon the equipment used. Some emulsion mills have fixed clearances with no latitude for variation. Although simple mixers can be used to produce low viscosity cutback asphalt, normally they are not used to produce emulsions.

116 Separate pumps are used to meter asphalt and the emulsifier solution into the colloid mill. Because the emulsifier solution can be highly corrosive, it is necessary to use a pump made of corrosion resistant materials.

A schematic diagram of a typical asphalt emulsion manufacturing plant is shown in Figure II-1.

2.10 THE EMULSIFYING PROCESS

In the general method of emulsifying asphalts, concurrent streams of molten asphalt cement and treated water are directed by positive displacement pumps into the intake of the colloid mill. The asphalt and emulsifying water are subjected to intensive shear stresses as they pass through the colloid mill. The newly-formed emulsion may then be pumped through a heat exchanger. The excess heat is used to raise the temperature of the incoming emulsifying water just before it reaches the colloid mill. From the heat exchanger the emulsion is pumped into bulk storage tanks. These tanks sometimes are equipped with some type of stirring device to keep the product uniformly blended.

Heated asphalt cement, the base of the asphalt emulsion, is fed into the colloid mill where it is divided into tiny droplets. At the same time, water containing the emulsifying agent is fed into the colloid mill. The asphalt, as it enters the colloid mill, is heated to ensure a low viscosity, and the water temperature is adjusted accordingly. These temperatures vary; they depend upon the emulsification traits of the asphalt cement and the compatibility between the asphalt and the emulsifying agent. Extremely high asphalt temperatures are not used because the temperature of the emulsion leaving the mill must be below the boiling point of water.

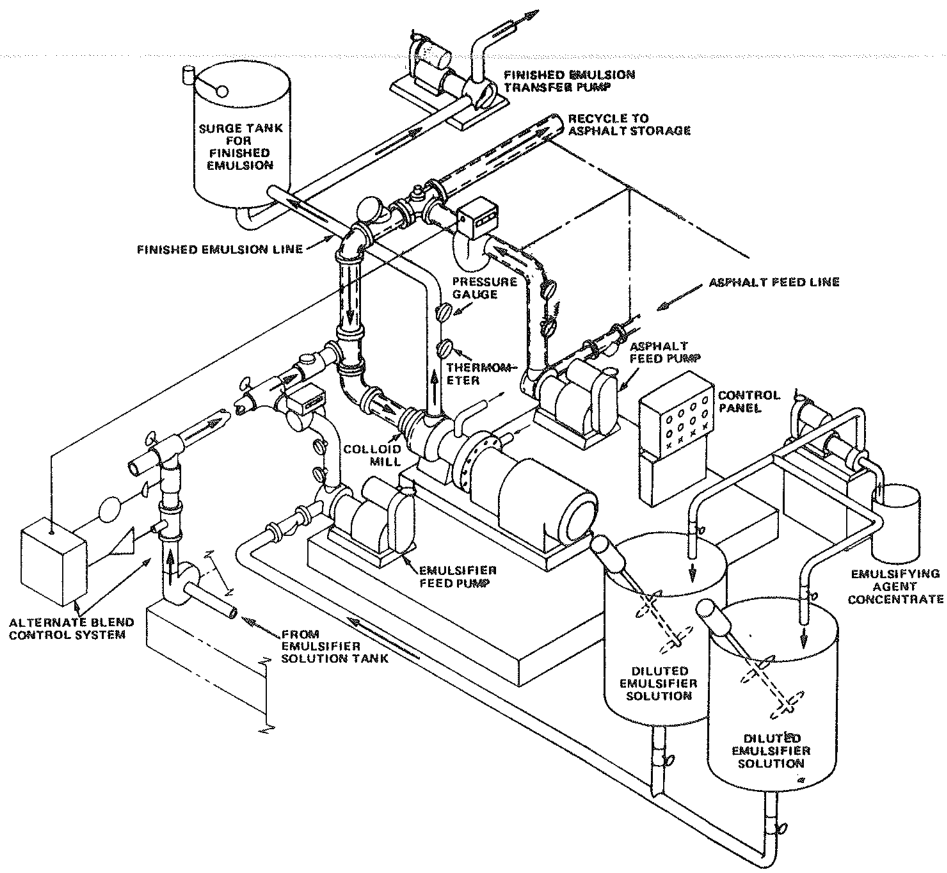

Figure II-1. Diagram of an asphalt emulsion manufacturing plant.
Courtesy Chemicolloid Laboratories, Inc.

The method of adding the emulsifier to the water varies according to the maker's procedure. Some emulsifiers, such as amines, must be mixed and reacted with an acid, such as hydrochloric, to attain water solubility. Others, such as fatty acids, must be mixed and reacted with an alkali, such as sodium hydroxide, to attain water solubility. Mixing is most typically done in a batch mixer. The emulsifier is introduced into warm water containing acid or alkali and agitated until completely dissolved.

Asphalt and emulsifier solution can be proportioned accurately. It can be done by monitoring the temperature of each phase and the mill discharge, or with meters. If the temperature regulation method of proportioning is used, the outlet temperature of the finished emulsion can be calculated from the temperatures of the various emulsion ingredients.

Asphalt particle size is a vital factor in making a stable emulsion. A microscopic photograph of a typical emulsion reveals the following average particle sizes:

Smaller than 0.001 mm (1μm)	28 percent
0.001–0.005 mm (1–5μm)	57 percent
0.005–0.010 mm (5–10μm)	15 percent

These microscopic-sized asphalt droplets are dispersed in water in the presence of the chemical surface-active emulsifier (surfactant). The surfactant causes a change in the surface tension at the contact area between the asphalt droplets and the surrounding water, and this permits the asphalt to remain in a suspended state. The particles, all having a similar electrical charge, repel each other, which also aids in their remaining in a suspended state. Figure II-2 is a photomicrograph showing the sizes and distribution of the asphalt particles.

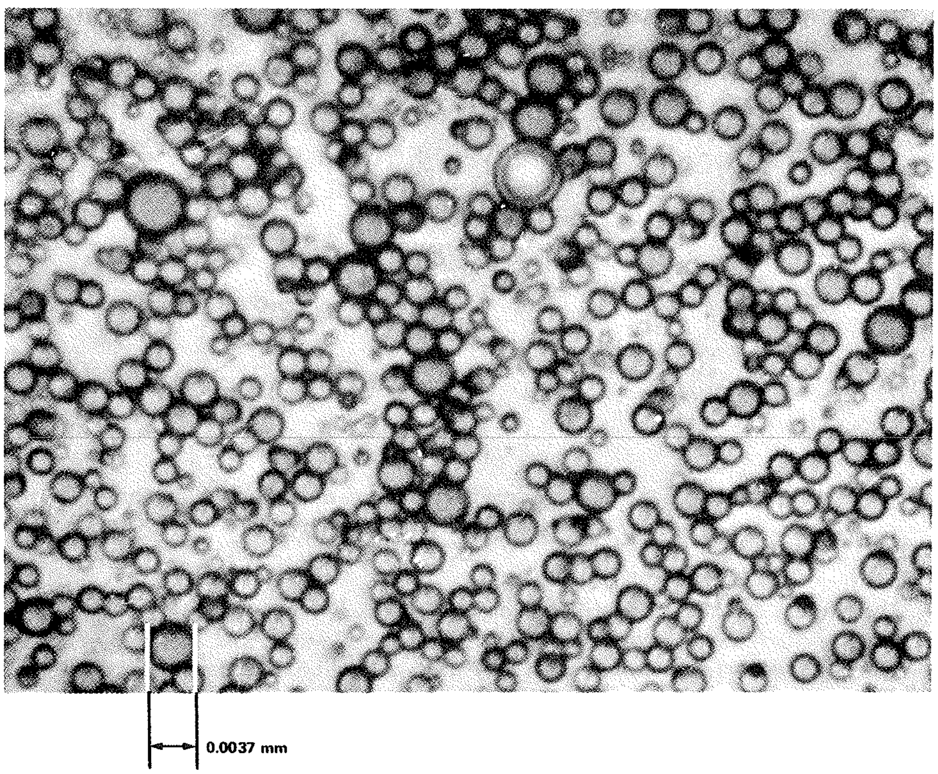

Figure II-2. Relative sizes and distribution of asphalt particles in an emulsion.
Courtesy Chevron U.S.A. Inc.

D. BREAKING AND CURING

2.11 BREAKING

If the asphalt emulsion is to perform its ultimate function of cementing and waterproofing, the asphalt must separate from the water phase. For surface treatments and seals, emulsions are formulated to break upon contact with a foreign substance such as aggregate or a pavement surface. The asphalt droplets coalesce and produce a continuous film of asphalt on the aggregate or pavement. For dense mixtures, more time is needed to allow for mixing and laydown. Therefore, emulsions used for mixtures are formulated for delayed breaking. Asphalt coalescence is commonly referred to as breaking, or setting. The rate at which the asphalt globules separate from the water phase is referred to as breaking or setting time. For example, a rapid-set emulsion will break within one to five minutes after being applied, whereas a medium- or slow-set material may take considerably longer.

The rate of breaking is controlled primarily by the specific type and concentration of the emulsifying agent used, as well as atmospheric conditions.

The fact that different aggregate types have different rates of absorption means that breaking is also related to the relative absorption characteristics of the aggregate used. Those with higher absorption rates tend to accelerate the breaking of the emulsion due to the more rapid removal of the emulsifying water.

In asphalt emulsion-aggregate mixtures, gradation and surface area of the aggregate also are significant factors in the rate of breaking. As the surface area changes, the breaking characteristic of the medium also changes because of the altered adsorption of the emulsifying agent by the aggregate. In order to achieve optimum results, it is necessary to control the sizing of the aggregate or to adjust the emulsion formulation to meet the specific requirements of the aggregate.

2.12 CURING

For paving uses, both anionic and cationic asphalt emulsions depend on the evaporation of water for development of their curing and adhesion characteristics. Water displacement can be fairly rapid under favorable weather conditions but high humidity, low temperatures, or rainfall soon after application can deter proper curing. Although surface and atmospheric conditions are less critical for cationic emulsions, these types still depend somewhat on weather conditions for optimum results. Perhaps the principal advantage of the cationics is their willingness to give up their water a little faster.

Traditional theory holds that anionic emulsions (with a negative charge on the asphalt droplets) perform best with aggregates having mostly positive surface charges—limestone and dolomite are examples. The theory also holds that cationic emulsions (with a positive charge on the asphalt droplets) perform best with aggregates having mostly negative surface charges—some examples are siliceous or granitic aggregates. Presently, there is not complete agreement on the subject of electrical charges on aggregate surfaces. Recent studies have challenged the traditional theories. The theories presented in this manual follow the line of traditional usage, which may change in the future.

When using either the anionic or cationic rapid-set emulsion the initial deposition of asphalt develops through an electrochemical phenomenon. But the main bond of strength between the asphalt film and the aggregates comes after the loss of emulsifying water. This water film can be displaced by evaporation, pressure (rolling), or by absorption. In actual use, breaking is usually a function of the combination of these three factors.

Medium- and slow-set emulsions, being more heavily stabilized, depend less on the aggregate type although the same basic principles of electrical charges with respect to selection of emulsion type still apply. When the MS and SS grades are used for paving mixes, the use of slightly damp aggregates facilitates the mixing and coating process. The development of strength in the SS types depends mainly on dehydration and absorption with removal of water by either of these mechanisms breaking the emulsion. Solvent-free CMS and CSS emulsions require that the moisture on the aggregate be at or near optimum for proper mixing and coating.

Some types of emulsions contain slight amounts of petroleum solvent to aid in the mixing and coating process. While the solvent does not enter directly into the breaking mechanism, provisions must be made for the evaporation of the solvent in order for the mixture to be properly cured. Where multiple courses are to be placed, a successive course should not be applied until the water (and solvent, if applicable) has been removed from the preceding course.

2.13 FACTORS AFFECTING SETTING RATE

In general, some of the factors that affect setting rate of an asphalt emulsion are as follows:

1. The rate that water is absorbed by the aggregate. A rough-textured, porous aggregate speeds the setting time by absorbing water from the emulsion.
2. Moisture content of the aggregate prior to mixing.
3. Weather conditions—temperature, humidity, and wind velocity all have a bearing on rate of set.
4. Mechanical forces brought to bear by rolling and by traffic. Roller pressure, to a limited extent, forces the water from the materials.
5. Size distribution and mineral composition of aggregate. Fine aggregate mixes tend to break faster because they possess greater surface area than an equal weight of coarse aggregate. The mineral composition also affects the speed at which the asphalt emulsion breaks. There may be some type of chemical reaction between the emulsifier and the aggregate surface. Also, dirty aggregate or excessive fines may accelerate breaking and retard curing.
6. The type and amount of emulsifying agent used.
7. Intensity of charge on aggregate versus intensity of emulsifier charge, in combination with surface area, is a major setting-rate determinant.
8. Chemical coagulation. The emulsion becomes unstable because of a decreased water content.

The above factors must be considered in determining working time after the emulsion has been sprayed or mixed with the aggregate in the field.

CHAPTER III

STORING, HANDLING, AND SAMPLING ASPHALT EMULSIONS

3.01 GENERAL

The storage and handling of asphalt emulsions require precaution beyond that used for other types of asphalt materials. Improper handling or storage of the emulsion, or both, may cause premature breaking, thereby making it useless. The Asphalt Institute, in recognition of these necessary precautions, has issued a Construction Leaflet, *Storing and Handling of Emulsified Asphalts* (CL-21), outlining some of the safeguards that must be followed. Failure to follow even a single one of them may cause the material to be unsatisfactory at the time of use. Careful study of each item is therefore suggested. Sticking to these simple rules will save time and money by having the material ready for use when needed. The safeguards listed in the Asphalt Institute leaflet are repeated below to help those who have had little or no experience with asphalt emulsions. However, it is not intended to give the impression that asphalt emulsions are so delicate as to limit their field use. The use of almost any other material would have a long list of admonitions for the uninitiated.

3.02 STORING ASPHALT EMULSIONS

Emulsified asphalt, being a dispersion of fine droplets of asphalt cement in water, has both the advantages and disadvantages of the carrier medium, water. When storing emulsified asphalts: 121

DO store as you would fluid water—between 50° F (10° C) and 185° F (85° C), depending on the use.

DO use hot water as the heating medium for storage tanks with heating coils. Low pressure or waste steam also may be used, with temperature controlled on the coil surface to not more than 185° F (85° C).

DO store at the temperature specified for the particular grade. For spray applications, the emulsions are stored at higher temperatures than for mixing with aggregate. For example, the higher viscosity rapid-set spray grades are stored at 125° F to 185° F (50° C to 85° C) since they are usually applied in this temperature range. The lower viscosity grades are stored at lower temperatures. Table III-1 shows the normal storage temperature ranges. Store the mixing grades at the lower end of the temperature ranges as shown in Table III-1.

DO NOT permit the emulsified asphalt to be heated above 185° F (85° C). Elevated temperatures evaporate the water, resulting in an increase in viscosity and an asphalt layer in the tank. The materials can no longer be used as intended and it will be difficult to empty the tank.

DO NOT let the emulsion freeze. This breaks the emulsion, separating the asphalt from the water. The result will be two layers in the tank, neither suited for the intended use, and the tank will be difficult to clean.

DO NOT allow the temperature of the heating surface to exceed 205° F (96° C). This will cause premature breakdown of the emulsion on the heating surface.

DO NOT use forced air to agitate the emulsion. It may cause the emulsion to break.

TABLE III-1 STORAGE TEMPERATURES FOR EMULSIFIED ASPHALTS

Grade	Temperature, °F (°C)	
	Minimum	Maximum
RS-1	70° (20°)	140° (60°)
RS-2, CRS-1, CRS-2	125° (50°)	185° (85°)
SS-1, SS-1h, CSS-1, CSS-1h, MS-1, HFMS-1	50° (10°)	140° (60°)
CMS-2, CMS-2h, MS-2, MS-2h, HFMS-2, HFMS-2h	125° (50°)	185° (85°)

3.03 STORAGE FACILITIES

For protection from freezing and best utilization of heat, storage tanks should be insulated. A skin of asphalt can form on the surface of emulsions when exposed to air. It is best, therefore, to use tall, vertical tanks as they expose the least amount of surface area to the air. Most fixed storage tanks are vertical but horizontal tanks are often used for short-term field storage. Skinning can be reduced by keeping horizontal tanks full to minimize the area exposed to air.

Side-entering propellers located about three feet (one metre) up from the tank bottom may be used to prevent surface skin formation. Large diameter, slow-turning propellers are best and should be used to roll the material over. Avoid overmixing. Secondly, tanks may be circulated top to bottom with a pump. Avoid over-pumping. In tanks not equipped with propellers, or a circulating system, a very light film of kerosene or oil on the surface can reduce skin formation. Emulsions that are rolled or circulated generally do not require a layer of kerosene or oil on the surface. Cathodic protection should be provided to avoid possible corrosion of tank walls and heating coils.

3.04 HANDLING EMULSIFIED ASPHALTS

DO when heating emulsified asphalt agitate it to eliminate or reduce skin formation.

DO protect pumps, valves, and lines from freezing in winter. Drain pumps or fill them with anti-freeze according to the manufacturer's recommendations.

DO blow out lines and leave drain plugs open when they are not in service.

DO use pumps with proper clearances for handling emulsified asphalt. Tightly fitting pumps can cause binding and seizing.

DO use a mild heating method to apply heat to the pump packing or casing to free a seized pump. Discourage the use of propane torches.

DO warm the pump to about 150° F (65° C) to ease start-up.

DO when a pump is to be out of service for even a short period of time, fill it with No. 1 fuel oil to ensure a free start-up.

DO when diluting grades of emulsified asphalt, check the compatibility of the water with the emulsion.

DO if possible, use warm water for diluting and always add the water slowly to the emulsion (not the emulsion to the water).

DO avoid repeated pumping and recycling, if possible, as the viscosity may drop and air may become entrained, causing the emulsion to be unstable.

DO guard against mixing different classes, types, and grades of emulsified asphalt in storage tanks, transports, and distributors. For example, if cationic and anionic emulsified asphalts are mixed, the blend will break and separate into water and coagulated asphalt that will be difficult to remove. Because it is hard to determine visually the difference between various emulsified asphalts, always make a trial blend of the newly-delivered emulsion and the stored emulsion before pumping off. Check the trial blend for compatibility.

DO place inlet pipes and return lines at the bottom of tanks to prevent foaming.

DO pump from the bottom of the tank to minimize contamination from skinning that may have formed.

DO remember that emulsions with the same grade designation can be very different chemically and in performance.

DO haul emulsion in truck transports with baffle plates to prevent sloshing.

DO mix by circulation, or otherwise, emulsions that have been in prolonged storage.

DO NOT use tight-fitting pumps for pumping emulsified asphalt; they may "freeze."

DO NOT apply severe heat to pump packing glands or pump casings. The pump may be damaged and the asphalt may become even harder.

DO NOT dilute rapid-setting grades of emulsified asphalt with water. Medium and slow setting grades may be diluted, but always add water slowly to the asphalt emulsion. Never add the asphalt emulsion to a tank of water when diluting.

DO NOT recirculate emulsified asphalts for too many cycles. They tend to lose viscosity when subjected to pumping. Also, air bubbles may become entrained which would render the emulsion unstable.

DO NOT load emulsified asphalt into storage tanks, tank cars, tank transports, or distributors containing remains of incompatible materials. See Tables III-2 and III-3.

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TABLE III-2 GUIDE FOR CONDITION OF EMPTIED TANKS BEFORE LOADING EMULSIFIED ASPHALTS

	LAST PRODUCT IN TANK					
PRODUCT TO BE LOADED	Asphalt Cement (includes Industrial Asphalt)	Cutback Asphalt	Cationic Emulsion	Anionic Emulsion	Crude petroleum and residual fuel oils	Any product not listed above
Cationic Emulsion	Empty to no Measurable Quantity	Empty to no Measurable Quantity	OK to load	Empty to no Measurable Quantity	Empty to no Measurable Quantity	Tank must be cleaned
Anionic Emulsion	Empty to no Measurable Quantity	Empty to no Measurable Quantity	Empty to no Measurable Quantity	OK to load	Empty to no Measurable Quantity	Tank must be cleaned

NOTE: All tanks to be emptied to 0.5 percent or less of capacity. Pump section, unloading line, and all piping must be drained.

TABLE III-3 POSSIBLE CAUSES OF CONTAMINATION OF ASPHALT MATERIAL OR SAMPLES AND SUGGESTED PRECAUTIONS

HAULERS AND HAULING VEHICLES

Field observations and studies of test results have indicated that contamination of materials during transportation often occurs.

Possible Causes	*Precautions*
(a) Previous load not compatible with material being loaded.	Examine the log of loads hauled or check with the supplier to determine if previous material hauled is detrimental. If it is, make sure vehicle tanks, unloading lines, and pump are properly cleaned and drained before being presented for loading. Provide a ramp at the unloading point at the plant that will ensure complete drainage of vehicle tank while material is still fluid.
(b) Remains of diesel oil or solvents used for cleaning and flushing of tanks, lines, and pump.	When this is necessary, make sure all solvents are completely drained.
(c) Flushing of solvents into receiving storage tank or equipment tanks.	Do not allow even small amounts to flush into storage tank as entire contents may be contaminated

(Continued on next page)

TABLE III-3 (con't.)

MIX PLANT STORAGE TANK AND EQUIPMENT

Many investigations and test results point to mix plant storage tanks and associated equipment as the source of contamination.

Possible Causes	*Precautions*
(a) Previous material left over in tank when changing to another material.	Any material allowed to remain must be compatible with new material; and the amount remaining in the tank must be insufficient to cause new material to become out-of-specification. If in doubt, check with your supplier. To be on the safe side, tank should be drained or cleaned prior to using tank for each different type or grade of asphalt. Be sure discharge line connects at low point of storage tank to ensure complete emptying when changing type or grades of asphalt or cleaning tank.
(b) Solvents used to flush hauling vehicle tank discharged into storage tank.	Observe unloading operations, caution driver about flushing cleaning materials into storage tank. If possible, provide place for hauler to discharge cleaning materials.
(c) Flushing of lines and pump between storage tank and hot-plant with solvents and then allowing this material to return to tank.	If necessary to flush lines and pump, suggest providing by-pass valves and lines to prevent solvents from returning to tank. A better solution is to provide insulated, heated lines and pump, thereby eliminating the necessity of flushing.
(d) Cleaning of distributor tank, pump, spray bar, and nozzles with solvents.	Be sure all possible cleaning material is drained off or removed prior to loading. Do not take sample from nozzle until sufficient material has been discharged to guard against taking a contaminated sample.
(e) Dilutions from hot oil heating systems.	Check reservoir on hot oil heating system. If oil level is low, or oil has been added, check system for leakage into the asphalt supply.

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NON-REPRESENTATIVE OR CONTAMINATED SAMPLE

Test results are greatly dependent upon proper sampling techniques. Extra care, on the part of the sampler, to obtain samples that are truly representative of the material being sampled will do much to eliminate the possibility of erroneous test results by reason of improper sampling. Make sure samples are taken only by those authorized persons who are trained in sampling procedures.

Possible Causes	*Precautions*
(a) Contaminated sampling device (commonly called a "sample thief").	If sampling device (of type described in AASHTO T 40 or ASTM D 140) is cleaned with diesel oil or solvent, make sure that it is thoroughly drained and then rinsed out several times with material being sampled prior to taking sample.
(b) Samples taken with sampling device from top of tank where, under certain conditions, contaminants can collect on the surface.	In taking a sample from the top of a tank lower sampling device below the extreme top before opening. Note: This sample may come from the top one-third of the tank.

(Continued on next page)

TABLE III-3 (Con't.)

Possible Causes	*Precautions*
(c) Contaminated sample container.	Use only new clean containers. Never wash or rinse a sample container with solvent. Glass or polyethylene containers should be used.
(d) Sample contaminated after taking.	**DO NOT** submerge container in solvent or even wipe outside of container with solvent-saturated rag. If necessary to clean spilled material from outside of container, use a clean dry rag. Make sure container lid is tightly sealed prior to storage or shipment. Ship to testing laboratory promptly.
(e) Samples taken from spigot in lines between storage tank and hot-plant.	If sampling spigot is in suction line between tank and pump, this necessitates stopping pump prior to taking sample. Samples thus taken are by gravity and only representative of material localized in the pipe area of the spigot. Rather, the spigot should be in lines between pump and return line discharge, thereby allowing slow withdrawal of material during circulation. **DO NOT** take sample while hauling vehicle is pumping into storage tank. **DO NOT** take sample without allowing sufficient time for circulation and thorough mixing of material. **DO** drain off sufficient material through spigot prior to taking sample to ensure removal of any contaminant lodged in spigot. **DO** take sample slowly during circulation to be more representative of material being used.
(f) Samples taken from unloading line of hauling vehicle.	Drain off sufficient material through spigot prior to taking sample to ensure removal of any contaminant lodged there. Sample should be taken after one-third and not more than two-thirds of the load has been removed. Take sample slowly to be sure it is representative of the material being used.

3.05 SAMPLING ASPHALT EMULSIONS

The purpose of any sampling method is to obtain samples that will show the true nature and condition of the material. The general procedure is described in the following articles. The standard procedure is detailed in "Standard Methods of Sampling Bituminous Materials," AASHTO T 40 or ASTM D 140.

3.06 SAMPLE CONTAINERS

(1) Containers for anionic emulsified asphalt samples shall be one-gallon wide-mouth jars or bottles made of glass or plastic.

(2) Containers for cationic emulsified asphalt samples shall be one-gallon wide-mouth jars or bottles made of plastic or wide-mouth plastic-lined cans with lined screw caps, or plastic-lined triple-seal friction-top cans.

(Bare metal cans are corroded by emulsified asphalts, particularly the cationic type. They also may cause the emulsion to break.)

3.07 SIZE OF SAMPLES

The size of samples shall correspond to the required sample containers.

3.08 SAMPLES

Whenever practicable, the emulsified asphalt shall be sampled at the point of manufacture or storage. If that is not practicable, samples shall be taken from the shipment immediately upon delivery. Three samples of the emulsified asphalt shall be taken. The samples shall be sent to the laboratory for testing as soon as possible.

3.09 SAMPLING PRECAUTIONS

(1) Sample containers shall be new. They shall not be washed or rinsed. If they contain evidence of solder flux or if they are not clean and dry they shall be discarded. Top and container shall fit together tightly.

(2) Care shall be taken to prevent the samples from becoming contaminated. The sample container shall not be submerged in solvent, nor shall it be wiped with a solvent saturated cloth. Any residual material on the outside of the container shall be wiped with a clean, dry cloth immediately after the container is sealed and removed from the sampling device.

(3) The sample shall not be transferred into another container.

(4) The filled sample container shall be tightly and positively sealed immediately after the sample is taken.

3.10 SAFETY PRECAUTIONS

(1) Safety precautions are mandatory at all times when handling asphalt materials. These safety precautions include, but are not limited to, the ones that follow.

(2) Gloves shall be worn and sleeves shall be rolled down and fastened over the gloves at the wrist while sampling and while sealing containers.

(3) Face shields should be worn while sampling.

(4) There shall be no smoking while sampling asphalts.

(5) The sampler shall stand on the windward side when taking the sample.

(6) During sealing and wiping the container shall be placed on a firm level surface to prevent splashing, dropping or spilling the material.

3.11 PROTECTION AND PRESERVATION OF SAMPLES

(1) Immediately after filling, sealing, and cleaning the sample containers shall be properly marked for identification with a wick marking pencil on the container itself, not on the lid. Linen tags also may be used for identification if they can be securely fastened to the container in such a manner as to ensure that they will not be lost in transit.

Linen tags shall not be attached to containers by using the lids to secure them.

(2) Samples of emulsions shall be packaged, labeled, and shipped in such a manner as to protect them from freezing.

(3) All samples should be packaged and shipped to the laboratory the same day they are taken. The containers, tightly sealed, should be packed in absorbent material, such as sawdust, excelsior, or vermiculite, to reduce the probability of damage during shipment.

(4) Each sample shall be identified with at least the following information:

(a) Shipper's name and bill of lading or loading slip number.

(b) Date sampled.

(c) Sampler's name.

(d) Product grade.

CHAPTER V

SELECTING THE RIGHT TYPE OF ASPHALT EMULSION

5.01 GENERAL

Asphalt emulsions can be used for almost any purpose for which cutback asphalts are used. Furthermore, they have a broader range of uses that include many not suited to cutbacks. That does not mean that they can be used indiscriminately. Successful performance of asphalt emulsions requires selecting the proper type for the intended use. Guidelines presented in this chapter should help select the specific grade and type of emulsion to be used.

5.02 CONSIDERATIONS FOR SELECTION

The first consideration in picking the right type of emulsion is the type of construction in which it will be used. Is it a seal coat or a plant mix (central or mixed-in-place)? Is it some type of surface application only? Is it for maintenance? Once this decision is made other project variables must then be considered. Some other factors that affect the selection are:

— Climatic conditions anticipated during construction: The selection of emulsion grade, design of mix or treatment, and construction equipment depend upon this factor.

— Aggregate type and availability.

— Construction equipment availability.

— Geographical location: hauling distance, and in some cases, water availability.

— Traffic control: can traffic be detoured?

— Environmental considerations.

While general guidelines can be given for selecting emulsions, laboratory testing is strongly recommended. There is no good substitute for a laboratory evaluation of the emulsion and the aggregate to be used. Different types and quantities of emulsion should be tried with the aggregate to find the best combination for the intended use. An experienced technician can determine the type and amount of emulsion to be used. He can also determine if additional water must be added, and the amount of time for breaking to occur.

5.03 GENERAL USES

Each grade of asphalt emulsion is designed for specific uses. They are described in general terms in the following paragraphs.

— *Rapid-Setting Emulsions:*
The rapid-setting grades are designed to react quickly with aggregate and revert from the emulsion state to asphalt. The RS grades produce a relatively heavy film. They are

used primarily for spray applications, such as aggregate (chip) seals, sand seals, surface treatments, and asphalt penetration macadam. The RS-2 and CRS-2 grades have high viscosities to prevent runoff.

— *Medium-Setting Emulsions:*

The medium-setting grades are designed for mixing with coarse aggregate. Because these grades do not break immediately upon contact with aggregate, mixes using them remain workable for a few minutes. They are used extensively in travel plants. The CMS grades have high viscosities to prevent runoff.

A newly standardized type of medium-setting asphalt emulsion, identified as high float, is anionic in nature. The major difference between this emulsion and the conventional medium-setting type is the high float characteristic, measured on the asphalt residue by the Float Test, AASHTO T 50 or ASTM D 139. It reportedly gives better aggregate coating and asphalt retention under extreme temperature conditions. While regular asphalts have a tendency to flow, or migrate, at about 140°F (60°C), the high float residues are designed to stay in place up to about 160°F (71°C). Therefore, high float residues are less susceptible to changes in temperature. They soften less in summer and do not harden as much in winter.

In 1977, the American Society for Testing and Materials standardized three types of high-float emulsions — HFMS-1, HFMS-2, and HFMS-2h. Their specifications are contained in ASTM D 977 (see Table II-1).

— *Slow-Setting Emulsions:*

The slow-setting grades are designed for maximum mixing stability. They are used with high fines content, dense-graded aggregates. The SS grades have long workability times to ensure good mixing with dense-graded aggregates. All slow-setting grades have low viscosities that can be further reduced by adding water. These grades, when diluted, can also be used for tack coats, fog seals, and dust palliatives. The SS type of emulsion depends entirely upon evaporation of the water for coalescence of the asphalt particles. If a faster setting rate is needed in mixtures, portland cement or hydrated lime can be added. The SS emulsions are generally used for dense-graded aggregate-emulsion bases, soil-asphalt stabilization, asphalt surface mixes, and slurry seals.

Table V-1 shows the general uses of standard emulsion types and grades.

5.04 ADHESIVE PROPERTIES

Success with any aggregate-emulsion combination depends greatly on the electrical surface charges of the asphalt droplets and the aggregate. The probability of good adhesion is diminished if the charges are similar. Conversely, the probability of good adhesion is greatly improved if the charges are different. The predominating charge on the aggregate surface determines whether anionic or cationic emulsion will produce the best results. The only way to be sure is to test in the laboratory.

5.05 GUIDELINES FOR SELECTION

In summary, success with any type of asphalt emulsion system is best ensured by adherence to each of the following steps:

1. Laboratory testing using the actual aggregate and emulsion that is to be used on the project.
2. Selection of grades in conformance with Table V-1 and Article 5.02. Table V-2 may be helpful also.
3. Strict adherence to the specifications and guides for usage.
4. Careful handling of the emulsion to prevent contamination, settlement of the asphalt droplets, or premature coalescence.
5. Consultation with the emulsion manufacturer's representative when special or unusual problems occur.

Asphalt emulsions as an alternative for use in paving and maintenance operations are now a reality. Following proper procedures will produce a system that should provide a high level of service.

TABLE V-1 GENERAL USES OF EMULSIFIED ASPHALT

D 3628

NOTE—Only those grades of emulsified asphalt in general use have been indicated herein. It is possible that under certain variations of aggregates, or climatic conditions, or both, additional selections might be appropriate. Where the use of emulsified asphalt for applications other than those listed in the table are contemplated, the emulsion supplier should be consulted.

Type of Construction[A]	Specification D 977							Specification D 2397 (Cationic)					
	RS-1	RS-2	MS-1, HFMS-1	MS-2, HFMS-2	MS-2h, HFMS-2h	SS-1	SS-1h	CRS-1	CRS-2	CMS-2	CMS-2h	CSS-1	CSS-1h
Bituminous-aggregate mixtures:													
For pavement bases and surfaces:													
Plant mix (hot) (D 3515)	...	...	...	...	X[B]	...	...	...	...	...	...	...	...
Plant mix (cold)													
Open-graded aggregate	...	...	...	X	X	...	...	...	...	X	X	...	...
Dense-graded aggregate	...	...	...	...	...	X	X	...	...	...	...	X	X
Sand	...	...	...	...	...	X	X	...	...	...	...	X	X
Mixed-in-place:													
Open-graded aggregate	...	...	X	X	X	...	...	...	...	X	X	...	...
Dense-graded aggregate	...	...	...	...	...	X	X	...	...	...	...	X	X
Sand	...	...	...	...	...	X	X	...	...	...	...	X	X
Sandy soil	...	...	...	...	...	X	X	...	...	...	...	X	X
Slurry seal	...	...	...	...	...	X	X	...	...	...	...	X	X
Bituminous-aggregate applications:													
Treatments and seals:													
Single surface treatment (Chip Seal)	X	X	...	...	...	...	...	X	X	...	...	...	...
Multiple surface treatment	X	X	...	...	...	...	...	X	X	...	...	...	...
Sand seal	X	X	X	...	...	...	...	X	X	...	...	...	...
Penetration macadam:													
Large voids	...	X	...	...	...	...	...	...	X	...	...	...	...
Small voids	X	...	...	...	...	...	...	X	...	...	...	...	...
Bituminous applications:													
Fog seal	...	...	X[C]	...	...	X[D]	X[D]	...	...	...	...	X[D]	X[D]
Prime coat-penetrable surface	...	...	...	...	...	X[D]	X[D]	...	...	...	...	X[D]	X[D]
Tack coat	...	...	X[C]	...	...	X[D]	X[D]	...	...	...	...	X[D]	X[D]
Dust binder	...	...	...	...	...	X[D]	X[D]	...	...	...	...	X[D]	X[D]
Mulch treatment	...	...	...	...	...	X[D]	X[D]	...	...	...	...	X[D]	X[D]
Crack filler	...	...	...	X	X	X	X	...	...	X	X	X	X
Maintenance mix:													
Immediate use	...	...	X	X	X	...	...	...	...	X	X	...	...

[A] For definitions of terms used in this table, refer to Section 2.

[B] Specification D 3515 permits the use of other emulsion grades by note, "Grades of emulsion other than MS-2h may be used where experience has shown that they give satisfactory performance."

[C] Diluted with water by the manufacturer.

[D] Diluted with water.

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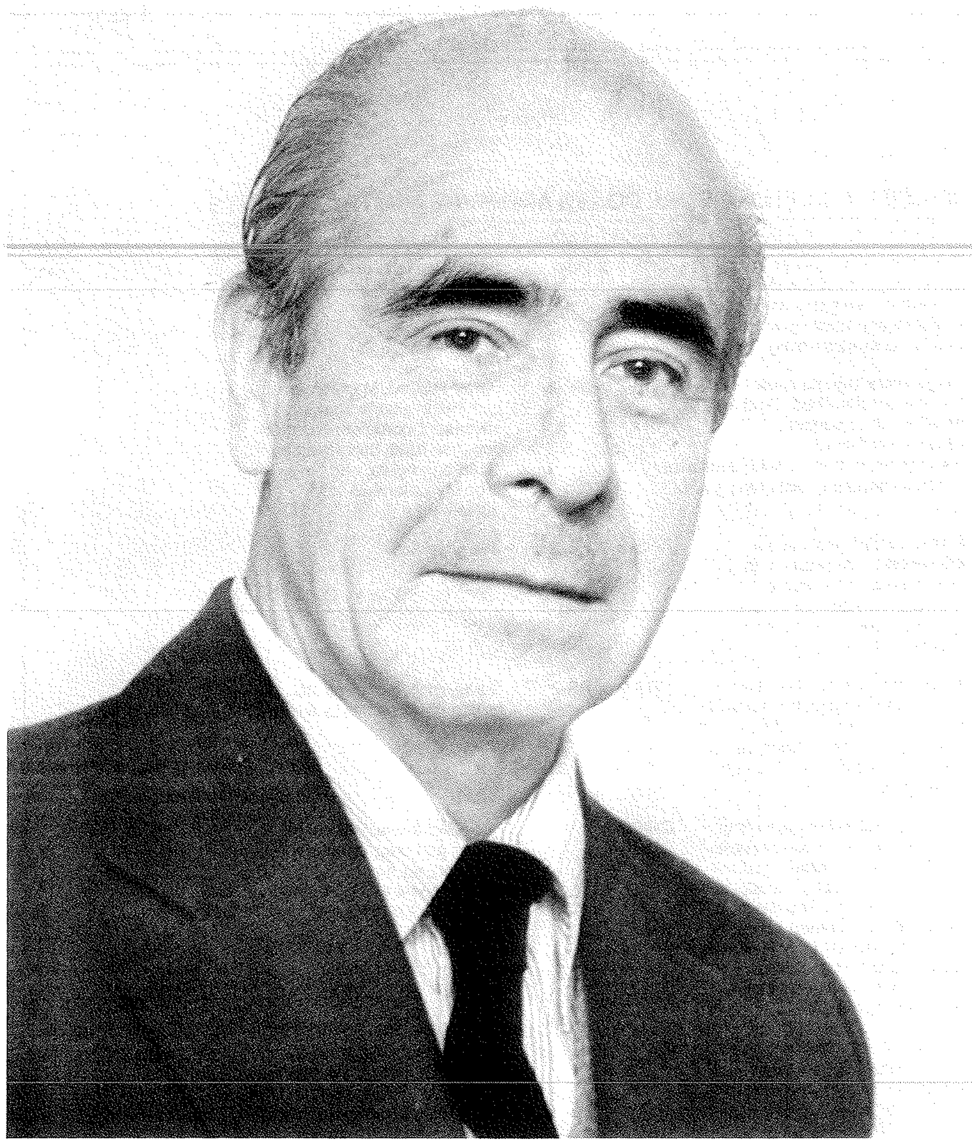
TABLE V-2 EMULSIFIED ASPHALT SEAL COATS AND SURFACE TREATMENTS

System	*Description and Uses*	*Emulsified Asphalt*	*Construction Hints*
SAND SEAL	Restores uniform cover. In city street work, improves street sweeping, traffic line visibility. Enriches dry, weathered pavements; reduces raveling.	CRS-1 or RS-1	Spray-applied with sand cover. Roll with pneumatic roller. Avoid excess binder.
CHIP SEAL	Single most important low cost maintenance method. Produces an all-weather surface, renews weathered pavements, improves skid resistance, lane demarcation, seals pavement.	CRS-2 or RS-2	Spray-applied. Many types of textures available. Key to success: Coordinate construction, use hard, bulky grained, clean aggregate, and have properly calibrated spray equipment.
DOUBLE SEAL	Similar to chip seal except the second chip application uses a small sized stone. Durable, provides some leveling, available in a number of textures.	CRS-2 or RS-2	See Chip Seal.
TRIPLE SEAL	Three applications of binder and 3 sizes of chips are applied. Provides up to a 2 cm thick, flexible pavement. Levels as well as providing a seal, tough wearing surface.	CRS-2 or RS-2	Spray-applied in three lifts. Drag broom between lifts to provide leveling.
DRAG SEAL	Low cost method of improving the riding quality of rough pavements. A rain-resistant medium-set emulsified asphalt is applied followed by chips. The pavement is drag-broomed to level spots and depressions. A second application of binder followed by a choke aggregate or sand is applied.	CMS-2	The CMS-2 tolerates more mixing and drag-brooming than the rapid-set emulsions. Use a wetting agent in the steel wheel roller to reduce pickup.
SLURRY SEAL	Used in airport and city street maintenance where loose aggregate cannot be tolerated. Seals, fills minor depressions, provides an easy-to-sweep surface. Made with crushed aggregate mixed with quick-set emulsified asphalt. The liquid slurry is machine-applied with a sled-type box containing a rubber-edged strike-off blade.	QS* grades	Pretest the aggregate and emulsion mix to achieve desired workability, setting rate, and durability. Calibrate equipment prior to starting the project.
CAPE SEAL	Combines a single chip seal with a slurry seal. Provides the rough, knobby surface of a chip seal to reduce hydroplaning yet has a tough sand matrix for durability.	CRS-2 and QS* grades, SS-1, SS-1h, CSS-1, or CSS-1h	Apply a large aggregate single chip seal. Broom and apply slurry seal. Have the strike-off ride on the rock surface to form the matrix.
	Test track data indicate better studded tire damage resistance than a chip seal.		Avoid excess slurry as this destroys the knobby stone texture desired.

**Not Standardized*



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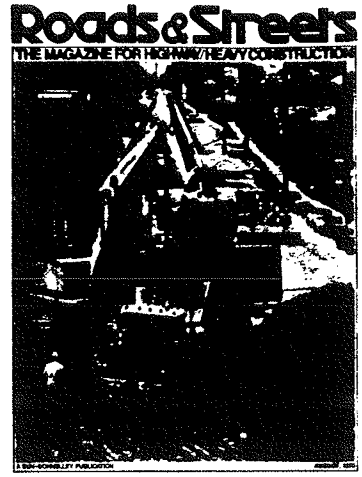
Roads & Streets

THE MAGAZINE FOR HIGHWAY/HEAVY CONSTRUCTION



Persistent rain forced a California contractor to revise his game plan for making a deep excavation. A large excavator could do its work while standing on firm ground and still reach haulage trucks also standing on firm ground. Story begins on page 24.

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BPA ABP

Bituminous

Seven fundamentals for durable spraybar work--jobs you can be proud of

Surface treating and sealcoating are among the most widely used highway and street techniques, yet among the most poorly understood. Almost anywhere can be seen examples of uneven, streaky, or too-flat surfaces thus constructed—work that will last only a third to half the length of time a really good job should serve.

Yet it's relatively easy to take a fresh grip on the simple principles involved in putting down long-lasting asphalt seals and treatments. Dr. Norman W. McLeod, vice president and asphalt consultant of Mc-Asphalt Engineering Services, Toronto, and foremost asphalt paving technologist, reviewed seven fundamentals a contractor should consider when he spoke at the annual meeting of the Asphalt Emulsion Manufacturers Association.

First, a surface treatment will fail without a good enough foundation. It has very little load carrying capacity in itself. All too familiar is the mistake of treating gravel roads that are too weak. Treatments placed on them are doomed to rapid failure.

While most contractors and engineers consider the terms "surface treatment" and "seal coat" interchangeable, technically the former is defined as one or more applications of liquid asphalt and cover aggregate on a prepared base of consolidated gravel, stone, macadam, earth or stabilized soil. "Seal coat" is the right term when applied on an existing hard pavement according to Transportation Research Board Committee Specification MC-A3.

Second, everyone on the job needs to have a clear mental picture of what a really top-quality surface treatment or seal coat looks like under traffic. What should be seen is chiefly aggregate without evidence of any flushing or bleeding. Examples of long-lasting treatments and seals in the US and in foreign countries prove that a good job need never bleed.

For example, in Australia the 15,000 miles of surface treatments on gravel have lasted an average of 10 years, with ranges from 6 to 15 years. Treatments in many cold regions, such as Sweden, have also lasted well despite the climate.

These and other good examples have only aggregates visible. Contractor and engineering personnel should walk along both good and bad jobs to fully understand the difference.

Third, look for these more common faults and how they can be avoided:

Streaking is caused by failure to apply the asphalt uniformly inch by inch across the road width. A streaky job doesn't last well. To find the cause, look for haphazard spray-nozzle alignment or incorrect spraybar height above the road surface. A paver's crewman can correct nozzle alignment with a wrench fitted with a proper stop to turn each nozzle to the angle recommended by the manufacturer. The height should be adjusted to the road crown to provide a triple overlap—uniform for all nozzles.

Streaking can also occur when asphalt is applied at too low a temperature since it will then not fan out properly from the spray nozzles.

Flushing or bleeding is due to applying too much asphalt or to loss of cover aggregates as when washed off by rain immediately after placement.

Loss of aggregate happens when too little asphalt has been sprayed to hold the material on the road.

Lack of bond between the asphalt and the existing surface can be blamed often on cold weather, moisture or dust. Or, both aggregate and cover stone may be lost along wheel paths when rainy weather follows immediately after laydown.

Fourth is one of the most neglected aspects of design and job control: the **cover aggregate gradation.** Here Dr McLeod again refers to the highly successful Australian experience. From 60 to 70 percent of the particles passing the specified nominal size must be retained on a sieve having an opening 0.7 of that size. To illustrate, 60 to 70 percent of a ¾-in. aggregate must lie between ¾ in. and 0.7 of ¾ in. or about ½ in.

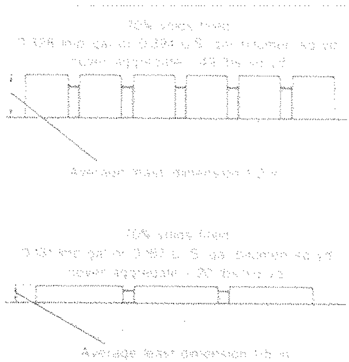
Australian engineers also **watch particle flatness** by specifying a maximum flakiness index (35, by British Standards Institution Text 812).

In the US the gradations coming closest to a one-sized aggregate are probably those specified by AASHTO M43 and ASTM 448. Tables 1 and 2 compare material meeting these standards with those used in Australia.

The correct amount of emulsified asphalt binder is an amount per sq yd that ideally will embed every particle of cover aggregate to 70 percent of its depth in residual asphalt. Stone particles embedded less than 50 percent will be whipped out by traffic. Those embedded 100 percent will be submerged in residual asphalt, leading to a flushed or slick pavement. In Fig 1, a selected aggregate gradation is plotted to show what you are up against

continued on page 104

An expert contractor probably already observes the seven fundamentals of good spraybar practice and produces work he can be proud of.



(Above) Fig. III Comparing bitumen and cover aggregate requirements for seal coats made with ½ in. cover aggregates of different particle shapes —one cubical, the other flat and elongated.

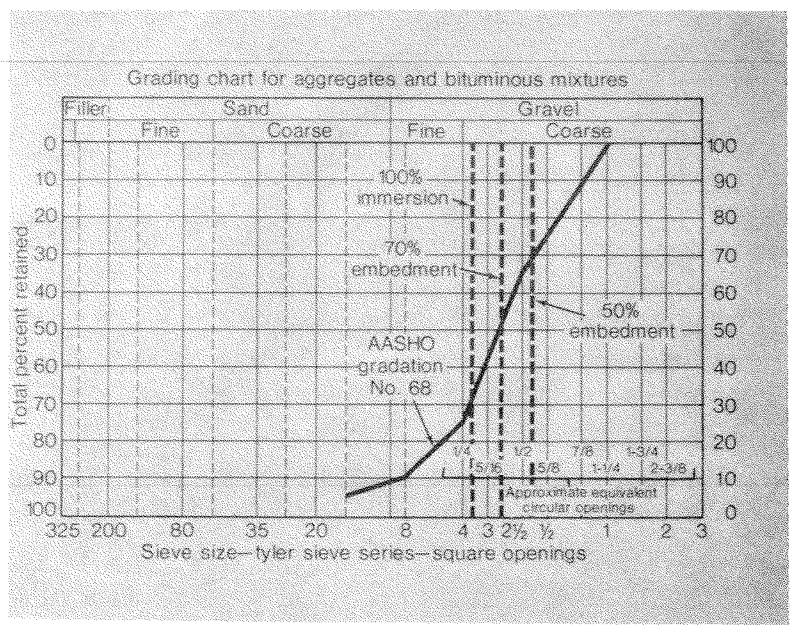


Fig. I Illustrating embedment of simplified practice gradation No. 68 cover aggregate in asphalt binder.

Seven fundamentals

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in trying to select a residual asphalt quantity to apply when the cover is to be a graded aggregate.

It can be assumed that the correct amount of asphalt binder will embed the median-sized particles, those corresponding to 50 percent passing, to 70 percent of its depth, this quantity of asphalt will completely submerge 29 percent of this aggregate. Yet 32 percent of the aggregate, the larger particles, will be immersed less than 50 percent, and will be dislodged by traffic.

This chart shows that the right amount of asphalt per sq yd for one of the size fractions of a graded stone is not the correct amount for most of the stone.

In contrast, Fig II shows a happier result with the ½-in. cover aggregate from Australian specifications in Table 1. Here, when enough binder is used to embed the median particle size to 70 percent of its depth, only 15 percent of the aggregate, the smaller sizes, would be fully submerged and only 3 percent of the largest size embedded less than 50 percent.

These two charts prove that more of the aggregate will be properly embedded when a basically one-size material is used. Yet, in the US large mileages continue to be treated using graded aggregates despite the inferior results. The main reason isn't hard to find. It's because such aggregates can be produced more cheaply than one-size cover stone.

A fifth handle for controlling the quality of the job—and another very important one—is to determine the **average least dimension** (ALD) of the cover stone. Stone particles tend to arrange themselves in flat position (the thinnest dimension vertical) after considerable warm-weather traffic. One aggregate passing a ½-in. square sieve opening may average 0.5 in. thick (ALD 0.5 in.) in this final position. Another stone passing the same nominal sieve size may average only 0.2 in. thickness when lying flat (ALD 0.2 in.).

The optimum quantity of residual asphalt needed to embed the stone to 70 percent figures out at 0.394 gal per sq yd, or 0.157 gal per sq yd—depending on aggregate.

This illustrates the importance of making such exact computations based on sieve analyses of the material to be used. And it explains

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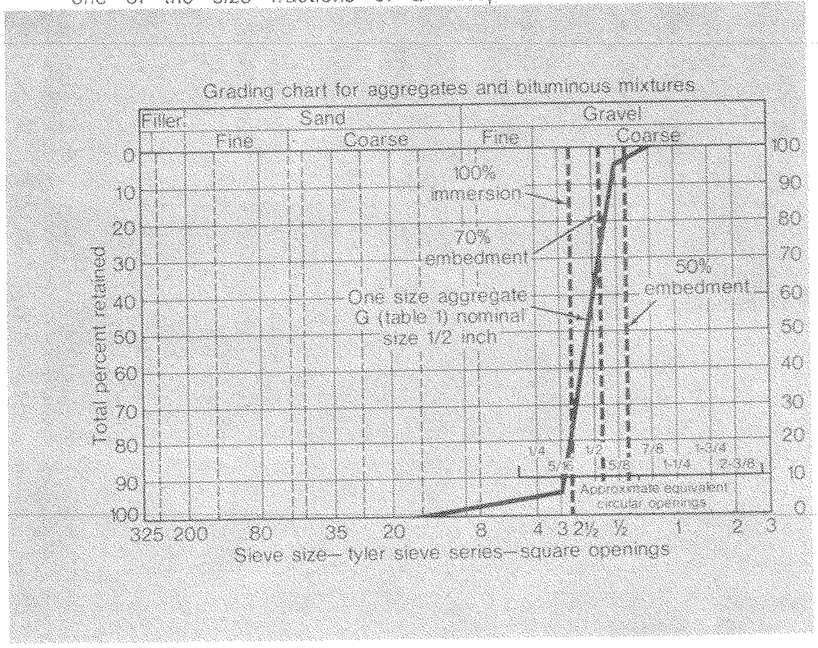
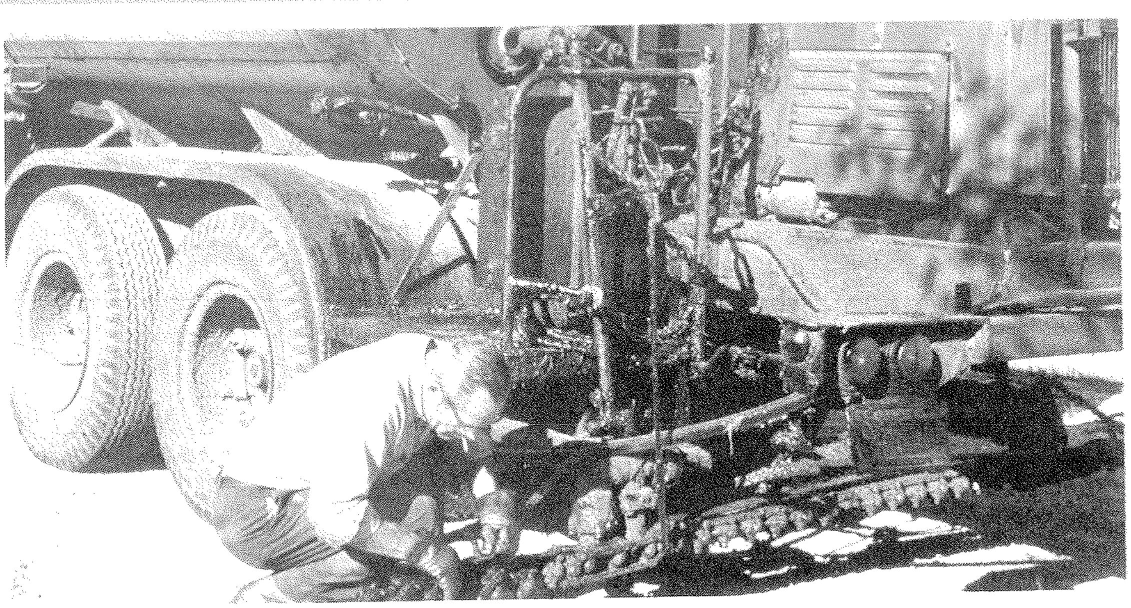


(Left) Fig. II Illustrating embedment of one size-aggregate G in asphalt binder. (Below) Correct nozzle settings can be produced by a crewman using a special wrench fitted with stops.



Seven fundamentals

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TABLE 1. Typical gradation requirements for one-size cover aggregate (National Association of Australian State Road Authorities)

Size number	Nominal size square openings	Per cent passing by dry weight U. S. standard sieve square openings									Particle shape flakiness index max
		1	3/4	5/8	1/2	3/8	1/4	No. 4	No. 8	No. 16	
E	3/4 in.	100	95-100	—	0-20	0-5	—	—	—	0-0.5	35
F	5/8 in.		100	95-100	—	0-15	0-5	—	—	0-0.5	35
G	1/2 in.		100	—	95-100	0-30	0-5	—	—	0-0.5	35
H	3/8 in.				100	95-100	0-40	0-5	—	0-0.5	35
I	No. 4						100	95-100	0-40	0-0.5	35

TABLE 2. Standard sizes of coarse aggregate for highway construction (AASHO M 43, ASTM D 448)

Size number	Nominal size square openings	Amounts finer than each laboratory sieve (square openings), percentage by weight.									
		1½	1	3/4	1/2	3/8	No. 4	No. 8	No. 16	No. 50	No. 100
5	1 to 1-1/2	100	90 to 100	20 to 55	0 to 5	0 to 5					
56	1 to 3/8	100	90 to 100	40 to 75	15 to 35	0 to 15	0 to 5				
57	1 to No. 4	100	95 to 100	—	25 to 60	—	0 to 10	0 to 5			
6	3/4 to 3/8		100	90 to 100	20 to 55	0 to 15	0 to 5	—			
67	3/4 to No. 4		100	90 to 100	—	20 to 55	0 to 10	0 to 5			
68	3/4 to No. 8		100	90 to 100	—	20 to 65	5 to 25	0 to 10	0 to 5		
7	1/2 to No. 4			100	90 to 100	40 to 70	0 to 15	0 to 5	—		
78	1/2 to No. 8			100	90 to 100	40 to 75	5 to 25	0 to 10	0 to 5		
8	3/8 to No. 8				100	85 to 100	10 to 30	0 to 10	0 to 5		
89	3/8 to No. 16				100	90 to 100	20 to 55	5 to 30	0 to 10	0 to 5	
9	No. 4 to No. 16					100	85 to 100	10 to 40	0 to 10	0 to 5	
	No. 4 to 0*					100	85 to 100	—	—	—	10 to 30

* Screenings NOTE: All sieve sizes expressed in terms of U.S. Standard Sieve Series.

the wide difference in the behavior of treatments and seals in service. The blame rests with the common custom of specifying some arbitrary, unvarying combination of ingredients, such as ¼ gal per sq yd of residual asphalt with, say, 25 lb per sq yd of cover stone. The asphalt could be too little, or too much, depending on the cover stone's ALD.

A sixth factor is **stone size.** Dr McLeod has concluded that good performance is more likely with larger cover aggregate. There is a larger safety factor in getting the right amount of aggregate for proper embedment when the stone is larger.

A seventh quality factor, again referring to the foreign practice, is to get **good adhesion.** The New Zealand National Road Board, for example, requires washing and precoating the aggregate. Precoating is done with about 1 gal per cu yd of a special cationic emulsion or cutback asphalt. The Australians utilize diesel fuel or MC30 or MC70 cutback.

These seven steps taken together can go far to assure that asphalt surface treatments and seal coats will give the taxpayer his money's worth and reflect to the credit of the engineers and the contractors. The steps add little if anything to a contractor's cost of the job. The problem is for everyone involved to know of these factors and realize why they are important.

The full details of Dr. McLeod's review and analysis of the fundamentals of surface treatments and seal coats are available from the Asphalt Emulsion Manufacturers Association, 1000 Vermont Ave NW, Washington, DC 20005. This 88-page publication, "Seal Coat and Surface Treatment Construction and Design Using Asphalt Emulsion," is available from AEMA at $5 postpaid. It also includes an example of how to figure material amounts, lists practical construction procedures and precautions, and contains extensive charts and tables. □

Selecting the right emulsion grade

ASTM has published specifications for the two grades of each of two types of asphalt emulsions, anionic and cationic, suitable for seal coat and surface treatment construction.

RS-1 and CRS-1 asphalt emulsions are more fluid grades and may be used with cover aggregate ⅜ in. and smaller. The greater quantities of these fluid grades required for larger cover aggregate would tend to drain from higher into depressed areas in the road surface and down the slope of any normally crowned road. Consequently, for cover aggregate ⅜ in. and larger, the more viscous RS-2 or CRS-2 grades are specified.

Recommended application temperatures for asphalt emulsions are: 75 deg to 130 deg F for RS-1, 110 deg to 180 deg F for RS-2, 75 deg to 130 deg F for CRS-1, and 110 deg to 180 deg F for CRS-2.

A design method for surface treatments or seal coats with asphalt emulsions should provide answers to three basic questions: What type and grade of asphalt emulsion should be selected? How much asphalt emulsion in gal per sq yd measured at 60 deg F should be applied? How many lb per sq yd of aggregate should be spread? □

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PROCEEDINGS

OF

THE ASSOCIATION OF ASPHALT PAVING TECHNOLOGISTS

TECHNICAL SESSIONS
HELD AT
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FEBRUARY 10, 11, and 12
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* In order of presentation at Annual Meeting Technical Sessions.

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WARD K. PARR

A GENERAL METHOD OF DESIGN FOR SEAL COATS AND SURFACE TREATMENTS

N. W. MCLEOD[1]

SYNOPSIS

It is the principal objective of this paper to demonstrate that one equation for the quantity of cover aggregate required and another equation for the quantity of asphalt binder to be applied, can be used for the design of either single application or multiple application surface treatments and seal coats.

The required characteristics of both cover aggregates and asphalt binders are reviewed. The superiority of one-size over graded cover aggregates is demonstrated.

Equations are developed for the quantities of cover aggregate and asphalt binder required for single application surface treatments and seal coats. A sample calculation illustrates their use for this purpose.

It is shown that these same equations can be employed for the design of multiple seal coats and surface treatments. Sample calculations are included to illustrate their use in this respect.

The principles of construction for single and multiple application surface treatments and seal coats are reviewed.

KEY WORDS single surface treatment, multiple surface treatment, asphalt emulsion, liquid asphalt, asphalt cement, design, construction.

I. INTRODUCTION

It is one of the principal objectives of this paper to demonstrate that two design equations, one for determining the quantities of asphalt binder to be applied per square yard, and the other for establishing the quantities of cover stone to be applied per square yard, can be successfully employed for the design of either single application or multiple application surface treatments and seal coats.

The most important asphalt surface in North America is hot-mix asphalt concrete. When one leaves the North American continent however, it very quickly beccmes apparent that traffic volumes on most of the world's highways would not justify the cost of hot-mix asphalt pavements. Consequently, on a world wide basis, the most important type of asphalt surface is a surface treatment on a consolidated granular base. From the point of view of economy, if they were properly designed and constructed, asphalt surface treatments on consolidated granular bases should be much more widely used here in North America for surfacing secondary highways, residential streets, and roads carrying lower traffic volumes.

For an excellent review of currently available information on surface treatments and seal coats, the reader is referred to the Highway

[1] Asphalt Consultant, Imperial Oil Ltd., Toronto, Ontario, Canada.

Research Board Special Report 96, "State of the Art: Surface Treatments, Summary of Existing Literature," by Herrin, Marek, and Majidzadeh, published in 1968.

In a paper presented before the AAPT Meeting in 1960 (1), the method of design that is employed by the Country Roads Board of Victoria, Australia, and by the National Roads Board of New Zealand, to build the most consistently successful surface treatments to be seen in the world was described. New Zealand specializes in double surface treatments, the second layer being placed about two years after the first, while single application surface treatments are generally used in Australia. Figures 1 to 6 are pictures of surface treatments taken by the author during a trip to New Zealand and Australia in 1967. Figures 1 and 2 are an overall view and a close-up of a double surface treatment

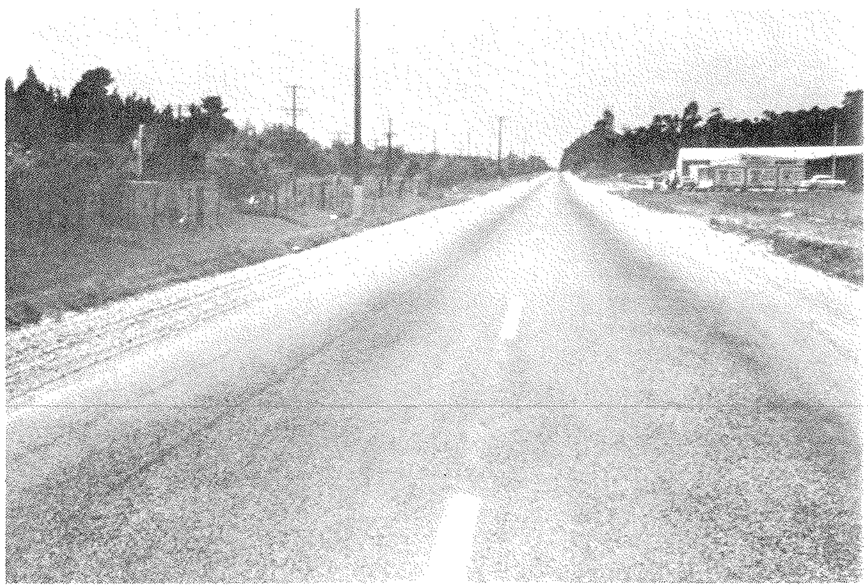

Fig. 1. New Zealand. Double Surface Treatment on Consolidated Granular Base, 15 Years Old, Carrying 3000 Vehicles per Day. Excellent Condition.

in New Zealand that is 15 years old and that is carrying 3000 vehicles per day. It appeared to be capable of serving the same traffic volume for an additional 15 years without further attention. Figure 3 illustrates a 4-lane divided highway in New Zealand, in which the asphalt surface is only a double surface treatment on a consolidated granular base. In New Zealand this type of construction is expected to carry up to 20,000 vehicles per day. Figures 4 and 5 are a panorama and a close-up of another first-rate double surface treatment on a well compacted granular base in New Zealand. Figure 6 provides a view of a

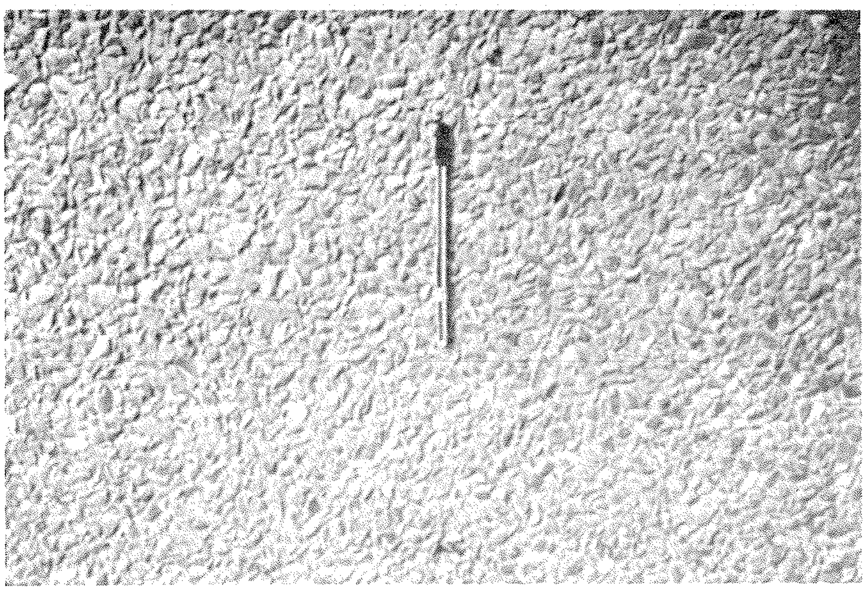

Fig. 2. Close-Up of Surface Treatment Shown in Figure 1.

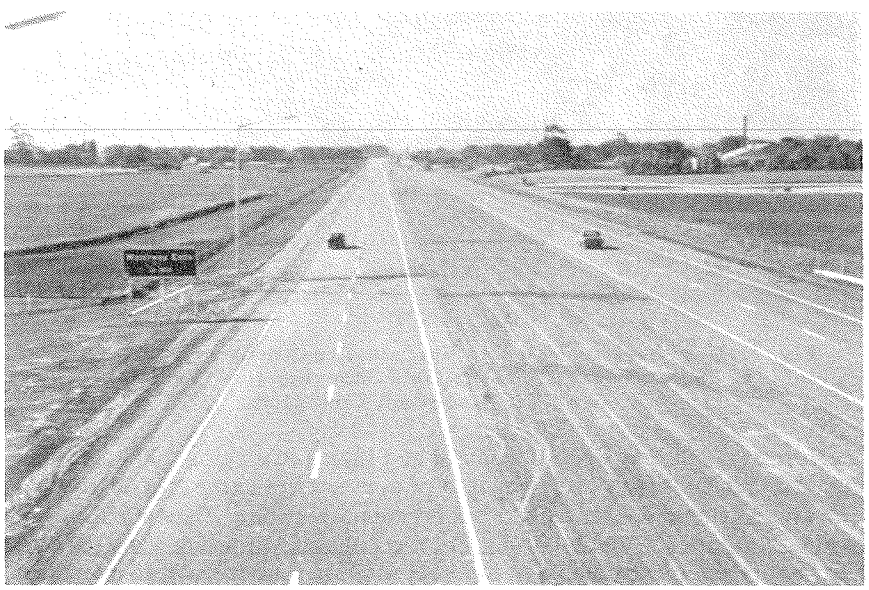

Fig. 3. New Zealand. Double Surface Treatment on Consolidated Granular Base on 4-Lane Divided Highway. This Construction Not Uncommonly Carries More Than 20,000 Vehicles per Day.

Fig. 4. New Zealand. Main Highway Taupo to Wellington. Double Surface Treatment on Consolidated Granular Base.

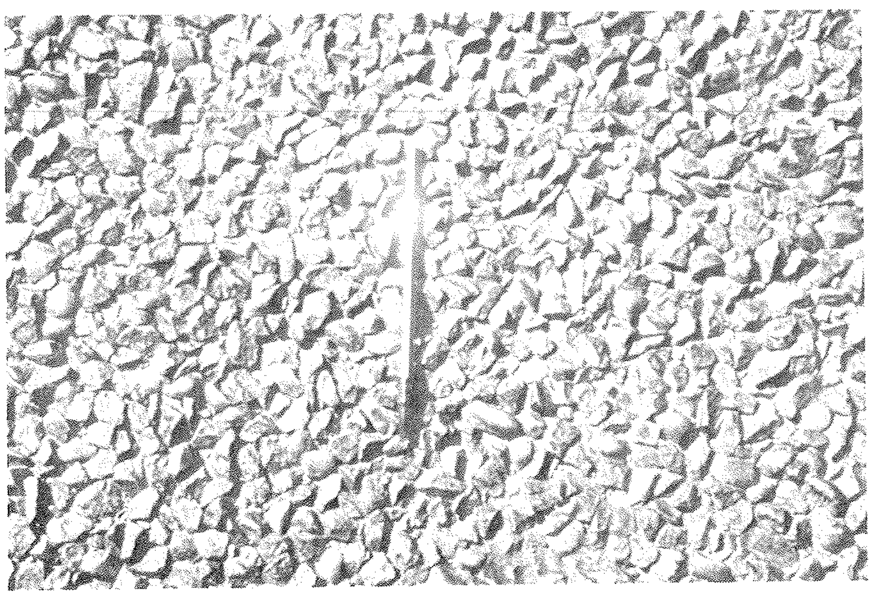

Fig. 5. Close-Up of Surface Treatment Shown in Figure 4.

Fig. 6. Victoria, Australia. Single Surface Treatment on Consolidated Granular Base on 4-Lane Divided Highway between Melbourne and Sydney--the Hume Highway Near Melbourne, 6 Years Old, Carrying 4000 Vehicles per Day.

4-lane divided highway section of the Hume Highway between Melbourne and Sydney, near Melbourne, Australia. It is a single surface treatment on a consolidated granular base. It is 6 years old, and is carrying 4,000 vehicles per day, many of them being heavily loaded trucks.

A modification of the methods of design employed so successfully in Victoria, Australia, and in New Zealand, forms the basis for the method of design to be recommended in this paper.

II. DEFINITIONS FOR SURFACE TREATMENTS AND SEAL COATS

Unfortunately, there are still no universally accepted definitions for the terms "seal coats" and "surface treatments." Consequently, for this paper, definitions for these expressions will be employed that have been proposed by several other writers (2), (3), (4), and that have been recommended by Subcommittee MC-A3(3) of the Highway Research Board Committee MC-A3 on Bituminous Surface Treatments, in its "Report on Designation for Surface Treatments," October, 1965.

Therefore, a "surface treatment" is defined as a bituminous surface that results from one or more successive alternate applications of bituminous binder and cover aggregate to a prepared consolidated gravel, crushed stone, waterbound macadam, earth, stabilized soil, or similar base. A "seal coat" is defined as a bituminous surface that results from one or more successive alternate applications of bituminous binder and cover aggregate to an existing paved surface.

III. TYPES OF SURFACE TREATMENTS AND SEAL COATS

There are several different types of surface treatments and seal coats as follows:

A. Single application
   (1) one-size cover aggregate
   (2) graded cover aggregate
B. Multiple application
   (1) double application
   (2) triple application
   (3) quadruple application

Single application surface treatments and seal coats are by far the most common type. They consist of a single application of asphalt binder to a prepared surface, followed by a single application of cover aggregate. They are assumed to be one-stone particle thick.

Double, triple, and quadruple application surface treatments consist of two, three, and four successive alternate applications of asphalt binder and cover stone, respectively. The cover stone employed for each successive layer is approximately one-half the size of that used for the immediately preceding layer.

IV. A STRONG FOUNDATION IS NEEDED

Like any other asphalt surface, a surface treatment or seal coat will fail quickly and disastrously unless it is placed on an adequate foundation.

Experience of the Department of Highways of New Brunswick, where typical Canadian road building conditions of frost and snow in winter, and rain, sun, and hot weather in summer, occur, illustrates the need for an adequate foundation for surface treatments. Following the serious failure of many miles of surface treatments laid initially without proper attention to the foundation, New Brunswick now has 4,000 miles of its secondary road system surfaced with very successful surface treatments. Success followed when the Department of Highways embarked on a 2-year program, in which an adequate foundation was constructed the first year, and the surface treatment itself was not laid until the second year.

V. PRINCIPAL FAULTS

The principal faults in surface treatments and seal coats were discussed in detail in the earlier paper (1), and will be reviewed only briefly here. They are (a) streaking, (b) flushing or bleeding, (c) loss of cover aggregate, and (d) failure to establish a satisfactory bond between the existing surface and the new surface treatment or seal coat.

Streaking is due to the failure to apply asphalt uniformly inch by inch across the road surface. The unevenness of the asphalt binder application shows up as gray or dark streaks due to a deficiency or excess of asphalt binder in the finished surface treatment or seal coat. Streaking may be caused by one or more of several factors. Partially plugged spray nozzles, spray nozzles of poor design, spray nozzles of different size in the spray bar, spray nozzles at various wrong angles in the spray bar, incorrect height of the spray bar above the road surface, varying the rate of discharge from the spray nozzles in gallons per minute per nozzle to obtain specified rates of application per square yard, and trying to spray the asphalt binder at too low a temperature, are some of the more common causes.

Flushed or bleeding surface treatments or seal coats are usually caused by the application of too much bituminous binder, the excess binder oozing out of the cover aggregate onto the surface. Flushing or bleeding may also result from a loss of a portion of the cover aggregate for any reason, such as rain falling shortly after construction, use of too hard an asphalt binder with which the cover aggregate fails to develop adequate adhesion, and use of cover stone that is too dirty or too wet to establish good adhesion to the asphalt binder.

Serious loss of cover aggregate occurs when for any reason there is inadequate embedment of the stone particles in the asphalt binder. Not enough asphalt binder may have been applied, too much of the asphalt binder may have been absorbed by the existing surface, or the asphalt binder applied may be too hard for the prevailing weather or climate. Late season construction can result in grave loss of cover stone when there is not enough warm weather traffic following construction to achieve sufficient embedment of the aggregate particles in the asphalt binder. Wet weather and freezing conditions tend to accelerate the loss of cover stone whenever it is poorly embedded.

A new seal coat or surface treatment may fail to establish a good bond with an existing surface due to a layer of dust or dirt, because the existing surface is wet or too cold, or because the asphalt binder is too hard. Normally, only a small area of a few square inches, or a few square feet, or occasionally a few square yards, but sometimes an entire surface treatment or seal coat fails for this reason.

VI. MATERIALS

Before considering the method of design to be presented, some essential characteristics of the materials employed for surface treatments and seal coats will be outlined. This will provide necessary background information. This topic was covered in considerable detail in the earlier paper (1) and only the items pertinent to the present paper will be reviewed here. The materials of construction for seal coats and surface treatments are cover aggregates and asphalt binders, which may consist of asphalt cements, asphalt emulsions, or liquid asphalts. These will be considered separately.

A. COVER AGGREGATES

1. General

In general, cover aggregates should consist of hard, tough, clean, dry fragments of stone, that have been produced either from quarried rock, or from clean, hard gravel. For high traffic volumes the Los Angeles abrasion rating should preferably be less than 20, while for light traffic it should not exceed a maximum value of 35, but frequently does.

2. Particle Shape

The preferred particle shape for cover aggregate is cubical or tetrahedral, and flat particles should be avoided. The tendency of an aggregate toward particle flatness is measured by the Flakiness Index test (Appendix A). The Flakiness Index represents the percentage by weight of flat particles having a least dimension smaller than 60 per cent of the mean size of each of one or more of the coarser sieve fractions. As an example, for aggregate passing a 3/4 inch square sieve and retained on a 1/2 inch square sieve, the mean sieve size is five-eighths of an inch, and the Flakiness Index of this particular size fraction would be the percentage by weight of particles having a least dimension smaller than three-eights of an inch (3/8 being 60 per cent of 5/8). The lower the Flakiness Index for any sample of cover aggregate, the more nearly the aggregate particles approximate cubical shape. As indicated by Table I, The National Association of Australian State Road Authorities (5) specifies 35 per cent as the maximum permissible Flakiness Index rating.

New Zealand controls particle shape by stipulating a maximum of 2.25 for the ratio of the average greatest dimension to the average least dimension of a cover aggregate. To meet this specification, New Zealand contractors have to employ a hammer mill or impact breaker, which tends to provide more cubically shaped particles than other types of rock crushers.

3. Gradation

Typical grading requirements specified by the National Association of Australian State Road Authorities (5) for one-size aggregates are recorded in Table I.

In North America, the nearest approach to one-size cover aggregates are the aggregate gradations specified in AASHO M-43, listed in Table II. In comparison with the one-size aggregates specified in Table I, the materials covered by Table II are graded aggregates.

When designing single application surface treatments and seal coats, it is assumed that the finished surface is just one-stone particle thick, Figure 7. In an earlier paper (1), grading curves were worked out to determine the range of gradation of coarse and fine aggregates that would make it theoretically possible to have a surface treatment or

Table I. Typical Gradation Requirements for One-Size Cover Aggregate (National Association of Australian State Road Authorities)

SIZE NUMBER	NOMINAL SIZE SQUARE OPENINGS	PER CENT PASSING BY DRY WEIGHT U.S. STANDARD SIEVES SQUARE OPENINGS									PARTICLE SHAPE
		1	3/4	5/8	1/2	3/8	1/4	NO. 4	NO. 8	NO. 16	FLAKINESS INDEX MAX.
E	3/4"	100	95 - 100	-	0 - 20	0 - 5	-	-	-	0 - 0.5	35
F	5/8"		100	95 - 100	-	0 - 15	0 - 5	-	-	0 - 0.5	35
G	1/2"		100	-	95 - 100	0 - 30	0 - 5	-	-	0 - 0.5	35
H	3/8"				100	95 - 100	0 - 40	0 - 5	-	0 - 0.5	35
I	NO. 4						100	95 - 100	0 - 40	0 - 0.5	35

seal coat exactly two stone particles thick. Four of the grading curves for aggregates with maximum particle sizes of 3/8, 1/2, 5/8, and 3/4 inch, obtained on this basis, are illustrated in Figure 8.

In Figure 9, a comparison is made between one of these theoretical grading curves with grading curves for Aggregates No's 7 and 78 from Table II. It is clear that Aggregate No. 78 contains more than enough fine aggregate to theoretically provide a surface treatment or seal coat 2-stone particles thick, while Aggregate No. 7 is at least borderline in this respect.

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The correct asphalt binder application should embed every cover aggregate particle in asphalt to 70 per cent of its depth, and particles that are embedded less than 50 per cent in asphalt binder are likely to be torn out by traffic.

Figure 10, which pertains to Aggregate No. 68 from Table II, illustrates the difficulty in providing the proper asphalt content for a graded cover aggregate. If it is assumed that the correct quantity of asphalt binder to be applied will embed the median particle size (the size corresponding to 50 per cent passing) to 70 per cent of its depth, Figure 10 demonstrates that this quantity of asphalt binder will completely

Table II. Standard Sizes of Coarse Aggregate for Highway Construction (AASHO M 43, ASTM D 448)

Size Number	Nominal Size Square Openings	Amounts finer than each laboratory sieve (square openings), percentage by weight.									
		1-1/2	1	3/4	1/2	3/8	No. 4	No. 8	No. 16	No. 50	No. 100
5	1 to 1½	100	90 to 100	20 to 55	0 to 5	0 to 5					
56	1 to 3/8	100	90 to 100	40 to 75	15 to 35	0 to 15	0 to 5				
57	1 to No.4	100	95 to 100	-	25 to 60	-	0 to 10	0 to 5			
6	3/4 to 3/8		100	90 to 100	20 to 55	0 to 15	0 to 5	-			
67	3/4 to No.4		100	90 to 100	-	20 to 55	0 to 10	0 to 5			
68	3/4 to No.8		100	90 to 100	-	30 to 65	5 to 25	0 to 10	0 to 5		
7	1/2 to No.4			100	90 to 100	40 to 70	0 to 15	0 to 5	-		
78	1/2 to No.8			100	90 to 100	40 to 75	5 to 25	0 to 10	0 to 5		
8	3/8 to No.8				100	85 to 100	10 to 30	0 to 10	0 to 5		
89	3/8 to No.16				100	90 to 100	20 to 55	5 to 30	0 to 10	0 to 5	
9	No.4 to No.16					100	85 to 100	10 to 40	0 to 10	0 to 5	
10	No.4 to 0*					100	85 to 100	-	-	-	10 to 30

* Screenings NOTE: All Sieve Sizes Expressed in Terms of US Standard Sieve Series.

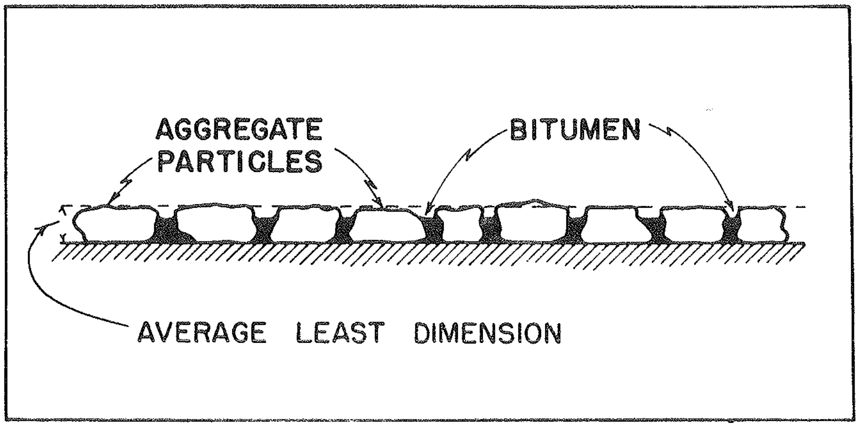

Fig. 7. Illustrating the Average Least Dimension of Cover Aggregate Particles, and the Ultimate Positions of These Particles in a Surface Treatment or Seal Coat After Considerable Traffic. (The Least Dimension of Each Particle Is Vertical.)

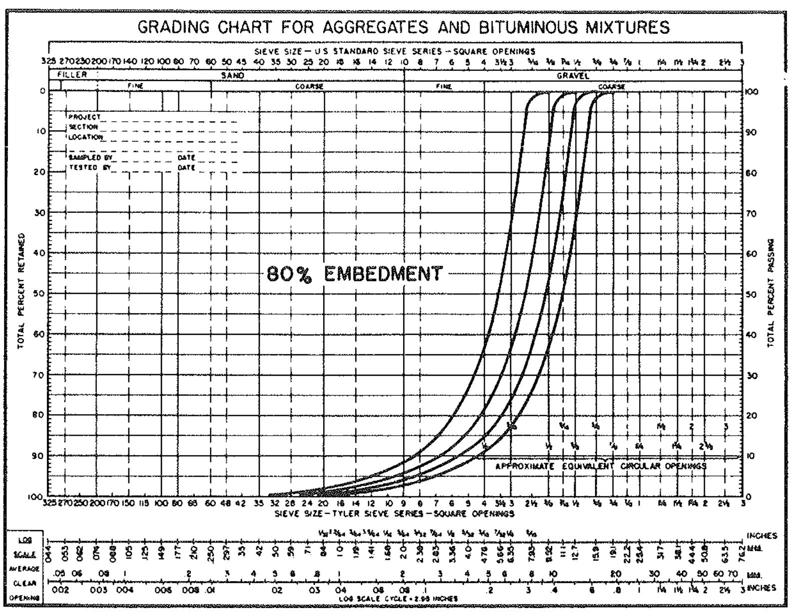

Fig. 8. Grading Curves for Cover Aggregates Capable of Providing Seal Coats or Surface Treatments Exactly 2-Stone Particles Thick Under Ideal Conditions.

submerge 29 per cent of this aggregate, while 32 per cent of the aggregate particles (the largest particles) will be immersed less than 50 per cent of their depth, and will therefore tend to be dislodged by traffic. Figure 10 emphasizes that the proper asphalt binder application for one of the size fractions of a graded cover aggregate, can be far from correct for even a majority of size fractions.

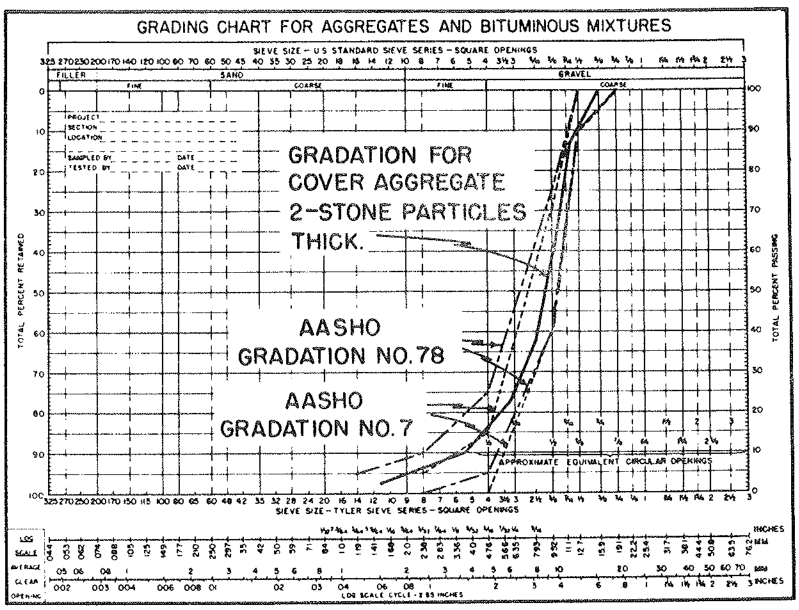

Fig. 9. Illustrating That AASHO Coarse Aggregate Gradations No. 7 and No. 78 Could Provide Seal Coats or Surface Treatments at Least 2-Stone Particles Thick.

Figures 11 and 12 examine one-size cover aggregates on this same basis. The solid curve in Figures 11 and 12 represents the widest possible range of gradation of particle sizes that will just satisfy the grading limits specified for Aggregate G from Table I. The broken line curve in Figure 11 illustrates the corresponding gradation of aggregate particles that could theoretically provide a single application seal coat or surface treatment exactly 2-stone particles thick. It can be seen that one-size Aggregate G does not contain sufficient fine aggregate to provide a single application surface treatment or seal coat 2-stone particles thick.

Figure 12, which applies to one-size Aggregate G demonstrates that when enough asphalt binder is applied to embed the median particle size to 70 per cent of its thickness, only 15 per cent of the cover aggregate (the smallest sizes) would be completely submerged in asphalt binder, while just three per cent of the particles (the largest sizes) would be embedded to less than 50 per cent of their depth.

A comparison of Figure 12 with Figure 10 makes it quite clear that when the optimum quantity of asphalt binder is applied, it satisfies the asphalt binder requirements for a much higher percentage of the particle sizes in a one-size cover aggregate, Table I, than in a graded aggregate, Table II. In addition, when graded cover aggregate is used, the finer particles tend to form a covering on the asphalt binder during construction that delays the wetting and the development of good adhesion between the binder and the larger stone particles. Many of these larger particles are therefore dislodged by traffic before adequate embedment in the asphalt binder can occur. All of these factors indicate that single surface treatments or seal coats that are constructed with graded cover aggregates, Table II, are likely to be less uniform, to be inferior in appearance, and to have a shorter service life than those made with one-size cover stone, Table I. Nevertheless, in spite of these disadvantages, large mileages of seal coats and surface treatments are likely to continue to be constructed with graded cover aggregates, chiefly because they can be produced at lower cost than one-size cover stone. However, it should be noted that the Country Roads Board, Victoria, Australia, employs only one-size cover aggregates although their cost delivered into roadside stockpiles averages approximately $6.00 (US) per cubic yard.

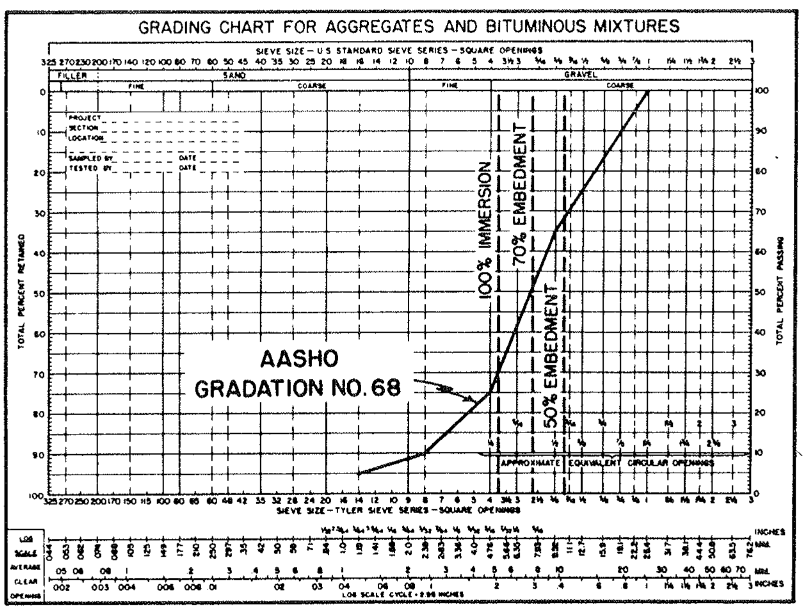

Fig. 10. Illustrating Poor Embedment of AASHO Coarse Aggregate Gradation No. 68 in Asphalt Binder.

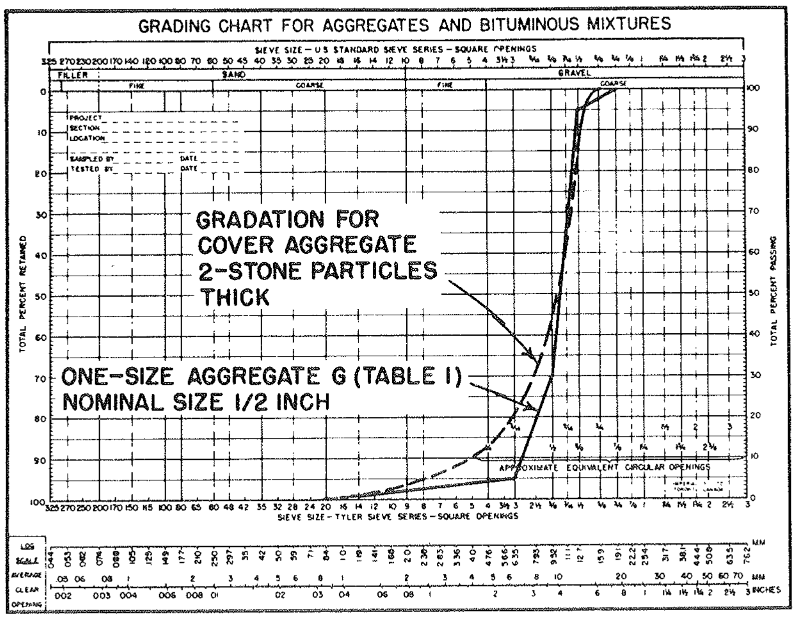

Fig. 11. Illustrating that Grading Curve for One-Size Cover Aggregate G Will Provide a Seal Coat or Surface Treatment Only 1-Stone Particle Thick.

4. Average Least Dimension versus Spread Modulus of Cover Aggregates

Hanson (6) made a most important contribution to the design of surface treatments and seal coats when he observed that after considerable traffic, particles of cover aggregate tend to lie on their flattest sides, Figure 7, with their shortest dimension vertical. Hanson recognized that this means that the average thickness of a seal coat or surface treatment is equal to the average of the smallest dimension of the cover aggregate particles, which he termed the Average Least Dimension or ALD. A method of test for measuring the Average Least Dimension of a cover aggregate is described in Appendix A.

The importance of the Average Least Dimension of the cover stone in both the design and service performance of an asphalt surface treatment or seal coat is illustrated in Figure 13. Both aggregates shown in the two diagrams of Figure 13 would be purchased as 1/2 inch cover stone, because each aggregate will just pass a 1/2 inch square opening. Nevertheless, because it is comprised of cubically shaped particles, the Average Least Dimension of the aggregate in the top diagram is 0.5 inch, while because it consists of elongated flat particles, the ALD of the aggregate in the bottom diagram is only 0.2 inch. If, in accordance with the practice of the Country Roads Board, Victoria, Australia, it is assumed that after substantial warm weather traffic the ultimate void space between the cover aggregate particles in a seal coat or surface treatment is 20 per cent, and that at the optimum asphalt binder application this void space is 70 per cent filled with residual asphalt, the quantity of the aggregate in the top diagram of Figure 13 to be applied for a surface treatment or seal coat is 49 pounds per square yard, and of the cover stone in the lower diagram is only 20 pounds per square yard. Also, the optimum quantity of asphalt binder required for the cover stone in the upper diagram is 0.394 US gallon per square yard (0.328 Imperial gal/sq. yd.) (1.78 litres per square metre), and for the cover aggregate in the bottom diagram is only 0.157 US gallon per

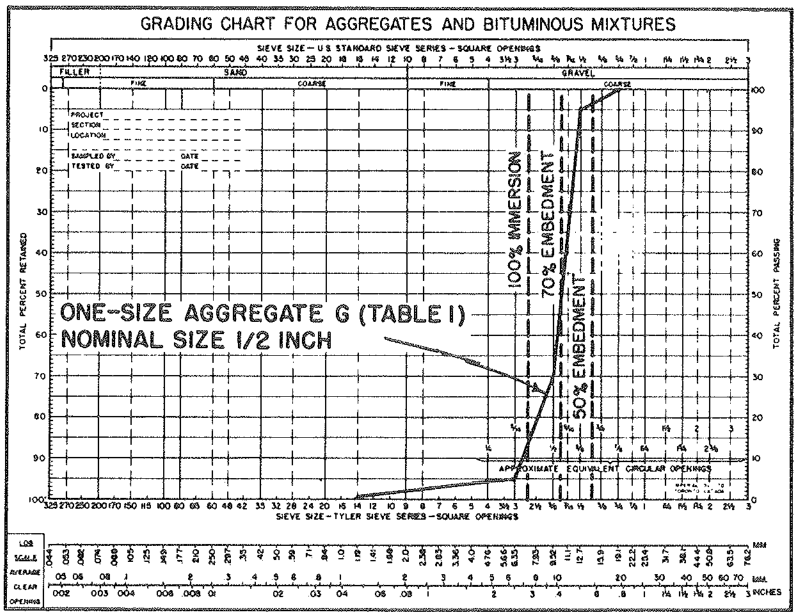

Fig. 12. Illustrating Excellent Embedment of One-Size Aggregate G in Asphalt Binder.

square yard (0.131 Imperial gal/sq. yd.) (0.71 litres per square metre). Consequently, Figure 13 emphasizes that both the asphalt binder and cover aggregate requirements per square yard for a seal coat or surface treatment depend on the cover aggregate's Average Least Dimension.

Figure 13 also provides an explanation for the wide differences in surface treatment and seal coat behaviour in service, and for the poor performance that so often results from the common current practice of recommending a quarter of a gallon of asphalt binder and 25 pounds of cover stone per square yard, or some similar combination of quantities, regardless of the shape of the cover aggregate particles.

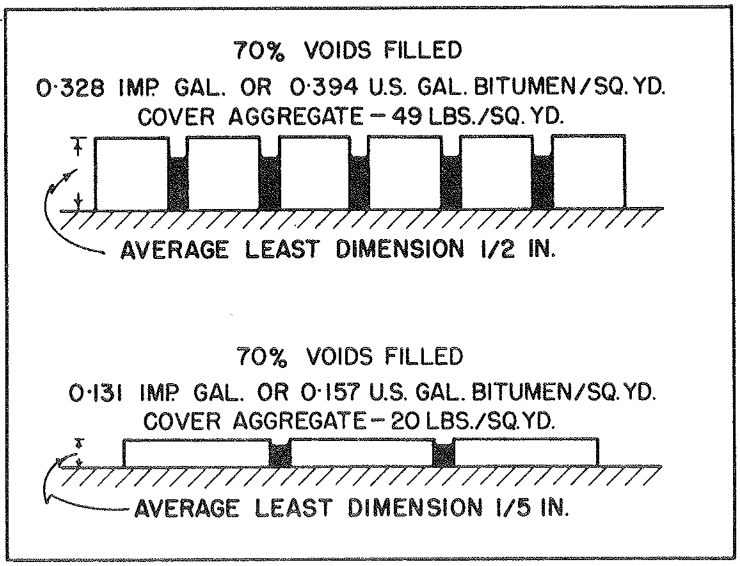

Fig. 13. Comparing Bitumen and Cover Aggregate Requirements per Square Yard for Seal Coats Made with 1/2 Inch Cover Aggregates of Different Particle Shapes—One Cubical, the Other Flat and Elongated.

In some sections of North America the design of surface treatments and seal coats to be constructed with graded cover aggregates, is based upon a measurement termed the Spread Modulus. It is assumed that the Spread Modulus provides a measure of the average thickness of a surface treatment or seal coat. As determined by some organizations, the Spread Modulus is calculated as the weighted average of the mean particle size of the largest 20 per cent, the middle 60 per cent, and the smallest 20 per cent of a graded cover aggregate. Therefore,

$$\begin{aligned} M &= 0.2\left(\frac{a+b}{2}\right) + 0.6\left(\frac{b+c}{2}\right) + 0.2\left(\frac{c+d}{2}\right) \\ &= 0.1\,(a+b) + 0.3\,(b+c) + 0.1\,(c+d) \end{aligned} \qquad [1]$$

where

M = the Spread Modulus, which is a measure of the average thickness in inches of a layer of graded cover aggregate
a = sieve opening in inches for 100 per cent passing
b = sieve opening in inches for 80 per cent passing
c = sieve opening in inches for 20 per cent passing
d = sieve opening in inches for 0 per cent passing

The following example illustrates the calculation of the Spread Modulus M by means of Equation [1] for the grading curve shown in Figure 14 for AASHO Aggregate No. 7.

$$M = 0.1\,(0.625 + 0.44) + 0.3\,(0.44 + 0.225) + 0.1\,(0.225 + 0.033)$$

$$= 0.332 \text{ inch.}$$

Like one-size cover stone, graded cover aggregates in seal coats and surface treatments are gradually reoriented by traffic until the aggregate particles are lying on their flattest sides, with their smallest dimensions vertical to the surface, Figure 7. Therefore, after

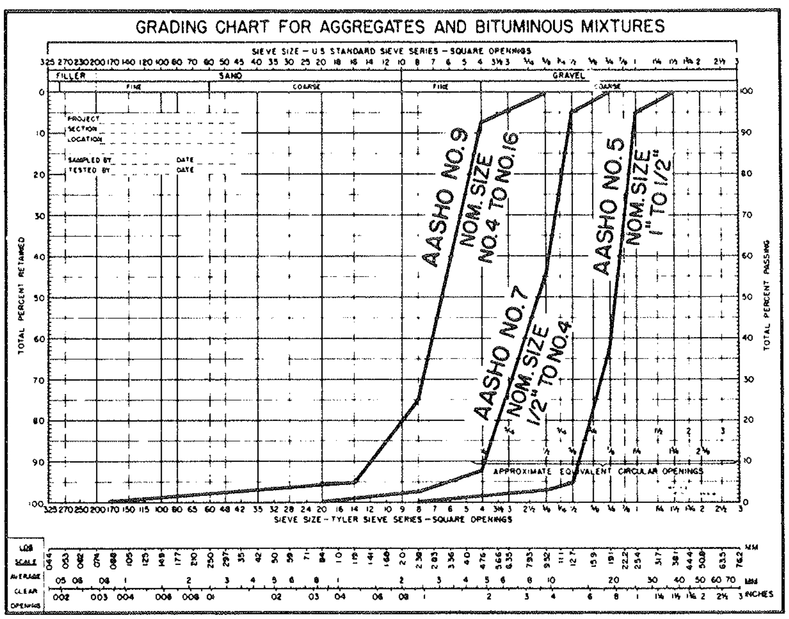

Fig. 14. Average Grading Curves for Three Standard Graded Cover Aggregates.

thorough compaction by warm weather traffic the average thickness of a surface treatment or seal coat made with graded cover stone is governed by the aggregate's Average Least Dimension.

It follows that unless there is some constant ratio between the Spread Modulus M, and the Average Least Dimension H of cover aggregates, the Spread Modulus M cannot be used to provide a simple rational method of design for seal coats and surface treatments constructed with all cover aggregates.

The relationship between the Spread Modulus M and the Average Least Dimension H is shown in Table III for each of twenty-five

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Table III. Test Data on One-Size Cover Aggregates

Average Least Dimension Inches (1)	Spread Modulus M Inches (2)	Median Size (50% Passing) Inches (3)	ASTM Bulk Specific Gravity (4)	Loose Bulk Weight Pounds per cu.ft. (5)	Voids Fraction Loose Weight Condition (6)	Flakiness Index Per cent (7)	$\frac{M}{ALD}$ (8)
0.42	0.61	0.61	2.798	91.0	0.479	23.3	1.45
0.42	0.55	0.56	2.680	90.7	0.457	15.1	1.31
0.39	0.58	0.60	2.695	83.1	0.506	32.7	1.49
0.37	0.50	0.54	2.660	90.6	0.454	26.9	1.35
0.37	0.49	0.47	2.690	94.4	0.438	9.5	1.32
0.36	0.46	0.46	2.660	100.2	0.396	10.5	1.28
0.35	0.42	0.44	2.576	-	-	6.0	1.20
0.35	0.47	0.49	-	-	-	22.0	1.34
0.34	0.44	0.43	2.720	97.5	0.425	9.0	1.29
0.32	0.36	0.40	2.690	89.0	0.47	9.9	1.13
0.32	0.48	0.49	2.680	78.1	0.533	31.8	1.50
0.31	0.44	0.44	2.801	91.7	0.475	21.7	1.42
0.31	0.43	0.44	2.760	-	-	21.8	1.39
0.31	0.35	0.37	2.720	108.0	0.364	4.0	1.14
0.30	0.46	0.43	2.803	90.1	0.485	25.0	1.53
0.30	0.41	0.41	-	-	-	20.3	1.37
0.30	0.40	0.42	-	-	-	24.9	1.33
0.27	0.38	0.40	2.685	83.7	0.5	31.1	1.41
0.24	0.32	0.32	2.748	87.4	0.49	16.2	1.33
0.23	0.32	0.31	2.797	90.5	0.48	20.6	1.39
0.22	0.28	0.28	2.660	87.9	0.47	14.7	1.27
0.22	0.27	0.28	2.641	92.8	0.438	9.8	1.23
0.21	0.27	0.28	2.631	90.4	0.45	18.6	1.29
0.20	0.25	0.25	2.670	102.7	0.383	15.1	1.25
0.18	0.26	0.27	2.650	88.3	0.466	34.7	1.44
					Overall Average		1.34

one-size cover aggregates, and in Table IV for twenty-five graded aggregates. In addition, Figure 15 provides a graph of the ratio of the Spread Modulus over the Average Least Dimension, M/H, versus Flakiness Index for the cover aggregates of Tables III and IV. Flakiness Index values provide a measure of the tendency of aggregate particles toward flatness in one dimension, and of the degree by which they fail to be perfect cubes.

The data in the right hand columns of Tables III and IV demonstrate that the ratio of Spread Modulus M to Average Least Dimension H, M/H, is far from being a constant. Values for this ratio range from 1.13 to 1.53 for the one-size cover aggregates of Table III, and from 1.11 to 1.50 for the graded cover aggregates of Table IV.

While there is considerable scatter of data, Figure 15 indicates that in general, the ratio of M/H increases with an increase in the Flakiness Index of cover aggregates. This is to be expected, since for an aggregate consisting of 1/2 inch cubes for example, M/H would have a value of 1.0. The value of M/H would be expected to increase gradually as the particles of cover aggregates become flatter in one dimension, that is, as their Flakiness Index values increase.

Tables III and IV indicate overall average values for M/H of 1.34 and 1.32, respectively. Therefore, for cover aggregates with M/H values in the vicinity of 1.33, long experience would gradually indicate the approximately correct asphalt binder applications to employ. However, only poor results could be expected for seal coats and surface

Table IV. Test Data on Graded Cover Aggregates

Average Least Dimension Inches (1)	Spread Modulus M Inches (2)	Median Size Inches (3)	ASTM Bulk Specific Gravity (4)	Loose Bulk Weight pounds per cu.ft. (5)	Voids Fraction Loose Weight Condition (6)	Flakiness Index Per cent (7)	M/ALD (8)
0.46	0.58	0.56	2.720	108.0	0.364	5.2	1.26
0.38	0.56	0.55	2.690	87.8	0.477	25.5	1.47
0.37	0.50	0.49	2.658	92.1	0.445	13.8	1.35
0.36	0.50	0.52	2.692	-	-	27.2	1.39
0.36	0.44	0.46	2.630	98.3	0.401	12.5	1.22
0.31	0.40	0.40	2.663	86.9	0.447	12.9	1.29
0.29	0.35	0.36	2.684	90.7	0.460	10.0	1.21
0.28	0.38	0.40	-	-	-	23.0	1.36
0.28	0.36	0.37	2.673	-	-	17.6	1.29
0.27	0.36	0.35	2.690	99.5	0.407	9.0	1.33
0.27	0.35	0.37	-	-	-	19.7	1.30
0.26	0.36	0.36	2.728	-	-	24.3	1.38
0.26	0.34	0.34	2.680	86.2	0.487	17.5	1.31
0.26	0.29	0.32	2.680	102.2	0.387	9.3	1.11
0.25	0.33	0.33	2.686	89.8	0.463	13.4	1.32
0.24	0.32	0.32	2.748	87.4	0.490	16.2	1.33
0.23	0.30	0.31	2.660	94.1	0.433	21.0	1.30
0.22	0.30	0.30	2.690	91.4	0.455	22.8	1.36
0.22	0.27	0.28	2.655	89.2	0.462	10.9	1.23
0.22	0.33	0.32	-	-	-	26.6	1.50
0.21	0.30	0.30	2.664	82.6	0.504	25.4	1.43
0.21	0.28	0.28	-	-	-	18.0	1.33
0.21	0.26	0.26	2.682	-	-	10.5	1.24
0.20	0.26	0.26	2.730	-	-	12.5	1.30
0.18	0.27	0.27	2.660	91.3	0.449	31.8	1.50
					Overall Average		1.32

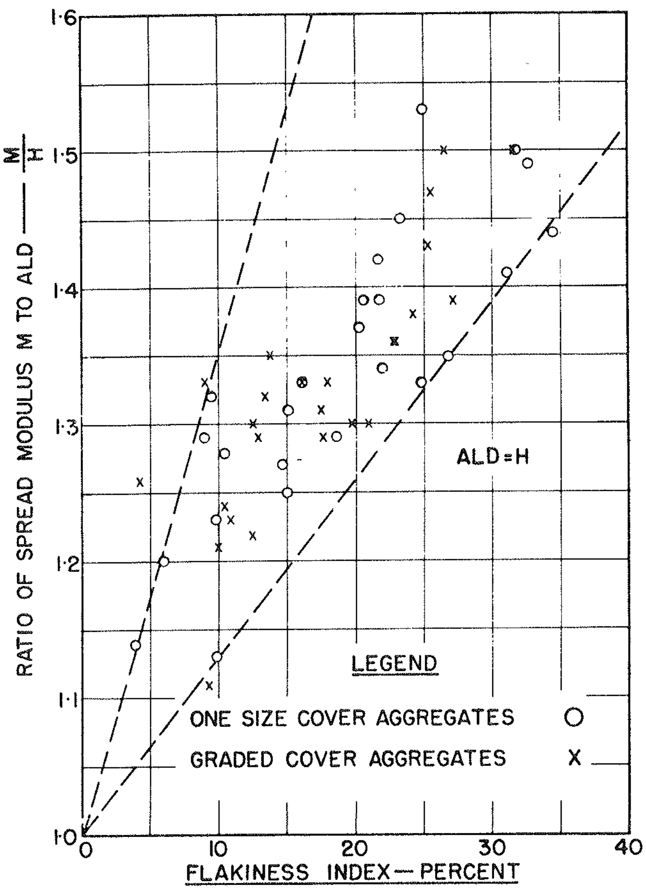

Fig. 15. Illustrating the Influence of Flakiness Index on the Ratio of Spread Modulus M to Average Least Dimension H for Cover Aggregates.

treatments designed on the basis of the Spread Modulus M, when the M/H values for the cover aggregates are quite different from 1.33.

Since a constant ratio between the Spread Modulus M and the Average Least Dimension of cover aggregates does not exist, the use of the Spread Modulus M as a basis for the design of surface treatments and seal coats can be expected to require the use of too much asphalt binder in some cases, and not enough asphalt binder in others. Consequently, in this paper, no further reference to the cover aggregate's Spread Modulus will be made, since it does not appear to be a reliable guide to the design of surface treatments and seal coats with either graded or one-size cover stone. Instead, the method of design to be advocated here will be based on the cover aggregate's Average Least

Dimension H, which provides a much more trustworthy indication of the average thickness of a surface treatment or seal coat made with either a one-size or graded cover aggregate after it has been thoroughly compacted by traffic.

It is to be strongly emphasized that if during the expected service life of a surface treatment or seal coat, there is some possibility that the cover aggregate particles may be forced by traffic part way into the surface on which the seal coat or surface treatment is to be constructed, this degree of penetration of the cover stone must be allowed for when determining the quantity of asphalt binder to be applied. Otherwise, a flushed or bleeding surface may result. In this case, the quantity of asphalt binder required should be based on the "effective" Average Least Dimension of the cover aggregate, which is its measured Average Least Dimension minus its estimated depth of penetration into the surface to which the surface treatment or seal coat is to be applied.

Incidentally, data in Columns 2 and 3 in Tables III and IV demonstrate that in spite of the somewhat involved methods employed to calculate the Spread Modulus M of a cover aggregate, for example Equation [1], the value derived for the Spread Modulus M for any given sample of cover aggregate is almost always very nearly equal to the aggregate's median particle size, which is obtained by merely reading from the grading chart the sieve opening corresponding to the particle size for 50 per cent passing.

5. Voids Fraction and Specific Gravity of Cover Aggregate

In this paper the design requirements for quantities of cover aggregates to be applied per square yard for a seal coat or surface treatment are based on the ASTM bulk specific gravity of the cover stone, and on the fraction of voids in its loose weight condition.

The ASTM bulk specific gravity G of a cover aggregate can be determined by ASTM C 127 for the corase aggregate fraction, and by ASTM C 128 for the fine aggregate portion. If a cover aggregate must be used for which the ASTM bulk specific gravity is not known, a list of aggregates of different mineralogical compositions and their corresponding ASTM bulk specific gravities is provided in Table V.

The fraction of voids V in a cover aggregate on a loose weight basis requires that the loose weight of a sample of the aggregate be measured by means of ASTM C 29, and it is then calculated on the basis of the following equation:

$$V = 1 - \frac{W}{62.4G} \qquad [2]$$

where

V = fraction of voids in the cover stone in its loose weight condition

W = weight of cover stone in its loose weight condition as measured by ASTM C 29
G = ASTM bulk specific gravity of the cover aggregate

For example, if the loose weight W of a sample of cover aggregate is 96 pounds per cubic foot, and if its ASTM bulk specific gravity is 2.66, the fraction of voids V in the cover aggregate in its loose weight condition is

$$V = 1 - \frac{96}{(2.66)(62.4)} = 1 - 0.578 = 0.422$$

Table V. Typical Values for ASTM Bulk Specific Gravities of Various Types of Aggregates

Aggregate Type	ASTM Bulk Specific Gravity
Gravel	2.65
Limestone	2.70
Dolomite	2.70
Traprock	2.90
Granite	2.65
Gneis	2.70
Quartzite	2.70
Rhyolite	2.60

6. Influence of Cover Aggregate Size on Service Performance

From observations of the field performance of numerous surface treatments and seal coats, it appears that successful service behaviour more often results when large size cover aggregate rather than small size is employed. As illustrated by Figures 16 and 17, this would seem to be due to the larger safety factor in terms of gallons per square yard or litres per square metre with regard to the application of either too much or too little asphalt binder that the use of larger cover stone provides. Added advantages associated with larger size cover aggregate of acceptable quality are longer service life for a surface treatment or seal coat, and the ability to carry higher traffic volumes.

The amount of asphalt binder to be applied should on the average embed the cover stone particles to 70 per cent of their depth. Dangerous flushing or bleeding will occur if the quantity of asphalt binder embeds the cover stone to 100 per cent of its average thickness. Consequently, the difference in asphalt quantity per square yard between 70 per cent and 100 per cent average embedment of the cover aggregate provides a measure of the factor of safety against applying too much asphalt. On the other hand, serious loss of cover stone can be expected

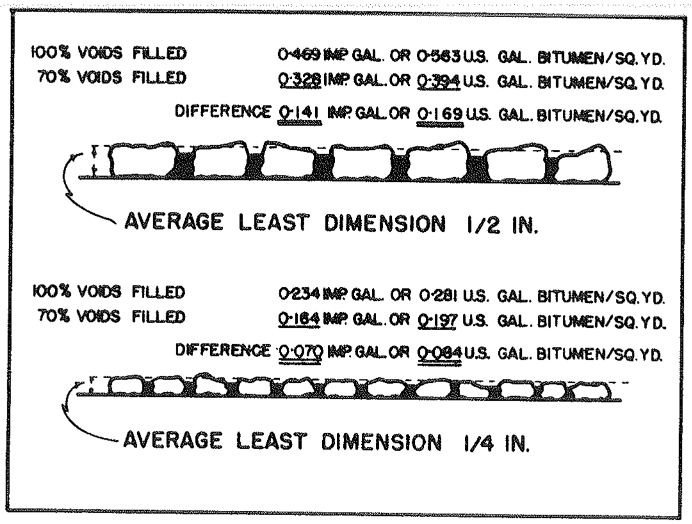

Fig. 16. Illustrating that Surface Treatments or Seal Coats Made with Larger Cover Aggregates Are Less Sensitive to Small Variations in Bitumen Application Than When Smaller Cover Aggregates Are Used.

if the quantity of asphalt binder applied embeds the cover stone to less than 50 per cent of its average depth. Therefore, the difference in asphalt quantity per square yard between 70 per cent and 50 per cent embedment of the cover aggregate provides a measure of the factor of safety against applying too little asphalt binder.

For the larger cover stone illustrated in the top diagram of Figure 16, which has an Average Least Dimension of 0.5 inch, 70 per cent average embedment of the cover stone requires a 0.394 US gallon per square yard (0.328 Imperial gal/sq. yd.)(1.78 litres per square metre) of asphalt binder, while 0.563 US gallon per square yard (0.469 Imperial gal/sq. yd.) (2.55 litres per square metre) would provide an average embedment of 100 per cent. A measure of the margin of safety against serious flushing or bleeding of the seal coat or surface treatment in this case is given by the difference between 100 per cent and 70 per cent embedment, 0.563 - 0.394 = 0.169 US gallon per square yard (0.141 Imperial gal/sq. yd.) (0.77 litre per square metre). Similarly, the bottom diagram in Figure 16 shows that for a smaller aggregate with an ALD of 0.25 inch, a measure of the margin of safety against flushing or bleeding is given by 0.281 - 0.197 = 0.084 US gallon per square yard (0.07 Imperial gal/sq. yd.) (0.38 litre per square metre).

Figure 16 demonstrates therefore, that the margin of safety against flushing or bleeding of a surface treatment or seal coat is very much greater, 0.169 versus 0.084 US gallon per square yard, or about 1/6 versus 1/12 US gallon per square yard (about 1/7 versus 1/14 Imperial gal/sq. yd.) (about 3/4 versus 3/8 litre per square metre), when the larger size cover aggregate is employed.

For the small size cover aggregate illustrated by the diagram at the top of Figure 17, with an ALD of 0.2 inch, 70 per cent embedment of the cover stone requires 0.157 US gallon per square yard (0.131 Imperial gal/sq. yd.) (0.71 litre per square metre) of asphalt binder, while 50 per cent embedment needs 0.113 US gallon per square yard (0.094 Imperial gal/sq. yd.) (0.51 litre per square metre). A measure of the margin of safety against loss of this particular cover stone is given by the difference in the asphalt requirement for 70 per cent and for 50 per cent embedment, 0.157 - 0.113 = 0.044 US gallon per square yard (0.037 Imperial gal/sq. yd.) (0.20 litre per square metre). Similarly, the sketch at the bottom of Figure 17 shows that for the much larger cover stone with an ALD of 0.6 inch, the margin of safety against serious loss of cover aggregate is 0.472 - 0.337 = 0.135 US gallon per square yard (0.112 Imperial gal/sq. yd.) (0.61 litre per square metre).

For the particular comparison illustrated in Figure 17 therefore, the margin of safety against loss of cover stone because not enough asphalt binder has been applied is very much greater, 0.135 versus 0.044 US gallon per square yard, or about 1/7.5 versus 1/23 US gallon per

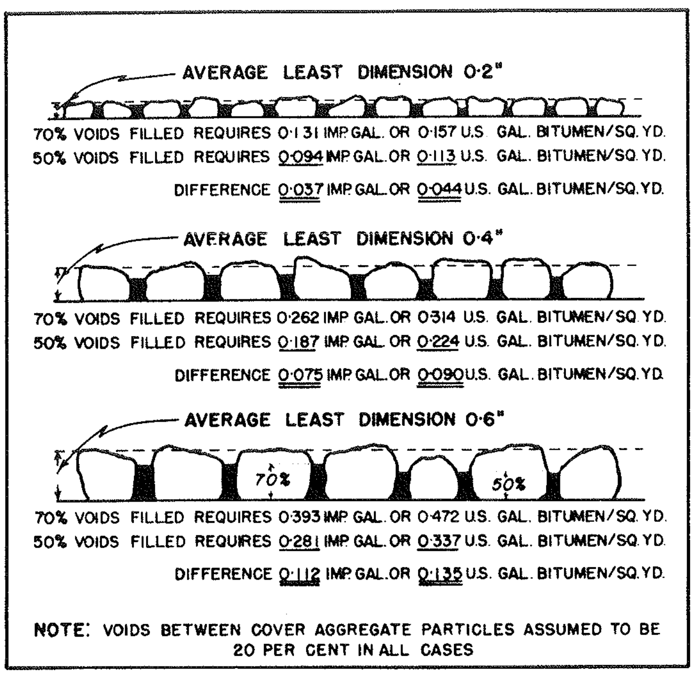

Fig. 17. Influence of Cover Aggregate Size on the Critical Range of Bitumen Quantity Required for a Seal Coat or Surface Treatment.

square yard (about 1/9 versus 1/27 Imperial gal/sq. yd.) (about 3/5 versus 1/5 litre per square metre), in favour of the larger size cover stone.

Consequently, Figures 16 and 17 demonstrate that the margin of safety against flushing or bleeding caused by the application of too much asphalt binder, or against loss of cover stone resulting from not applying enough binder, is very much greater for large size than for small size cover stone. On a percentage basis, the margins of safety illustrated in Figures 16 and 17 against applying either too much or too little asphalt binder are the same both for large size and for small size cover aggregate. However, the amount of play, backlash, or irregularity of operation in the various parts of an asphalt distributor that is in poor mechanical condition, and that may be badly worn, improperly adjusted, carelessly operated, etc., may introduce variations into the quantity of bitumen being applied that do not occur on a percentage basis.

Incidentally, Figures 16 and 17 also demonstrate the need for calibrating and frequently checking asphalt distributors so that the quantity of asphalt binder being applied per square yard is known precisely. For example, the top diagram of Figure 17, which pertains to 3/8 inch cover stone, demonstrates that unless the quantity of asphalt binder being sprayed is known within 1/23 US gallon per square yard (1/27 Imperial gal/sq. yd.) (1/5 litre per square metre), serious loss of cover aggregate could occur due to not enough asphalt binder being applied. This could easily happen if the distributor was thought to be applying 0.157 US gallon per square yard (0.131 Imperial gal/sq. yd.) (0.71 litre per square metre), but was actually applying less than 0.113 US gallon per square yard (0.094 Imperial gal/sq. yd.) (0.51 litre per square metre) needed for a minimum average cover aggregate embedment of at least 50 per cent. How many asphalt distributors can actually apply asphalt binder uniformly and consistently within 1/23 US gallon per square yard (1/27 Imperial gal/sq. yd.) (1/5 litre per square metre) of the quantity that good design has specified? Consequently, Figures 16 and 17 emphasize the fact that in addition to the care taken when designing the quantity of asphalt binder to be applied, it is equally important for the asphalt distributor to be in good mechanical condition, and that it be operated to apply accurately and uniformly the quantity of asphalt binder per unit of area called for by the design procedure being employed.

7. Adhesion between Cover Aggregate and Asphalt Binder

The development of rapid adhesion between cover aggregate and asphalt binder depends very largely on the degree of fluidity of the binder when the cover aggregate is applied. Good adhesion will develop very slowly if the asphalt binder is too hard or too viscous. Nevertheless, assuming that the asphalt binder is of the proper viscosity, to be rapidly wetted by the binder, and to develop fast adhesion, the cover stone should be free from dust or dirt, it should be dry (except when the binder is an asphalt emulsion), and it should not be markedly hydrophilic.

Every effort should be made therefore, to have the aggregate as clean as possible, by washing it, if necessary.

The development of rapid adhesion between the cover aggregate and the asphalt binder can be accelerated by precoating the aggregate. The National Roads Board of New Zealand requires all cover aggregate used for surface treatments and seal coats on state roads to be precoated. Before precoating, the cover stone must be washed to remove dust and dirt. Since coal tar is plentiful, precoating of the cover stone is achieved by mixing it with from one to one and one-half gallons of light coal tar per cubic yard. The cover stone may be passed through a drier and then into a pugmill where the coal tar is added. Alternatively, the cover stone is sprayed with coal tar as it passes through a loading chute into the truck. Elsewhere, precoating may consist of coating the cover aggregate with about one per cent by weight of MC 30 (MC 0) or MC 70 (MC 1).

Figures 18 and 19 illustrate precoating cover aggregate with diesel fuel oil in Australia. The workman in the foreground in Figure 18 is operating a hand pump to transfer diesel fuel oil from the drum to the spray nozzle being directed by the second workman onto the aggregate being lifted from the stockpile by a bucket elevator, Figure 19. This operation could be mechanized. In going through the trommel screen on the way to the truck, fine material is removed, and the diesel fuel oil is distributed more evenly over the surface of the cover aggregate.

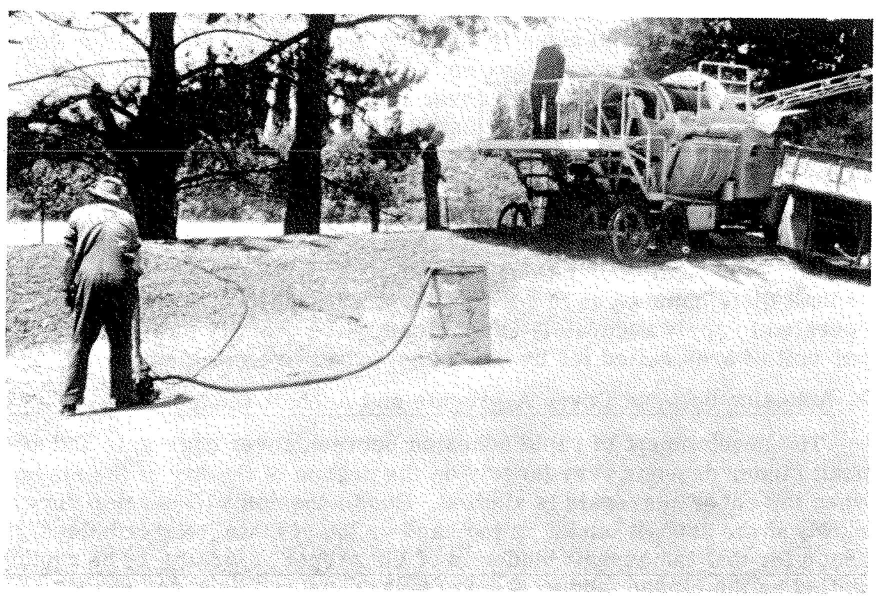

Fig. 18. Victoria, Australia. Precoating Cover Aggregate with Diesel Fuel Oil as It Is Being Lifted from Stockpile to Haulage Truck.

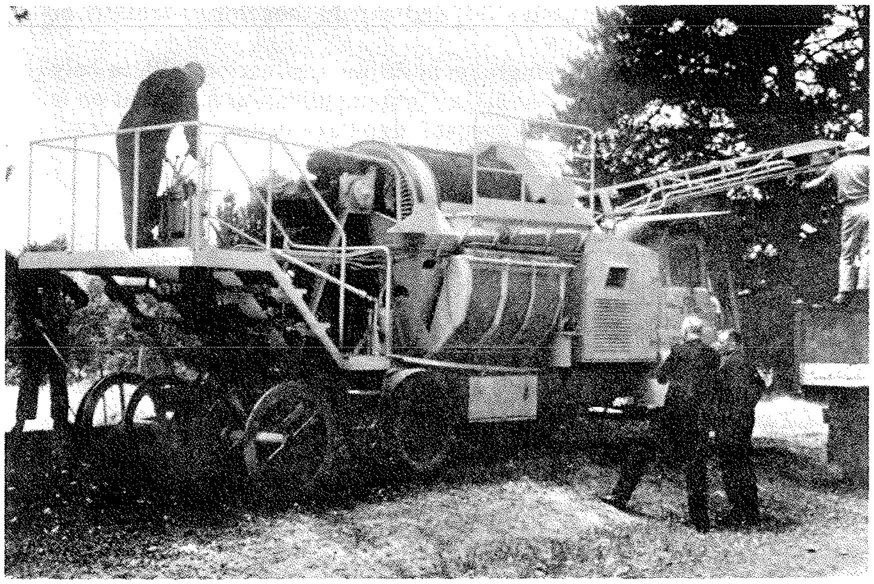

Fig. 19. Victoria, Australia. Stockpiled Cover Aggregate Is Sprayed with Diesel Fuel Oil as It Is Lifted by Bucket Elevator to Trommel Screen on Way to Haulage Truck. Trommel Screen Assists in Coating the Aggregate Particles with Fuel Oil, and Screens Out Any Fine Material.

From 0.5 to 2.5 gallons of diesel fuel oil are applied per cubic yard of aggregate. The quantity of diesel fuel oil coating on each stone particle should dampen it, but there should be no tendency for fluid to drip from any particle. The cover aggregate should preferably be applied the same day that it is precoated.

Because it promotes the development of rapid wetting and good adhesion, precoating of the cover aggregate enables successful surface treatments and seal coats to be constructed with more viscous asphalt binders, and under less favourable conditions than when the cover stone is not precoated.

8. Selection of Cover Aggregate

Any cover aggregate size that is listed in Tables I or II may be used for a surface treatment or seal coat. However, the size selected should be related to the conditions expected at the project site, such as:

(a) The nature and type of asphalt binder to be used. For example, if only a very fluid asphalt binder is available, the cover stone size should ordinarily not exceed 3/8 or 1/2 inch.

(b) Nature and volume of traffic anticipated. Larger size cover stone may be specified for higher traffic volumes.

(c) Nature and condition of the existing surface. If the base or existing surface is soft or weak, large size cover stone may be partly forced into it by a roller or traffic, and should therefore normally be avoided.

(d) Type of treatment, single or multiple application. While only one aggregate size is selected for a single application seal coat or surface treatment, at least two aggregate sizes are ordinarily required for multiple application construction.

B. ASPHALT BINDER

1. Residual Asphalt

The asphalt binder may consist of an asphalt cement, an asphalt emulsion, or a liquid asphalt. Like many others, the author has observed that regardless of which of these three types of asphalt binder is used, in successful surface treatments and seal coats the average degree of embedment of the cover aggregate particles in the residual asphalt is about 70 per cent. The gradual rise of asphalt binder around cover aggregate particles is illustrated in Figure 20, which demonstrates that after a substantial amount of warm weather traffic, the

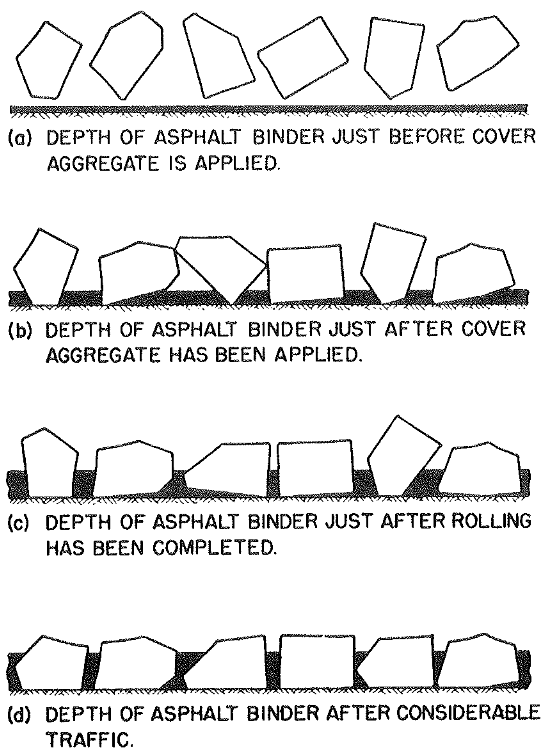

Fig. 20. Illustrating Gradually Increasing Depth of Asphalt Binder between Initial and Final Stages of a Seal Coat or Surface Treatment.

depth of the asphalt binder is from four to six times its thickness immediately before the cover stone is applied. Consequently, in agreement with the Country Roads Board (7), British Road Research Laboratory (8), Idaho Department of Highways (9), Kerr (10), Hanson (6), Tagle (11), Nevitt (12), Kearby (13), Winnitoy (14), and Benson (4), the author recommends that the design of a surface treatment or seal coat should be based on the residual asphalt content of the asphalt binder. This means that when determining the quantity of an asphalt binder to be applied, allowance must be made for the solvent content of liquid asphalts, and for the water content of asphalt emulsions and also their solvent content, if any. The fraction of residual asphalt "R" in any liquid asphalt binder is the fraction of the residue from distillation to 680 F, and in any asphalt emulsion is the fraction of the residue from distillation to 500 F. For asphalt cements, "R" = 1.0. When this information is not available for any particular asphalt binder being used, representative values for "R" for a wide range of asphalt binders are given in Table VI.

Table VI. Average Values for Fraction "R" of Residual Asphalt (by Volume) Contained in Asphalt Binders Used for Surface Treatments and Seal Coats

Asphalt Binder	Fraction of Residual Asphalt "R" by Volume
Asphalt Cements	1.00
Liquid Asphalts	
RC 3000	0.87
RC 800	0.84
RC 250	0.79
RC 70	0.71
RC 5	0.87
RC 4	0.85
RC 3	0.82
RC 2	0.78
RC 1	0.73
RC 0	0.62
Asphalt Emulsions	
RS 3K	0.69
RS 2K	0.63
RS 2	0.65
RS 1	0.58

2. Asphalt Application Temperatures

For successful seal coat and surface treatment construction, it is important that the asphalt binder in the distributor be at a sufficiently high temperature to fan out properly from the spray nozzles. Spraying asphalt binder that is too cold is a common cause of streaking in a finished surface treatment or seal coat, because the spray nozzles are unable to apply the asphalt binder uniformly inch by inch across the road surface.

Recommended spraying temperatures for asphalt emulsion grades used for seal coats and surface treatments are as follows:

Asphalt Emulsion Grade	Recommended Temperature for Spraying
RS-1	75 to 130 F
RS-2	110 to 160 F (180)
CRS-1 (RS 2K±)	75 to 130 F
CRS-2 (RS 3K±)	110 to 160 F (180)

Spraying temperatures that are recommended for liquid asphalts and asphalt cements can be read from the viscosity-temperature chart of Figure 21 for these materials. Figure 21 provides viscosity versus temperature curves for the recently adopted grades RC 70, 250, 800

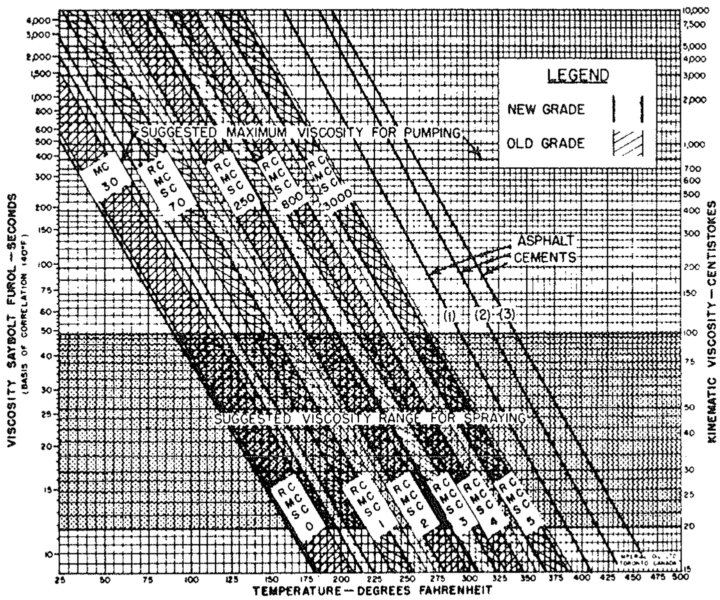

Fig. 21. Illustrating the Viscosity Limits for Liquid Asphalt Grades, with Recommended Viscosity Range for Spraying for Seal Coat and Surface Treatment Construction.

and 3000, and similar information for the older designations RC 0, 1, 2, 3, 4, and 5, which are still in use in many countries. The spraying temperatures recommended in Figure 21 correspond to a range of viscosity from 20 to 100 centistokes (10 to 50 seconds Saybolt Furol). If 50 centistokes is selected as the optimum viscosity for spraying, Figure 21 indicates that the spraying temperature for RC 800 for example, is 255 F, while for RC 2, it shows that the spraying temperature should be 210 F.

In hot climates, asphalt cements ranging in penetration at 77 F from 85/100 to 200/300, are used successfully as binders. The asphalt supplier can provide the temperature viscosity curves for these asphalt cements. For asphalt cement No. 2 for example, if 50 centistokes is selected as the spraying viscosity, Figure 21 indicates that the corresponding spraying temperature should be 355 F.

3. Volume of Asphalt Binder at Its Spraying Temperature

The quantity of asphalt binder that is calculated for use when designing a seal coat or surface treatment, is based upon its volume measured at 60 F. However, as already indicated, spraying temperatures may range from 75 F to more than 350 F. Like most materials, asphalt binders expand when heated, and to control the quantities being applied during construction, measurements of asphalt binder must be made in the distributor at the spraying temperature. Depending upon their specific gravities, and the temperature, the coefficients of expansion of asphalt materials range from 0.00035 to 0.00045 per F over the range of construction and service temperatures to which they are normally subjected. For asphalt emulsions, the coefficient of expansion is about 0.00025 per F.

ASTM Designation D 1250 provides comprehensive tables of volume corrections to be made due to coefficients of expansion, when the temperature of petroleum products is other than 60 F. Figure 22 has been prepared from the data in these tables. Figure 22 indicates by how much a given volume of asphalt binder at 60 F changes in volume when it is heated or cooled to some other temperature within the range of 0 to 500 F. The three curves in Figure 22 illustrate these volume changes for three different groups of asphalt binders. Line (1) pertains to asphalt binders with specific gravities within the range of 0.850 to 0.966 (Group 1), which would usually be the lower viscosity liquid asphalt grades such as RC 70 or RC 250 (RC 1 or RC 2). Line (2) is employed for asphalt binders, usually asphalt cements and the more viscous grades of liquid asphalts having specific gravities higher than 0.966 (Group 0). Line (3) provides temperature volume corrections for asphalt emulsions.

Suppose for example, that the specified rate of application of an asphalt binder at 60 F is 0.28 gallon per square yard, and that Figure 21 indicates that the application temperature should be 250 F. If the specific gravity of the asphalt binder at 60 F is higher than 0.966, Line (2) in Figure 22 shows that one gallon of asphalt at 60 F expands to 1.07 gallon at 250 F, which is a volume increase of seven per cent. Therefore, the required rate of application at 250 F is (0.28) (1.07) = 0.30 gallon per square yard.

4. Selecting the Asphalt Binder

For the particular conditions associated with each surface treatment or seal coat project, the asphalt binder should be selected to satisfy the following two basic requirements:

(a) It must be fluid enough *at the road surface temperature* to rapidly wet the particles of cover stone as soon as they are spread

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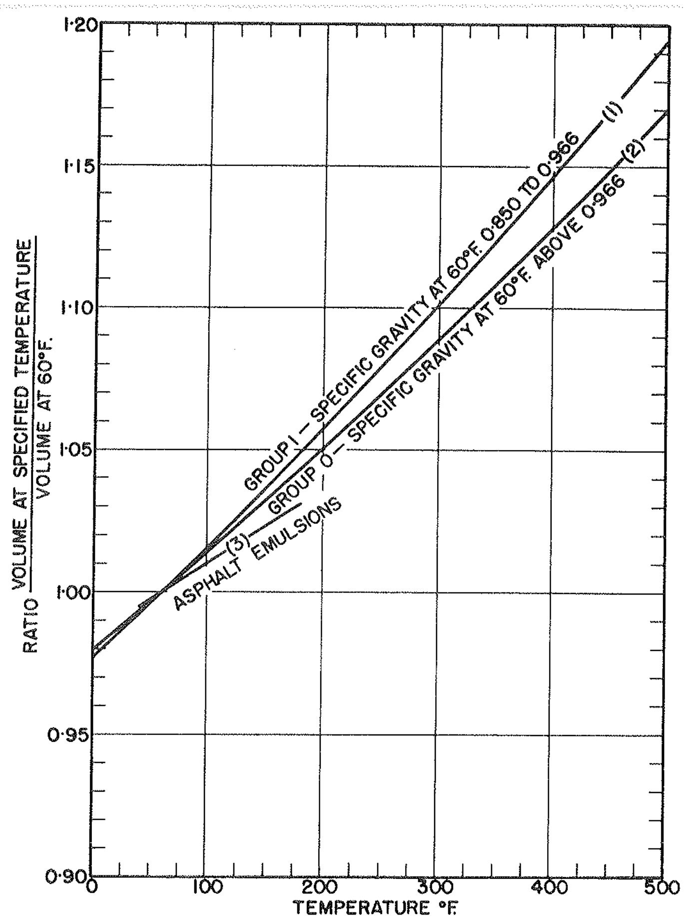

Fig. 22. Influence of Temperature on Volume Change in Asphalt Binders.

over it, and thereby promote fast initial adhesion between the cover aggregate and the binder. When the binder is selected with this degree of fluidity in mind, it will also ordinarily establish a firm bond to any clean dry surface to which it is applied.

(b) Immediately after construction, the asphalt binder should be viscous enough to cement the cover stone so tenaciously to the road surface, that the stone particles are not dislodged by passing vehicles when the new seal coat or surface treatment is opened to traffic.

It is obvious that these two basic requirements are completely opposite to each other, the first requiring a fluid, the second a viscous material. Consequently, a compromise must be made, and with actual job conditions always in mind, the asphalt binder selected should be fluid enough to provide for satisfactory wetting, and the development of rapid initial adhesion between the cover aggregate and the binder, but viscous enough for good aggregate retention when traffic begins to use the finished surface treatment or seal coat.

The selection of the asphalt binder should also be influenced by the road surface temperature, by the size of the cover aggregate, and by the climate of the region. Regardless of its spraying temperature, the asphalt binder chills to the road surface temperature within two minutes after application (15, 16). In cool weather therefore, a more fluid asphalt binder should be selected, for example RC 250 (RC 2) instead of the RC 800 (RC 4) that may have been employed in warm weather, if rapid adhesion is to be developed between the binder and the cover stone. Consequently, it is usually wrong to insist that a single asphalt binder, for example, 150/200 penetration, or RS-2, or RC 800, must always be employed for a seal coat or surface treatment regardless of job circumstances. Nevertheless, this is sometimes done. When all other conditions are the same, experience has demonstrated that large size cover stone requires the application of a more viscous asphalt binder to hold it in place against the dislodging tendency of traffic immediately after construction, than small size cover aggregate. Probably because of the higher daily temperatures and longer period of hot weather, for the same size of cover aggregate, a more viscous asphalt binder can be specified in a hot climate for the same road surface temperature than in a temperate or colder climate.

With all these factors in mind, the selection of liquid asphalt and asphalt cement binders for a wide range of conditions is summarized in Figures 23, 24, 25, and 26 both for cooler and for hot climates. The basis for Figures 23 to 26 has been discussed elsewhere (1). In each of these four figures, the ordinate represents viscosity of the binder, and the abscissa, road surface temperature. A rough correlation between ambient air temperature on sunny days and road surface temperature is also indicated, but the basic relationship illustrated in these four figures is in terms of road surface temperature which can be easily measured with suitable thermometers. The diagonal lines from upper left to lower right on each figure are viscosity versus road surface temperature curves for the grades of asphalt binder indicated. The horizontal lines on each figure represent different nominal sizes of cover stone. Figures 23 and 24 are based on rapid curing liquid asphalt grades RC 0 to RC 5, while Figures 25 and 26 are based on the corresponding new designations RC 70 to RC 3000. Figures 23 and 25 are for use in cooler climates like those of the Northern United States, Canada and Western Europe north of the Alps Mountains. Figures 24 and 26 are intended to be employed in tropical or sub-tropical climates like the Southern United States, and Australia. Similar charts could be prepared for intermediate climates, or for the special climatic conditions of certain regions.

It is very easy to use Figures 23, 24, 25, and 26 for the selection of the correct grade of asphalt binder. Suppose for example, that in one of the Northern States or Canada, the size of cover stone to be used

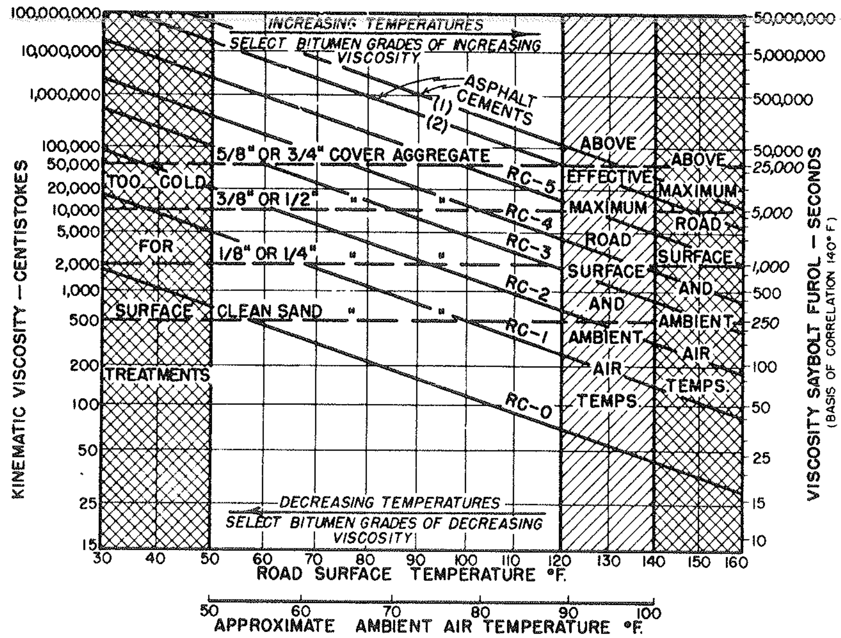

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Fig. 23. Influence of Road Surface Temperatures and Size of Cover Aggregate on Selection of Bituminous Binder for Surface Treatments or Seal Coats in Cooler Climates. Old Liquid Asphalt Designations.

is 1/2 inch (Aggregate G from Table I), and that the road surface temperature is 110 F. What grade of asphalt binder should be selected? Enter the bottom of Figure 25 at a road surface temperature of 110 F, and proceed vertically upward to intersect with the horizontal line labelled "3/8 or 1/2 inch cover aggregate". The nearest diagonal line to this point of intersection is the viscosity temperature curve for RC 800. Consequently, the grade of asphalt binder to be selected is RC 800. Employing a similar procedure with Figure 23 indicates that RC 4 would be selected.

Figures 24 and 26 show that for the same conditions in a tropical or sub-tropical climate, a grade of asphalt cement having the viscosity temperature characteristics of Line (3) should be selected.

Figures 23 to 26 indicate that when other conditions are equal, the grade of asphalt binder to be selected should vary with the road surface temperature. In North America, and in other parts of the world where the asphalt binders used are all made at refineries, it would of course be impossible as a practical construction operation to vary the grade of asphalt binder being applied with the change in road surface temperature hour by hour during the day. However, at the very least, Figures 23 to 26 emphasize that harder grades of asphalt binder should be used in warm or hot weather, and softer grades in cold weather.

The need for an asphalt binder with sufficient fluidity to develop rapid adhesion to the cover stone as soon as it is applied, but with much higher viscosity to retain the cover stone when the finished job is opened to traffic, is quite effectively satisfied by the use of rapid setting, RS, asphalt emulsions, and by the use of rapid curing, RC, liquid asphalts. An RC liquid asphalt grade that is just fluid enough to provide fast and adequate adhesion to the cover stone, normally loses much of its gasoline solvent by evaporation during the construction period. This results in the substantial increase in viscosity required to retain the cover stone when controlled traffic begins to travel over the newly completed surface treatment or seal coat. RS asphalt emulsions perform in a somewhat similar manner. They are normally

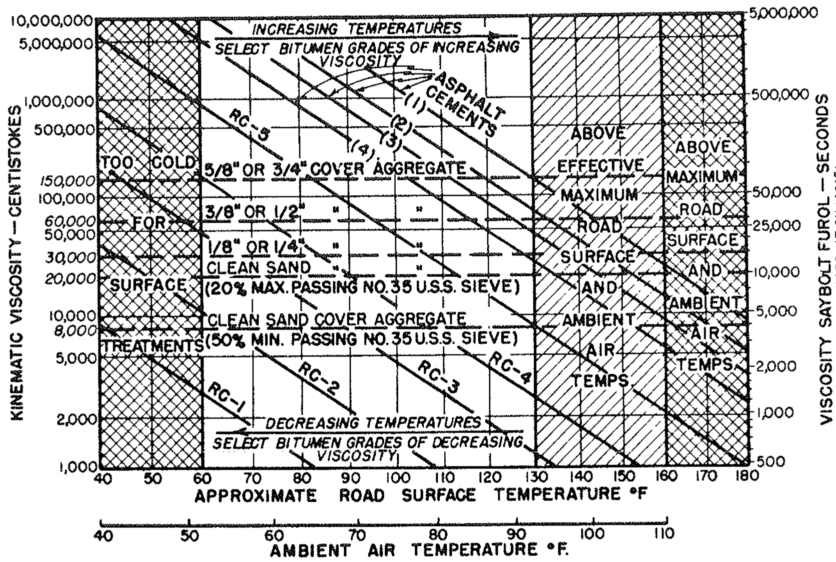

Fig. 24. Influence of Road Surface Temperatures and Size of Cover Aggregate on Selection of Bituminous Binder for Surface Treatments or Seal Coats in Hotter Climates. Old Liquid Asphalt Designations.

sufficiently fluid when applied to develop fast initial adhesion to the cover stone. By partially breaking during construction operations, they become much more viscous, and they have usually developed satisfactory aggregate retention when construction is complete and controlled traffic is permitted.

The necessary compromise between the two opposite requirements for an asphalt binder must be considered with particular care when the binder selected is an asphalt cement, since its viscosity at any given road surface temperature can be expected to change very little between the beginning and the end of the construction period. An asphalt cement contains neither solvent nor water that it can lose. Consequently, a soft asphalt cement may be selected that is fluid enough to develop rapid initial adhesion to the cover aggregate, but is not sufficiently viscous to retain the cover aggregate when the finished surface treatment or seal coat is opened to traffic, or vice versa. The former set of conditions is more likely to occur in the hottest weather, and the latter in cool or cold weather. When an attempt is made to employ asphalt cement binders in cooler climates, Figures 23 and 25, or under cool weather conditions in hot climates, there is usually a tendency to select asphalt cements that are viscous enough for good aggregate retention, but that are not sufficiently fluid to wet a large area of each aggregate particle quickly, and thereby develop fast and adequate adhesion to the cover stone immediately after it has been spread. Whenever this poor wetting or adhesion occurs, much of the cover aggregate may be removed by vehicles as soon as traffic is permitted when construction is complete.

When using asphalt emulsion binders, the lower viscosity RS-1 and CRS-1 are usually selected for the smaller sizes of cover aggregate. RS-2 and CRS-2 grades are normally chosen when the cover aggregate is 3/8 inch and larger.

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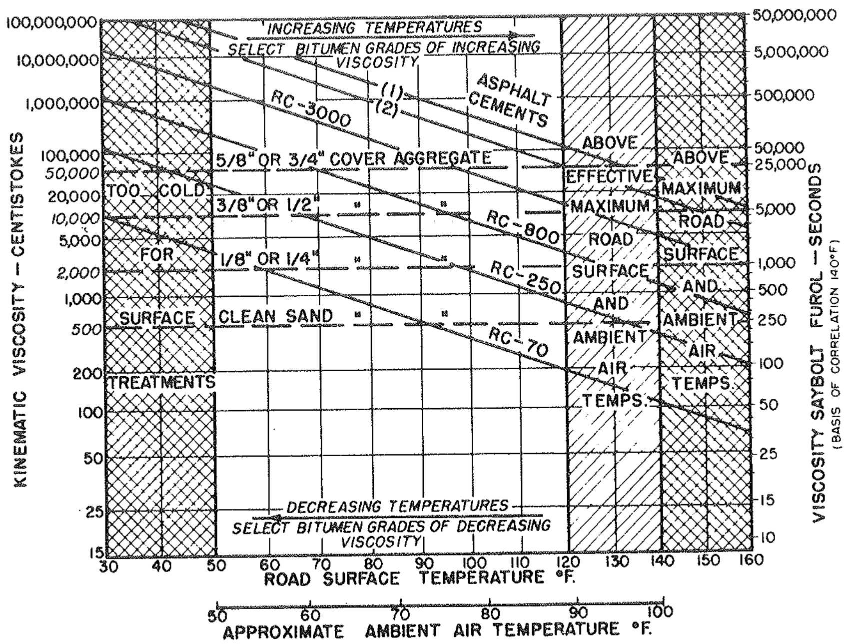

Fig. 25. Influence of Road Surface Temperatures and Size of Cover Aggregate on Selection of Bituminous Binder for Surface Treatments and Seal Coats in Cooler Climates. New Liquid Asphalt Designations.

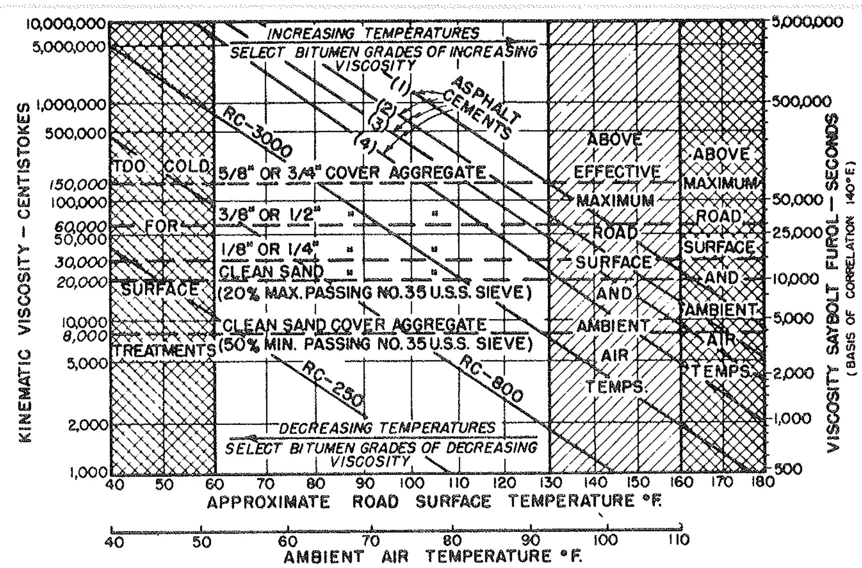

Fig. 26. Influence of Road Surface Temperatures and Size of Cover Aggregate on Selection of Bituminous Binder for Surface Treatments or Seal Coats in Hotter Climates. New Liquid Asphalt Designations.

RS-1 and RS-2 asphalt emulsions are anionic, while CRS-1 and CRS-2 are cationic. Cationic emulsions are considered to be more effective for use under difficult conditions such as cool, damp weather.

5. Influence of Traffic Volume on the Quantity of Asphalt Binder to be Applied

The quantity of asphalt binder to be applied for a seal coat or surface treatment is affected very substantially by the traffic volume it is expected to carry. Much less asphalt binder should be applied when the traffic volume is high than when it is low. This is because the void space between the cover aggregate particles becomes less under high than under low traffic volumes.

From his investigations, Hanson (6) concluded that the optimum asphalt application for a seal coat or surface treatment should fill 70 per cent of the ultimate void space between the cover aggregate particles. The ultimate void space is the minimum void space between the cover aggregate particles in a surface treatment or seal coat that eventually results from exposure to the volume of traffic being carried. On the average therefore, at the optimum asphalt content, the cover aggregate particles should ultimately be embedded for 0.7 of their depth.

Experience of both the National Roads Board of New Zealand (17), and of the Australian State Road Authorities (5), has been that the ultimate per cent of voids between the particles of cover stone varies with the traffic volume. Therefore, the asphalt application required to provide the optimum embedment of the cover aggregate in residual asphalt at all times, could be obtained by multiplying the ultimate void space associated with each traffic volume by 0.7.

However, the Country Roads Board prefers to assume that the theoretical void space between the cover aggregate particles remains constant at 20 per cent. Based on many years of experience, to determine the optimum residual asphalt contents for seal coats or surface treatments for different traffic volumes, they multiply this assumed constant ultimate void space of 20 per cent by the appropriate Traffic Factor "T" in Table VII, to provide 0.7 embedment of the cover aggregate in all cases.

Table VII. Values of Traffic Factor "T" for Surface Treatments and Seal Coats

Cover Aggregate	Values of Traffic Factor "T"				
	Traffic Volume - Vehicles per day				
	Under 100	100 to 500	500 to 1000	1000 to 2000	Above 2000
Recognized good types of angular cover aggregates	0.85	0.75	0.7	0.65	0.60

NOTE: For rounded cover aggregates, the values of the Traffic Factor "T" given above should in each case be increased by 0.05. For example, for a traffic volume of 100 to 500 vehicles per day, the Traffic Factor "T" given above for angular cover aggregate is 0.75, but it would become 0.75 + 0.05 = 0.80 if rounded cover aggregate were to be used.

6. Other Factors That Influence the Asphalt Binder Requirement

Two other factors that influence the quantity of asphalt binder to be applied for a surface treatment or seal coat are:

(a) The quantity of asphalt binder that is lost by absorption into the cover aggregate

(b) the quantity of asphalt binder that is lost in the texture of the surface to which it is applied.

The amount of asphalt binder absorbed by most normal cover aggregates is so small, that the correction, A, to allow for it, is normally neglected when determining the total quantity of asphalt binder to be applied for a surface treatment or seal coat. In the case of cover stone that is known to be quite absorptive, the Country Roads Board increases the asphalt binder application by 0.03 US gallon per square yard, (0.025 Imperial gal/sq. yd.) (0.136 litre/sq. metre). This amounts to an asphalt absorption of about one per cent and two per cent by weight for 3/4 inch and 3/8 inch cover stone particles, respectively.

When cover stone that is likely to be unusually absorptive must be used, such as certain limestones, volcanic pumice, and some expanded shale light weight aggregates, their asphalt absorption values should be checked by Rice's vacuum saturation method, ASTM D 2041. To reduce or eliminate their absorption after application as cover stone, these highly absorptive aggregates may be first dried by heating, cooled to from 150 to 200 F, and then thoroughly and uniformly coated in a pug-mill with from one to two per cent of MC 70 (MC 1) or MC 250 (MC 2) liquid asphalt. The quantity of MC 70 (MC 1) or MC 250 (MC 2) employed should not prevent the precoated aggregate from flowing freely when applied by mechanical cover aggregate spreaders. This precoating of the cover stone will also contribute greatly to the development of fast initial adhesion between the cover aggregate and the asphalt binder.

A correction S in gallons per square yard, Table VIII, must be added to the quantity of asphalt binder applied for a surface treatment or seal coat because of the texture of the existing surface. Depending upon the texture and nature of the existing surface, as indicated by Table VIII, it may be rated black, smooth, or hungry, and the corresponding asphalt binder correction may be negative, nil, or positive,

Table VIII. Correction "S" to the Asphalt Binder Requirement Due to the Textural Rating of an Existing Surface

Textural Rating of Existing Surface	Required Correction "S" to Asphalt Binder Requirement Residual Asphalt			
	Operation	U.S. gal/sq.yd.	Imp. gal/sq.yd.	Litre/sq.m.
Black	Subtract	up to 0.06	up to 0.05	up to 0.272
Smooth	Nil	Nil	Nil	Nil
Hungry 1h	Add	0.03	0.025	0.136
Hungry 2h	Add	0.06	0.05	0.272
Hungry 3h	Add	0.09	0.075	0.408

respectively. An existing surface that is rated "smooth" is one that is firm and smooth into which no asphalt binder will be lost, and which contains no excess of binder. Therefore, the correction S is nil. If an existing surface is flushed or bleeding, a correction S of up to 0.06 US gallon per square yard (0.05 Imperial gal/sq. yd.) (0.272 litre/sq. metre), is subtracted from the asphalt requirement for a "smooth" surface. If the existing surface is rated "hungry," it may receive a rating of 1h, 2h, or 3h, depending upon the estimate of the loss of asphalt binder into the surface texture. As indicated by Table VIII, if the existing surface is rated 1h, 2h, or 3h, the correction S of 0.03, 0.06, or 0.09 US gallon per square yard (0.025, 0.05, or 0.075 Imperial gal/sq. yd.) (0.136, 0.272, or 0.408 litre/sq. metre), respectively, is added to the normal asphalt binder requirement.

An existing bituminous surface that is to be seal coated should be carefully examined *in the wheel paths* when its degree of textural roughness is being estimated. Furthermore, the hunger rating 1h, 2h, or 3h, assessed to an existing surface should be influenced by the size of the cover aggregate to be employed for the seal coat. Because large 3/4 inch cover stone particles would tend to remain on the top of any existing surface texture, an existing surface might require a textural rating of 3h. On the other hand, if 3/8 inch cover stone were to be used, many of the particles might nestle into the voids in the textural roughness of the surface, and with this smaller size cover aggregate the hunger rating would be only 2h and even 1h.

Attempts have been made to develop quantitative methods for measuring the textural roughness of a surface by means of oil, water, or fine sand (11), (15). The reported degree of success with any of these methods is so variable, that their value for general practice appears to be questionable.

Any existing surface that is rated 2h or 3h is likely to have such a variable surface texture, that the finished seal coat or surface treatment may not be too successful. For surfaces with these textural ratings, it is strongly recommended that they be swept and thoroughly cleaned, and then given a pretreatment consisting of about 0.1 gallon per square yard (about 0.5 litre/sq. metre) of RC 70 (RC 1) liquid asphalt, or RS-1 or CRS-1 asphalt emulsion, covered with from six to ten pounds per square yard of clean fine sand, and opened to traffic. The sand should be periodically broomed back over the surface. This pretreatment should preferably be left under traffic for from several weeks to one year. The rating of this surface will then ordinarily be "smooth," and experience has shown that a very successful seal coat or surface treatment can then be applied.

When rating an existing surface for smoothness or roughness of texture, and for degree of "hunger," a very clear distinction must be made between surface texture, and the porosity if any, of the surface or pavement. Porosity refers to the internal void space in a pavement, into which a substantial portion or even the whole of the asphalt binder could be absorbed, leading to serious loss of the cover stone because not enough binder is left on the surface to hold it in place. Relatively new dense graded hot-mix or cold-mix asphalt surfaces constructed either as complete pavements or as maintenance patches, are usually quite porous even when they appear to be smooth and tight. The application of a few drops of lubricating oil (taken if necessary from the dipstick on the engine of an automobile), can be useful for identifying a porous surface. If the oil remains on the surface, little or no harmful porosity exists, and the normal allowance for the textural rating of the surface, for example, 1h, 2h, etc., is the only correction (Table VIII) to the asphalt binder requirement that is needed. On the other hand, if the oil is more or less completely absorbed into the surface within a few minutes, it is evidence of sufficient porosity that a considerable portion of an asphalt binder, particularly of the liquid asphalt type, applied for a surface treatment or seal coat, could be lost by absorption. In this case, the surface should be given a pretreatment of about 0.1 gallon per square yard (about 0.5 litre/sq. metre) of RC 0 or RC 70 (RC 1) liquid asphalt, or of RS-1 or CRS-1 asphalt emulsion, covered with from six to ten pounds per square yard of clean fine sand, and left to traffic for from several weeks to one year, with occasional brooming of the sand back over the surface. This pretreatment will plug the pores in the existing surface, its textural rating will then ordinarily be smooth, and a seal coat or surface treatment can then be successfully applied.

VII. DESIGN OF SINGLE APPLICATION SURFACE TREATMENTS AND SEAL COATS

It is the principal objective of any adequate method of design for surface treatments or seal coats to obtain answers to each of the following six basic questions:

1. What type and size of cover aggregate is to be used?
2. How many pounds of cover aggregate should be applied per square yard?
3. What type and grade of asphalt binder is to be selected?
4. What spraying temperature should be specified for the asphalt binder?
5. How much asphalt binder in gallons per square yard measured at 60 F should be applied?
6. How much asphalt binder should be applied, measured in gallons per square yard at the spraying temperature?

The first thorough investigation of the design of single application surface treatments and seal coats was undertaken by Hanson (6), whose studies were conducted in both the field and the laboratory. Hanson's principal findings were as follows: 181

1. Single application surface treatments and seal coats are essentially one-stone particle thick.
2. When cover aggregate is first applied during seal coat or surface treatment construction, the cover stone particles occupy random positions, and the voids between the aggregate particles are approximately 50 per cent, Figure 27.
3. During the rolling operation, the cover aggregate particles are partly reoriented, and the void space between the stone particles at the end of average rolling is approximately 30 per cent.
4. After considerable warm weather traffic, the particles of cover stone become reoriented into their final positions, and the void space between the particles is approximately 20 per cent, Figure 7.
5. Following substantial warm weather traffic, the cover stone particles are lying on their flattest sides with their thinnest dimension vertical, Figure 7. This means that the final average thickness of a single application seal coat or surface treatment is given by the Average Least Dimension of the cover stone particles, Figure 7. A laboratory procedure for determining the Average Least Dimension of any cover aggregate is provided in Appendix A.
6. The optimum asphalt application for a surface treatment or seal coat should be just sufficient to fill the ultimate 20 per cent of void space between the cover aggregate particles about two-thirds (70 per

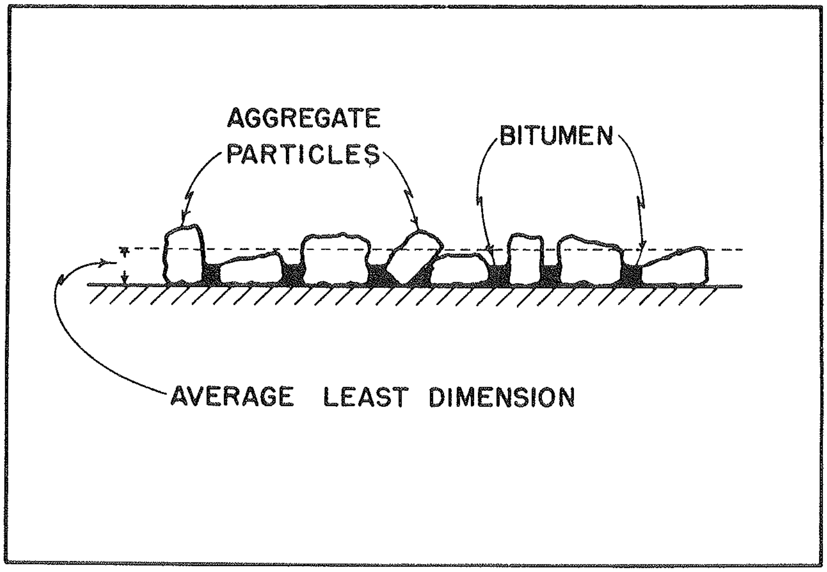

Fig. 27. Illustrating the Haphazard Positions of Cover Aggregate Particles Immediately After Application from a Stone Chip Spreader.

cent) with residual asphalt. That is, on the average each cover stone particle is embedded in residual asphalt to about 70 per cent of its thinnest dimension.

On the basis of many years of experience with Hanson's method of design, the Country Roads Board of Victoria, Australia has found that the fraction "T" of the 20 per cent of ultimate void space assumed for the cover aggregate, to be filled with residual asphalt, should vary with the traffic volume anticipated, Table VII.

A. SINGLE APPLICATION DESIGN WITH ONE-SIZE AGGREGATE

1. Quantity of One-Size Cover Aggregate to be Applied per Square Yard

The design of single application seal coats and surface treatments with one-size cover aggregate in New Zealand and Australia is based on Hanson's (6) findings (a) that the average thickness of a seal coat or surface treatment is given by the Average Least Dimension of the cover stone, and (b) that after substantial traffic, the voids between the cover aggregate particles are 20 per cent. This means that after ultimate compaction by traffic, the cover stone particles occupy 80 per cent of the volume of a seal coat or surface treatment. Therefore, as has been indicated elsewhere (18), the quantity of cover aggregate to be applied as pounds per square yard can be derived as follows, (basis of calculation is one square yard):

$$C = \left(\frac{36 \times 36 \times 0.8H}{1728}\right) 62.4GE \qquad [3]$$

which simplifies to

$$C = 37.4HGE$$

where

C = number of pounds of cover aggregate to be applied per square yard
H = Average Least Dimension of cover aggregate in inches
G = ASTM bulk specific gravity of the cover aggregate
E = wastage factor due to per cent of cover stone lost due to whip-off by traffic and to unevenness of spread, Table IX.

As an example of the use of Equation [3], if the Average Least Dimension H of the cover stone is 0.27 inch, if its ASTM bulk specific gravity G is 2.68, and if the anticipated loss of cover aggregate due to whip-off by traffic is five per cent, the quantity of cover stone to be applied is

Table IX. Cover Aggregate Wastage Factors

Per Cent Wastage Allowed for	Wastage Factor E
1	1.01
2	1.02
3	1.03
4	1.04
5	1.05
6	1.06
7	1.07
8	1.08
9	1.09
10	1.10
11	1.11
12	1.12
13	1.13
14	1.14
15	1.15
16	1.16
17	1.17
18	1.18
19	1.19
20	1.20

* Due to whip-off by traffic and to uneven application.

$$C = (37.4)(0.27)(2.68)(1.05)$$

$$= 28.4 \text{ pounds per square yard.}$$

2. Quantity of Asphalt Binder to be Applied per Square Yard

The quantity of asphalt binder measured at 60 F to be applied *per square yard* can be derived as follows, (basis of calculation is one square yard):

$$B = \left(\frac{36 \times 36 \times 0.2H}{231}\right)\left(\frac{T}{R}\right) + \frac{S + A}{R} \qquad [4]$$

which simplifies to

$$B = \frac{1.122HT + S + A}{R}$$

where

B = total asphalt binder to be applied in US gallons per square yard
H = Average Least Dimension of cover stone measured in inches
T = traffic factor, which depends upon the anticipated traffic volume, Table VII
R = fraction of residual asphalt in the asphalt binder selected, Table VI
S = surface texture correction in US gallons per square yard measured at 60 F, resulting from expected gain or loss of asphalt binder due to the textural characteristics of the existing surface, Table VIII
A = absorption correction in gallons per square yard measured at 60 F due to loss of asphalt binder by absorption into the particles of cover stone. With all but unusually absorptive aggregates, this correction can be neglected. When necessary, the Country Roads Board makes an aggregate absorption correction of 0.03 US gallon per square yard, (0.025 Imperial gal/sq. yd.) (0.136 litre/sq. metre).

For example, suppose the Average Least Dimension of the cover aggregate is 0.27 inch, the anticipated traffic volume is 700 vehicles per day, the fraction of residual asphalt in the asphalt binder is 80 per cent, the textural rating of the existing surface is 1h and the cover stone is relatively non-absorptive. Substituting in Equation [4] gives

$$B = \frac{(\sout{1.22}\ 1.122)(0.27)(0.7) + 0.03 + 0}{0.8}$$

$$= \frac{0.21 + 0.03}{0.8} = 0.30 \text{ US gallons per square yard.}$$

B. SINGLE APPLICATION DESIGN WITH GRADED COVER AGGREGATE

When utilizing Equation [4] for determining the quantity of asphalt binder to be applied for a seal coat or surface treatment, the author has sometimes experienced difficulty because too much asphalt binder has been applied and some flushing or bleeding has occurred. This has been particularly true when using a graded cover aggregate, which is ordinarily the only cover material available. This experience has led to questioning the assumption that the ultimate void space between the cover aggregate particles in a surface treatment or seal coat is always approximately 20 per cent.

There does not appear to be any laboratory test that is capable of duplicating the action of substantial warm weather traffic in orienting cover aggregate particles into their positions of maximum density. Consequently, if a correction to the assumed ultimate voids value of 20 per cent is to be made, it must be determined on the loose weight basis.

The Country Roads Board establishes the amount of cover aggregate to be applied as square yards per cubic yard (but equivalent to Equation [3]), by assuming that in its loose condition as applied, the voids between the aggregate particles are 50 per cent. During the past few years, the author has measured the voids in a large number of both one-size and graded cover aggregates in the loose weight condition by means of ASTM C 29. As indicated by Tables III and IV, very seldom are the voids in the loose weight condition exactly 50 per cent. Occasionally they may be less than 40 per cent.

The assumption is made that if a cover aggregate with 50 per cent voids in the loose weight condition, closes up under traffic to 20 per cent voids as assumed by the Country Roads Board, then if for example, the voids in a cover aggregate in the loose weight condition are only 40 per cent, the voids in the cover stone in a seal coat or surface treatment after substantial warm weather traffic will be only $40/50 \times 20 = 16$ per cent.

It can be seen that when the ultimate voids in a cover aggregate are only 16 per cent, if the asphalt binder to be applied is based on an assumed 20 per cent of voids, Equation [4], twenty-five per cent ($20/16 \times 100 = 125$) too much asphalt binder will have been applied, and serious flushing or bleeding could be expected. This is in agreement with the author's experience when calculating the quantity of asphalt binder to be applied by means of Equation [4].

The fraction of voids V in a cover aggregate can be determined by means of Equation [2] described in a previous section.

1. Quantity of Graded Cover Aggregate to be Applied per Square Yard

Introducing this correction due to the fraction of voids V in the cover aggregate, leads to the following modification of Equation [3] for determining the quantity of a graded cover aggregate to be applied per square yard, (basis of calculation is one square yard):

$$C = \frac{36 \times 36 \times \left(1 - \frac{V}{0.5}0.2\right) H}{1728} 62.4GE$$

$$= \frac{36 \times 36 \times (1 - 0.4V)H}{1728} 62.4GE$$

which simplifies to

$$C = 46.8(1 - 0.4V)HGE \qquad [5]$$

where each symbol has the significance already defined for it.

For example, suppose the Average Least Dimension H of the graded cover aggregate = 0.27 inch, the fraction of voids V = 0.4, the ASTM bulk specific gravity G = 2.68, and E = 1.05, then

$$C = (46.8)(1 - 0.4 \times 0.4)(0.27)(2.68)(1.05)$$

$$= 29.9 \text{ pounds per square yard.}$$

Compared with the previous calculation, the voids correction has increased the quantity of cover aggregate to be applied per square yard by 29.9 - 28.4 = 1.5 pounds.

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2. Quantity of Asphalt Binder to be Applied per Square Yard

The voids correction V results in the following modification of Equation [4] for determining the quantity of asphalt binder to be applied per square yard, (basis of calculation is one square yard):

$$B = \left(\frac{36 \times 36 \times \frac{V}{0.5} 0.2H}{231}\right)\left(\frac{T}{R}\right) + \frac{S + A}{R}$$

$$= \left(\frac{36 \times 36 \times 0.4VH}{231}\right)\left(\frac{T}{R}\right) + \frac{S + A}{R}$$

which simplifies to

$$B = \frac{2.244HTV + S + A}{R} \qquad [6]$$

where each symbol has already been defined.

For example, if the Average Least Dimension of the cover aggregate, H, is 0.27 inch, if the expected traffic volume is 700 vehicles per day, if the voids fraction V is 0.4, if the fraction of residual asphalt in the asphalt binder is 80 per cent, if the textural rating of the existing surface is 1h, and if the cover stone is relatively non-absorptive, substituting the appropriate values in Equation [6] gives

$$B = \frac{(2.244)(0.27)(0.7)(0.4) + 0.03 + 0}{0.8}$$

$$= \frac{0.17 + 0.3}{0.8}$$

$= 0.25$ US gallon per square yard.

In comparison with the previous sample calculation, the voids correction has reduced the quantity of asphalt binder to be applied by $0.30 - 0.25 = 0.05$ US gallon per square yard, a difference of 20 per cent.

C. COMPARISON OF DESIGN EQUATIONS BASED ON ONE-SIZE AND GRADED COVER AGGREGATES FOR SINGLE APPLICATION SEAL COATS AND SURFACE TREATMENTS

It should be recognized that one-size cover aggregates, in which the voids in the loose weight condition are 50 per cent, and to which Equations [3] and [4] therefore apply, *are only a special category of graded cover aggregates*, which represent the general case. Since this is so, it can be shown that when the fraction of voids V in a cover aggregate is 0.5, Equation [3] giving the required quantity of one-size cover aggregate per square yard, and Equation [4] providing the quantity of asphalt binder to be applied per square yard, can be easily derived from Equations [5] and [6] respectively, which pertain to graded cover aggregates.

When $V = 0.5$ is substituted in Equation [5] we have

$$C = 46.8(1 - 0.4V)HGE \quad [5]$$

$$= 46.8(1 - 0.4 \times 0.5)HGE$$

$$= 46.8(1 - 0.2)HGE$$

$$= 46.8(0.8)HGE$$

$$= 37.4\ HGE \quad [3]$$

Also, when $V = 0.5$ is substituted in Equation [6] it follows that

$$B = \frac{2.244\ HVT + S + A}{R} \quad [6]$$

$$= \frac{2.244\ HT(0.5) + S + A}{R}$$

$$= \frac{1.122\ HT + S + A}{R} \quad [4]$$

Consequently, if the fraction of voids $V = 0.5$ is assumed or determined for one-size cover aggregate in the loose condition, use of Equations [5] and [6] will result in exactly the same rates of application of cover aggregate and asphalt binder respectively, as Equations [3] and [4]. Whenever the rates of application of any given cover stone and asphalt binder provided by Equations [5] and [6] are different than those given by Equations [3] and [4] respectively, it is because the fraction of voids V in the cover aggregate does not have a value of exactly 0.5 for the loose weight condition. Table III shows that the value of the voids fraction V even in a one-size aggregate usually differs from 0.5.

It is clear therefore that Equations [5] and [6] are general equations of design for single application surface treatments and seal coats. Consequently, regardless of whether one-size or graded cover aggregates are to be employed, the quantities of cover stone and of asphalt binder to be applied per square yard, should be determined by means of Equation [5] and [6] respectively.

D. OTHER UNITS OF MEASUREMENT FOR RATES OF APPLICATION OF ASPHALT BINDER AND COVER STONE

For surface treatment and seal coat design, the unit of measurement employed in this paper for quantity of cover stone to be spread is pounds per square yard, and for the rate of application of asphalt binder is US gallons per square yard. However, when applying cover aggregate, other units of measurement than pounds per square yard are used to express the quantity to be spread, for example, square yards per cubic yard. In much of the world, liquid measure is expressed in terms of Imperial gallons. Furthermore, over a large part of the world, weights and volumes are measured in units of the metric system.

Therefore, in Table X, equivalent equations are listed in terms of several units of measurement that may be employed for the quantity of cover stone to be applied on either a weight or volume basis per unit of area, in both the English and Metric systems of measurement. In Table XI, equivalent equations in both English and Metric units of measurement are given for the volume of asphalt binder to be applied per unit of area.

For the same design criteria, each of the equations in Table X requires the same rate of application of cover stone, and identical rates of application of asphalt binder are indicated by all equations in Table XI.

Table X. Equivalent Equations in Both English and Metric Systems of Measurement for Total Quantity of Cover Aggregate to Be Applied per Unit of Area for a Surface Treatment or Seal Coat

UNIT OF MEASUREMENT	EQUATION
ENGLISH SYSTEM (H measured in inches).	
BY WEIGHT	
pounds per square yard	$C = 46.8\,(1-0.4V)\,HGE$ OR $C = \frac{0.75\,(1-0.4V)\,HWE}{1-V}$
square yards per short ton (2000 pounds)	$C = \frac{42.74}{(1-0.4V)\,HGE}$ OR $C = \frac{2667\,(1-V)}{(1-0.4V)\,HWE}$
square yards per long ton (2240 pounds)	$C = \frac{47.86}{(1-0.4V)\,HGE}$ OR $C = \frac{2987\,(1-V)}{(1-0.4V)\,HWE}$
BY VOLUME	
cubic feet per square yard (loose weight)	$C = \frac{0.75\,(1-0.4V)\,HE}{1-V}$
square yards per cubic yard (loose weight)	$C = \frac{36\,(1-V)}{(1-0.4V)\,HE}$
METRIC SYSTEM (H measured in Millimetres)	
BY WEIGHT	
kilograms per square metre	$C = (1-0.4V)\,HGE$ OR $C = \frac{(1-0.4V)\,HWE}{1-V}$
BY VOLUME	
litres per square metre (loose weight)	$C = \frac{(1-0.4V)\,HE}{1-V}$
square metres per cubic metre (loose weight)	$C = \frac{1000\,(1-V)}{(1-0.4V)\,HE}$

Table XI. Equivalent Equations in Both English and Metric Systems of Measurement for the Optimum Quantity of Asphalt Binder to Be Applied per Unit of Area for a Seal Coat or Surface Treatment

UNIT OF MEASUREMENT	EQUATION
ENGLISH SYSTEM (H measured in inches)	
U.S. gallons per square yard	$B = \frac{2.244\,HTV + S + A}{R}$
Imperial gallons per square yard	$B = \frac{1.868\,HTV + S + A}{R}$
METRIC SYSTEM (H measured in Millimetres)	
Litres per square metre	$B = \frac{0.4\,HTV + S + A}{R}$

E. SAMPLE CALCULATION FOR DETERMINING RATES OF APPLICATION OF COVER AGGREGATE AND ASPHALT BINDER FOR A SINGLE APPLICATION SURFACE TREATMENT OR SEAL COAT

I. THE FOLLOWING CONDITIONS ARE ASSUMED
(a) Climate—cool
(b) Traffic volume—800 vehicles per day
(c) Road surface temperature—70 F
(d) Textural rating of existing road surface—1h
(e) Properties of cover aggregate selected
(1) Nominal size—1/2 inch
(2) Size Number (Table II)—AASHO No. 7 (Figure 14)
(3) Median size—0.35
(4) Flakiness Index—9.5
(5) Average Least Dimension H—0.28
(6) ASTM bulk specific gravity G—2.67
(7) Dry loose weight W—91 pounds per cubic foot
(8) Fraction of voids $V = 1 - \frac{91}{(62.4)(2.67)} = 0.454$
(9) Asphalt absorption A—negligible
(10) Loss by whip-off, etc.—5 per cent
(11) Wastage factor E (Table IX)—1.05

190 II. THE FOLLOWING ITEMS OF INFORMATION ARE REQUIRED
(a) What grade of asphalt binder should be selected?
(b) What spraying temperature is recommended?
(c) How much asphalt binder measured at 60 F should be applied per square yard?
(d) How much asphalt binder measured at the spraying temperature should be applied per square yard?
(e) What quantity of cover aggregate should be spread per square yard?

III. SOLUTION
(a) Figure 25, which is applicable to cooler climates like that of the Northern USA and Canada, indicates that for 1/2 inch cover aggregate and a road surface temperature of 70 F, if a liquid asphalt binder is selected, the grade should be RC 250.
(b) From Figure 21, for an optimum spraying viscosity of 50 centistokes, the recommended spraying temperature for RC 250 is 215 F.
(c) The volume correction factor for RC 250 at 215 F, Figure 22, Line (1), is 1.06.
(d) Fraction of residual asphalt R in RC 250, Table VI, is 0.79.
(e) Traffic Factor T for a volume of 800 vehicles per day, Table VII, is 0.7.
(f) Asphalt binder correction for a textural rating of 1h—add 0.03 US gallon per square yard.
(g) Asphalt binder correction A for loss of asphalt by absorption into the cover stone—Nil.

(h) Total rate of application of RC 250 measured at 60 F; Equation [6]:

$$B = \frac{(2.244)(0.28)(0.7)(0.454) + 0.03 + 0}{0.79}$$

$$= \frac{0.20 + 0.03}{0.79} = 0.29 \text{ US gallon per square yard}$$

(i) Total rate of application of RC 250 measured at the spraying temperature of 215 F:

$$= (0.29)(1.06) = 0.31 \text{ US gallon per square yard}$$

(j) Rate of application of dry cover aggregate, Equation [5]:

$$C = (46.8)(1 - 0.4 \times 0.454)(0.28)(2.67)(1.05)$$

$$= (46.8)(1 - 0.18)(0.28)(2.67)(1.05)$$

$$= 30.1 \text{ pounds per square yard.}$$

IV. THE SOLUTION CAN THEREFORE BE SUMMARIZED AS FOLLOWS:

(a) Grade of asphalt binder to be used—RC 250
(b) Spraying temperature for RC 250—215 F
(c) Rate of application of RC 250 at 60 F—0.29 US gallon per square yard
(d) Rate of application of RC 250 at spraying temperature of 215 F --0.31 US gallon per square yard
(e) Rate of application of dry cover aggregate--30.1 pounds per square yard.

Note: Table XII is a suggested data sheet that may be used for the design of single application surface treatments and seal coats, and it provides a more concise illustration of these design calculations.

V. USE OF ASPHALT EMULSION BINDER

If CRS-2 asphalt emulsion had been selected for this design example, instead of RC 250, the design calculations would be very similar to those just illustrated. For CRS-2 asphalt emulsion, Table VI indicates that an average value for the fraction of residual asphalt R is 0.69. For a spraying temperature of 160 F, the volume correction factor, Figure 22, Line (3), is 1.025. The following design summary would have been obtained:

(a) Grade of asphalt binder to be used—CRS-2
(b) Spraying temperature for CRS-2—160 F (max)
(c) Rate of application of CRS-2 asphalt emulsion measured at 60 F—0.33 US gallon per square yard

Table XII. Design Data Sheet. For Determining Quantities of Asphalt Binders and Cover Aggregates for a Single Surface Treatment or Seal Coat

Date
Project
Location

Report By
Checked By

A. Given Conditions

1. Traffic volume - 800 vehicles per day
2. Road surface temperature - 70°F
3. Textural rating of existing surface - 1h
4. Properties of cover aggregate selected:
   - (a) Nominal size - 1/2 inch
   - (b) Size number - No. 7
   - (c) Median size - 0.35 inch
   - (d) Flakiness Index - 9.5
   - (e) Average Least Dimension H - 0.28
   - (f) Weight lb/cu.ft.(loose)W - 91
   - (g) ASTM bulk specific gravity G - 2.67
   - (h) Voids fraction V - 0.454
   - (i) Asphalt absorption A - negligible
   - (j) Expected loss by whip-off percent - 5
   - (k) Wastage factor E (Table 9 - 1.05)

B. Solution

5. Quantity of cover aggregate to be applied (Equation 5)
   $C = 46.8(1 - 0.4V)HGE = (46.8)(0.82)(0.28)(2.67)(1.05) = 30.1$ pounds per sq.yd.
6. Grade of asphalt binder selected (Figure 23) - RC 250
7. Recommended spraying temperature (Figure 19) - 215°F
8. Residual asphalt factor R - 0.79
9. Traffic Factor T (Table 7) - 0.7
10. Surface textural correction S - add 0.03 US gallons/square yard
11. Quantity of RC 250 asphalt binder required at 60°F (Equation 6)
    $$B = \frac{2.244\ HTV + S + A}{R} = \frac{(2.244)(0.28)(0.7)(0.454) + 0.03 + 0}{0.79}$$
    = 0.29 US gallons per square yard
12. Correction factor for RC 800 for spraying temperature of 235 F (Figure 20) - 1.06
13. Quantity of RC 250 asphalt binder to be applied at 215°F = (0.29)(1.06) 0.31 US gallon/square yard.

C. Summary

(a) Cover aggregate selected - Size Number - No. 7 (1/2 inch).
(b) Quantity of cover aggregate to be applied - 30.1 lbs/sq.yd.
(c) Asphalt binder selected - RC 250
(d) Spraying temperature for RC 250 - 215°F
(e) Quantity of RC 250 at 60°F required - 0.29 US gallon/sq.yd.
(f) Quantity of RC 250 to be applied at 215°F - 0.31 gallon/sq.yd.

(d) Rate of application of CRS-2 asphalt emulsion measured at a spraying temperature of 160 F—0.34 US gallon per square yard
(e) Rate of application of dry cover aggregate—30.1 pounds per square yard.

VI. USE OF ASPHALT CEMENT BINDER

For the same design conditions, but in a hot climate, an asphalt cement of 150/200 penetration might be employed as the binder. The spraying temperature is assumed to be 340 F for the particular 150/200 penetration asphalt cement selected, and the volume correction factor from Figure 22, Line (2) is 1.10. The required calculations are similar to those already illustrated, and they provide the following design summary:

(a) Grade of asphalt binder to be used—150/200 penetration asphalt cement
(b) Spraying temperature for 150/200 penetration asphalt cement —340 F.
(c) Rate of application of 150/200 penetration asphalt cement measured at 60 F—0.23 US gallon per square yard
(d) Rate of application of 150/200 penetration asphalt cement measured at a spraying temperature of 340 F—0.25 US gallon per square yard.

(e) Rate of application of dry cover aggregate—30.1 pounds per square yard.

VII. COMPARISON OF MATERIAL REQUIREMENTS PER SQUARE YARD

Materials	150/200 Penetration Asphalt Cement	RC 250 Liquid Asphalt	CRS-2 Asphalt Emulsion
Asphalt Binder, U.S. gallons per square yard at 60 F	0.23	0.29	0.33
Cover Aggregate, pounds per square yard	30.1	30.1	30.1

F. MODIFICATION OF SINGLE APPLICATION SURFACE TREATMENT AND SEAL COAT CONSTRUCTION TO ELIMINATE WINDSHIELD AND VEHICLE DAMAGE DUE TO FLYING PARTICLES OF COVER AGGREGATE

There are two serious criticisms of single application surface treatments and seal coats as they are presently constructed. These are:

1. The damage to windshields, headlights, and bodies of motor vehicles that occurs due to the loose particles of cover stone that fast traffic throws into the air for several days immediately after construction.

2. The shortness of the construction season. At least one month of warm weather traffic is required to reorient the cover aggregate particles and firmly embed them in the asphalt binder before winter arrives. In Canada, this means that no single application surface treatment or seal coat should be constructed after the end of August.

Several years ago, one of our provincial departments of highways is reported to have received claims for $300,000 for motor vehicle damage, when several miles of single application seal coat were constructed on a main highway immediately before a July 1 and July 4 long week-end, the dates of national holidays for Canada and the United States, respectively. The criticism based on damage to motor vehicles from flying particles of cover aggregate immediately after construction is so serious, that seal coats are usually not even considered (in North America) for resurfacing heavily travelled asphalt pavements.

The reason why cover aggregate particles are so susceptible to dislodgment by fast traffic immediately after construction, is that assuming the 30 per cent of voids in the cover stone immediately after rolling as reported by Hanson (6), the aggregate particles are embedded less than 50 per cent on the average, and the embedment of the largest particles of a graded cover aggregate may be only 25 per cent or less.

This is quite obvious to anyone who examines the particles of cover stone that end up on the road shoulder following single application seal coat or surface treatment construction. Consequently, for some days just after construction, the larger cover aggregate particles are easily dislodged and thrown into the air by fast traffic, because of their low degree of embedment in the asphalt binder.

There is a rather simple solution to this problem of damage to motor vehicles due to flying cover stone particles. It involves applying the asphalt binder for a single application seal coat or surface treatment in two applications, with the cover stone being applied after the first application. Since the second application is sprayed over the cover aggregate, the cover stone particles are firmly cemented to the road surface. Following the second application of asphalt binder would be an application of clean sand or stone screenings just sufficient to prevent the asphalt binder from sticking to the tires. By employing this method of construction, the only flying particles at any time would come from the sand, and these do not ordinarily cause any motor vehicle damage.

By employing two applications of asphalt binder for single surface treatments or seal coats, the construction season is also lengthened because the second application of asphalt binder cements the cover stone particles to the road surface. It is not necessary to have one month of warm weather traffic to enable the cover stone particles to become reoriented and embedded 70 (hopefully) per cent of their depth in asphalt binder on the average, before winter arrives.

For construction in warm weather, 60 per cent of the total asphalt binder would be sprayed as the first application followed by the cover aggregate, and 40 per cent of the asphalt binder would be applied for the second application. After the end of August, or an equivalent period, the first application would consist of 40 per cent of the total asphalt required, followed by the cover aggregate, and 60 per cent of the asphalt would be sprayed for the second application. Because of the limited amount of warm weather traffic after the end of August (in Canada), a higher percentage of asphalt binder should be applied for the second application to cement the cover stone to the road surface.

Since this in effect is a double surface treatment, designing for the quantity of asphalt binder and cover stone to be applied will be described in the next section under multiple surface treatments.

VIII. DESIGN OF MULTIPLE SURFACE TREATMENTS AND SEAL COATS

Multiple surface treatments and seal coats consist of two, sometimes three, and occasionally four successive alternate applications of asphalt binder and cover aggregate. For each successive layer, the size of the cover stone should be one-half the size of the cover aggregate employed for the immediately preceding layer. When larger sizes of cover aggregate are employed, the thickness of the surface treatment or seal coat may approach or exceed one inch.

The principal criticisms of single application surface treatments or seal coats are (a) shortness of the construction season because of the need for at least one month of warm weather traffic to provide adequate embedment of the cover stone particles before winter arrives, (b) the damage to motor vehicles from flying stone particles that occurs for several days following construction, (c) the tire noise when large size cover stone is used, and (d) loss of larger particles from the surface when a graded cover aggregate is employed.

Each of these criticisms can be avoided by changing to a double or other multiple surface treatment or seal coat. Because the largest cover stone is used for the first layer, and because these large particles are firmly cemented to the road surface by the second application of asphalt binder, only some of the smaller aggregate particles applied for the second layer can be dislodged by fast traffic, and damage to motor vehicles is minor or nil. Because the first layer of large size cover stone is fastened securely to the road surface by the second application of asphalt binder, there is no need for warm weather traffic to obtain adequate embedment of the cover aggregate in the asphalt binder. Therefore, the construction season can be lengthened substantially. Since the smaller aggregate particles employed for the second layer fill the large void spaces in the much larger cover aggregate in the first layer, tire noise is effectively suppressed. Furthermore, the normal loss of the largest particles of graded cover aggregate from a single surface treatment or seal coat because of insufficient embedment in the binder, is averted, because the second application of asphalt cements them firmly into place. Consequently, multiple seal coats or surface treatments should be considered: 195

(a) for heavier traffic volumes
(b) to provide a longer construction season
(c) to minimize broken windshields and other motor vehicle damage from flying stone particles for several days following construction
(d) when graded cover aggregates must be used
(e) to eliminate tire noise
(f) for effective surface treatments over stabilized soil bases
(g) to facilitate street cleaning in urban areas
(h) when coarse aggregates are of inferior quality
(i) to provide better traction for vehicles on paved surfaces from which snow and ice are not completely removed. The tips of the cover stone particles projecting above a layer of compacted snow or ice promote improved traction.

The method of design for multiple surface treatments and seal coats that is recommended in this paper, is based on the assumption that the quantity of asphalt binder and cover aggregate required for *each layer* of a multiple surface treatment or seal coat is identical, with minor adjustments, to the quantity of asphalt binder and cover aggregate that would be applied if each layer were to serve as an isolated single application surface treatment or seal coat. On this basis, Equations [5] and [6] that were developed for single application surface treatments and seal coats can also be employed with slight modification for the design of multiple surface treatments and seal coats.

This means, as indicated in the opening paragraph in the introduction to this paper, that *the same equations* can be employed for the design of *either single application or multiple application seal coats and surface treatments.*

Methods for determining the quantities of asphalt binder and cover aggregate to be applied for each layer of a multiple surface treatment or seal coat have been published by ASTM (19), AASHO (20), Bureau of Public Roads (21), Federal Aviation Agency (22), Country Roads Board (7), (1), National Association of Australian State Road Authorities (5), Tagle (11), Benson (4), and The Asphalt Institute (23). These methods range from the purely empirical, which consist of tabulations of recommended quantities for each layer arrived at from experience, through semi-empirical, to theoretical procedures.

A careful investigation and comparison of these several methods has shown that they do not agree among themselves, and that for some of them the amount of cover stone required is too little, while the quantity of asphalt binder stipulated is excessive. This investigation has also shown that the quantities of cover aggregate and asphalt binder indicated by Equations [5] and [6] respectively, for multiple surface treatments and seal coats, approximate the averages of the quantities of these two materials required by the above methods. However, the design of multiple surface treatments and seal coats by means of Equations [5] and [6] is somewhat unique, in that consideration is given to each of the following important factors: gradation of cover aggregate in each layer; reorientation of the cover aggregate in a surface treatment or seal coat under traffic, and therefore recognition of the need for determining each cover aggregate's Average Least Dimension; traffic volume to be carried; fraction of residual asphalt in the asphalt binder; asphalt binder correction for the textural characteristics of the surface to which the multiple surface treatment or seal coat is to be applied; and correction for the loss, if any, of a portion of the asphalt binder into the cover aggregate.

A. DESIGN ASSUMPTIONS FOR MULTIPLE SURFACE TREATMENTS AND SEAL COATS

1. It is assumed that each successive layer of a multiple surface treatment or seal coat will be built immediately after the preceding layer has been constructed, with no traffic being permitted between layers.

When a year or more of service is scheduled for the first layer of a double surface treatment before the second layer is applied, the double surface treatment becomes in effect two single surface treatments insofar as both design and construction is concerned.

2. Each layer of a multiple surface treatment is assumed to be one-stone particle thick.

3. For the first layer of a multiple surface treatment or seal coat, the cover aggregate should preferably be one-size cover stone, Table I, but graded cover aggregate with a limited amount of finer sizes, Table II, may be employed for all layers.

4. The size of the cover aggregate selected for each layer of a multiple surface treatment or seal coat should be approximately one-half the size of the cover stone employed for the immediately preceding layer. For example, if Aggregate E (3/4 inch one-size aggregate) from Table I, or Aggregate No. 6 (3/4 inch to 3/8 inch graded aggregate) from Table II, is selected for the first layer of a double surface treatment, the cover aggregate for the second layer should be either Aggregate H (3/8 to 1/4 inch one-size aggregate) from Table I, or Aggregate No. 8 (3/8 inch to No. 8 graded aggregate) from Table II.

5. The total quantities of asphalt binder and cover aggregate required for a multiple surface treatment or seal coat are obtained by assuming (with some minor qualifications), that each layer is to be designed as though it were an independent single application surface treatment or seal coat.

6. The quantity of cover aggregate to be applied for the first layer of a multiple surface treatment is to be calculated by Equation [5].

7. The quantity of cover aggregate required for the second layer of a double surface treatment or seal coat, or for each of the second and third layers of a triple surface treatment or seal coat, is calculated by the following modification of Equation [5]: 197

$$C = M\ 46.8(1 - 0.4V)HGE \qquad [7]$$

where M is a multiplying factor that must be evaluated by experience with local conditions of climate, traffic, aggregate, etc., and may be less than or greater than 1.0, depending on local conditions. While the author has always used a value for $M = 1.0$, experience elsewhere may indicate the need for employing a value of $M = 0.9$, 0.8, 1.1, etc.

The other symbols have been already defined.

8. It is to be emphasized that for the cover aggregate for every layer of a multiple surface treatment or seal coat, the normal value for the wastage factor $E = 1.0$. That is, when cover aggregate is applied by a competently operated self-propelled aggregate spreader, or similar well controlled spreading equipment, when calculating the quantity of cover aggregate to be applied for every layer of a multiple surface treatment or seal coat, no allowance is ordinarily made for loss of aggregate due to whip-off, or for any slight unevenness of spread.

9. The Average Least Dimension H of the cover aggregate for each layer should be measured by the procedure outlined in Appendix A.

10. The loose weight W of the cover aggregate for each layer should be determined by ASTM C 29.

11. The fraction of voids V in each cover aggregate in its loose weight condition is calculated by means of Equation [2].

12. The grade of asphalt binder selected for a multiple surface treatment or seal coat depends upon whether a liquid asphalt, an asphalt emulsion, or an asphalt cement is to be used. In a multiple surfact treatment or seal coat, a smaller size of cover aggregate is normally employed for each successive layer, and this would normally call for a different grade of asphalt binder for each layer. However, to simplify construction operations, a single grade of asphalt binder should be specified for all layers of a multiple surface treatment or seal coat.

In the case of liquid asphalt or asphalt cement binders, it is recommended that the single grade of asphalt binder selected should be one grade softer than would ordinarily be selected from Figures 23 to 26 for the climate, road surface temperature, and size of cover aggregate to be applied for the first layer of a multiple seal coat or surface treatment. For example, if Figure 25 indicated that RC 3000 would normally be selected for the road surface temperature and for the cover aggregate size for the first layer, then RC 800 should be chosen for both applications for a double surface treatment, and for all three applications for a triple surface treatment.

198 When the asphalt binder is to be an asphalt emulsion, either RS-2 or CRS-2 would usually be applied for all layers of a multiple surface treatment or seal coat, unless the cover aggregate for each layer is quite small, when either RS-1 or CRS-1 might be selected.

13. The quantity of asphalt binder calculated for each layer of a multiple seal coat or surface treatment is determined by the following modification of Equation [6]:

$$B = K\left(\frac{2.244\ HVT + S + A}{R}\right) \qquad [8]$$

where

K - is a multiplying factor that must be determined by experience with local conditions of climate, traffic, aggregate, etc., and may have a value either less than or greater than 1.0. Within the author's experience K = 1.0. However, for heavy traffic in tropical climates, K may have a value of 0.9 or some other value less than 1.0, while elsewhere, experience may indicate the need for employing a value for K higher than 1.0. The other symbols have the significance already defined for them.

14. The correction S, Table VIII, should be made to the quantity of asphalt binder required for the *first* layer on the basis of the textural characteristics of the surface on which the multiple surface treatment or seal coat is to be placed.

15. *No correction* S, for the textural characteristics of the surface to which it is applied (the surface of the first layer in the case of a

double surface treatment or seal coat, or the surfaces of the first and second layers in the case of a triple surface treatment), is to be made when calculating the quantity of asphalt binder required for the second layer of a double surface treatment or seal coat, or for the second and third applications of asphalt binder to be applied for a triple surface treatment or seal coat.

16. For most cover aggregates, the correction A for loss of a portion of the asphalt binder by absorption into the aggregate is nil. However, a correction A should be added when the cover aggregate employed is decidedly absorptive (asphalt absorption more than two (2) per cent by Rice's vacuum saturation method ASTM D 2041). The Country Roads Board adds a correction A of 0.03 US gallon per square yard (0.025 Imperial gallon/sq. yd.) (0.136 litre/sq. metre), when an allowance for absorption by any cover aggregate must be made.

17. For a multiple seal coat or surface treatment constructed during the early warm weather portion of the construction season, the large aggregate particles in the first layer are rapidly oriented by warm weather traffic to provide adequate embedment in the asphalt binder. Therefore, for construction in early season warm weather, a larger percentage of the total asphalt binder requirement should be sprayed for the first application.

On the other hand, for late season construction of multiple surface treatments or seal coats, sufficient warm weather traffic may not occur before winter arrives to embed the first layer of cover aggregate particles adequately, and the multiple surface treatment may be damaged by loss of cover stone during the ensuing winter or spring, or even earlier. Therefore, during late season construction, to achieve better retention of the cover aggregate in the first layer, a smaller percentage of the total asphalt requirement should be sprayed for the first application, and a larger percentage should be applied for the second application for a double surface treatment or seal coat, or for the total of the second and third applications for a triple seal coat or surface treatment.

Consequently, after the total quantity of asphalt binder required for a double surface treatment or seal coat has been determined, it should be applied as follows:

(a) During the warm weather portion of the construction season:
1st application, 60 per cent of the total asphalt binder
2nd application, 40 per cent of the total asphalt binder

(b) For late season construction:
1st application, 40 per cent of the total asphalt binder
2nd application, 60 per cent of the total asphalt binder

For a triple surface treatment or seal coat, the total asphalt binder requirement should be applied as follows:

(a) During the warm weather portion of the construction season:
1st application, 40 per cent of the total asphalt binder
2nd application, 40 per cent of the total asphalt binder
3rd application, 20 per cent of the total asphalt binder

(b) For late season construction:
1st application, 30 per cent of the total asphalt binder
2nd application, 40 per cent of the total asphalt binder
3rd application, 30 per cent of the total asphalt binder

The application of these assumptions to the actual design of a multiple surface treatment or seal coat will be illustrated by sample calculations for the design of first a double, and then a triple surface treatment or seal coat.

B. SAMPLE CALCULATION FOR THE DESIGN OF A DOUBLE SURFACE TREATMENT OR SEAL COAT

I. THE FOLLOWING CONDITIONS ARE ASSUMED

(a) Climate—cool
(b) Traffic volume—1700 vehicles per day
(c) Road surface temperature—100 F
(d) Textural rating of the existing road surface—1h
(e) Properties of the graded cover aggregates selected:
(1) For first layer, AASHO No. 5, Table II, Figure 14
(2) For second layer AASHO No. 7, Table II, Figure 14
(3) Average Least Dimension H, AASHO No. 5—0.53 inch
(4) Average Least Dimension H, AASHO No. 7—0.25 inch
200 (5) ASTM bulk specific gravity G, AASHO No. 5—2.68
(6) ASTM bulk specific gravity G, AASHO No. 7—2.65
(7) Loose weight W, AASHO No. 5—98 pounds/cu. ft.
(8) Loose weight W, AASHO No. 7—94 pounds/cu. ft.
(9) Fraction of voids V, AASHO No. 5—0.414
(10) Fraction of voids V, AASHO No. 7—0.432
(11) Asphalt absorption, both aggregates—Nil
(12) Wastage factor E, Table IX, first layer—1.0
second layer—1.0

II. THE FOLLOWING ITEMS OF INFORMATION ARE REQUIRED

(a) What quantity of cover stone in pounds per square yard is required for each layer?
(b) What grade of asphalt binder should be selected?
(c) What spraying temperature is recommended?
(d) What quantity of asphalt binder per square yard measured at 60 F should be sprayed for each application?
(e) What quantity of asphalt binder per square yard measured at the spraying temperature should be sprayed for each application?

III. SOLUTION

1. <u>Cover Aggregate Requirements</u>

The quantity per square yard of cover aggregate No. 5 to be applied for the first layer, and of cover aggregate No. 7 required for the second layer can each be calculated by means of Equation [7]:

$$C = M\,46.8(1 - 0.4V)HGE \qquad [7]$$

While the author has so far always used a value for $M = 1.0$, experience elsewhere may indicate the need to employ a value for M that is less than or greater than 1.0 to obtain satisfactory results.

(a) Required quantity of aggregate No. 5 for the first application of cover stone

$$C = (1.0)(46.8)(1 - 0.4 \times 0.414)(0.53)(2.68)(1.0)$$

$$= (1.0)(46.8)(0.834)(0.53)(2.68)(1.0)$$

$$= 55.4 \text{ pounds per square yard.}$$

(b) Required quantity of aggregate No. 7 for the second application of cover stone

$$C = (1.0)(46.8)(1 - 0.4 \times 0.432)(0.25)(2.65)(1.0)$$

$$= (1.0)(46.8)(0.827)(0.25)(2.65)(1.0)$$

$$= 25.6 \text{ pounds per square yard.}$$

(c) Therefore, the total quantity of cover aggregate required for this double surface treatment or seal coat is 55.4 + 25.6 = 81.0 pounds per square yard.

2. Asphalt Binder Requirements

(a) For cooler climates like that of Canada and the Northern U.S.A., for 1 inch to 1/2 inch graded cover aggregate (Aggregate No. 5, Table II, Figure 14), and for a road surface temperature of 100 F, if an RC liquid asphalt binder is to be used, Figure 25 indicates that RC 3000 should be selected. However, to simplify construction operations, only one asphalt binder is to be employed for both applications, and because a somewhat softer asphalt binder is required to achieve fast wetting and firm adhesion to the smaller aggregate of the second layer, the asphalt binder should be one grade softer than RC 3000. Therefore, the asphalt binder selected for both applications is RC 800.

(b) Figure 21 indicates that for average conditions a spraying viscosity of 50 centistokes is required, and for RC 800 it is seen that this corresponds to a spraying temperature of 255 F.

(c) The quantity of RC 800 asphalt binder in U.S. gallons per square yard measured at 60 F, required for each layer is provided by Equation [8]

$$B = K\left(\frac{2.244\ HTV + S + A}{R}\right) \qquad [8]$$

In keeping with the author's experience, a value of K = 1.0 is assumed here. However, experience elsewhere may indicate that a value for K that is less than or greater than 1.0 provides more satisfactory results.

Therefore:

(1) Quantity of RC 800 asphalt binder measured at 60 F required for this first layer is

$$B = \frac{(1.00)(2.244)(0.53)(0.65)(0.414) + 0.03 + 0}{0.84}$$

$$= \frac{0.32 + 0.03}{0.84} = 0.42 \text{ U.S. gallon per square yard.}$$

(2) Quantity of RC 800 asphalt binder measured at 60 F required for the second layer is

$$B = \frac{(1.00)(2.244)(0.25)(0.65)(0.432) + 0 + 0}{0.84}$$

$$= 0.19 \text{ U.S. gallon per square yard.}$$

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(3) Total quantity of RC 800 liquid asphalt binder measured at 60 F to be applied for this double surface treatment or seal coat

$$= 0.42 + 0.19 = 0.61 \text{ US gallon per square yard.}$$

(d) For a spraying temperature of 255 F, Line (2), Figure 22 indicates that the correction factor for volumetric expansion of the asphalt binder is 1.07. Therefore, the total quantity of RC 800 to be applied at a spraying temperature of 255 F is (0.61)(1.07) = 0.65 U.S. gallon per square yard.

(e) For the *warm weather portion* of the construction season, 60 per cent of the total asphalt binder requirement should be sprayed for the first application and 40 per cent for the second. Therefore, the following quantities of RC 800 asphalt binder should be sprayed for each application:

For warm weather construction

Application	U.S. gal/sq. yd. Measured at 60 F	U.S. gal/sq. yd. Measured at Spraying Temperature, 255 F
First	0.37	0.39
Second	0.24	0.26
	0.61	0.65

(f) For *late season construction*, to more securely cement the coarser cover aggregate in the first layer to the road surface, 40 per cent of the total asphalt binder requirement should be sprayed for the first application, and 60 per cent for the second. The following quantities of RC 800 asphalt binder should therefore be sprayed for each application:

For late season construction

Application	U.S. gal/sq. yd. Measured at 60 F	U.S. gal/sq. yd. Measured at Spraying Temperature, 255 F
First	0.24	0.26
Second	0.37	0.39
	0.61	0.65

IV. SUMMARY

1. For the warm weather portion of the construction season:

Application	Asphalt Binder				Cover Aggregate	
	Grade	Spraying Temp. F	US gal/sq.yd. at 60 F	US gal/sq.yd. at Spray Temp.	Size Designation	lb/sq.yd.
First	RC 800	255	0.37	0.39	No. 5	55.4
Second	RC 800	255	0.24	0.26	No. 7	25.6
	Total Quantities		0.61	0.65		81.0

2. For late season construction:*

Application	Asphalt Binder				Cover Aggregate	
	Grade	Spraying Temp. F	US gal/sq. yd. at 60 F	US gal/sq.yd. at Spray Temp.	Size Designation	lb/sq.yd.
First	RC 800	255	0.24	0.26	No. 5	55.4
Second	RC 800	255	0.37	0.39	No. 7	25.6
	Total Quantities		0.61	0.65		81.0

*Note: Because lower road surface temperatures tend to prevail during construction in cool weather late in the season, RC 250 would probably be substituted quite frequently for RC 800, and the quantities of asphalt binder for each application would be increased somewhat due to the smaller fraction of residual asphalt in RC 250, Table VI.

V. USE OF ASPHALT EMULSION BINDER

If RS-2 asphalt emulsion had been selected for this double surface treatment or seal coat instead of RC 800, the design calculations are similar to those just illustrated. Table VI indicates that an average value for the fraction R of residual asphalt in RS-2 asphalt emulsion is 0.65, and Line (3) in Figure 22 shows that for a maximum spraying temperature of 160 F, the correction factor for volumetric expansion is 1.025. When using RS-2 asphalt emulsion, the following summary is obtained for the same design conditions:

1. For the warm weather portion of the construction season:

	Asphalt Binder				Cover Aggregate	
Application	Grade	Spraying Temp. F	US gal/sq.yd. at 60 F	US gal/sq.yd. at Spray Temp.	Size Designation	lb/sq.yd.
First	RS-2	160	0.47	0.48	No. 5	55.4
Second	RS-2	160	0.31	0.32	No. 7	25.6
	Total Quantities		0.70	0.80		81.0

2. For late season construction:

	Asphalt Binder				Cover Aggregate	
Application	Grade	Spraying Temp. F	US gal/sq.yd. at 60 F	US gal/sq.yd. at Spray Temp.	Size Designation	lb/sq.yd.
First	RS-2	160	0.31	0.32	No. 5	55.4
Second	RS-2	160	0.47	0.48	No. 7	25.6
	Total Quantities		0.78	0.80		81.0

VI. USE OF AN ASPHALT CEMENT BINDER

If the same design conditions existed in a hot climate, 200/300 penetration asphalt cement, Figures 24 and 26, might be selected as the binder for a double surface treatment or seal coat, instead of RC 800, or RS-2, but the design calculations are similar to those already illustrated. As shown by Table VI, the fraction R or residual asphalt in 200/300 penetration asphalt cement is 1.0. Depending upon its viscosity temperature characteristics, the spraying temperature for 200/300 penetration asphalt could be 320 F, Figure 21, and as indicated by Line (2), Figure 22, the volume correction factor for this spraying temperature is 1.10. Consequently, when using 200/300 penetration for the same conditions of design, the following summary is obtained:

1. For the warm weather portion of the construction season:

Application	Asphalt Binder				Cover Aggregate	
	Grade	Spraying Temp. F	US gal/sq. yd. at 60 F.	US gal/sq.yd. at Spray Temp.	Size Designation	lb/sq.yd.
First	200/300 pen.	320	0.31	0.34	No. 5	55.4
Second	200/300 pen.	320	0.20	0.22	No. 7	25.6
	Total Quantities		0.51	0.56		81.0

2. For late season construction:*

Application	Asphalt Binder				Cover Aggregate	
	Grade	Spraying Temp. F	US gal/sq. yd. at 60 F.	US gal/sq.yd. at Spray Temp.	Size Designation	lb/sq.yd.
First	200/300 pen.	320	0.20	0.22	No. 5	55.4
Second	200/300 pen.	320	0.31	0.34	No. 7	25.6
	Total quantities		0.51	0.56		81.0

*Note: For late season construction in even a hot climate, if the weather is cool, 200/300 penetration asphalt cement could be too hard a grade of asphalt binder to use, and better results might be obtained by using one of the liquid asphalt or asphalt emulsion binders.

VII. COMPARISON OF TOTAL MATERIAL REQUIREMENTS PER SQUARE YARD

The following table summarizes the total material requirements per square yard for this particular double surface treatment or seal coat:

Materials	200/300 Penetration Asphalt Cement	RC 800 Liquid Asphalt	RS-2 Asphalt Emulsion
Asphalt binder US gallons per square yard at 60 F	0.51	0.61	0.78
Cover aggregate pounds per square yard	81.0	81.0	81.0

C. SAMPLE CALCULATION FOR THE DESIGN OF A TRIPLE SURFACE TREATMENT OR SEAL COAT

I. THE FOLLOWING CONDITIONS ARE ASSUMED:

The triple surface treatment or seal coat is to consist of a third layer to be added to the double surface treatment or seal coat of the previous sample calculation (B above). Consequently, all of the conditions assumed for the previous sample calculation apply with the following additions:

(a) Properties of cover aggregate for the third layer:

(1) Gradation—AASHO No. 9, Table II, Figure 14.

(2) Average Least Dimension H—from Table IV assume

$$\frac{\text{50 per cent passing size}}{1.32} = \frac{0.14}{1.32} = 0.106 \text{ inch}$$

(3) ASTM bulk specific gravity G = 2.66

(4) Loose weight W = 88 pounds per cubic foot

(5) Fraction of voids V = 0.47

(6) Asphalt absorption = nil

(7) Wastage factor E = 1.0

II. THE FOLLOWING ADDITIONAL ITEMS OF INFORMATION ARE REQUIRED

(a) What quantity of cover stone is required for the third layer?

(b) What quantity of asphalt binder measured at 60 F is required for the third layer?

(c) What quantity of asphalt binder measured at the spraying temperature is required for the third layer?

III. SOLUTION

(a) The quantity of cover aggregate required for the third layer is given by Equation [7]:

$$C = (1.0)(46.8)(1 - 0.4 \times 0.47)(0.106)(2.66)(1.0)$$
$$= (1.0)(46.8)(0.812)(0.106)(2.66)(1.0)$$
$$= 10.7 \text{ pounds per square yard.}$$

(b) The quantity of RC 800 asphalt binder measured at 60 F required for the third layer is given by Equation [8]

$$B = \frac{(1.0)(2.244)(0.106)(0.65)(0.47) + 0 + 0}{0.84}$$

$$= 0.09 \text{ US gallon per square yard.}$$

(c) The quantity of RC 800 asphalt measured at the spraying temperature of 255 F required for the third layer = (0.09)(1.07) = 0.10 US gallon per square yard.

(d) The total quantity of RC 800 asphalt binder required for all three layers

(1) Measured at 60 F = 0.42 + 0.19 + 0.09 = 0.70 US gallon per square yard

(2) Measured at a spraying temperature of 255 F = (0.70)(1.07) = 0.75 US gallon per square yard.

(e) The quantity of RS-2 asphalt emulsion binder measured at 60 F required for the third layer is given by Equation [8]

$$B = \frac{(1.0)(2.244)(0.106)(0.65)(0.47) + 0 + 0}{0.65}$$

$$= 0.11 \text{ US gallon per square yard.}$$

(f) The quantity of RS-2 asphalt emulsion binder measured at a spraying temperature of 160 F required for the third layer = (0.11) (1.025) = 0.11 US gallon per square yard.

(g) The total quantity of RS-2 asphalt emulsion required for all three layers:

(1) Measured at 60 F = 0.54 + 0.24 + 0.11 = 0.89 US gallon per square yard.

(2) Measured at a spraying temperature of 160 F = (0.89)(1.025) = 0.91 US gallon per square yard.

(h) The quantity of 200/300 penetration asphalt cement measured at 60 F required for the third layer is given by Equation [7]

$$B = \frac{(1.0)(2.244)(0.106)(0.65)(0.47) + 0 + 0}{1.0}$$

$$= 0.07 \text{ US gallon per square yard}$$

(i) The quantity of 200/300 penetration asphalt cement measured at a spraying temperature of 320 F required for the third layer = (0.07) (1.10) = 0.08 US gallon per square yard.

(j) The total quantity of 200/300 penetration asphalt required for all three layers:

(1) Measured at 60 F = 0.35 + 0.16 + 0.07 = 0.58 US gallon per square yard.

(2) Measured at a spraying temperature of 320 F = (0.58)(1.10) = 0.64 US gallon per square yard.

IV. SUMMARY OF MATERIAL QUANTITIES REQUIRED FOR EACH APPLICATION DURING THE CONSTRUCTION OF A TRIPLE SURFACE TREATMENT OR SEAL COAT

For the construction of a triple surface treatment or seal coat during warm weather, 40 per cent of the total asphalt binder requirement should be applied for the first application, 40 per cent for the second application, and 20 per cent for the third. For late season construction, 30 per cent of the total asphalt binder requirement should be applied for the first application, 40 per cent for the second, and 30 per cent for the third application. In summary therefore:

1. For warm weather construction:

	Asphalt Binder				Cover Aggregate	
Application	Grade	Spraying Temp. F	US gal/sq.yd. at 60 F	US gal/sq.yd. at Spray Temp.	Size Designation	lb/sq.yd.
Asphalt Binder—Liquid Asphalt RC 800						
First	RC 800	255	0.28	0.30	No. 5	55.4
Second	RC 800	255	0.28	0.30	No. 7	25.6
Third	RC 800	255	0.14	0.15	No. 9	10.7
	Total Quantities		0.70	0.75		91.7
Asphalt Binder—Asphalt Emulsion RS-2						
First	RS-2	160	0.35	0.36	No. 5	55.4
Second	RS-2	160	0.36	0.37	No. 7	25.6
Third	RS-2	160	0.18	0.18	No. 9	10.7
	Total Quantities		0.89	0.91		91.7
Asphalt Binder—200/300 penetration asphalt cement						
First	200/300 pen.	320	0.23	0.25	No. 5	55.4
Second	200/300 pen.	320	0.23	0.26	No. 7	25.6
Third	200/300 pen.	320	0.12	0.13	No. 9	10.7
	Total quantities		0.58	0.64		91.7

2. For late season construction:

Application	Grade	Spraying Temp. F	Asphalt Binder US gal/sq.yd. at 60 F	US gal/sq.yd. at Spray Temp.	Cover Aggregate Size Designation	lb/sq.yd.
Asphalt Binder—Liquid Asphalt RC 800						
First	RC 800	255	0.21	0.22	No. 5	55.4
Second	RC 800	255	0.28	0.30	No. 7	25.6
Third	RC 800	255	0.21	0.23	No. 9	10.7
	Total quantities		0.70	0.75		91.7
Asphalt Binder—Asphalt Emulsion RS-2						
First	RS-2	160	0.26	0.27	No. 5	55.4
Second	RS-2	160	0.36	0.36	No. 7	25.6
Third	RS-2	160	0.27	0.28	No. 9	10.7
	Total quantities		0.89	0.91		91.7
Asphalt Binder—200/300 penetration Asphalt Cement						
First	200/300 pen.	320	0.17	0.19	No. 5	55.4
Second	200/300 pen.	320	0.23	0.26	No. 7	25.6
Third	200/300 pen.	320	0.18	0.19	No. 9	10.7
	Total quantities		0.58	0.64		91.7

V. COMPARISON OF TOTAL MATERIAL REQUIREMENTS PER SQUARE YARD

The following table summarizes the total material requirements per square yard for this particular triple surface treatment or seal coat:

Materials	Material Requirements per Square Yard: 200/300 Penetration Asphalt Cement	RC 800 Liquid Asphalt	RS-2 Asphalt Emulsion
Asphalt binder, gal/sq. yd. at 60 F	0.58	0.70	0.89
Cover aggregate, pounds per square yard	91.7	91.7	91.7

IX. CONSTRUCTION OF SURFACE TREATMENTS AND SEAL COATS

It has been shown that design procedures are available to determine the optimum quantities of asphalt binder and cover aggregate to be applied for either single application or multiple application surface treatments and seal coats.

It is the objective of the construction equipment and procedures employed, to apply these quantities accurately and uniformly to the road surface under suitable weather and other conditions, and to protect the surface treatment or seal coat from damage by vehicles both during construction and during the critical initial period after it is opened to traffic following construction. Consequently, the service performance of seal coats and surface treatments is influenced by each of the following factors:

(a) climate and weather
(b) preparation of the existing surface
(c) construction equipment
(d) construction operations
(e) traffic control during construction and during the critical initial period following construction.

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1. Climate and Weather

Seal coats and surface treatments are more likely to be successful if they are constructed in warm dry weather in the early summer. Traffic during the ensuing hot weather provides adequate embedment of the cover aggregate in the asphalt binder, improves the adhesion between the binder and aggregate, and increases the strength or stability of the surface treatment or seal coat by developing firmer cover aggregate interlock.

During construction, asphalt binder and cover aggregate should be applied only during daylight hours, and when the ambient air temperature is not less than 50 F and rising. The road surface should be dry when liquid asphalt and asphalt cement binders are used, but may be damp when the binder is an asphalt emulsion. High atmospheric humidity which may delay the development of good adhesion between the cover aggregate and asphalt binder, the imminence of rain which can damage a newly finished surface, or any other temporary conditions likely to have a detrimental effect on the success of the finished surface treatment or seal coat, should be carefully considered when deciding whether construction operations should proceed or be stopped at any time.

In the Northern United States and Canada, single surface treatments should not be constructed after August 31 so as to allow for about one month of warm weather traffic that is necessary to obtain adequate embedment of the cover stone particles before winter arrives. Multiple surface treatments on the other hand, while preferably constructed in warm weather, can be built much later in the construction season.

2. Preparation of the Existing Surface

The preparation of a consolidated crushed stone or gravel surface for a surface treatment requires blading to the specified cross-section, watering if necessary, and compaction by rolling and by traffic to provide a firm, smooth, uniform surface. The surface is then primed with from 0.1 to 0.25 gallon of MC 70 (MC 1) per square yard (0.5 to 1.25 litre per square metre) if it is tightly bonded or of medium porosity, and with from 0.2 to 0.5 gallon per square yard (1.0 to 2.5 litre per square metre) if it is a relatively porous, poorly bonded surface. The primer should be left to cure for several days before the seal coat is applied. If traffic is likely to damage the primed surface, the primer may be followed by an application of from six to ten pounds per square yard of clean, fine sand. All loose and foreign material is swept or otherwise removed from the surface immediately before the surface treatment is applied.

Before a seal coat is constructed, all defects and breaks in an old paved surface should be adequately repaired. When large areas of an old bituminous surface are seriously cracked and badly worn, an emulsified asphalt sand slurry seal may be applied to fill the cracks and give a uniform texture to the entire surface. Immediately before a seal coat is applied the old paved surface should be thoroughly swept with a power broom to remove all loose and foreign material. The removal of any hardened mud or similar extraneous material may require the use of a pick and shovel, followed by washing with water, if necessary.

3. Construction Equipment

The basic equipment for the construction of a surface treatment or seal coat should include:

(a) asphalt distributor
(b) aggregate spreader
(c) rollers
(d) rotary broom and other cleaning equipment
(e) broom drag
(f) trucks for hauling cover aggregate.

The asphalt distributor must be able to apply asphalt binder uniformly across and along the road surface at the specified rate per square yard. The asphalt distributor should preferably be one in which the asphalt pump is synchronized with the forward speed of the truck in such a way that the same quantity of asphalt binder is applied per square yard regardless of small variations in the forward speed of the distributor due to changes in grade, direction of travel, etc. To establish its general mechanical condition, the distributor should be calibrated at a central testing station (24), (25), (26). Cotton pads should be employed (15) to check the transverse and longitudinal distribution of asphalt binder across the road surface on the job. The asphalt distributor should be operated to apply asphalt binder within ± 7.5 per cent of the average application in the longitudinal direction, and within ± 10 per cent of the average application for any 4-inch width in the transverse direction.

When a double surface treatment or seal coat is being constructed, for the second application of asphalt binder, *the asphalt distributor should be operated in the opposite direction* to that employed for the first application. This will avoid two applications of either too much or too little binder over the same widths of road surface due to either a deficiency or excess of asphalt binder being applied by one or more spray nozzles. Furthermore, for half-width construction, the centre joint for asphalt application on successive layers should be offset by from six to twelve inches.

It is the function of the aggregate spreader to apply cover aggregate uniformly at the specified rate per square yard. If it is of the self-propelled type, its system for discharging aggregate onto the road surface should be synchronized with the forward speed of the spreader. This tends to ensure uniform application of cover stone in spite of small differences in the forward speed of the spreader due to changes in grade, direction of travel, etc.

The aggregate spreader should be tested to establish its ability to spread the specified quantity of cover aggregate per square yard. Figure 28 illustrates the use of a steel pan of exactly one square yard for this purpose. An even better arrangement would be three steel pans,
212 18 inches to each side (0.25 square yard) uniformly distributed across the width of road surface covered by the aggregate spreader.

After the cover stone has been applied, it is the purpose of the rolling operation to press the cover stone particles firmly into the asphalt binder to improve embedment, to promote adhesion, and to obtain better cover aggregate interlock. For single surface treatments or seal coats, the rollers should be of the pneumatic-tire type. No existing surface is entirely smooth, and pneumatic tires are able to reach down into small depressions and firmly press the cover aggregate into the asphalt binder. However, *for multiple surface treatments or seal coats* pneumatic-tire rollers should be employed for initial rolling, but *two passes by a steel-wheel roller should be made for the final rolling of each layer.* Steel wheel rollers appear to orient cover aggregate particles into a flatter surface, which is important when constructing multiple surface treatments.

A rotary broom should be used to clean the existing surface immediately before a seal coat or surface treatment is applied. To remove the layer of dust that is often heaviest near the edges of an existing surface, a blower may be required. In extreme cases, the surface may have to be cleaned by flushing with water. Lumps of clay or other hard foreign material may have to be removed with picks and shovels.

If the cover aggregate spreading equipment is unable to apply cover aggregate at a uniform rate per square yard, it should be followed by a broom drag for this purpose. When operating a broom drag, care must be taken to avoid turning over any cover aggregate particles that are already embedded in the asphalt binder.

Fig. 28. Use of a One Square Yard Steel Pan to Adjust Cover Aggregate Spreader to the Setting Required for Application of Cover Aggregate at the Specified Rate per Square Yard.

An adequate number of trucks should be provided to avoid any delay in construction operations due to lack of cover aggregate. The bodies of the trucks should be designed to avoid any impingement of the truck body on the aggregate spreader at any time.

4. Construction Operations

Construction operations for a seal coat or surface treatment proceed in the following order:

(a) Spraying the asphalt binder
(b) Spreading the cover aggregate
(c) Broom dragging if necessary to obtain more uniform aggregate distribution
(d) Rolling
(e) The repetition of this sequence one or more times for a multiple surface treatment or seal coat.

Figure 29 illustrates this sequence of construction operations, and also demonstrates excellent seal coat and surface treatment construction practice. The asphalt distributor is only a short distance ahead of the self-propelled cover aggregate spreader. This promotes faster wetting and the development of better initial adhesion between the cover aggregate and the asphalt binder. The forward self-propelled pneumatic-tire roller is working immediately behind the aggregate spreader, and makes its first pass over the cover aggregate within a few minutes after the asphalt binder has been sprayed. This provides more effective embedment of the cover aggregate in the asphalt binder, and also promotes better adhesion between the cover aggregate and the asphalt binder.

Fig. 29. Illustrating Excellent Technique for Seal Coat or Surface Treatment Construction. The Bituminous Distributor, Self-Propelled Flaherty Chip Spreader, Truck Loads of Stone Chips, and Roller, Work Together in Such Close Coordination that the First Pass of the Roller Over the Cover Aggregate Is Completed within a Very Few Minutes After the Bituminous U.S. Binder Has Been Applied to the Road Surface. (North America).

Figure 30 was taken during the construction of a double surface treatment, and illustrates the junction at the centre of the road between the No. 5 cover aggregate of the first application on the right, and the No. 7 cover aggregate on the left, with the black strip of asphalt binder from the second application left for overlap during half-width construction, between them. The striking difference in surface texture between the coarser No. 5 cover stone for the first layer on the right, and the finer No. 7 cover aggregate on the left, can be easily observed.

As pointed out earlier, *when constructing a multiple surface treatment or seal coat,* while initial rolling of every layer should be done

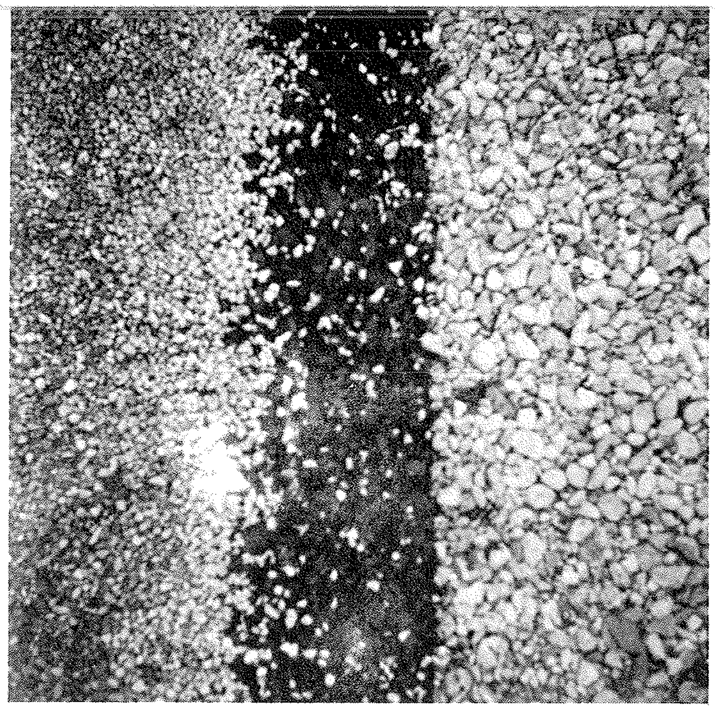

Fig. 30. Illustrating Coarse Aggregate Used for the Bottom Layer on the Right and Finer Aggregate on the Left for the Top Layer of a Double Surface Treatment, Together with a Portion of the Second Application of Asphalt Binder.

with a pneumatic-tire roller, *each layer should receive two passes with a steel-wheel roller before the next layer is placed.*

Figure 31, illustrates a finished double surface treatment 3-years old, that was designed and constructed in accordance with the principles that have been described in this paper.

5. Traffic Control

The objectives of traffic control are to protect workmen, construction equipment, and motor vehicles, and to avoid damage to the surface treatment or seal coat as construction proceeds and during the critical period when the finished job is first opened to traffic.

Whenever possible, traffic should be detoured until construction is complete. When detouring is not possible, half width construction is essential, with traffic being confined to the lane not under construction.

Traffic control through the section under construction should be maintained by means of a pilot truck for convoying groups of vehicles, warning signs, traffic lane markers, and flagmen.

All traffic should be kept off seal coats and surface treatments during their construction. This includes construction equipment which should be routed to the work site in the direction opposite to that in which construction is progressing.

When rolling is complete, and the new surface treatment or seal coat is opened to traffic, it requires protection from high speed vehicles. Flagmen should be provided, and traffic should be convoyed over the new surface at speeds that are low enough to avoid damage to it.

The length of time during which a newly constructed surface treatment or seal coat must be protected against high speed traffic, depends upon existing conditions. It can vary from a few hours in hot dry weather, to one or more days in humid, cool, or wet weather.

Fig. 31. Canada. Illustrating the Excellent Appearance of a Double Surface Treatment on a Consolidated Granular Base, in Its Third Year of Service, that Was Designed and Constructed in Accordance with the Principles Described in the Paper.

X. OPENING A NEWLY CONSTRUCTED SURFACE TREATMENT OR SEAL COAT TO TRAFFIC

There are several reasons why a newly constructed seal coat or surface treatment is particularly susceptible to damage by fast traffic. These factors should be kept clearly in mind when considering the time of day for opening a newly constructed surface treatment or seal coat to traffic, and the need for rigidly controlling traffic speeds for several hours and sometimes for the first one or two days.

1. Immediately after rolling, the voids in the cover aggregate are still about 30 per cent (6), and therefore the cover aggregate interlock is only partially developed. Also the cover aggregate is only partly embedded in the asphalt binder and is not yet firmly cemented into place. If an RS asphalt emulsion has been employed as binder, it will be only partially broken, and not yet firm. If the asphalt binder is an RC liquid asphalt, it will contain considerable solvent or cutter stock and will still be relatively fluid. Consequently, for reasons associated partly with the cover aggregate and in part with the asphalt binder, a newly constructed seal coat or surface treatment does not yet have high stability, and it can be quickly and badly damaged by the disruptive forces of high speed traffic.

2. Because of this lower initial stability, for the first day, and particularly for the first several hours, traffic speeds should be kept low by means of flagmen, convoy vehicles, etc.

3. During hot sunny weather, the most critical time of day to open a new seal coat or surface treatment to traffic is between mid-day and late afternoon. The high road surface temperatures during these hours make the asphalt binder much more fluid, and it is least able to hold the cover stone. By waiting until late evening, or after dark to open the surface treatment or seal coat to traffic, the asphalt binder becomes much firmer at the lower evening temperatures, and its greater cementing power provides increased resistance to loss of cover stone under traffic.

For example, suppose that because the cover aggregate size is 1/2 inch, and because the morning road surface temperature is 70 F, that RC 250 has been selected as the asphalt binder, Figure 25, and that the construction of the seal coat or surface treatment has been completed by two o'clock. When should it be opened to traffic? Figure 25 indicates that at a road surface temperature of 70 F, the viscosity of RC 250 is 9000 centistokes. However, by two o'clock on a hot sunny day, the road surface temperature may be 120 F, and Figure 2 shows that the viscosity of RC 250 at this temperature is only about 900 centistokes, which is only one-tenth of its morning viscosity. By waiting until after dark to open a surface treatment or seal coat completed in the early afternoon to traffic, the road surface temperature may have dropped to 70 F. At the same time, due to evaporation of solvent or cutter stock, the RC 250 will probably have become RC 800. At 70 F, Figure 25 shows that the viscosity of RC 800 is 50,000 centistokes.

Consequently, under the conditions assumed for this illustration, the afternoon viscosity of this binder is only about one tenth of its morning viscosity, while its viscosity is about 55 times as great in the evening as in midafternoon. Therefore, a hot afternoon is the poorest time to open a new surface treatment or seal coat to traffic. Just after dark is the best time, partly because of the very much higher viscosity of the asphalt binder, and partly because controlled evening and night traffic will develop increased stability in the seal coat or surface treatment before it enters the high temperature period of the next day. Since this principle applies to all asphalt binders, it is good engineering practice to recognize it and to use it whenever possible as a guide when opening a new surface treatment or seal coat to traffic.

4. If rain begins to fall within a few hours after its construction, a new seal coat or surface treatment should be barricaded, and no traffic should be permitted until it has become thoroughly dry.

SUMMARY

1. One equation for asphalt binder, and one equation for cover aggregate requirements are proposed for both single application and multiple application surface treatments and seal coats.

2. Four major faults of surface treatments and seal coats and their causes are briefly described.

3. The advantages of one-size over graded cover aggregates are illustrated and discussed.

4. Cover aggregate and asphalt binder characteristics and requirements are reviewed.

5. The design of a single application seal coat or surface treatment is described and is illustrated with a sample calculation.

6. The advantages of multiple application surface treatments and seal coats are outlined.

7. Designs of a double and of a triple seal coat or surface treatment are described and are illustrated by sample calculations.

8. Principles of construction for single and multiple surface treatments and seal coats are briefly outlined.

9. Factors to be considered when opening a newly constructed seal coat or surface treatment to traffic are reviewed.

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APPENDIX A

METHOD FOR DETERMINING THE AVERAGE LEAST DIMENSION OF COVER AGGREGATES FOR BITUMINOUS SURFACE TREATMENTS AND SEAL COATS[2]

This method describes a simplified procedure which is to be followed to determine the Average Least Dimension of a cover aggregate intended for use in a bituminous surface treatment or seal coat.

METHOD:

(a) The Sieve Analysis shall be carried out by the method described in Part 1.
(b) The Flakiness Index shall be determined by the method described in Part 2.
(c) The Average Least Dimension shall be determined from Figure C.

PART 1

SIEVE ANALYSIS

SAMPLE:

Weight of Sample for Sieve Analysis (U.S. Standard Sieves square openings).

Table A-1.

Nominal Size Inches	Minimum Weight of Sample for Sieving Grams
2	20,000
1-1/2	15,000
1	10,000
3/4	5,000
5/8	4,000
1/2	2,500
3/8	1,000
1/4	750

METHOD:

The surface-dry sample shall be weighed and the following distribution of particle sizes obtained by means of sieves with square openings, employing the procedure laid down in A.S.T.M. C 136.

[2] With credit to The Country Roads Board, Victoria, Australia.

Passing	Retained
1-1/2 inch	1 inch
1 inch	3/4 inch
3/4 inch	5/8 inch
5/8 inch	1/2 inch
1/2 inch	3/8 inch
3/8 inch	1/4 inch
1/4 inch	No. 4
No. 4	No. 8
No. 8	No. 16
No. 16	

WEIGHING:

On completion of sieving, the material retained on each sieve shall be weighed on a balance sensitive to 0.1% of weight of the test sample. This is recorded on the work sheet and the weight passing each sieve is expressed as a percentage of the total weight of the sample.

REPORT:

Results are reported to the nearest one per cent, and the grading curve is plotted as illustrated in Figure A.

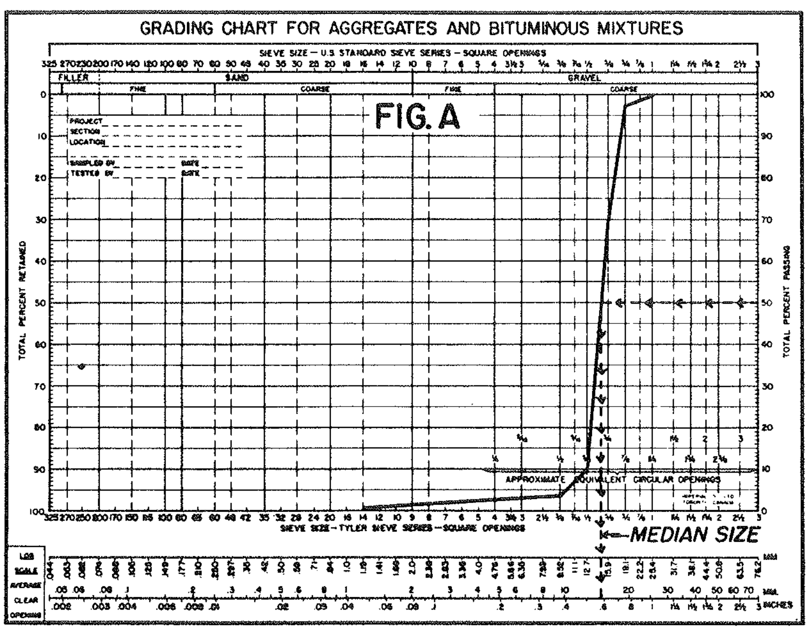


Fig. A. Grading Chart for Aggregates and Bituminous Mixtures.

MEDIAN SIZE:

The Median Size is that theoretical sieve size in inches through which 50% of the material will pass.

The Median Size may be read off from the scale at the bottom of Figure A.

PART 2

FLAKINESS INDEX

SAMPLE:

The material employed in this test shall consist of all aggregate used in the sieve analysis that falls within the size ranges specified below.

ONE-SIZE AGGREGATES

Table A-2. One-Size Aggregates

Size Number*	Nominal Range of Sizes U.S. Standard Sieves Square Openings		All Material Larger Than
	Passing	Retained	
E	3/4 inch	1/2 inch	1/2 inch
F	5/8 "	3/8 "	3/8 "
G	1/2 "	3/8 "	3/8 "
H	3/8 "	1/4 "	1/4 "

*Country Roads Board Size Designation

GRADED AGGREGATES

Table A-3. Graded Aggregates

Size Number*	Nominal Range of Sizes U.S. Standard Sieves Square Openings		Material			Material			Material	
	Passing	Retained	Pass.	Ret.		Pass.	Ret.		Pass.	Ret.
5	1 inch	1/2 inch	1"	3/4"	and	3/4"	1/2"		-	-
6	3/4 "	3/8 "	3/4"	1/2"	"	1/2"	3/8"		-	-
7	1/2 "	No. 4	1/2"	3/8"	"	3/8"	1/4"		-	-
8	3/8 "	No. 8	3/8"	1/4"	"	1/4"	No.4		-	-
56	1 "	3/8 inch	1"	3/4"	"	3/4"	1/2"		-	-
67	3/4 "	No. 4	3/4"	1/2"	"	1/2"	3/8"	and	3/8"	1/4"
68	3/4 "	No. 8	3/4"	1/2"	"	1/2"	3/8"	"	3/8"	1/4"
76	1/2 "	No. 8	1/2"	3/8"	"	3/8"	1/4"	"	1/4"	No.4

*A.S.T.M. Designation: D448
AASHO Designation: M 43

METHOD:

Each fraction of material, as shown in the previous paragraph, shall be tested particle by particle for its ability to pass through an appropriate slotted sieve[3]

[3] See British Standards Institution 812.

Table A-4.

Size of Material Passing	Retained	Slot Width Inch	Approximate Width of Slotted Sieves Issued Inch
1-1/2"	1"	0.750	0.757
1"	3/4"	0.525	0.532
3/4"	1/2"	0.375	0.384
1/2"	3/8"	0.263	0.258
3/8"	1/4"	0.184	0.184
1/4"	No. 4	0.131	0.123

(or a gauge made by filing an elongated slot of the required width in a sheet of metal 1/16" thick). The size of slots required for each fraction is given in Table A-4 and illustrated in Figure B.

WEIGHING:

The total amount passing the appropriate slotted sieve openings shall be weighed to an accuracy of at least 0.1 per cent of the weight of the test sample.

FLAKINESS INDEX:

The Flakiness Index is the total weight of the material passing the appropriate slotted sieve openings expressed as a percentage of the combined weight of the fractions tested on the slotted sieve.

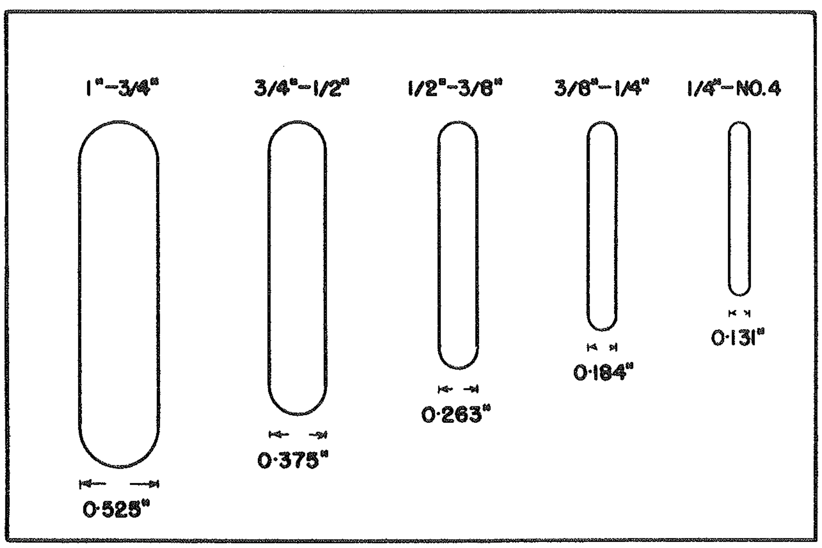


Fig. B. Slotted Sieve Openings for Testing Aggregates for Elongated Flat Particles.

EXAMPLE

(a) SIEVE ANALYSIS

The Material is One-Size Aggregate "E".
From the Grading Curve, Figure A, the *Median Size* is *0.58* inch.

Table A-5. Full Grading
(Total Weight of Dry Sample = 6,600 grams)

Sieve No. U.S. Standard Square Opening	Weight Retained Grams	Weight Passing Grams	Total Passing Per Cent
1"	-	6600	100
3/4"	60	6540	99.1
1/2"	4984	1556	23.6
3/8"	1418	138	2.1
1/4"	96	42	0.6
No. 4	4	38	0.5

The Material is One-Size Aggregate "E".

From the Grading Curve, Figure A, the Median Size is 0.58 inch.

(b) FLAKINESS INDEX

Table A-6. Flakiness Index

Sieve Size U.S. Standard Square Opening Inch	Width of Slotted Sieve Inch	Weight Retained Slotted Sieve Grams	Weight Passing Slotted Sieve Grams	Total Weight Grams	Flakiness Index Per Cent
1 - 3/4	0.525	50	10	60	
3/4 - 1/2	0.375	3666	1318	4984	
Total		3716	1328	5044	26.3

Note: Where there is an insignificant amount of material (not more than 5%) of any one size, it may be neglected in determination of Flakiness Index. Material 1" - 3/4" could be neglected in above Flakiness Index test and the result would not be appreciably changed.

(c) AVERAGE LEAST DIMENSION

On Figure C, proceed horizontally from the median size on the vertical axis to the diagonal line representing the flakiness index for the sample. From this point of intersection, proceed vertically to the horizontal axis and read off the Average Least Dimension.

For this particular aggregate sample, the median size is 0.58 inch, and the flakiness index is 26 per cent. The broken line on Figure C indicates that the Average Least Dimension (A.L.D.) of this sample is 0.40 inch (reading to the nearest 0.01 inch).

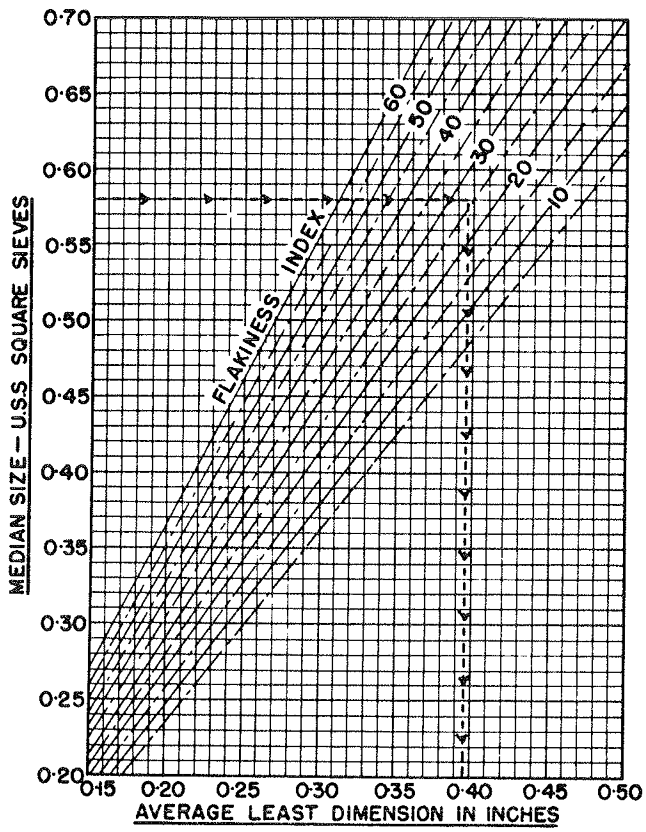


Fig. C. Determination of Average Least Dimension of Cover Aggregate.

Discussion

MR. C. W. CHAFFIN (Prepared Discussion): I congratulate Dr. McLeod on this very excellent paper of such a practical and immediately useful nature. Most of us are aware of the extensive study on this subject started by the author over a decade ago and summarized in the 1960 Proceedings supplement. This presentation today is a very fitting culmination to this work. It gives a design and construction procedure for seal coats and surface treatments which embodies the best ideas from the several previously published methods, as well as significant contributions from the author.

This type construction is certainly important in Texas. In fact, over 90% of our approximately 37,000 miles of secondary roads (Farm to Market and Ranch to Market) system is of the surface treatment type. In addition, several thousand miles of our primary system is also surface treatment. Then each year several hundred miles of seal coat is placed not only on original surface treatments, but on many miles of asphaltic concrete, even on the Interstate system.

The method of design presented here today is worthy of serious study by all who do this type of work, and it is recommended that it be adapted to your local conditions without delay.

Now an observation or two based on our Texas experience. The author calls our attention to the advantages of precoated aggregate. We certainly agree to this for crushed limestone cover material. It is used almost entirely for seal coats on our primary highways. We use a little heavier material (higher asphalt content) than the MC-30 or MC-70 mentioned in the paper. Texas has a special precoat material, but it is very close to MC-250, the main difference is that it has a little less volatile diluent in it. This material makes a precoated limestone aggregate that will stockpile satisfactorily for several months.

The prevention of windshield damage due to flying aggregate depends entirely on bonding almost every particle in the case of conventional large aggregate. We have found that lightweight or synthetic aggregate completely eliminates this problem. This aggregate also adheres excellently to the binder and has maintained superior skid resistance. It is now being used extensively for seal coats on our primary system.

The paper suggests that a seal coat may have better chance of success in cooler weather if a portion of the asphalt binder is placed in
226
two applications but the last application necessarily being followed by application of sand or stone screenings. The author cautions that this is a special case of a double seal. It is agreed that a double has somewhat a better chance of success under adverse conditions, but a caution is offered in that one be sure to note that the author states that this type design is covered under the multiple course procedure. If you merely apply the asphalt for a single surface design in two applications, followed by an application of sand or fine stone screenings, this finer material will fill the voids and flush out the asphalt.

Dr. McLeod's design takes in consideration the condition of the old surface to be sealed. The problem often is one of non-uniformity of the old surface and here is an additional suggestion for your consideration. Generally the old surface in case of a surface treatment will be smoother in the wheel paths while it will be dry next to the center line and along the edges, unless it is a very narrow highway. Since this pattern usually is uniform in the longitudinal direction, it can be taken into account by using smaller nozzles over the smoother wheel paths and larger nozzles along the center and edge. You may even wish to try such an adjustment on the original construction of a surface treatment.

Again, this paper presented today is extremely useful and it is predicted that its principles will become a manual of seal coat and surface treatment design for many.

MR. A. E. HOLBERG (Prepared Discussion): I wish to compliment you, Dr. McLeod on your detailed and well prepared presentation. I had an opportunity to review your paper briefly prior to your presentation and also like to extend my compliments to Mr. Perkins for the drafting of the excellent diagrams.

May I very briefly review the situation in Canada. Most Provinces use predominantly Emulsified Asphalt for Seal Coats and Surface Treatments and there is a pronounced trend toward the use of Cationic Emulsified Asphalt, designated CRS in the United States and RSK in Canada. In some parts of Canada we have consistently successful seal coats and in other parts occasionally Surface Treatments and Seal Coats produced have performed poorly. When one examines success and failures, one recognizes the importance of good workmanship, equipment and proper selection of aggregates and binder versus lack of control and poor supervision.

Most engineers involved with Surface Treatments and Seal Coats are familiar with the basic design principles that are employed by the Country Roads Board of Victoria and the National Roads Board of New Zealand and some of these principles have been included in local design methods. Projects concerned are considerable in some Provinces. The Highways Department in Alberta maintains a special work crew and every new highway in the Province is Seal Coated and up to 12 miles of 24' pavement are Seal Coated within a 10 hour day and the distributor is being re-loaded while in continuous spraying. The Department of Highways in British Columbia kept records on Seal Coat and Surface Treatment work back to the year 1954 and detailed data since 1958. The same Department published a report September 1967 which draws the conclusion that Seal Coats with Emulsified Asphalt over a period of up to 8 years are performing well with a minimum of maintenance and that on some Seal Coated sections on the Trans-Canada Highway close to 5 million vehicles have travelled during the period concerned. The conclusion in the report reads:

> "Some excellent sealcoats have been constructed in this Province using Emulsified Asphalts and it would appear from the results of its use in recent years that the emulsion has a definite place in our sealcoat work. Preference is shown towards the Cationic Emulsion as it is not so slow in breaking or setting up as the Anionic which with our undependable weather becomes a great asset. Stripping tests carried our in our Laboratories indicated that it has superior coating qualities on many of our aggregates."

It seems to me, that engineers from Australia or New Zealand would find it most interesting to study Canadian experience with Emulsified Asphalts. As you well know, Cationic Emulsified Asphalts have not been available in Australia and New Zealand for any length of time, while we in Canada use them extensively for Seal Coat and Surface Treatment work since 1959. I am in full agreement with you, that the method of design that is employed by the Country Roads Board of Victoria and the National Roads Board of New Zealand is most valuable but it is based on many years of field experience using liquid asphalts (cutbacks). To my knowledge Cationic Emulsified Asphalts as we use them have not been involved in these studies. It seems to me therefore, that the audience and the reader of your paper should be aware, that the application of the Australian/New Zealand design method to Emulsified Asphalts is your very own recommendation. Some of these recommendations may be applicable but at this time we have in my opinion not sufficient field data to confirm or deny the general method of design as proposed by you and applicable to Emulsified Asphalt.

MR. C. F. PARKER: I would also like to congratulate Dr. McLeod on this fine paper. I have heard him present many papers over the past 20 years and they have all been excellent.

I do have one question. He has given us very little information on the quality of the aggregate used in these seal coats, specific gravity, absorption, wear tests, and so on. What is the quality of these aggregates?

DR. MCLEOD: With respect to cover aggregates, New Zealand has probably the finest cover stone available throughout the country of any nation in the world. New Zealand specifies a maximum Los Angeles abrasion rating of 20 for cover stone. In Australia, the maximum Los Angeles abrasion ratings specified are 18 for a traffic volume of at least 1500 vehicles per day, 27 for traffic volumes between 300 and 1500 vehicles per day, and 35 for traffic volumes below 300 vehicles per day.

Concerning particle shape, New Zealand has the most restrictive specification of any country. New Zealand specifies a maximum of 2.25 for the ratio of the average greatest dimension to the average least dimension of a cover aggregate. This ensures particles that are more nearly cubical or tetrahedral in shape. While the specification says nothing about the crushing method to be used, New Zealand contractors have found by experience that this requirement for particle shape normally means that cover aggregates for seal coats and surface treatments must be crushed in a hammer mill or impact breaker. This type of crushing equipment seems to result in particles that are more nearly cubical in shape.

In Australia, particle shape for cover aggregate is controlled by a flakiness index test, which is a British Standards Institution test, B.S. 812. Very roughly, the flakiness index test measures the degree by which particles fail to be perfect cubes, because of flattening of the particles. Australia specifies a maximum flakiness index requirement of 35.

With regard to grading, Australia obtains essentially one-size cover stone by specifying that at least two-thirds by weight of the aggregate passing a sieve of specified size must be retained on a sieve opening that is seven-tenths of the specified size. New Zealand obtains basically one-size aggregate by specifying that a minimum high percentage (ranging from 65 to 80 per cent as the specified size of cover stone becomes smaller) of the aggregate must lie within 0.1 inch from the aggregate's Average Least Dimension.

New Zealand restricts the amount of fine particles by specifying that not more than one (1) per cent of a seal coat or surface treatment aggregate can pass a No. 8 sieve. Australia achieves the same objective by permitting not more than 0.5 per cent to pass the No. 16 sieve.

MR. V. OBRCIAN: I noticed on the occasion of my trip to Nigeria that they use two cover aggregates. Is this something that we would have to take into account for obtaining the average dimension that you mentioned?

DR. MCLEOD: I have seen the surface treatments in Nigeria to which you refer. When designing a surface treatment or seal coat, three items of information on the cover aggregate should be obtained. First, its Average Least Dimension should be determined. This requires use of the Flakiness Index Test. Second, the loose weight of the cover aggregate in pounds per cubic foot or in kilograms per litre should be measured by means of ASTM C 29. Third, the ASTM bulk specific gravity of the cover stone should be determined. From these three items of data, the average thickness of a surface treatment or seal coat, and the void space between the cover aggregate particles are determined. This information is needed in order to calculate the quantities of asphalt binder and of cover stone that are required per unit of area.

In many countries, it is difficult to obtain one-size cover stone. While surface treatments and seal coats can be constructed with graded cover aggregates, the degree of success achieved is normally going to be limited, particularly if these aggregates contain excessive fines. 229

MR. OBRCIAN: I am sorry if I confused you. They do not use the graded aggregate. They use a one size type aggregate.

MR. J. M. EDWARDS: I would like to support Dr. McLeod's reference to the fact that a very large percentage of the world's roads are maintained by surface treatments. I certainly also have to support his approach to the design of such treatments. There is, however, one factor which I think is important but which was not covered in his presentation although it may have been referred to in the written paper. It is also relevant to the question about the use of rounded aggregates. This factor is that chippings become embedded into the existing surface whether this is gravel or bituminous. The degree of embedment affects the total amount of asphalt that should be sprayed. In the case of a rounded cover aggregate there is little embedment and the quantity of asphalt required is high, whereas in the case of crushed cover stone there is more embedment and less asphalt is required to prevent flushing.

DR. MCLEOD: The point you make is a very important one. If the cover aggregate is going to be forced part way into the existing surface, this in effect reduces the Average Least Dimension of the cover aggregate particles. This in turn means that there is less void space for asphalt binder. Consequently, the quantity of asphalt binder to be applied should be reduced, otherwise as Mr. Edwards has stated, flushing or bleeding will occur.

In cases where this partial penetration of cover aggregate into an existing surface is likely to occur, the quantity of asphalt binder to be applied should be based on the *effective* Average Least Dimension of the cover stone, which is its Average Least Dimension minus its anticipated depth of partial penetration into the existing surface.

MR. W. H. CAMPEN: Dr. McLeod, the type of surface treatment we have been talking about at times is designated as of two types, seal coats and armor coats. What distinction do you make between the two, if you make any at all?

DR. MCLEOD: The paper defines only two types, which however are intended to cover the many different names that are currently given to this class of asphalt surface. If this type of asphalt surface construction is applied over a consolidated gravel or similar base it is called a single or multiple surface treatment. If it is applied to a paved surface of any kind, it is referred to as a single or multiple seal coat. Consequently, the term "armor coat" and similar designations would be covered by one or the other of these two definitions.

MR. W. J. KARI (by letter): It has been suggested that the rate of
230 application of emulsions for surface treatments be increased over that used for asphalt cement. The theory is that the total asphalt content for both emulsion surface treatments and for those using asphalt cements should be the same. The purpose of this discussion is to present another approach to the design and construction of emulsion surface treatments, one which holds that the rate of application should be the same, on a gallon-for-gallon basis, as that used with asphalt cement.

In emulsion surface treatments, the water in the emulsion has three major functions: lowers application viscosity so the emulsion can be applied at a lower temperature than the asphalt cement from which it was made, serves as a carrier for adhesion agents to insure a good bond between asphalt, pavement, and aggregate, and to effect a volume change (or "film collapse") to insure bond yet minimize subsequent bleeding. This volume change, illustrated in Figure A, permits use of emulsions at the same application rate as asphalt cement. The emulsion level immediately after application of the aggregate is high on the stone. When the emulsion sets, there is a 30 to 35 per cent volume reduction due to evaporation of water. The film collapses due to this volume change. The asphalt film forms a saddle, i.e., remains high on the stone and low in the spaces between the aggregate. This insures a high surface contact area between the asphalt and stone to prevent aggregate whip-off by traffic. Also, the amount of asphalt in the spaces between the stones is kept low to prevent bleeding should the aggregate embed into the pavement due to heavy traffic or show wear due to use of tire chains or studded tires during winter.

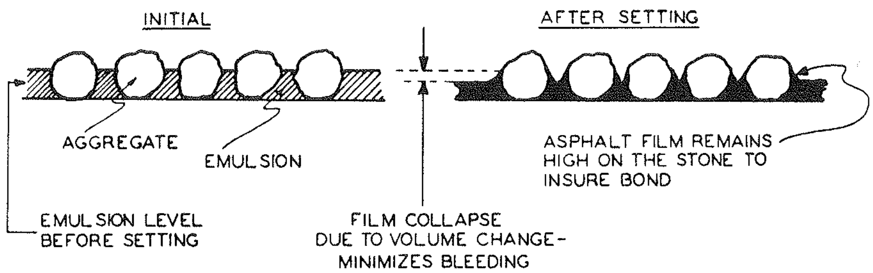


Fig. A. Emulsified Asphalt Seal Coat.

To make maximum use of the volume change, the following construction practices should be followed for emulsion surface treatments:

1. Apply the emulsion at the same rate of application as you would use with penetration grade paving asphalt. If the emulsion content is increased, the benefits of film collapse are lost.
2. Apply damp aggregate as soon as possible. This insures maximum embedment of rock into the emulsion.
3. Roll with a pneumatic roller as soon as possible. This permits the stone particles to orient to their most stable position while the emulsion is still at a fluid viscosity.
4. Avoid use of excess aggregate. This is not needed to blot up excess binder as with other types of surface treatments. The emulsion volume change minimizes bleeding.

AUTHOR'S CLOSURE: The author would like to thank Mr. Holberg for his instructive comments, and Mr.. Chaffin for his useful and generous remarks.

Mr. Holberg has referred to the very extensive use of cutback asphalts and asphalt cements in Australia and New Zealand for surface treatments and seal coats, relative to the wide use of asphalt emulsions in Canada for this purpose. In reply, it might be pointed out that asphalt emulsions are manufactured in New Zealand and Australia, and that serious efforts have been made to have asphalt emulsions adopted for surface treatments and seal coats. Consequently, Australia and New Zealand are quite familiar with both anionic and cationic asphalt emulsions, and some asphalt emulsion is used for surface treatment and seal coat construction. However, it would appear that as a result of many years of experience with each of these types of binders, asphalt cements and cutback asphalts are so firmly established as binders for surface treatments and seal coats, that Australia and New Zealand seem unlikely to change over to asphalt emulsions in any major way, at least in the immediate future.

Mr. Holberg has stated that the method of design suggested in the paper is my own recommendation. This is only partly correct, for the method of design recommended is largely a modification of the design method that has been used with such outstanding success for many years in Australia and New Zealand, to make it applicable to the conditions that exist in North America and in many other parts of the world. Both New Zealand and Australia have for many years insisted on the use of cover stone that is much more nearly one-size than is ordinarily available in North America and other countries where only graded cover aggregates can usually be obtained. As shown in the paper, the ultimate voids between the aggregate particles in a surface treatment or seal coat made with a graded cover aggregate are normally much less than are assumed in Australia when one-size cover aggregate is employed. Consequently, for surface treatments and seal coats to be made with graded cover aggregates, it has been necessary to develop the modified design equations (5) and (6) for the required quantities of cover aggregate and asphalt binder per unit area. As indicated in the paper itself, these equations are of general application, and can be applied even when one-size cover stone is employed, since one-size cover stone is only a special case of cover aggregates in general. It has been shown in the paper, that for the one-size cover stone and design assumptions employed in Australia, that the general design equations (5) and (6) revert to equations (3) and (4) which represent Australian design. Consequently, the general design equations (5) and (6) recommended in the paper, make it possible to apply the Australian principles of design to surface treatments and seal coats that are to be made with either graded or one-size cover aggregates.

Reading between the lines of the last paragraph of Mr. Holberg's prepared discussion, I would gather that he questions the use of the same equations to design surface treatments or seal coats with asphalt cements, cutback asphalts, or asphalt emulsions. During the past 15 years I have examined many surface treatments made with asphalt emulsions, cutback asphalts, and asphalt cements. In every case, when the surface treatment or seal coat has been providing satisfactory service for several years, the cover aggregate particles have been embedded in asphalt binder to from approximately two-thirds to three-quarters of their depth. Consequently, in my opinion at least, whether a seal coat or surface treatment is to be constructed with asphalt cement, asphalt emulsion, or cutback asphalt, *the same amount of residual asphalt* must be provided. Equations [4], [6], and [8] recognize this principle.

In his paper published nearly 35 years ago, Hanson referred to a rule of thumb often cited in connection with the quantity of asphalt emulsion to be applied per unit area for a surface treatment or seal coat, namely, apply asphalt emulsion at the same rate per unit area as asphalt cements or cutback asphalts. Hanson commented in effect, that this rate of application was often satisfactory for asphalt emulsions only because far too much asphalt cement or cutback asphalt was normally applied, with resulting flushing or bleeding.

As pointed out in the paper itself, the need for basing the design of seal coats and surface treatments *on the quantity of residual asphalt required*, appears to have been clearly recognized by many organizations and individuals including the British Road Research Laboratory, Country Roads Board, Idaho Department of Highways, Utah Department of Highways, Kerr, Hanson, Tagle, Nevitt, Kearby, Winnitoy, and Benson. When surface treatments and seal coats are designed on the basis of the *same residual asphalt requirement*, because of the current composition of asphalt binders, this will always require the application of more finished asphalt emulsion in gallons per unit area, than of cutback asphalt or asphalt cement.

The information contained in Mr. Chaffin's prepared discussion, which is based on the very extensive experience of the Texas Highway Department with surface treatments and seal coats, provides a highly useful addition to the paper itself. Mr. Chaffin's reference to precoated cover aggregate for improved adhesion, and to the use of lightweight cover aggregate to avoid windshield damage from flying cover aggregate particles, should be particularly noted.

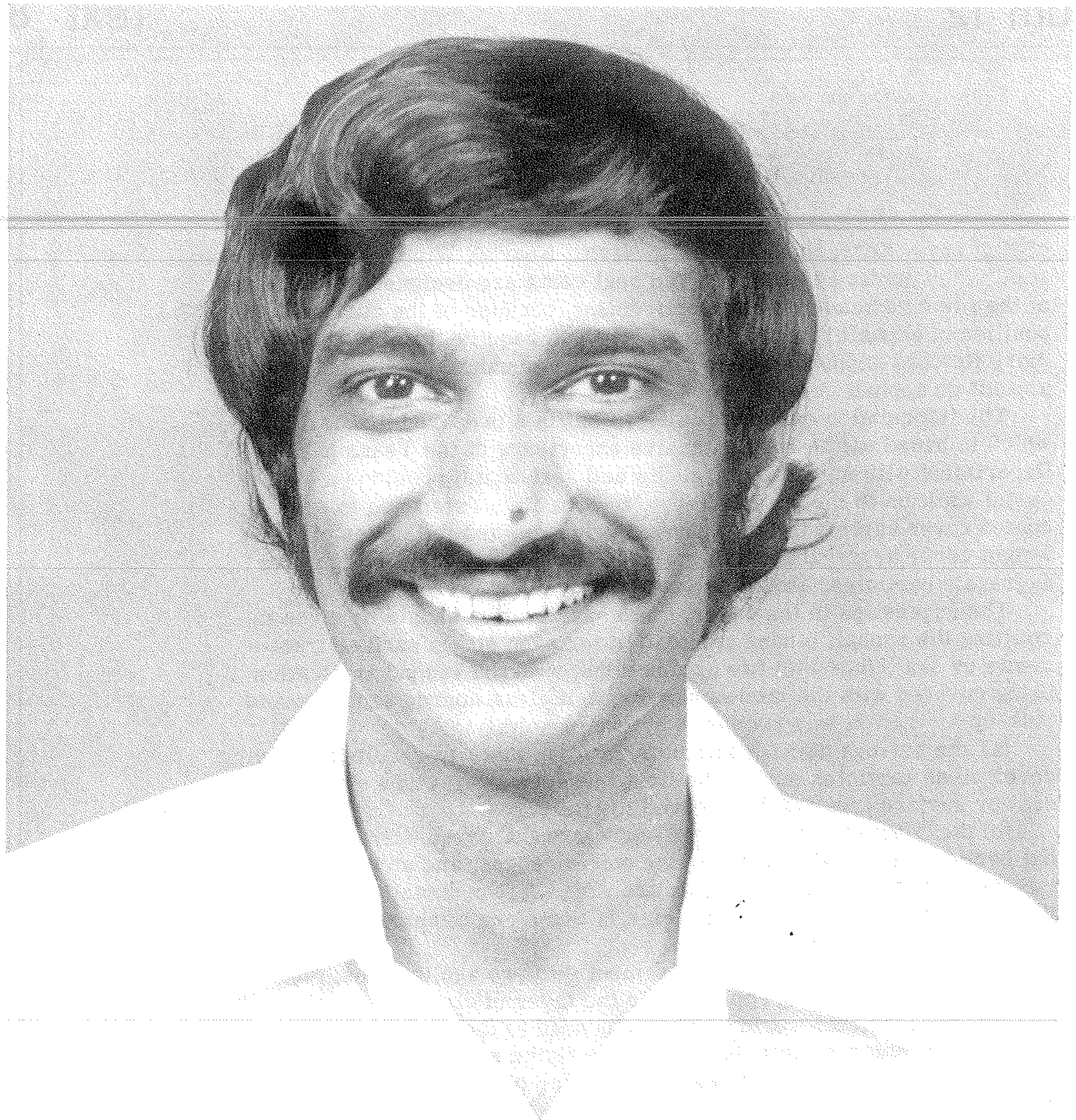
The suggestion in the paper, that consideration should be given to splitting the asphalt binder application for even single surface treatments or seal coats into two applications, with the second application being covered with the minimum amount of clean coarse sand to avoid pick-up by traffic, was prompted by two observations:

(a) the serious damage to motor vehicles that can result from flying cover stone particles during the first few days after a new single seal coat or surface treatment is opened to traffic.

(b) the complete loss of cover aggregate that frequently occurs from the portions of a seal coat along the outside edges, and sometimes from the centre of the pavement, which are areas that ordinarily receive little traffic, and the cover aggregate is therefore often poorly embedded in asphalt binder. 233

By splitting the bitumen requirement into two applications, the second application being applied over the layer of cover stone, the cover stone particles would be firmly bonded to the surface. This would avoid motor vehicle damage due to flying particles, and loss of cover stone from the outside edge and centre of the pavement. The second application of asphalt binder would of course have to be followed by an application of clean coarse sand, and rolling, in order to carry traffic.

Mr. Chaffin points out that the coarse sand used for the second application might tend to fill the voids and cause flushing or bleeding. On the other hand, for double surface treatments, the Country Roads Board of Victoria, Australia, indicates that clean coarse sand all passing 1/8 inch can be used as cover aggregate for the second layer of a double surface treatment when the cover stone employed for the first layer is 1/2 inch or larger. Consequently, provided the amount of clean coarse sand that is applied for the second application is held to a minimum that will avoid pick-up by traffic, it should not result in flushing or bleeding. The problems presented by current single seal coat construction are so serious, particularly vehicle damage due to flying particles, that some modification of present construction practice is necessary, if single seal coats are to be considered for heavily travelled pavements. However, we are in agreement with Mr. Chaffin that in this case, it would be highly preferable to employ the standard design procedure for a double surface treatment.



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THE HASHEMITE KINGDOM OF JORDAN

HIGHWAY MAINTENANCE MANUAL

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Ministry of Public Works

Highway Department

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APPENDIX

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TABLE 2
SUGGESTED TEMPERATURE FOR USE OF ASPHALTIC MATERIALS(1)

Type and Grade of Asphalt	Suggested Temperature in Degrees Centigrade For Spraying	For Plant Mixing
Asphalt Cements		
40 – 50 pen.	***	135 – 171
50 – 60 pen.	146 – 207	129 – 166
85 – 100 pen.	143 – 204	124 – 160
120 – 150 pen.	141 – 202	118 – 154
200 – 300 pen.	135 – 196	112 – 149
Liquid Asphalt		
RC. MC and SC Grades		
30	29 – 70	16 – 41
70	49 – 88	35 – 60
250	74 – 112	57 – 79
800	92 – 131	74 – 96
3000	110 – 149	93 – 116

In the absence of suitable temperature-viscosity data, the above table provides a guide for use in determining application temperatures.

(1) Adapted from the Asphalt Institute.
*** Seldom used for spraying.

NOTE: Deleted material deals with Maintenance of Asphaltic Concrete Pavements. The above Table 2 is referenced on page 32 of this text.

D. **Maintenance of Surface Treatment or Seal Coats**

1. **General.** Surface treatment is a broad term that covers several types of applications of asphaltic material and aggregate. A surface treatment may be applied to almost any kind of road surface. Surface treatments are classified as single surface treatments and multiple surface treatments.

A single surface treatment consists of a single application of asphalt covered with a single application of stone or gravel. The finished treatment is about the thickness of the maximum size aggregate particles.

A multiple surface treatment is formed by applying asphalt in two or more applications and covering each with a layer of stone or gravel. The size of the stone used to cover the first application for asphalt largely controls the thickness of the finished mat, for the following reason. The maximum size of the pieces of stone in each spread after the first one is smaller than the maximum size of stone in the previous spread. The idea is that the smaller pieces of stone will fit or "key" between the stones of the next larger size, and the completed surfacing will therefore be stronger and more dense. The finished thickness of a multiple surface treatment will be between 2 and 5 centimeters.

A single surface treatment waterproofs the road surface, protects the surface from wear, and makes the surface more skid proof. A multiple surface treatment serves the same purposes as a single treatment, and in some cases it also adds slightly to the strength of the road.

There are two main uses of surface treatments. One, a surface treatment is used as the wearing course on a granular base that has just been built; two, a surface treatment is used to improve an older asphaltic surface that has begun to wear under traffic.

A surface treatment has the potential of being a relatively long lasting and economical wearing course, provided it is properly designed. Satisfactory surface treatment design gives consideration to the surface condition of an existing pavement in that a deteriorated pavement may be "asphalt rich", "medium" or "asphalt hungry". Also to be considered are aggregate types and quality with particular attention given to the Average **Least Dimension** of aggregate particles.

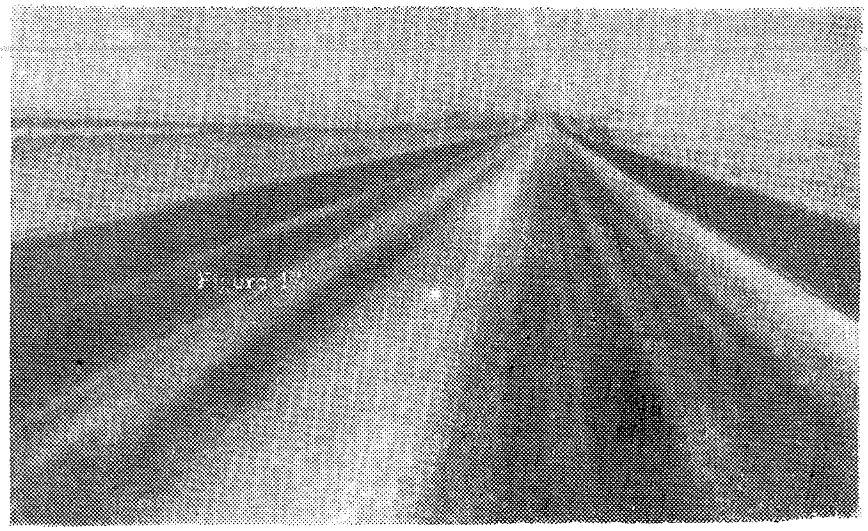
An abbreviated procedure for proper surface treatment design is attached as an appendix to this manual.

Types of defects that commonly occur in surface treatments are alligator cracking, pot-holes, raveling, bleeding, corrugations, and stripping.

a. Alligator cracking in a surface treatment is usually caused by lack of good support underneath. Some settlement almost always accompanies such cracking.

b. Pot-holes in a surface treatment are caused by local surface failure, and the formation of a pot-hole in the surface treatment is ususally followed by breaking up of the material under the surfacing.

c. Raveling of a surface treatment is caused by a dry and brittle



Serious flushing in surface treatment creates a traffic hazard and spoils the appearance of a highway in which careful engineering is obvious in connection with every detail but the surface treatment itself.

Figure 24

condition of the asphalt binder brought about by aging. The binder is no longer able to grip and hold the pieces of aggregate.

d. Bleeding of asphaltic material to the surface of a surface-treated road is usually caused by several conditions. Either too much asphaltic material was used in the treatment in the first place, improperly graded cover material was used, or not enough aggregate was placed on the asphaltic material to cover it properly (Figure 24).

e. Corrugations are surface ripples. They are sometimes found on a roadway on which a mat of some thickness has been built up by a number of surface treatments over a period of time: such a mat becomes rippled because it is unstable and moved under the pushing action of traffic.

f. Stripping of the asphalt film from aggregate particles may occur when certain types of aggregate are used. Such aggregates can be detected by laboratory testing. Therefore new aggregate sources or sources which are suspect should be tested. Stripping can then be avoided by proper aggregate choice or by adding an anti-stripping agent to the liquid asphalt binder material.

2. **Correction of Defects and Failures.** It is important to keep in mind that the following remarks primarily apply to roadways that are constructed by the application of one or more surface treatments on top of a granular or Telford base. Methods of repairing asphaltic concrete pavements that have received surface treatment or seal coats are the same as those described previously under asphaltic concrete pavements.

When a failure occurs in a surface treatment, the first step is to determine the type and size of the failure. The next step is to outline the area of the surface to be repaired.

a. **Repair of Alligator Cracking.** If the area in which alligator cracking has occurred is small, and the settlement is not extensive, temporary repairs can be made as follows: The surface is cleaned with brooms or compressed air, then an even coating of asphaltic material is applied and covered at once with chips of stone, gravel, or sand. The kind of cover to use will depend on the extent of settlement and the type of asphaltic material used. It is important to make sure that the existing surface is dry and that there are no loose particles.

This type of repair does nothing to correct lack of support from beneath. The treatment merely helps prevent surface water from entering the weak base and increasing the extent of damage. It may also raise the low spot to grade. If there are signs that subgrade material is working up through the cracks or if the surface is loose, other steps must be taken. The old cracked surface treatments must first be removed. Then the base must be examined for water and subgrade soil that may have worked up from the subgrade. If water and subgrade soil are found, it is necessary to remove the base to the subgrade. The water may have seeped in below the surface or the shoulders from the side ditches, or down through the cracked surface. The water source must be found, and good drainage provided.

After defects in drainage have been corrected, new base material is placed. The new base material should be as good or better than that in the original construction. It can be compacted with hand tampers, vibratory tampers, or rollers. The best method will depend on the size of the failure. The top of the new base after compaction, or the top of the old base (if it did not have to be removed) will be lower than the surface around the patch.

The surface of the new or old base must be lightly primed with about ½ liter per square meter of MC - 250 cutback asphalt. After the prime has been allowed to cure, a new surface treatment must be applied to bring the patch up to grade.

b. **Repair of Pot-holes.** The sides and bottom of each pot-hole in a surface treatment must first be cleaned. The hole must then be shaped to form a square or rectangle whose sides are parallel or at right angles to the direction of traffic, and the edges must be neat and as nearly vertical as possible. The trimming of pot-holes in a surface treatment can usually be done with an ax. The patch may be made with a surface treatment or with a premixed patch material.

If a hole that is more than 5 centimeters deep is to be patched with a surface treatment, it will be necessary to add enough granular base material to bring the top of the base to within 2.5 centimeters of the finished grade. If more than 10 centimeters of granular material for the base is needed, that material must be compacted with hand or vibratory tamps. After the base has been properly compacted, the bottom of the hole must be primed. As soon as the prime coat has cured, a new surface treatment must be applied. Enough material must be used to bring the surface of the patch about 5 millimeters above the level of the rest of the pavement to allow for further compaction by traffic.

There will be times when it will be necessary or desirable to use premixed material for patching the base, because of weather conditions or the lack of well-graded granular base material. In such a case, the pot-hole must be trimmed and the surface of the compacted premixed material raised about 5 millimeters above the grade of the adjacent pavement.

c. **Repair of Raveling.** Raveling of a surface can be corrected by applying a new single surface treatment to the raveled spot or portion. First, it is necessary to broom out all dirt and loose stones. The repair is made by applying asphalt on the raveled areas, spreading cover aggregate over the asphalt with the aid of hand brooms to produce a level surface, and then rolling.

If the depression caused by raveling is too deep for one course of the aggregate cover that is used, more courses of surface treatment must be placed on the low spots before the final course is applied, so that the entire raveled area can be covered properly at the same time by the final course.

d. **Correction of Bleeding.** Bleeding of a surface treatment occurs when vehicle tires come into direct and prolonged contact with the liquid asphalt used for surface treatment. Since any grade of asphaltic material that is suitable for surface treatment tends to come to the surface of the pavement, the only way to prevent bleeding is to place an adequate cover of aggregate over the road surface.

By making a detailed inspection of each portion of surface treatment that is bleeding, it will be possible to determine whether bleeding is caused by loss of cover aggregate or by the use of too much asphalt. In either case, enough asphalt must be available to hold a new cover. When a defect of this kind is to be corrected, the best time to perform the work is during the hottest part of the day.

Where a surface treatment is just beginning to show a tendency to bleed, as indicated by black marks along the wheel tracks, the necessary correction can frequently be made by using sand to blot up the excess asphalt. In such a case, the sand must be spread, and the rolling must be done during the hottest part of the day.

Where a surface treatment is bleeding badly, the remedy is to cover it with 5 to 10 kg/M^2 of minus No. 10 sieve aggregate, and to roll the surfacing with a rubber-roller. Rolling must be continued until the aggregate is seated securely. Traffic will dislodge some of the aggregate, the loose material should be broomed back evenly over the surface, and rolling repeated.

Wherever measures have been taken to correct bleeding, it is advisable to establish some system of traffic control to hold vehicle speed below 40 Kilometers per hour for at least 24 hours.

e. **Correction of Corrugations.** The only satisfactory method of correcting corrugations in a surface-treated roadway on a granular base is to scarify the material to a suitable depth. After the surface course and some of the base material have been well scarified, the loosened material must be recompacted as part of the base, and the surface of the base must be brought to the proper grade and cross section. The compacted base must then be primed, and a surface treatment applied.

When corrugations develop in a surface treatment that is supported on a Telford base, the only method of correcting the defect is to remove or trim the surface. After that course has been removed, the base must be then be primed, and a surface treatment applied.

3. **Asphaltic Materials for Surface Treatments.** The RC (rapid curing) types of asphalt cutback, which have been thinned with naphtha or gasoline, are often used for surface treatment work, because the solvent evaporates quickly and the cover aggregate is gripped by the asphalt before it can be whipped off by traffic. The grade to be used depends mainly on the season. In hot weather, grade RC - 800, or a heavier grade of medium-curing cut-back may be used. In cool weather, material of grade
250 RC - 250 will give the results because it will remain soft until the aggregate is spread.

4. **Equipment for Surface Treatments.** Success in applying a surface treatment depends primarily on the equipment used, its condition, and the way in which it is handled. All equipment must be in good mechanical condition, properly adjusted, and free from wear which would impair the quality of the work. It is the responsibility of the Foreman in charge of a team assigned to surface treatment to make a routine daily inspection of each piece of equipment under his jurisdiction, and to see to it that all equipment is maintained properly and cleaned at the end of each day's work.

The type and amount of equipment needed for repairing a failure or performing routine resurfacing work depends on the type and size of the job. Small areas can be repaired by applying asphaltic material with a trailer type asphalt distributor using either the spray bar or hand spray. Cover aggregate may be spread with hand tools and the surface may be rolled with a small roller. Large areas require the use of pressure distributors with capacities from 3000 to 4500 or more liters, stone spreaders, brooms, and both steel-wheeled and rubber-tire rollers.

a. **Distributor.** The most important piece of equipment on a surface treatment job is the distributor for applying asphaltic material. It is made specifically to apply liquid asphalt uniformly to a surface in exact quantities, and to maintain the specified rate for the entire load, regardless of changes in the grade or direction of the road.

The operator of a distributor must be properly trained and experienced in all phases of its operation. He must have a full knowledge of the manufacturer's recommendations in regard to the size and adjustment of the nozzles, pump pressures, operation of the burners, and the spray-bar height. Also, the manufacturer's calibration chart must be kept in the distributor at all times.

Figure 25 illustrates the variation in distance between spray bar and road surface during spraying operations when the distributor is not equipped to maintain a constant spray bar height. Figure 26 shows the influence of spray bar height and Figure 27 depicts the distributor attachment which maintains constant spray bar height. Incorrect spray bar height or nozzle adjustment will result in non-uniform asphalt application or streaking as shown in Figure 28.

At the beginning of each days work, the following check list must be gone over by each operator of a distributor:

1) Are the heaters and pumps functioning properly?
2) Are all pressure gages and measuring devices functioning properly?
3) Is each spray-bar clean and properly set to produce an even spread?
4) Are the nozzles clean, free of "burrs", and at the correct angle?
5) Is the hand hose clean and operating properly?
6) Is the bitumeter wheel free and functioning properly? (For truck mounted units only.)

When a distributor has been out of use, it must be flushed out with a cutback or a suitable oil before it is loaded with hot asphalt. If even a very small amount of water is trapped in a pipe or valve serious boiling and foaming will occur when hot asphaltic material comes in contact with the water.

b. **Aggregate Spreaders.** The aggregate spreader is next in impor-

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tance to the distributor in obtaining a good surface treatment. A suitable aggregate spreader that is operated properly will conserve aggregate and produce a uniform spread. There are various types of spreaders. The simplest type is one which is equipped with fixed vanes and is attached to the tail gate of an aggregate truck. Two other examples are shown in Figures 29 and 30.

The following check list may be used for each aggregate spreader:

1) Has the aggregate spreader been checked for proper operation?
2) Have all adjustments been made in accordance with the manufacturer's operating manual?
3) Have the hitches on all trucks been checked to make sure they may be connected quickly and positively to the spreader?
4) Has the application rate of the spreader been checked?

c. **Rollers.** Proper seating of the aggregate particles is very important operation in applying a surface treatment. There are several types of compactors, but the types generally used for surface treatments are pneumatic-tire rollers and steel-wheeled rollers. A rubber-tire roller is preferred for all surface treatment work. The resilient tires on the roller force the aggregate firmly into the asphalt binder without crushing the particles. A steel-wheel roller will bridge over smaller particles and over small depressions in the surface, and will fail to press the aggregate into the asphalt at these places. A steel-wheeled roller also may crush the softer aggregate particles so that degradation takes place even before traffic uses the new surface.

Every roller must be inspected at the beginning of the construction season or when it is first used by a team, and also periodically throughout the season. Where applicable, the following items must be checked:

1) The total weight
2) The weight per centimeter of width for a steel-wheeled roller
3) The average contact pressure in kilograms per square centimeter for a rubber tire roller
4) If self-propelled, the mechanical condition, especially its ability to start, stop, and reverse smoothly
5) The precise steering

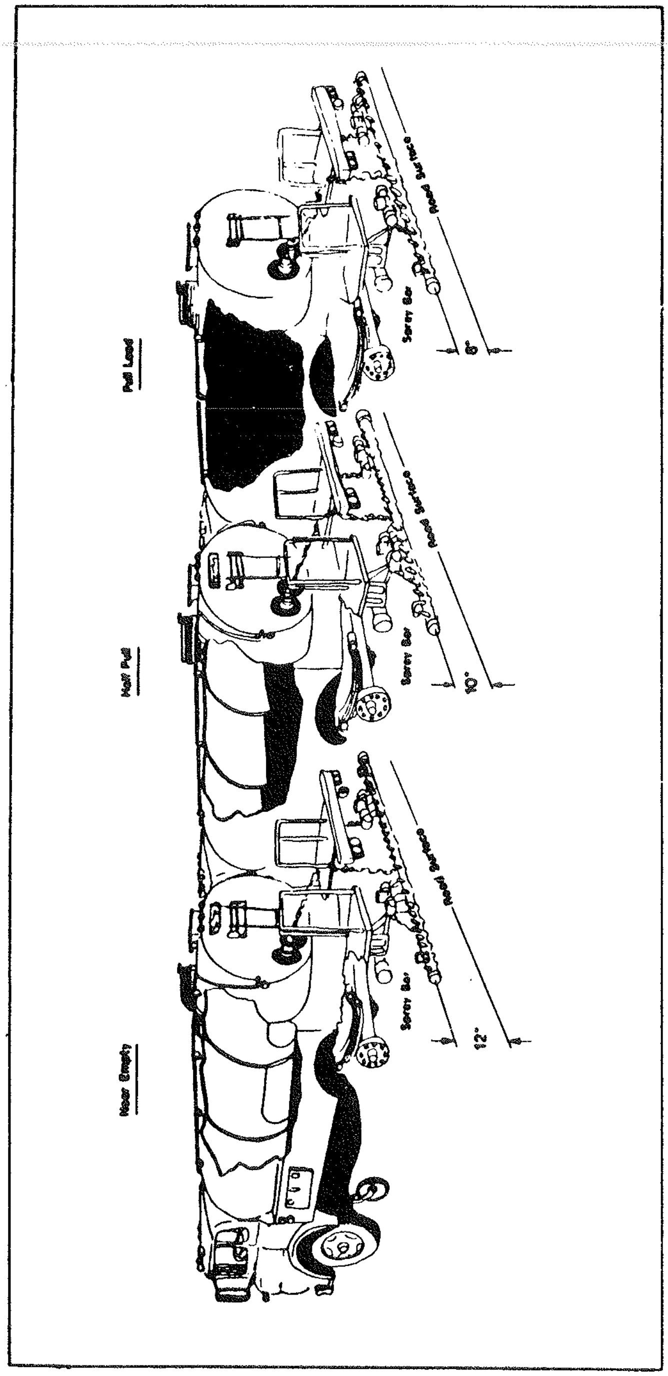
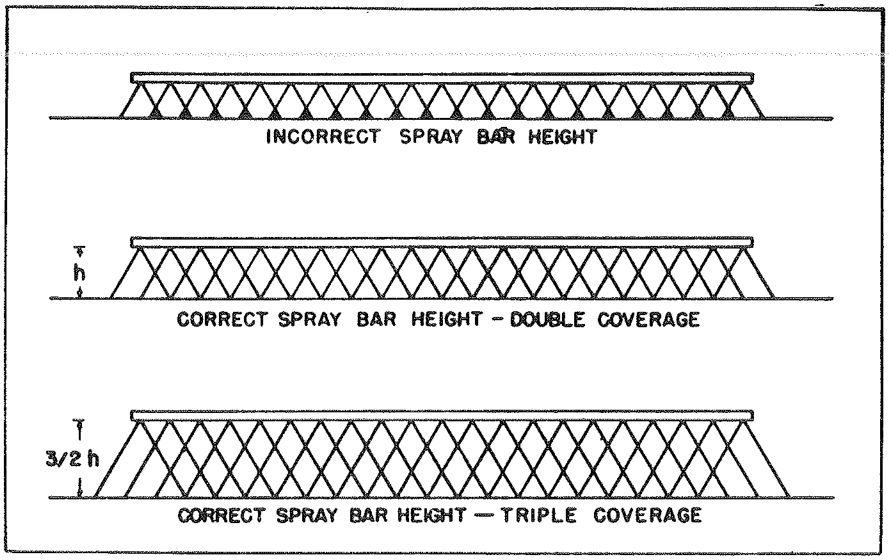


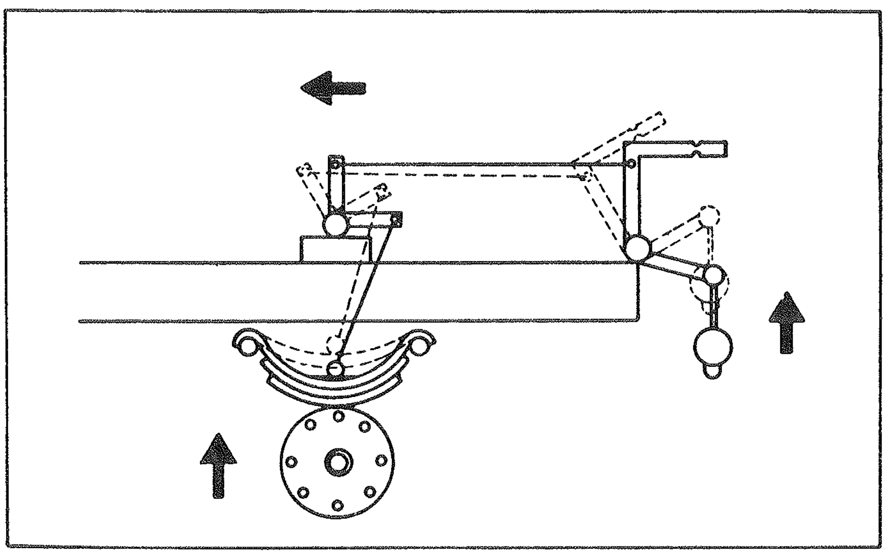
Figure 25

Spray bar height increases during spraying operation on distributors not equipped to maintain constant spray bar height



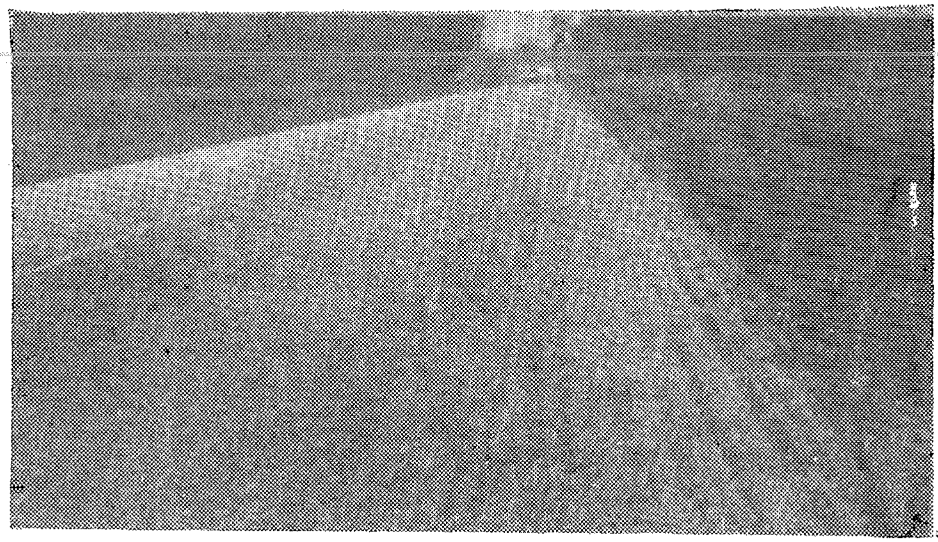
Influence of spray bar height.

Figure 26



Constant spray bar height attachment maintains uniform nozzle height for controlled double or tripple lap coverage regardless of load or spring deflection of the distributor truck.

Figure 27



Longitudinal streaking of surface treatment-due to non-uniform asphalt application.

Figure 28

Before the rolling operations on a particular job are started, all tires must be checked for the specified inflation. The maximum permissible range of pressure between high and low on all tires is 0.4 kilograms per square centimeter. Tires must also be visually inspected for good condition and smooth tread. Oscillating wheels must be tested for freedom to move vertically.

Each steel-wheel must be inspected with a sharp metal straightedge for wear of its rim. If there are grooves or pits in the rolling surface of a wheel, the roller should not be used. Every king pin must be inspected for slackness, and any necessary correction must be made. If the wheel bearings are found to be worn excessively, they must be replaced before operations begin. Scrapers on steel-wheeled rollers and pads on rubber-tire rollers must be in place and in good condition.

d. **Power Brooms and Air-Compressors.** A power broom is useful for cleaning off large areas of a surface that will not need to be cut out and removed. A hand broom or an air compressor that is fitted with hoses and nozzles is useful for cleaning small areas of a surface where a patch is to be placed. Each power broom must be checked for proper operation of the power drive and for the amount of wear and the condition of the brush. The bristles over the full width of the brush must be long enough to clean the surface thoroughly.

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e. **Miscellaneous Equipment.** Various other pieces of equipment are also required. Among them are the following:

1) Mechanical tampers of the vibrating and impact types
2) Hand tamps
3) Hand brooms
4) Cutting tools, such as axes and picks
5) Shovels
6) Trucks to haul equipment, material and personnel
7) Traffic-control devices

5. **Details of Applying Surface Treatment.** All needed repairs to the existing surface must be made before resurfacing operations are started. The weather has to be right, the surface must be clean, the materials must be on the job, and the equipment must be in good working order.

Weather has an important role in the success of a surface treatment.

It should be hot and dry while the new material is being placed, and for several weeks after the surfacing has been applied.

The surface to be treated must be cleaned immediately before the asphalt is sprayed. All hardened mud and other foreign matter must be removed, and the surface must be swept thoroughly with power brooms. Where sod or dirt is found on the edge of the shoulder, a grader must be used to cut the material back far enough to permit the entire shoulder surface to be cleaned and sprayed.

The type of asphalt, the type of cover aggregate, and the rate of application of each material will be determined by the District Maintenance Engineer before the materials are ordered. The delivery of materials to the job must be coordinated so that there will be no delays after the work starts. Enough asphaltic material must be at the job or delivered to it to complete each days work without undue delays. The number of trucks used for aggregate must be ample to assure complete coverage of each application of asphaltic material with aggregate. The aggregate stockpiles must be built up in time to allow excess water to drain off from washed material.

a. **Spreading Asphalt.** Before the spraying of asphaltic material is started, and if the edge of the road or shoulder cannot be used for a guide, a line must be marked to guide the distributor operator. The thermometer on the distributor must be checked to make sure that asphaltic material is at the correct application temperature. A table of temperatures is shown in **Table 2.** 257

The length of asphalt application should be limited to provide uniform embedment of the maximum amount of aggregate before the asphalt cools and congeals. The optimum length depends on many factors, but a 400 to 600 meter application length is a satisfactory range in which to begin the work.

To determine the length in meters that can be covered by the aggregate in a certain number of trucks, it is necessary first to find the net weight of material in each truck. Then, the following calculations are performed:

Step 1: The total number of kilograms of aggregate is obtained.

Step 2: The width of spread, in meters, is multiplied by the rate of application, in kilograms per square meter.

Step 3: The value found in Step 1 divided by the result found in Step 2 gives the distance over which a number of truckloads of aggregate should be spread.

When the amount of asphaltic material to be spread is the governing factor in determining the length of application, the calculations are as follow:

Step 1: The number of liters to be spread is obtained.

Step 2: The width of the spread, in meters, is multipled by the rate of application, in liters per square meter.

Step 3: The value found in Step 1 is divided by the result found in Step 2.

The number of liters to be spread from a load is found by subtracting 200 liters from the volume shown by gaging at the start of the run. This 200 liter margin assures the full rate of application right up to the end of the run. If an attempt is made to use up all the material in the distributor, the pump will start to suck air near the end of the load, and the spread will be uneven.

The amount of asphaltic material actually used for each application must be measured in the following manner:

258 Before and after an application, the distributor is stopped on a level area, and a gage stick is inserted through the dome down to the material in the tank. The volume corresponding to the measurement shown on the stick is then found from a table of volumes that is furnished with the distributor.

The temperature of the material can be read on the thermometer attached to the distributor. The temperature at which the volume of asphaltic material is usually computed for application or charging is 60° F or 15.6° C. For that reason, it is necessary to convert the volume measured by the gage stick at the temperature shown on the thermometer to volume at 60° F or 15.6 C. by referring to the conversion factors in **table 3.**

If it is likely that the appearance of a culvert headwall, a bridge parapet, or some struture will be marred by flying spray from the distributor, the structure must be protected with paper before the application is started. Used building paper must be carefully removed and disposed of in an approved manner.

b. **Transverse Joints.** Rough and unsightly transverse joints in a surface treatment can be avoided by starting and stopping the spread of asphaltic material and aggregate on building paper (see Figure 31). One length of paper is laid across the lane to be treated in such a position that the forward edge will be at the place at which the treatment will start. When the distributor reaches this paper, it must be traveling at the correct speed for

TABLE 3

TEMPERATURE - VOLUME CORRECTIONS

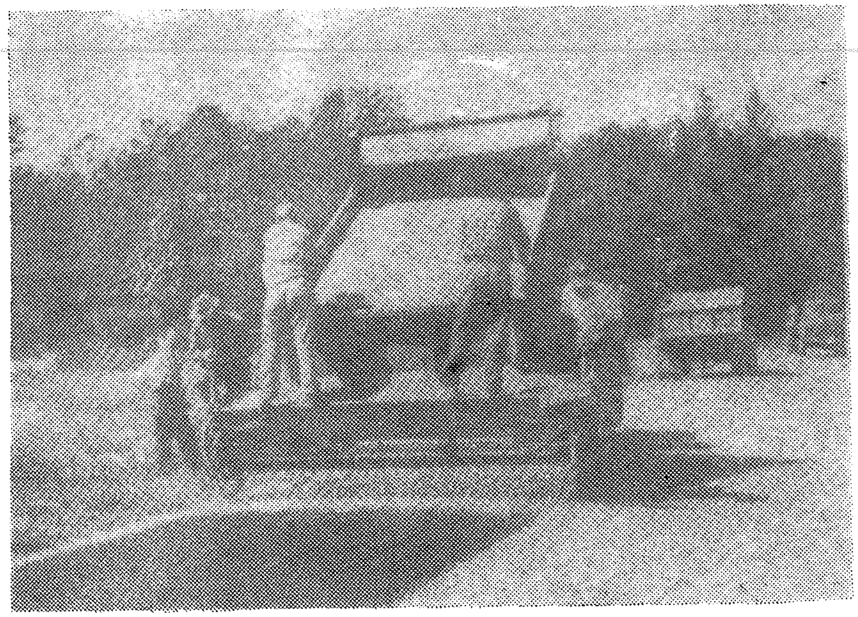
FOR

ASPHALTIC MATERIAL

Temperature Degrees Centigrade	Group 0 (1) Volume Conversion Factor	Group 1 (2) Volume Conversion Factor
15.6	1.0000	1.0000
20	0.9972	0.9968
30	0.9909	0.9897
40	0.9847	0.9826
50	0.9785	0.9756
60	0.9723	0.9686
70	0.9662	0.9616
80	0.9601	0.9547
90	0.9540	0.9478
100	0.9479	0.9410
110	0.9419	0.9343
120	0.9359	0.9275
130	0.9299	0.9208
140	0.9240	0.9142
150	0.9181	0.9076

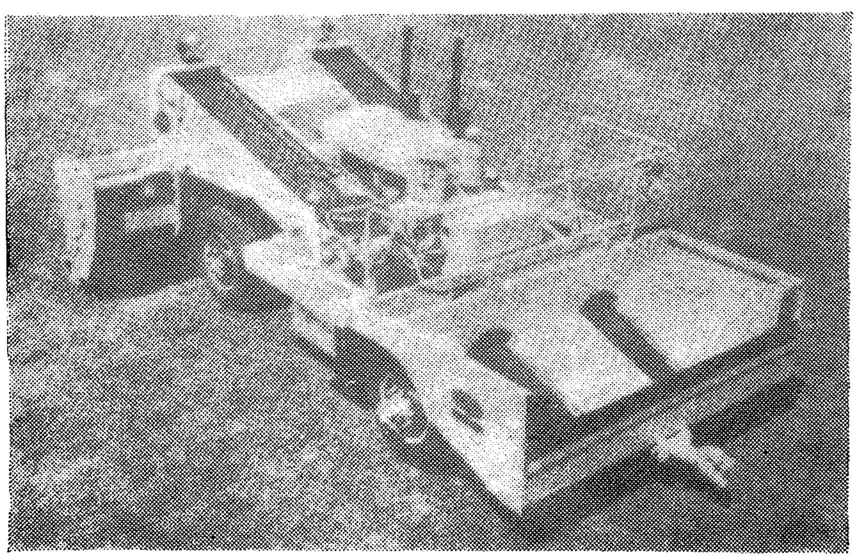
Note : (1) Group 0 has a specific gravity at 15.6° Centigrade above 0.966

(2) Group 1 has a specific gravity at 15.6° Centigrade of from 0.850 to 0.966



Typical tailgate spreading operation.

Figure 29



Self-propelled aggregate spreader.

Figure 30

the desired application rate. The flow will then be started. The material first discharged will be sprayed onto the paper; and by the time the distributor reaches the exposed surface, the spray bar will be making a full, uniform application. A second length of building paper is placed across the predetermined location of the joint. The full flow from the distributor will be continued until the paper is reached, and any material discharged after the cutoff point will be sprayed onto the paper. In this way a straight sharp transverse joint can be obtained. Immediately after the aggregate spreader has passed over the paper, it must be removed and destroyed.

For the next application, the first length of paper is placed on the previously laid treatment so that its leading edge will be about 1 or 2 centimeters back of the end of that treatment. This exposure will prevent a gap between the two spreads.

c. **Longitudinal Joints.** The only way to eliminate a longitudinal joint in a surface treatment is to apply the treatment to the entire width of the area to be treated at one time, however, this is seldom possible. By careful application of asphalt and aggregate, joints can be made that are not noticeable.

The spray nozzles on the distributor are generally positioned so that the spray from each nozzle overlaps the spray from the adjacent nozzle. There is no overlap for the outer half of the spray from the end nozzle. This overlap is accomplished with the next adjacent application of asphalt. A good longitudinal joint is made by:

1) Not placing aggregate on the partial asphalt application produced by the end nozzle until it has been overlapped by the next adjacent application.
2) Making a perfectly matched overlap of the spray from the end nozzle on adjacent applications.
3) Matching perfectly the spread of aggregate at the joint without overlap of aggregate.

d. **Spreading Cover Aggregate.** All aggregate needed for the planned spread must be on hand before any of the asphaltic material is applied. When the distributor moves forward to spray the asphaltic material, the aggregate spreader must start right behind it as in Figure 32. An essential requirement is that the asphaltic material must be covered and rolled within 15 minutes. Otherwise, the increase in viscosity which takes place when asphalt is exposed may prevent good wetting and binding of the aggregate.

Another important requirement is that the aggregate must be spread uniformly and at the proper rate. Only aggregate which is in contact with the asphaltic material can stick to the surface. It is therefore useless and wasteful to apply aggregate at a rate greater than that required to establish a thickness the size of the largest praticle.

A high degree of control is possible with use of a mechanical spreader pushed by a truck. A uniform application rate can be assured with a properly adjusted spreader if a tachometer is used to maintain uniform speed. Another aid in controlling distribution rate is to lay off the length which each truck load of aggregate is expected to cover.

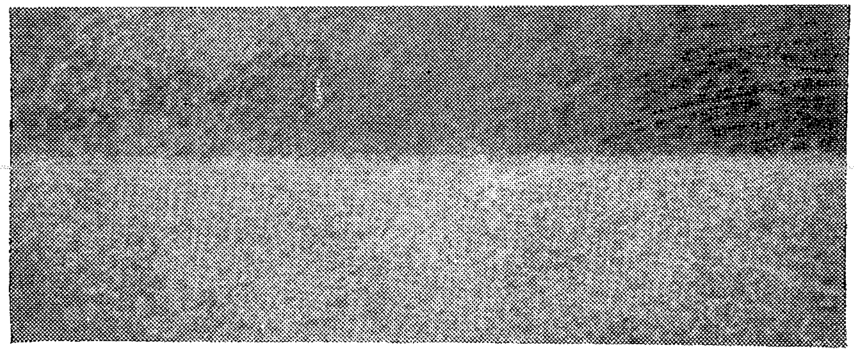
If too much aggregate is applied in some spots, the excess must be removed immediately with square-pointed shovels. Where the initial application is insufficient, additional aggregate must be added. When the aggregate spreaders are adjusted and operated properly, hand work will be held to a minimum.

Aggregate application rate may be checked by placing a one square meter pan in the path of the aggregate spreader, as shown in Figure 33. Aggregate caught in the pan is then weighed to determine kilograms of aggregate spread per square meter.

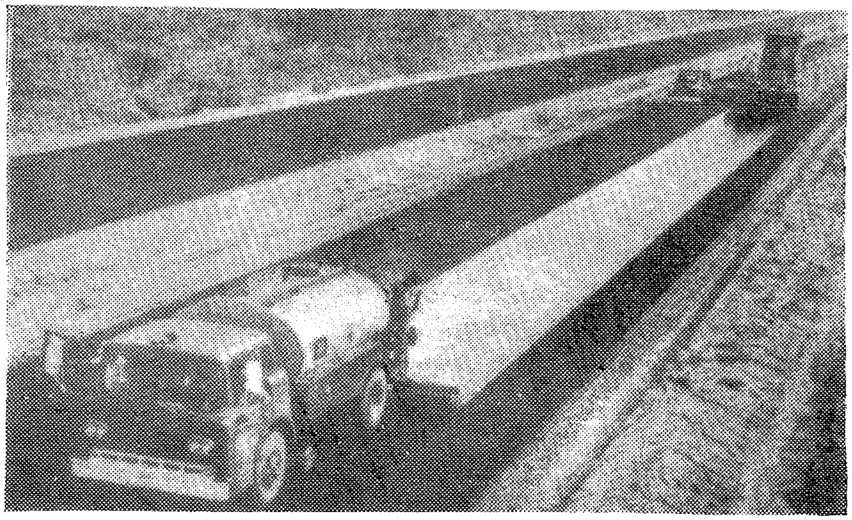
e. **Rolling.** Rolling seats the aggregate in the asphaltic material and thus improves the bond which is necessary to resist traffic stresses. The cover material should be rolled immediately after it has been spread. Preferably rolling should be accomplished with only a rubber-tire roller. If a steel-wheel roller is used it must be in conjunction with a pneumatic roller and the aggregate rolled first with the steel-wheel roller, followed by the pneumatic roller.

It is advisable to continue rolling until all the cover aggregate has been properly seated in the asphaltic binder. Rolling must be started at the outer edge of the treatment and must proceed in a longitudinal direction while the roller is moved toward the center, or inside edge in the case of shoulders, in stages. The path for each trip will usually overlap that for the previous trip by about one-half the width of the front wheels or roll.

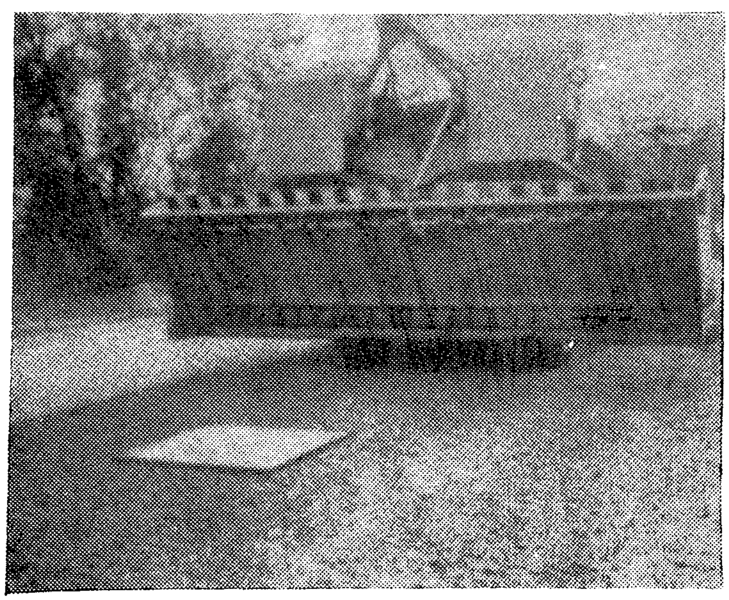
f. **Removing Excess Aggregate.** In spite of all precautions, there usually will be some loose aggregate on the road surface after the rolling operation is completed. Before the adjacent lane is covered with asphalt, loose aggregate should be swept from along the joint and, if necessary, from the rest of the uncovered lane.



Close-up of termination of application that stopped on paper.
Figure 31



A typical scene on modern asphalt pavement construction, with a pressure distributor followed closely by an aggregate spreader.
Figure 32



Use of a one square meter steel pan to adjust cover Aggregate Spreader to the setting required for application of cover aggregate at the specified rate per square meter.
Figure 33

Aggregate which does not stick creates a problem since tires on fast-moving vehicles will pick up the loose particles and throw them against following vehicles, often damaging headlights and windshields. This loose aggregate may be removed by lightly brooming with a rotary power broom during the cool of early morning, after final set of the asphalt has occurred.

g. **Control of Traffic.** Control of traffic through the work area is important while a surface treatment is being applied and for a short time after the construction has been completed when a road surface is involved. A vehicle traveling over a fresh surface treatment at a high speed displaces the aggregate. Traffic must be diverted to the lane not under construction. Traffic must be directed through the work area in a manner designed to provide maximum safety for the workmen and the least possible interruption of work.

The job must be laid out so that treatment starts at the point farthest from the aggregate stockpile and progresses toward the stockpile. Then the hauling trucks will not have to travel over newly surfaced road.

h. **Multiple Surface Treatments.** When it is necessary to use a double or triple surface treatment, the largest aggregate is placed in the lowest course and the aggregate in each succeeding course is smaller than that in the course below. The thickness of the layer of aggregate for each course, except the top one, is made greater than the size of the largest particle in the course, in order to allow for leveling with a broom drag.

The steps in the construction of a multiple surface treatment are essentially the same as those for a single surface treatment, but the operations are repeated either two or three times. The procedure for a double-surface treatment consists of the following steps:

1) Applying the first course of asphalt
2) Placing the first course of aggregate
3) Using a broom drag on the first course of aggregate
4) Rolling the first course of aggregate
5) Applying the second course of asphalt
6) Placing the second course of aggregate
7) Rolling the second course of aggregate.

Time must be allowed for proper curing after the first treatment.

Appearance and texture of a typical double surface treatment are shown in Figure 34.

For a triple surface treatment, Steps 1, 2, 3, and 4 are repeated for the second course, and Steps 5, 6, and 7 are then preformed for the third course.

E. **Asphaltic Patching Materials.**

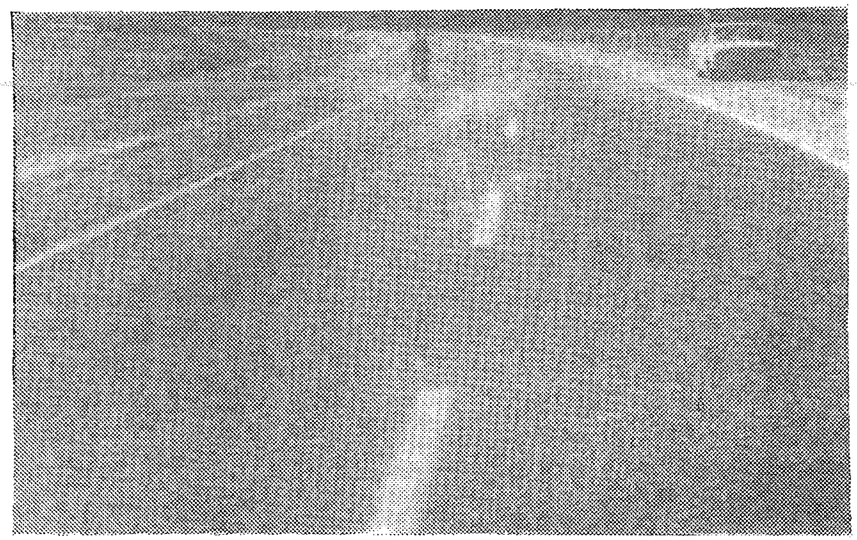
1. **General.** Asphaltic patching materials have a very important function in the maintenance of paved surfaces. These materials are classified as cold-mix patching materials and hot-mix patching materials. However, in order that the asphalt and the aggregates for a cold mixture may be mixed properly, the asphalt usually must be heated or at least warmed. Each class has certain advantages and disadvantages. The capabilities and limitations of each must be understood in order that the proper kind of mixture will be selected and it will be used to its best advantage.

2. **Cold-mix Patching Materials.** Many different kinds of liquid asphaltic materials are used for making cold mixes. The kind and grade used will depend on the grading of the aggregate, on how soon the mixture will be used after it is mixed, and on the method used for mixing the materials. Some of the different kinds of cold patching mixtures are shown in **Table 4.**

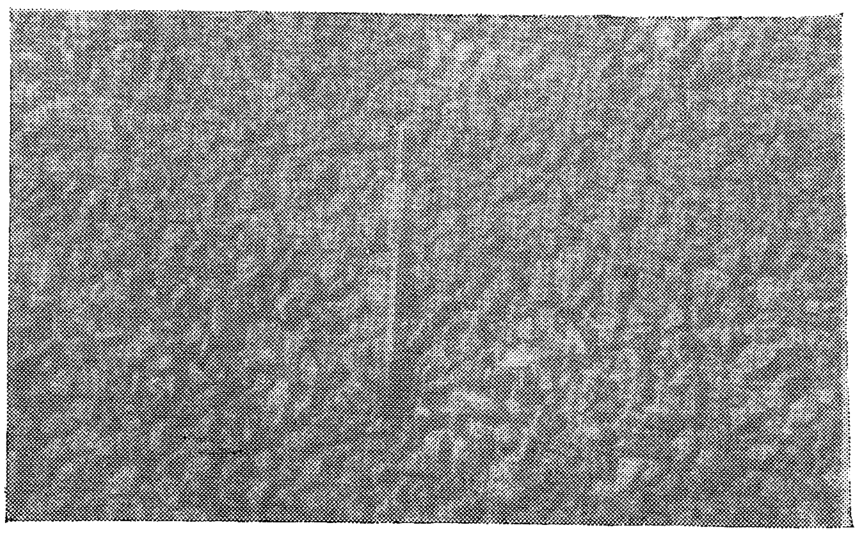
When the asphaltic material in a cold-mix patching mixture is a medium-curing or slow-curing cutback asphalt, the mixture can be stockpiled for a long period of time and can be used as needed. Such a mixture has a big advantage over a hot-mix material in this respect. However, a cold mixture made with a rapid-curing cutback asphalt must be used as soon as it has been prepared. Large quantities of cold patching mixture can be made by the "blade-mix" method. In this method, the aggregate and the asphaltic material are mixed by blading the materials back and forth with a grader. 265

a. **General Requirements.** Before aggregate are used in a patching mixture, samples of each material must be sent to the District office. The District Maintenance Engineer will have a check made to be sure that the materials are suitable for the intended use. The aggregates must be clean and properly graded in size. A recommendation will also be made as to the type and amount of asphaltic material which will be best suited for the patching mix wanted.

Commonly, the maximum size of aggregate particles for a patching mix is 3/8 or 1/2 inch. Such a mix "feathers" out better, provides a smoother



Double surface treatment on consolidated granular base.



Close - up of surface treatment shown above.

Figure 34

driving surface, and is less likely to ravel. At the time a cold patching mix is prepared, the amount of moisture in the aggregate (sand, stone, or gravel) must be less than about three percent. If excessive moisture exists mixing of the aggregate and asphaltic material must be delayed while the damp aggregate is repeatedly turned and the sun and air have reduced the moisture content to three percent or less.

TABLE 4

KINDS OF COLD PATCHING MIXTURES

Kind of Asphaltic Material	Temperature Range at Time of Mixing (Degrees c)	Aggregate Gradation
RC - 250 Cutback	79 - 112	Open graded
RC - 800 Cutback	96 - 131	Open graded
MC - 250 Cutback	79 - 112	Dense graded
MC - 800 Cutback	96 - 131	Dense graded

Blade mixing is accomplished on a hard, smooth mixing "floor" or runway. An abandoned section of road surface makes a good mixing floor (Figure 35). A less satisfactory, but usable floor may be made as follows: A conveniently located strip of natural ground is leveled so that it is firm and smooth. It is then covered with a coat of cutback material, such as asphalt of grade MC - 250 which is applied under pressure from a distributor or by use of a hand hose fitted with a spray nozzle. The required amount of cutback will depend on the ease with which the cutback soaks into the ground, but 1.0 to 2.0 liters per square meter is usually enough. The cutback must be allowed to cure out for several days before materials for the patching mixture are placed on the treated surface. After the surface has been used for mixing over an extended period of time a thick and durable layer will have accumulated. Less care will then be needed to prevent soil from getting into the patching mixture while it is being prepared or loaded into a truck.

Cold patching material from a stockpile is loaded onto a truck by hand, by a front-end loader or in some other suitable manner and is hauled to location at which it is to be used.

General mixing requirements are as follows: Coarse and fine mineral aggregate shall be deposited in a single windrow in the proportions required to provide a total aggregate conforming with the specified grading. After the proportions of coarse and fine aggregate are adjusted, the total loose aggregate shall be mixed thoroughly with a motor grader. Immediately prior to application of the asphalt, the windrow of mixed aggregate shall be bladed to a uniform cross-section approximately 5 centimeters thick. If damp, it shall first be bladed back and forth until surface dry. Upon the layer of graded aggregate the asphalt shall be applied uniformly with the asphalt distributor at the temperature and at the rate specified. The aggregate and asphalt shall be mixed as described in the following paragraph. Successive treatments of asphalt shall then be applied and mixed in the quantities, not exceeding three liters per square meter each.

The motor grader shall follow the distributor immediately after each application of asphalt and shall continue to operate on the treated strip until all free asphalt is mixed into the aggregate. After the aggregate has received its total application of asphalt, mixing shall continue until a thoroughly uniform mixture is produced. If, before the process is completed, the mixture should become wet, the mixing operation shall be continued until it dries out. After final mixing the material shall be brought to a single windrow and stockpiled on an approved level storage space.

Mixing and aerating cold mixes may also be accomplished by special equipment as shown in Figure 36.

The exact amount of asphalt in the design mixture may not always be provided for, consequently, an occasional check is desirable. Two methods which provide quite accurate results are ASTM D 1097 "Extraction by Centrifuge", and ASTM D 762, "Reflex or Hot Extraction". However, these tests are not always conveniently performed; therefore, it may be more desirable to maintain a daily check on the asphalt content of the mix by dividing the weight of asphalt used during the day by the total weight of mix for the day.

As an example:

1) Volume of materials mixed during the day:
   - a. 120 metric tons of aggregate
   - b. 7200 liters of asphalt
2) Assume specific gravity of the asphalt as 0.959 (always use the specific gravity as reported by the refinery for the particular asphalt material used).
3) Total weight of mixed materials:

a. Aggregate 120 tons × 1000 kg/ton = 120,000 kg
7200 liters × 0.959 kg/liter = 6,905 kg

Total Weight 126,905 kg

4) Asphalt content of mixture:

$$\frac{\text{Weight of Asphalt used} \times 100}{\text{Weight of Total Mix}} = \frac{6{,}905 \text{ kg} \times 100}{126{,}905 \text{ kg}} = 5.44 \text{ percent}$$

b. **Blade Mixing of Dense-graded Mix.** The aggregates used for dense graded mix will depend on the locality. In general, all aggregate must be clean and well graded. The required quantity of asphaltic material will depend on the type and gradation of the aggregate. The finer the aggregate or the denser the mix the greater will be the quantity of asphaltic material needed to coat the increased surface area of the aggregate particles in a given volume. It is preferable to make a laboratory test, but **Table 5** may be used to select a trial value for the amount of asphaltic material.

When a mix has been prepared the correct amount of asphaltic material for the gradation used may be judged by considering the color of the mix. The correct color is dull black showing that all particles are coated and not shiny black. When a mixture containing the correct amount of asphaltic material is thrown into a pile, it will creep (the particles will slowly roll over one another), and will not slump into a solid mass. The tendency in blade mixing is to use too much asphaltic material in order to get a coating on the aggregate with as little work as possible. 269

Mixing and aeration must be continued until the moisture and other volatiles are evaporated to the proper extent. If the mix is to be used immediately it must be aerated more than if it is to be stockpiled. A mix with material of grade MC - 250 can be stockpiled for many months.

c. **Blade Mixing of Open-graded Mix.** Gradation of the aggregate in an open-graded maintenance mixture are often within the following limits:

Sieve Size	Percent Passing
1/2 Inch	100
No. 4	20 to 40
No. 8	0 to 10

The asphaltic material used for this type may be rapid curing cutback asphalt of grade RC - 800. The suggested amount if laboratory tests are not available is 4.5 percent, by weight, of the total mix. These mixes will cure quite rapidly, and such a mix cannot be stockpiled for long. Also, the surface of the patch must be protected with a seal coat.

3. **Hot-mix Patching Materials.** The disadvantages of a hot-mix patching material is that the material must be used soon after it has been prepared. Since a material of this type cannot be stockpiled for later use care must be taken to make sure that only the amount needed to do a specific job is mixed. The main advantage in using a hot-mix material is that it will provide a permanent patch when properly installed.

Hot-mix patching material is prepared in a central mixing plant. Since the material will remain workable for only a limited time, it is suitable only for a large patch or a number of small patches in a limited area. Before a load of hot-mix patching material is delivered to the job site, enough areas to be patched must be prepared to use the entire load.

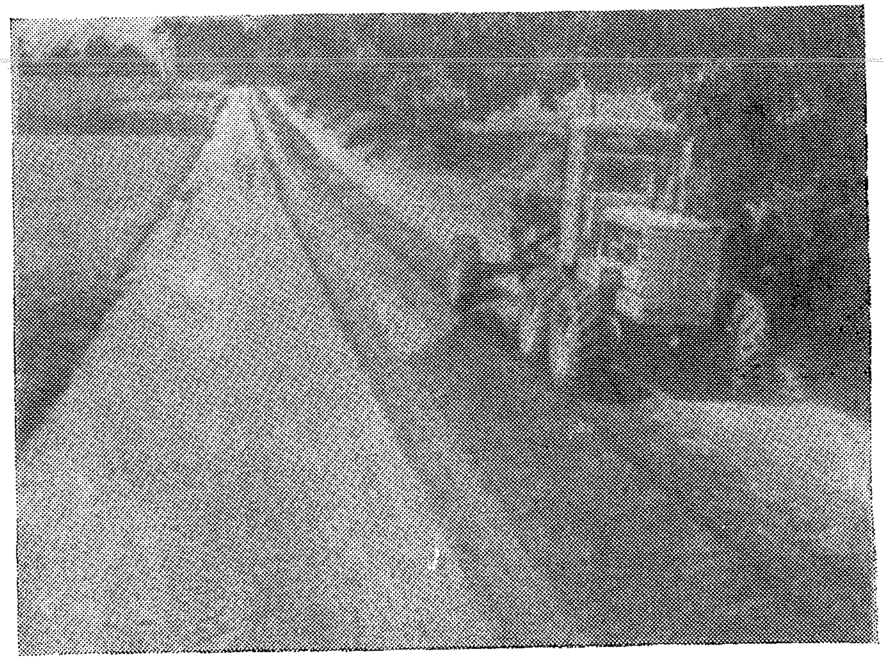
A hot asphaltic mixture must meet the requirements of the **Standard Specifications** or must be proportioned according to a special job mix formula issued by the District Maintenance Engineer. The binder used must be an asphalt cement having a penetration appropriate for the climate. A hot mixture from a central plant is hauled to the patching site in trucks
 that have clean, smooth metal-lined bodies. Hot-mix patching operations have been described in the subsection dealing with the repair or pot-holes in an asphaltic concrete surface course.

TABLE 5

PROPORTIONS FOR DENSE - GRADED MIXTURES

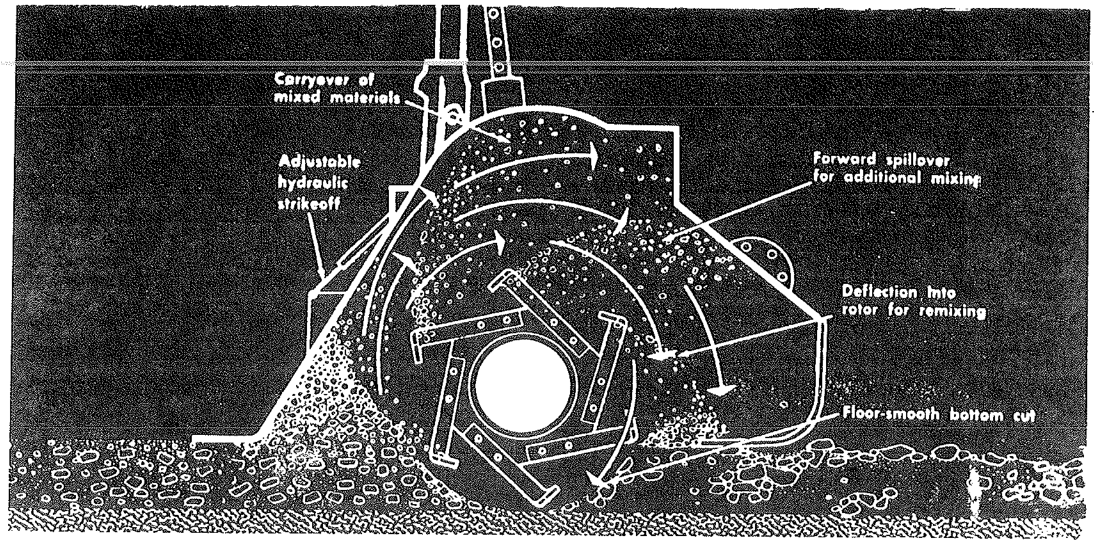
Kind of Asphaltic Material	Percent of Aggregate Passing		Percent in Mixture by Weight	Asphaltic Material Liters per Cubic Meter of Dry Aggregate
	No. 10	No. 200		
Medium-curing	60	7	5.5	97.5
Cutback Asphalt	50	3	4.8	84.7
(MC - 250, MC - 800)	40	2	4.4	77.2

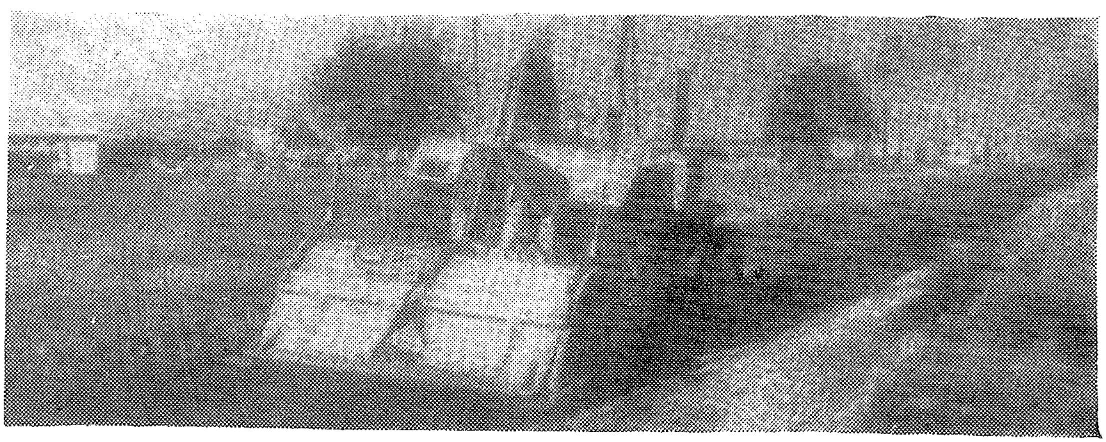
Computations are based on dry aggregate weighing 1660 kilograms per cubic meter.



Motor grader mixing combined aggregate - asphalt to which liquid asphalt has been previously applied by pressure distributor.

Figure 35





Mixing and aerating cold mixed asphaltic paving material.

Figure 36

Bibliography

The following bibliography contains two sets of references. The first set consists of a reference for each selected text that appeared in the preceding part of this compendium. The second set consists of references to additional publications that either were cited in the selected texts or are closely associated with material that was presented in the overview and selected texts. Each reference has five parts that are explained and illustrated below.

(a) Reference number: This number gives the position of the reference within this particular bibliography. It is used in the compendium index but should ***not*** be used when ordering publications.

(b) Title: This is either the title of the complete publication or the title of an article or section within a journal, report, or book.

(c) Bibliographic data: This paragraph gives names of personal or organizational authors (if any), the publisher's name and location, the date of publication, and the number of pages represented by the title as given above. In some references, the paragraph ends with an order number for the publication in parentheses.

Bibliografía

La siguiente bibliografía contiene dos series de referencias. La primera serie consiste en una referencia para cada texto seleccionado que apareció en la parte anterior de este compendio. La segunda serie consiste en referencias a publicaciones adicionales que fueron mencionadas en los textos seleccionados o que se asocian íntimamente con el material que se presentó en la vista general y los textos seleccionados. Cada referencia tiene cinco partes que se explican y se ilustran abajo.

(a) Número de referencia: este número indica la posición de la referencia dentro de esta bibliografía en particular. Se utiliza en el índice del compendio pero ***no*** deberá utilizarse al pedir publicaciones.

(b) Título: el título de la publicación completa o el título de un artículo o sección dentro de una revista, informe, o libro.

(c) Datos bibliográficos: este párrafo da los nombres de autores personales u organizacionales (si hay alguno), el nombre del editor y su dirección, la fecha de publicación, y el número de páginas representadas por el título en la parte (b). En algunas referencias el párrafo termina con un número de pedido para la publicación en paréntesis.

Bibliographie

La bibliographie qui suit contient deux catégories de références. La première catégorie consiste en une référence pour chaque texte choisi qui est inclus dans la partie précédente de ce recueil. La deuxième catégorie contient des références pour des documents qui ont soit été cités dans les textes choisis, ou soit sont étroitement associés avec des écrits qui sont présentés dans l'exposé ou les textes choisis, Chaque référence est composée de cinq parties qui sont expliquées et illustrées ci-dessous:

(a) Numéro de la référence: ce numéro indique la position de cette référence dans cette bibliographie. Ce numéro est indiqué dans l'index du recueil mais ***ne doit pas*** être utilisé pour les commandes de publications.

(b) Titre : cela indique ou le titre du livre entier, ou le titre d'un article ou d'une section d'une revue, un rapport, ou un livre.

(c) Données bibliographiques: ce paragraphe indique les noms des auteurs personnels (quand il y en a) ou des auteurs collectifs (organisation), le nom de l'éditeur et son adresse, la date de l'édition, et le nombre de pages qui sont incluses sous le titre dans (b). Certaines références se terminent par un numéro entre parenthèses qui indique le numéro de commande.

(d) Availability information: This paragraph tells how the referenced publication is available to the reader. If the publication is out-of-print but may be consulted at a particular library, the name of the library is given. If the publication can be ordered, the name and address of the organization from which it is available are given. *The order should include all information given in parts (b) and (c) above.*

(e) Abstract: This paragraph contains an abstract of the publication whose title was given in part (b).

(d) Disponibilidad de la información: este párrafo indica la disponibilidad al lector de la publicación referenciada de una de dos formas como sigue. (1) La publicación está agotada pero puede ser consultada en la biblioteca indicada, donde se sabe que se posee una copia, o (2) la publicación puede ser pedida de la organización cuyo nombre y dirección están indicados. *El pedido deberá incluir toda la información dada en las partes (b) y (c).*

(e) Resumen: este párrafo es un resumen de la publicación cuyo título se dió en la parte (b).

(d) Disponibilité des documents: ce paragraphe indique les deux façons dont le lecteur peut acquérir les documents: (1) L'édition est épuisée, mais une certaine bibliothéque détient ce document et il peut être consulté. (2) Le document peut être commandé à l'organisation dont le nom et l'adresse sont indiqués ici. *L'ordre de commande doit inclure toutes les informations données dans les parties (b) et (c).*

(e) Analyse : ce paragraphe est une analyse du texte dont le titre est cité dans la partie (b).

Illustration (from Comp. 1) **Ilustración** (del Comp. 1) **Illustration** (du Recueil 1)

(a) Reference number
(a) Número de referencia
(a) Numéro de la référence

(b) Title
(b) Título
(b) Titre

(c) Bibliographic data
(c) Datos bibliográficos
(c) Données bibliographiques

(d) Availability information
(d) Disponibilidad de la información
(d) Disponibilité des documents

(e) Abstract
(e) Resumen
(e) Analyse

The order should include all information given in parts (b) and (c) above.

El pedido deberá incluir toda la información dada en las partes (b) y (c).

L'ordre de commande doit inclure toutes les informations données dans les parties (b) et (c).

Reference 5
A REVIEW OF HIGHWAY DESIGN PRACTICES IN DEVELOPING COUNTRIES

Cron, Frederick W. Washington, DC: International Bank for Reconstruction and Development; 1975 May. 57 p.

Order from: International Bank for Reconstruction and Development, 1818 H Street, N.W., Washington, DC 20433.

The design standards of some 150 highway projects financed by the International Bank for Reconstruction and Development between 1960 and 1970 are reviewed, and areas of agreement between the standards of the 63 countries studied are identified; practical highway standards based on these areas of agreement are sketched for the guidance of planners in developing countries. The roads discussed here, fall into three functional categories: a small group of expressways, freeways and toll roads carrying large volumes of traffic; a very large group of 2-lane highways carrying a wide range of traffic volumes serving both local and long distance traffic; and a smaller group of low-traffic tertiary or special purpose roads existing primarily for land service. Comments are made on the problem of classifying highway standards, and on the comparison of standards. Conclusions regarding standards for the capacity- related elements of design and standards for the velocity-related elements of design (radius of curvature, stopping sight distance, passing sight distance) are discussed, as well as the horizontal and vertical clearances for bridges. The standard live loadings for bridges, the structural capacity of pavements and legal load limits are covered, and conclusions relating to pavement design, design standards for 2-lane highways, incremental development of highways, and levels of service are presented.

Reference 1
DUST-LAYING ON UNSURFACED EARTH GRAVEL ROADS

Road Research Laboratory. Harmondsworth, U.K. Reprinted 1971. 23 p. (Road Research, Overseas Bulletin No. 14).

Order from: Transport and Road Research Laboratory, Crowthorne, Berkshire RG11 6AU, U.K.

Methods that can be used to combat dust on gravel and earth roads are reviewed. The principal binding agents used in dust-laying are classified under the headings (I) water (fresh or sea); (II) deliquescent and hygroscopic chemicals; (III) other inorganic chemicals; (IV) organic, non-bituminous binders (includes a variety of industrial waste products such as sulphite liquors and molasses residues, and animal fats and vegetable oils); and (V) tar and bituminous materials. Methods of treatment, rates of spread, and the advantages and disadvantages of each binding agent are described. The comparative costs of these methods are also discussed.

Reference 2
GUIDE ON PRIME COATS, TACK COATS AND TEMPORARY SURFACINGS FOR THE PROTECTION OF BASES

National Institute for Road Research. Pretoria, South Africa; February 1970. 17 p. (Technical Recommendations for Highways TRH 1).

Order from: National Institute for Transport and Road Research, P.O. Box 395, Pretoria, 0001 South Africa.

The text deals principally with prime coats and temporary surfacings for granular road bases that use cut-back bitumens, coke-oven tar, gas-works tar, and low-temperature tar. The functions of the prime coat, requirements of a prime, types of prime, selection of type and grade of prime and rate of application are covered. The book provides a guide to the priming process and it recommends the use of a higher rate of application of a higher-viscosity prime to give a thicker bituminous coating, followed by the immediate construction of the final surface treatment, if soluble salts are present. The text describes the use of additional tack coats on primed areas before the final surface treatment where areas of exceptionally high shearing stresses are induced, such as on steep gradients and sharp bends. The functions of a tack coat, the use of tack coats with premix surfacings or overlays, the binders used and rates of application, and the construction of tack coats are described. The text also describes the Australian practice of constructing a temporary surfacing called Primerseal (i.e. a layer of small graded aggregate is applied to the freshly sprayed prime coat), to protect base courses that are to be used for long periods before the final surface treatment is applied.

Reference 3
SPECIFICATION FOR PERFORMANCE REQUIREMENTS FOR MECHANICAL SPRAYERS OF BITUMINOUS MATERIALS

2nd ed. National Association of Australian State Road Authorities. Sydney, Australia; 1969. 20 p.

Order from: National Association of Australian State Road Authorities, P.O. Box J141, Brickfield Hill, N.S.W. 2000, Australia.

These specifications describe the requirements that apply to sprayers used for the distribution of hot and/or cold bituminous materials in sprayed bituminous surfacing. The text covers such aspects as legal requirements, certificates, spraying table, sprayer vehicle, sprayer tank, heating, pumping and spraying equipment, operation of the sprayer, and fire extinguishers. The appendix describes sprayer inspection, the road-speed indicator, pump tachometer, pressure gauge, tank calibration, pump output, consistency of sprayer output, transverse distribution, power thermometer, mixing and circulation, spray nozzle, and spray commencement and cut-off. A metric addendum is provided as an aid to the conversion of Imperial gallons (used in original text) to liters.

Reference 4
ASPHALT SURFACE TREATMENTS AND ASPHALT PENETRATION MACADAM

2nd ed. Asphalt Institute. College Park, Maryland; second printing; January 1975. 213 p. (Manual Series No. 13; MS-13).

Order from: The Asphalt Institute, The Asphalt Institute Building, College Park, Maryland 20740.

This guide to the proper design and construction of surface treatments, describes the materials and equipment and explains the surface treatment process. It lists the types of asphaltic surface treatments and includes tables for the selection of the proper type of asphalt for surface treatment, and temperature viscosity for handling liquid asphalt. The tables apply to the newer designation of cut-back asphalt grades (70, 250, 800 and 3000). Materials and equipment used in surface treatment work are described and illustrated. Generalized asphalt distributor data furnished by nine manufacturers are tabulated. The why and how in the construction of successful surface treatments are detailed and cover aspects of the project survey, repair of defects, preparation for construction, and the surface treatment operation. Appendixes are included that provide information on the design of surface treatments, specifications for surface treatments and penetration macadams, a method of field test for the determination of distributor spread rate, determination of the flakiness index of aggregate, and asphalt temperature, volume and weight. Copies of the Spanish edition of this book may be obtained from Universidad Central de Venezuela, Departamento de Ingeniería Vial, Caracas, Venezuela.

Reference 5
SPECIFICATIONS FOR ASPHALT CEMENTS AND LIQUID ASPHALTS (AS OF DECEMBER 5, 1963)

6th ed. Asphalt Institute. College Park, Maryland; January 1964. 6 p. (Specification Series No. 2 (SS–2)).

Out of print.

Two sets of specifications for Rapid Curing (RC), Medium Curing (MC) and Slow Curing (SC) liquid asphalts are presented. 1964 Asphalt Institute specifications (adopted by the Asphalt Institute in December 1961) for these materials and former Asphalt Institute specifications are included. The publication contains a complete set of specifications for cationic emulsified asphalts adopted by the Asphalt Institute in June 1963 and specifications for an MC–30 grade of Medium Curing liquid asphalt adopted in December 1963. Comparison of tables in the current specifications (see Reference 11) with the tables in this publication will permit the user to select the new designation that most nearly duplicates the asphaltic materials mentioned in the compendium.

Reference 6
A BASIC ASPHALT EMULSION MANUAL

Asphalt Institute. College Park, Maryland; March 1979. 260 p. (Manual Series No. 19; MS–19).

Order from: The Asphalt Institute, Asphalt Institute Building, College Park, Maryland 20740.

This manual attempts to impart a basic understanding of asphalt emulsions, and is designed to be of use in choosing the emulsion that best fits a project's specific conditions. It is also designed to help in evaluating pavement systems for construction and maintenance. The chemistry of asphalt emulsions is described, and the storage, handling, and sampling of asphalt emulsions are reviewed. Emulsified asphalt tests are detailed. Selection of the right type of asphalt emulsion is discussed, and asphalt emulsion and aggregate application, as well as asphalt emulsion and aggregate mixes, are considered in detail. Miscellaneous asphalt emulsion applications, maintenance mixes, and various aspects of recycling are also covered. Emulsified asphalt-aggregate mix design methods detailed include the Asphalt Institute Method and the proposed Illinois method.

Reference 7
SEVEN FUNDAMENTALS FOR DURABLE SPRAYBAR WORK—JOBS YOU CAN BE PROUD OF

Roads and Streets. Dun-Donnelley Publishing Corporation, Chicago, Illinois; August 1975; pp. 102–104, 106. (Vol. 118, No. 8).

Order from: Dun-Donnelley Publishing Corporation, 222 South Riverside Plaza, Chicago, Illinois 60606.

This article, which stresses the use of emulsions as binder material in surface treatment work, reviews seven fundamental points a contractor must consider. First, a surface without a good foundation will fail. Second, all personnel need to have a clear concept of what a top-quality surface treatment or seal coat looks like under traffic. The seal coat should chiefly consist of aggregate without evidence of any flushing or bleeding. Third, look for common faults (streaking, flushing or bleeding, loss of aggregate, and lack of bond) and ways in which they can be avoided. The fourth point relates to cover aggregate gradation. A highly successful Australian experience is noted in which from 60 to 70 percent of the particles passing the specified nominal size must be retained on a sieve having an opening 0.7 of that size. Australian engineers also watch particle flatness by specifying a maximum flakiness index. Charts are included to illustrate the correct amount of asphalt binder that will imbed the particles. A fifth point that is important in controlling the quality of the job is to determine the average least dimension (ALD) of the cover stone. A sixth factor is stone size. Good performance is more likely with larger cover aggregate. A seventh quality factor is to get good adhesion. Washing and precoating the aggregate are required practice in Australia.

Reference 8
A GENERAL METHOD OF DESIGN FOR SEAL COATS AND SURFACE TREATMENTS

McLeod, N.W. Proceedings of the Association of Asphalt Paving Technologists. Technical Sessions Held at Los Angeles, California, February 10, 11 and 12, 1969. Minneapolis, Minnesota: Association of Asphalt Paving Technologists; 1969; pp. 537–628 (Volume 38).

Order from: Associaton of Asphalt Paving Technologists, Office of Secretary-Treasurer, University of Minnesota, 155 Experimental Engineering Building, Minneapolis, Minnesota 55455.

This paper demonstrates that one equation for the quantity of cover aggregate required and another equation for the quantity of asphalt binder to be applied can be used for the design of either single-application or multiple-application surface treatments and seal coats. The required characteristics of both cover aggregates and asphalt binders are reviewed. The superiority of one-size over graded cover aggregates is demonstrated. Equations are developed for the quantities of cover aggregate and asphalt binder required for single application surface treatments and seal coats. A sample calculation illustrates their use for this purpose. These same equations can be used for the design of multiple seal coats and surface treatments. Sample calculations are included to illustrate such use. The principles of construction for single and multiple application surface treatments and seal coats are reviewed.

Reference 9
HIGHWAY MAINTENANCE MANUAL

Ministry of Public Works. Amman, Jordan; 1972. 113 p.

Order from: Ministry of Public Works, Highway Department, Amman, Jordan.

This manual is presented in eight sections. Section 1 gives a general introduction to the topics covered. Section 2 covers miscellaneous structures and appurtenances. The construction of retaining walls, concrete and stone-masonry walls, crib walls, gabion type walls, and the inspection and maintenance of walls are described in this section. Section 3 covers the maintenance of paved surfaces. It includes the maintenance of asphaltic concrete pavements, the correction of base and surface failures, rehabilitation, the maintenance of surface treatments or seal coats, asphaltic materials for surface treatments, equipment for surface treatments, details of applying surface treatment, and asphaltic patching materials. Section 4 covers shoulder and roadway maintenance. This section describes the maintenance of both paved and earth shoulders as well as snow removal. Section 5 reviews the maintenance of highway drainage and drainage structures. Specifically, it covers surface drainage, pipe culverts, backfilling around pipes, storm sewers and catch basins, box culverts, subsurface drainage, erosion control, bridge maintenance, stream maintenance, and records and reports. Section 6 discusses the maintenance of signs and markings. This section covers the requirements and responsibilities of maintenance, maintenancne of permanent and temporary signs, pavement markings, protection of workmen, the maintenance and operation of machines, flammable gases and liquids, handling and storage of materials, and fires in buildings. Section 7 covers maintenance needs due to slides and rockfalls. Section 8 covers operational safety. It discusses safety programs, as well as bridge and culvert inspection. An appendix gives information on the determination of bitumen and aggregate rate for seal coats.

ADDITIONAL REFERENCES

Reference 10
BASIC PRINCIPLES FOR THE DESIGN AND CONSTRUCTION OF SEAL COATS AND SURFACE TREATMENTS WITH CUTBACK ASPHALTS AND ASPHALT CEMENTS

McLeod, N.W. Proceedings of the Association of Asphalt Paving Technologists; Technical Sessions Held at Memphis, Tennessee. January 25, 26, 27, 1960. Minneapolis, Minnesota: Association of Asphalt Paving Technologists; 1960. 156 p.

Order from: Association of Asphalt Paving Technologists, Office of Secretary-Treasurer, 155 Experimental Engineering Building, Minneapolis, Minnesota 55455.

This paper is the result of observations of bituminous surface treatments and seal coats on roads in many countries. Streaking, due to nonuniform application of bituminous binder across the road surface, excess binder that results in flushing or bleeding on the surface that is hazardous to traffic in wet weather, insufficient binder to cement the cover stone into place, and loss of cover aggregate are the four major defects in surface treatments and seal coats in nearly all countries. The paper indicates how each of these faults can be avoided by careful attention to design and construction details. Requirements for bituminous distributors and cover aggregate spreaders are reviewed. Hanson's method of design, which is based on one-size cover aggregate that is assumed to result in a seal coat or surface treatment one-stone particle thick and that is used by the Country Roads Board of Victoria, Australia, to build the consistently best surface treatments and seal coats in the world, is described. Some evidence that single application surface treatments or seal coats made with graded cover aggregates containing limited amounts of the finer sizes tend to be two-stone particles thick, is presented. Country Roads Board practice for single application surface treatments and seal coats constructed with graded aggregates and for double surface treatments is outlined. Photographs of surface treatments and seal coats that range from excellent to poor are included. The necessity for an adequate foundation for surface treatments on gravel or crushed stone bases is stressed. The preparation of existing surfaces for seal coats and surface treatments is discussed. The basic engineering requirements for cover aggregates and for bituminous binders of the cutback asphalt and asphalt cement types are reviewed. The need for recognizing and stressing certain basic principles for good spray patch maintenance is emphasized. Methods for protecting newly constructed surface treatments and seal coats from damage by fast traffic are described.

Reference 11
SPECIFICATIONS FOR PAVING AND INDUSTRIAL ASPHALTS

Asphalt Institute. College Park, Maryland; October 1978. 52 p. (Specification Series No. 2 (SS-2) 1978-1979 Edition).

Order from: The Asphalt Institute, Asphalt Institute Building, College Park, Maryland 20740.

This is a publication of the American Association of State Highway and Transportation officials' (AASHTO) and American Society for Testing and Materials (ASTM) specifications for the following types of asphalt: asphalt cement (AC), rapid-curing (RC) liquid asphalts, medium-curing (MC) liquid asphalts, slow-curing (SC) liquid asphalts, anionic emulsified asphalts, and cationic emulsified asphalts. ASTM and AASHTO specifications for the following types of asphaltic materials are also reproduced and may be used for appropriate hydraulic, building and roadway applications: asphalt for use in waterproof membrane construction, asphalt for undersealing Portland cement concrete pavements, asphalt for dampproofing and waterproofing, and primer for use with asphalt for dampproofing and waterproofing. ASTM specifications for asphalt used in roofing, for asphalt-base emulsions used as protective coatings for built-up roofs, and for slow-curing liquid asphalts are included.

Reference 12
1980 ANNUAL BOOK OF ASTM STANDARDS, PART 15; ROAD AND PAVING MATERIALS; ROOFING, WATERPROOFING, AND BITUMINOUS MATERIALS; TRAVELED SURFACE CHARACTERISTICS

American Society for Testing and Materials. Philadelphia, Pennsylvania; 1980. 1298 p.

Order from: American Society for Testing and Materials, 1916 Race Street, Philadelphia, Pennsylvania 19103.

This is one of 48 parts that comprise the 1980 Annual Book of ASTM Standards. It contains all currently, formally approved ASTM Standard specifications, test methods, classifications, definitions, and practices, and related material such as charts. Several highway construction materials are covered. Specifications are presented for roofing and waterproofing materials and for fillings for homogenous bituminized fiber drains and sewer pipes, and for bituminized fiber pipes. Proposed methods and recommended practices are detailed. Specifications and methods of testing skid resistance are described. Methods for aggregates and for testing aggregates are set forth. Creosote and general methods of testing and metric practice are also covered. New standards presented in the publication include practices for evaluating the effects of heat on asphalts, for application of aluminum-pigmented asphalt roof coating, and a test for skid resistance of paved surfaces using the North Carolina State University variable-speed friction tester.

Reference 13
LETS GET ACQUAINTED WITH ASPHALT EMULSIONS

Kandhal, Prithvi S. Harrisburg, Pennsylvania: Department of Transportation; April 1974. 26 p. (Informational Report).

Order from: Commonwealth of Pennsylvania Department of Transportation, Materials and Testing Division, Harrisburg, Pennsylvania 17120.

This informational report explains the nature of asphalt emulsions, the manner in which they work, and the ways in which they differ from cutbacks. Anionic and cationic emulsions and emulsion grades are described. Guidelines are provided for the use of emulsions for seal coats and surface treatments. These guidelines relate to emulsified asphalt, cover material, conditioning of the existing surface, weather, application of emulsified asphalt, application of cover material, rolling operation, and traffic control. Guidelines on using emulsions for base and surface course mixes are also given. These guidelines cover the selection of asphalt emulsion, aggregate, weather, mixing, aeration and rolling, and traffic control.

Reference 14
BITUMINOUS EMULSIONS FOR HIGHWAY PAVEMENTS

Transportation Research Board. Washington, DC; 1975. 76 p. (National Cooperative Highway Research Program, Synthesis of Highway Practice 30).

Order from: Transportation Research Board, Publications Office, 2101 Constitution Avenue, N.W., Washington, DC 20418.

This report reviews and assesses current practice in the use of emulsified asphalts in highway and street construction and maintenance. Detailed information is presented on structural design, mixture design, materials selection, and construction and maintenance techniques for using emulsified asphalts in pavements. Construction problems that have been faced in the past, along with solutions found workable, are described.

Reference 15
BITUMINOUS PATCHING MIXTURES AND SEAL COATS

Highway Research Board. Washington, DC; 1959. 37 p. (Highway Research Board Bulletin 215).

Order from: University Microfilms International, 300 North Zeeb Road, Ann Arbor, Michigan 48106.

This bulletin contains two papers. The first, entitled "Cutback Asphalt Patching Mixtures", presents the results of a project to produce a mixture that would be suitable for road mixing or plant-mixing by the maintenance forces in the field, could be made with local materials wherever possible, would be suitable at all times of the year, and would have a suitable stability for use soon after mixing yet would retain sufficient workability so that it can be used after long periods of storage. Dolomitic limestone was used for all phases of the project and two methods of curing were employed. Series of mixes using both MC and RC cutter stocks were used. A Marshall stability of 500lb. was chosen as the desirable minimum stability satisfactory for patching. Patching mixtures prepared with blended cutback gave the desired results. The second paper, entitled "Seal Coat: Laboratory Contributions Toward Better Performance", describes studies relating to improvement of seal coats, including development of tests, apparatus, materials and application procedures. A method for checking the uniformity of the transverse and longitudinal spread rates of the asphalt distributor is degradation of the screenings, seasonal effects on pavement performance, the use of atmometers for determining drying conditions and setting times of the binder are described. The possible use of a centrifugal test to predict adherence of screenings is discussed.

Reference 16
STATE OF THE ART: SURFACE TREATMENTS; SUMMARY OF EXISTING LITERATURE

Highway Research Board, Washington, DC; 1968. 98 p. (HRB Special Report 96).

Order from: Transportation Research Board, Publications Office, 2101 Constitution Avenue, N.W., Washington, DC 20418.

All existing pertinent information on surface treatments has been compiled in this report. The first section of this report summarizes the status of the published knowledge of seal coats and surface treatments. The basic constituents of a surface treatment, aggregate and binder, and factors influencing their behavior in a finished treatment are discussed in detail. Several known current methods of design are discussed, and the limitations of each are noted. An appendix presents each design method in detail, and an example design is given when possible. Areas requiring research are summarized. The second section of the report consists of a bibliography on seal coats and surface treatments. All information included in this report has been prepared from literature published before 1967.

Reference 17
PRINCIPLES AND PRACTICE OF BITUMINOUS SURFACING: VOLUME 1—SPRAYED WORK

National Association of Australian State Road Authorities. Sydney, Australia; 1975. 129 p.

Order from: National Association of Australian State Road Authorities, The Secretariat, P.O. Box J141, Brickfield Hill, N.S.W. 2000, Australia.

This publication covers various aspects of bituminous surfacing. The types of sprayed work (priming, primersealing, sealing, resealing, dustlaying, and surface enrichment) are defined and described. Factors affecting selection and design (existing surface conditions, alignment and grades, traffic, pavement strength, road life, stage construction, shape, availability of materials, climate, surface drainage and economy) are discussed. The various aspects of design are also covered. The materials discussed include aggregate, bitumen, flux, cutter, cutback bitumen, bitumen emulsion, adhesive agents, precoating materials, and rubber. The factors affecting and the methods of promoting adhesion of binder to aggregate are covered, as well as tests of adhesion. Factors affecting skid resistance, improvement of skid resistance, and the measurement of skid resistance are discussed. Preparing for work, preparation of the surface, preparation of the primer and the binder, and the preparation of the aggregate are reviewed. The spraying of the primer and binder and applying the aggregate are detailed. Traffic control and the maintenance of work records are also discussed.

Reference 18
TRH 3, BITUMINOUS SURFACE TREATMENTS FOR NEWLY CONSTRUCTED RURAL ROADS

National Institute for Road Research. Pretoria, South Africa; 1971. 59 p. (Technical Recommendations for Highways 3).

Order from: Council for Scientific and Industrial Research, National Institute for Road Research, P.O. Box 395, Pretoria, South Africa.

A number of different surface treatment methods are used by road authorities in South Africa to provide a newly constructed road with a bituminous surfacing. These are generally variations in double- or triple-surface treatments with layers of stone or sand or with a layer of stone over which slurry is spread to fill the voids. Surface treatments are usually used on roads carrying from about 125 to 1000 vehicles/lane/day. It is common practice to use a premix surfacing on roads carrying more than 1000 vehicles/lane/day. This guide describes some of the commonly used methods that have proved satisfactory in practice, introduces a new design method based on the results of road experiments carried out by the National Institute for Road Research, and gives brief recommendations for the construction of surface treatments.

Reference 19
BITUMINOUS BASES AND SURFACINGS FOR LOW-COST ROADS IN THE TROPICS

Hitch, L.S.; Russel, R.B.C. Great Britain Road Research Laboratory, Overseas Unit; 1977. 33 pages plus charts. (TRRL Supplementary Report 284).

Order from: Transport and Road Research Laboratory, Crowthorne, Berkshire RG 11 6 AU, U.K.

Mechanically stable materials for road bases are often not obtainable in developing countries. In the Middle East, aggregates are often scarce but oil products are readily available. The region has therefore provided some of the earliest examples of bituminous stabilization, which originally consisted of thin running surfaces over compacted sand. Bituminous stabilization can also enable local sand to be used for base construction, and various tests and design criteria have been proposed for such applications. The report describes full-scale experimental trials, supported by laboratory research, which have enabled acceptance criteria for bitumen-stabilized sand bases for light/medium traffic to be proposed. Construction methods for bituminous stabilization are also described. Details are given of methods of surface dressing, which is important both as an initial running surface on new bases and as a maintenance treatment. Premixed bituminous materials, both as bases and surfacings, might perhaps be considered as inadmissible for low-cost roads. Such roads, however, usually require progressive improvement because of the traffic growth that accompanies development. There is a growing use of strengthening overlays, and the report briefly discusses premixed materials and their applications.

Reference 20
ASPHALT POCKETBOOK OF USEFUL INFORMATION

Asphalt Institute. College Park, Maryland; November 1974. 110 p. (Manual Series No. 6 MS–6).

Order from: The Asphalt Institute, Asphalt Institute Building, College Park, Maryland 20740.

Thus publication has been prepared in convenient pocket form to furnish engineers and inspectors on asphalt construction with information on unloading tank cars, temperature-volume corrections of asphalts, and useful tables. Many of the tables are arranged so that values other than those listed in the table may be readily obtained by simple addition, multiplication, or division of table quantities. Generally, the formula used in the computation of a table is shown so that calculations for conditions different from those covered by the table may be readily made. Other manuals have been published by the Institute that deal with various types of asphalt construction.

Index

The following index is an alphabetical list of subject terms, names of people, and names of organizations that appear in one or another of the previous parts of this compendium, i.e., in the overview, selected texts, or bibliography. The subject terms listed are those that are most basic to the understanding of the topic of the compendium.

Subject terms that are not proper nouns are shown in lower case. Personal names that are listed generally represent the authors of selected texts and other references given in the bibliography, but they also represent people who are otherwise identified with the compendium subjects. Personal names are listed as surname followed by initials. Organizations listed are those that have produced information on the topic of the compendium and that continue to be a source of information on the topic. For this reason, postal addresses are given for each organization listed.

Numbers that follow a subject term, personal name, or organization name are the page numbers of this compendium on which the term

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Indice

El siguiente índice es una lista alfabética del vocablo del tema, nombres de personas, y nombres de organizaciones que aparecen en una u otra de las partes previas de este compendio, es decir, en la vista general, textos seleccionados, o bibliografía. Los vocablos del tema que aparecen en el índice son aquellos que son necesarios para el entendimiento de la materia del compendio.

Los vocablos del tema que no son nombres propios aparecen en letras minúsculas. Los nombres personales que aparecen representan los autores de los textos seleccionados y otras referencias dadas en la bibliografía, pero también pueden representar a personas que de otra manera están conectadas a los temas del compendio. Los nombres personales aparecen con el apellido seguido por las iniciales. Las organizaciones nombradas son las que han producido información sobre la materia del compendio y que siguen siendo fuentes de información sobre la materia. Por esta razón se dan las direcciones postales de cada organización que aparece en el índice.

Los números que siguen a un vocablo del tema, nombre personal, o nombre de organización son los números de página del compendio donde el vocablo o nombre aparecen. Los números romanos se refieren a las páginas en la vista general, los números arábigos se refieren a páginas en los textos seleccionados, y los numeros de referencia (por ejemplo, Ref. 5) indican referencias en la bibliografía.

Algunos vocablos del tema y nombres de organizaciones están seguidos por la palabra ***see.*** En tales casos los números de página del com-

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Index

Cet index se compose d'une liste alphabétique de mots-clés, noms d'auteurs, et noms d'organisations qui paraissent dans une section ou une autre de ce recueil, c'est à dire dans l'exposé, les textes choisis, ou la bibliographie. Les mots-clés sont ceux qui sont le plus élémentaires à la compréhension de ce recueil.

Les mots-clés qui ne sont pas des noms propres sont imprimés en minuscules. Les noms propres cités sont les noms des auteurs des textes choisis ou de textes de référence cités dans la bibliographie, ou alors les noms d'experts en la matière de ce recueil. Le nom de famille est suivi des initiales des prénoms. Les organisations citées sont celles qui ont fait des recherches sur le sujet de ce recueil et qui continueront à être une source de documentation. Les adresses de toutes ces organisations sont incluses.

Le numéro qui suit chaque mot-clé, nom d'auteur, ou nom d'organisation est le numéro de la page où ce nom ou mot-clé parait. Les numéros or name appears. Roman numerals refer to pages in the overview, Arabic numerals refer to pages in the selected texts, and reference numbers (e.g., Ref. 5) refer to references in the bibliography.

Some subject terms and organization names are followed by the word *see*. In such cases, the compendium page numbers should be sought under the alternative term or name that follows the word *see*. Some subject terms and organization names are followed by the words *see also*. In such cases, relevant references should be sought among the page numbers listed under the terms that follow the words *see also*.

The foregoing explanation is illustrated below.

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pendio se encontrarán bajo el término o nombre alternativo que sigue a la palabra *see*. Algunos vocablos del tema y nombres de organizaciones están seguidos por las palabras *see also*. En tales casos las referencias pertinentes se encontrarán entre los números de página indicados bajo los términos que siguen a las palabras *see also*.

La explicación anterior está subsiguientemente ilustrada.

écrits en chiffres romains se rapportent aux pages de l'exposé et les numéros écrits en chiffres arabes se rapportent aux pages des textes choisis. Les numéros de référence (par exemple, Ref. 5) indiquent les numéros des références de la bibliographie.

Certains mots-clés et noms d'organisations sont suivis du terme *see*. Dans ces cas, le numéro des pages du recueil se trouvera après le mot-clé ou le nom d'organisation qui suit le terme *see*. D'autres mots-clés ou noms d'organisations sont suivis des mots *see also*. Dans ce cas, leurs références se trouveront citées après les mots-clés qui suivent la notation *see also*.

Ces explications sont illustrées ci-dessous.

Illustration (from Comp. 1) **Ilustración** (del Comp. 1) **Illustration** (du Recueil 1)