TRANSPORTATION TECHNOLOGY SUPPORT
FOR DEVELOPING COUNTRIES

COMPENDIUM 4

Low-Cost Water Crossings

Travesías de agua de bajo costo

Ouvrages de franchissement d'eau économiques

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: 104-m timber bridge, Rio Preto, Brazil.

Contents
Tabla de Materias
Table des Matières

Project Description

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 doc-

Descripción del Proyecto

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 en las regiones rurales de países en desarrollo todos dependen en gran parte de los medios de transporte. Aunque en ciertas áreas los medios de ferrocarril y agua desempeñan una parte importante, una necesidad universal y dominante es para sistemas viales que proveen un medio asegurado pero relativamente poco costoso para el movimiento de gente y mercancías. La gran parte de esta necesidad es para caminos de bajo volúmen que generalmente mueven unicamente unos 5 a 10 vehículos por día y que pocas veces mueven tanto como 400 vehículos por día.

Con respecto a la economía, calidad, y rendimiento, el planeamiento, diseño, construcción y manutención de caminos de bajo volúmen para regiones rurales de países en desarrollo pueden ser mejorados en gran parte 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 mas desarrollados, y alguna se produce continuamente en los países menos y mas

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 à l'information par l'intermédiaire de moyens éducatifs et d'autres moyens de communication, dépendent en grande partie des moyens de transport. Bien que les transports par voie férrée 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 en technologie, qui éxistent déjà et sont accéssibles dans beaucoup 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 déumented in papers, articles, and reports that have been written by experts in the field. But much of the technology is undocumented 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, conferences in the United States and abroad, and

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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 esta documentada y existe principalmente en las mentes de aquellos que han desarrollado y aplicado la tecnología por necesidad. En cualquier caso, los conocimientos en existencia sobre la tecnología de caminos de bajo volúmen están grandemente esparcidos geograficamente, varían bastante con respecto al idioma y su forma, y no se encuentran facilmente disponibles para su aplicación a las necesidades de los países en desarrollo.

En octubre de 1977 el Transportation Research Board (TRB) comenzó con 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 manutención 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 información técnica, se provee acciones recíprocas personales con los usuarios por

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veloppés, 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'éxiste que dans l'esprit de ceux qui ont développé et appliqué cette technologie par nécessité. 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 durée 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 éxistante 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. Généralement, l'aboutissement 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.

En plus de la dissémination de cette documentation technique, des visites, des conférences aux Etats Unis et à l'étranger, et 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

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medio de visitas de campaña, 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 asistir 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 tiene la responsabilidad para 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 relativamente limitados

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d'autres formes de communication permettent 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 de 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.

Le personnel attaché à ce projet 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 sera relativement limité, des synthèses de connaissances et de pratique sur des sujets beaucoup plus généraux, et finalement des comptes-rendus practice on somewhat broader 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 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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temas, la síntesis del conocimiento y práctica sobre temas un poco mas ámplios, 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 sintesis 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 formularios de retroacción con los productos informativos 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 directo 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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de conférences sur les routes à faible capacité qui seront organisées complètement ou en partie par ce projet. Environ 6 recueils par an sont preparés par le personnel attaché au projet. Deux synthèses par an sont écrites par des experts. 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, le 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 le personnel et les usagers. Finalement, des colloques annuels sont organisés pour les étudiants des pays en voie de développement qui étudient dans les universités americaines.

Foreword and Acknowledgments

This compendium is the fourth 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 low-cost water crossings. 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:
Indian Roads Congress, New Delhi;
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Prefacio y Agradecimientos

Este compendio es el cuarto 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 travesías de agua de bajo costo. Se pedirá a los corresponsales en los países en desarrollo información sobre los resultados, para utilizarse en el asesoramiento del grado al cuál se ha obtenido ese objetivo y para influenciar la naturaleza de productos subsequentes.

Se reconoce a los siguientes editores por el permiso dado para re-imprimir las porciones de texto seleccionadas de este compendio:

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U.S. Department of the Army, Washington, D.C.;
U.S. Forest Service, U.S. Department of Agriculture, Washington, D.C.; y
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Avant-propos et Remerciements

Ce recueil représente le quatrième volume de 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 responsables des ouvrages de franchissement d'eau économiques. La réaction des correspondants des pays en voie de développement sera sollicitée et tuilisée 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 des éditeurs qui ont gracieusement donné leur permission de reproduire les textes sélectionnés pour ce recueil:

Indian Roads Congress, New Delhi;
Texas State Department of Highways and Public Transportation, Austin;
Office of International Transportation Programs, U.S. Department of Transportation, Washington, D.C.;
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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). Photographs provided by TRRL have been reproduced by permission of Her Majesty's Stationery Office.

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, William C. LaBaugh, Jr., Daniel Mann, Johnson and Mendenhall, 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 de la U.S. Department of Transportation y el Library and Information Service de la U.K. Transport and Road Research Laboratory (TRRL). Las fotografías proveídas por TRRL fueron reproducidas bajo permisión de Her Majesty's Stationery Office.

Finalmente, el Transportation Research Board agradece el consejo y dirección valiosos provisto por el Comité de Iniciativas, con especial reconocimiento a los señores R. G. Hicks, Oregon State University, William C. LaBaugh, Jr., Daniel Mann, Johnson and Mendenhall, 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). Les photos fournies par le TRRL ont été reproduites avec la permission de Her Majesty's Stationery Office.

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, William C. LaBaugh, Jr., Daniel Mann, Johnson and Mendenhall, 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

If a road is to be used in all seasons, adequate drainage must be provided. In Compendium 3, *Small Drainage Structures,* it was noted that such structures with fixed capacities cannot be upgraded economically. Therefore, as the first step in roadway development, small drainage structures should be sized and should be installed correctly.

Low-volume roads, as defined in Compendium 1, *Geometric Design Standards for Low-Volume Roads,* are those with an average daily traffic (ADT) volume of less than 50 (Class I) and those with an ADT of 50-400 (Class 2). Many low-volume roads can provide satisfactory service, even though they may be temporarily closed during heavy rainfall.

The cost of providing a bridge must be balanced against the cost of user delays, if the roadway is closed due to stream flooding. Many factors must be considered when

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Vista General

Antecedentes y Alcance

Caminos que son utilizados durante todo el año deben estar proveídos con drenaje adecuado. Se indicó en el Compendio 3 que pequeñas estructuras de drenaje con capacidades fijas no pueden ser economicamente mejoradas. Por lo tanto estas estructuras deben ser escogidas de acuerdo a su tamaño e instaladas correctamente como el primer paso en el desarrollo del camino.

Como se definen en el Compendio 1, los caminos de bajo volúmen son aquellos de Clase 1 con un volúmen de TMDA menos que 50, y de Clase 2 con un de TMDA de 50 a 400. Muchos caminos de bajo volúmen pueden proveer un servicio satisfactorio aunque estén temporalmente cerrados durante períodos de mucha lluvia.

Si el camino está cerrado debido a inundaciones de corrientes de agua, se debe balancear el costo de proveer un puente contra el costo de demoras del usuario. Se deben considerar muchos factores al evaluar las demoras del usuario. Estos incluyen (a) el número de vehículos demorados, (b) el período de tiempo

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Exposé

Historique et description

Si l'on veut qu'une route soit praticable en toutes saisons, un dispositif de drainage adéquat est nécessaire. Dans le recueil no. 3, "Petits ouvrages de drainage", nous avions remarqué que ces ouvrages, dont la capacité est fixe, ne peuvent pas être agrandis de façon économique. Par conséquent, la première étape de la construction d'une route consiste à dimensionner et installer ces petits ouvrages d'art correctement.

Les routes à faible capacité, comme nous les avons définies dans le recueil no. 1, "Normes de dimensionnement géométrique pour routes à faible capacité", sont celles qui ont un ADT (trafic moyen journalier) de moins de 50 (Classe 1) et celles qui ont un ADT de 50 à 400 (Classe 2). Beaucoup de ces routes peuvent fournir un service satisfaisant même si elles doivent être temporairement fermées lors de grosses averses.

evaluating user delays. They include (a) the number of vehicles delayed, (b) the length of time of each delay, and (c) the number of times per year that delays occur. These delays are due to the temporary increase of water flow in a stream or river during or shortly after a heavy rainstorm.

Delays due to the saturation of the roadbed after heavy rainfalls are not considered temporary delays (see Overview, Compendium 3). If the roadbed becomes saturated, the road may be unusable for days or weeks. Road material that becomes saturated during a short heavy rainfall will also become saturated during a prolonged light rainfall. A road that does not become saturated is said to have an all-weather surface. A road with an all-weather surface, which is always usable at stream or river crossings, is called an all-weather road.

Compendium 4 concerns stream and river crossings. It introduces many of the types of low-water crossings that are available. It discusses the design, construction, and economic features of these crossings. Low-volume roads can be built with fords, dips, or submersible bridges. This reduces the initial investment. Later, they can be upgraded by construction of large culverts or bridges as warranted by the cost of delays. Each decision should be based upon an economic evaluation of the water crossing.

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de cada demora, y (c) el número de veces por año que ocurren estas demoras. Las demoras se deben al aumento temporario del flujo de agua en un arroyo ó río durante ó después de una fuerte tormenta de lluvia.

Las demoras debidas a la saturación del firme del camino después de fuertes lluvias no se consideran temporarias. Se habla sobre estas demoras en la Vista General del Compendio 3. Si se satura el firme, el camino puede ser inutilizable por días ó semanas. El material de camino que se sature durante una corta tormenta fuerte también se vá a saturar en una lluvia ligera prolongada. Un camino que no se sature se dice tiene una superficie para toda intemperie. Un camino con tal superficie que siempre es utilizable en travesías de arroyos ó ríos se llama un camino para todo el tiempo.

Este compendio trata sobre travesías de arroyos y ríos. Introduce muchos de los tipos disponibles de travesías para niveles bajos de agua. Habla sobre las características de diseño y construcción de cada uno y también presenta los aspectos económicos de estas travesías. Los caminos de bajo volúmen pueden ser construídos con vados, badenes ó puentes sumergibles. Esto reduce la inversión inicial. Pueden ser mejorados por una construcción posterior de alcantarillas grandes ó puentes a medida que éstas se justifiquen por el costo de demoras. Cada decisión debe ser basada sobre una evaluación económica de la travesía de agua.

Exposición razonada para este compendio

Este compendio resume los requisitos

On doit mettre en balance, d'une part le coût d'ériger un pont, et d'autre part, le coût des délais que doivent souffrir les usagers quand la route est fermée à cause d'inondation des cours d'eau. Beaucoup de facteurs doivent être pris en considération quand on tente d'évaluer le coût résultant de ces délais. Sont inclus dans ces facteurs: (a) le nombre de véhicules retardés, (b) la durée de chaque délais, et (c) le nombre de fois par année que ces délais ont lieu. Ces délais sont causés par la crue temporaire d'une rivière ou d'un fleuve pendant ou tout de suite après une grosse chute de pluie.

Les délais causé par la saturation du corps de la chaussée après de grosses pluies, ne sont pas considérés comme temporaires (voir l'exposé du recueil 3). Si le corps de la chaussée est saturé, la route peut devenir impraticable pendant des jours ou même des semaines. Le matériau qui devient saturé quand il pleut fortement mais brièvement, deviendra saturé aussi lors d'une pluie légère mais de longue durée. Une route qui ne devient pas saturée a une surface de roulement tous temps. Une route avec une surface de roulement tous temps qui est toujours praticable lors du franchissement de rivières ou de fleuves, est appelée une route tous temps.

Le sujet de ce recueil no. 4 est le franchissement des rivières et des fleuves. Plusieurs sortes d'ouvrages de franchissement sont introduits. La conception, la construction et les caractéristiques économiques de ces

Rationale for This Compendium

Compendium 4 reviews the general requirements for proper roadway drainage. It includes the grading and shaping of the road so that falling water or water running down from higher ground will drain away with a minimum of damage.

Consideration is given to various types of crossings that can be built at stream or river sites. These crossings fall into two groups.

The first group consists of crossings that are submersible, such as fords, dips, and submersible bridges. They are normally built as the first step in the staged construction of a low-volume road and are not considered as permanent structures. In practice, many such structures are used over long periods of time. The engineer should not assume that such crossings are temporary; otherwise, they will be poorly designed and poorly built. In such cases, they will be truly temporary since they will wash away in the first heavy storm.

Crossings that are not submersible, such as bridges and ferries, form the second group. Bridges or large culverts are often built as the second step in the stage construction of a low-volume road. However, an economic evaluation may prove that they should be built as a first step. A large box culvert may cost less than a paved dip at a narrow stream crossing. Non-submersible structures are also

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generales para un correcto drenaje del camino. Incluye la nivelación y formación del camino para que agua que cae o agua que baja de terreno más alto se desaguara con un mínimo de daño.

Se consideran las varias clases de travesías que pueden ser construídas en las ubicaciones de arroyos ó ríos. Estas travesías caen en dos clasificaciones ó grupos.

El primer grupo consiste en la travesías que son sumergibles, tales como vados, badenes y puentes sumergibles. Se construyen normalmente como el primer paso en la construcción por etapas de un camino de bajo volúmen y no se consideran estructuras permanentes. En la práctica muchas de tales estructuras se utilizan sobre grandes períodos de tiempo. El ingeniero no deberá considerar a tales travesías como temporarias ó se diseñarán y construirán deficientemente. En tal caso verdaderamente serán temporarias ya que se destruirían en la primera tormenta fuerte.

En el segundo grupo están la travesías que no son sumergibles, tales como puentes y balsas. Muchas veces el segundo paso en la construcción por etapas de un camino de bajo volúmen son los puentes ó alcantarillas grandes. Sin embargo una evaluación económica puede indicar que deberán construirse como el primer paso. Una alcantarilla de cajón grande puede costar menos que un badén pavimentado en una travesía estrecha de arroyo. Las estructuras no-sumergibles también están sujetas a ser mejoradas como parte de un programa de construcción por etapas. El ejemplo más común es el ensanchamiento de un puente de una trocha

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ouvrages de franchissement sont discutées. Les routes à faible capacité peuvent être construites avec des passages à gué, des radiers ou des ponts submersibles. Cela réduit les dépenses initiales. Plus tard, ces routes peuvent être améliorées par la construction de ponceaux ou de ponts si le coût des délais le justifie. Chaque décision devrait être fondée sur une évaluation économique du franchissement d'eau.

Objet de ce recueil

Le recueil no. 4 passe en revue les conditions requises pour avoir un bon dispositif de drainage. Les travaux de nivellement et de profilage qui sont nécessaires afin que l'eau de pluie ou l'eau de ruissellement soient évacuées avec le minimum de dégats sont inclus. Différentes sortes d'ouvrages qui peuvent être bâtis pour franchir les rivières ou les fleuves sont considérés. Ces ouvrages peuvent être divisés en deux groupes.

Le premier groupe comprend les ouvrages de franchissement qui sont submersibles comme les passages à gué, les radiers et les ponts submersibles. Ces ouvrages sont généralement construits au premier stade de la mise en oeuvre à plusieurs couches et sont considérés comme des ouvrages provisoires. En fait, un grand nombre de ces ouvrages sont utilisés tels quels pendant de longues périodes. L'ingénieur ne doit pas présumer que ces ouvrages de franchissement subject to upgrading as a part of a staged construction program. The most common example is the widening of a bridge from one to two lanes.

In each case, the cost of the crossing should be evaluated before any construction is started. Each type of low-cost crossing described here has a proper place and use. However, there are overlapping areas of places and uses. It is not always clear which type of crossing will be the most economical in every situation. When doubt exists, alternate crossings should be evaluated and the least costly crossing should be constructed. The true cost of a crossing is the cost of the construction and the maintenance of that crossing during its useful life span.

This compendium discusses these types of low-cost water crossings: (a) fords; (b) dips, Irish bridges, or culverted fords; (c) causeways or submersible bridges; (d) timber bridges with timber or steel stringers; (e) Bailey bridges; (f) Uniflote ferries; and (g) floating bridges. Each type of crossing is described, and the design and construction techniques and problems associated with each type are discussed. The uses and costs of each type of crossing are compared. Finally, the recommendation that guidelines be established for choosing a ford, ferry, or bridge is made.

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a dos.

En cada caso, el costo de una travesía deberá evaluarse antes de comenzar cualquier construcción. Cada tipo de travesía de bajó costo que se describe abajo tiene su correcta disposición y uso. Sin embargo, hay áreas de disposición y uso sobrepuestas. No siempre es claro cuál sería el tipo más económico en cada situación. Cuando existen dudas se deberán evaluar travesías alternativas y se construirá la más económica. El costo verdadero de una travesía es el costo de su construcción y su mantenimiento a través de su vida útil.

Este compendio considera los siguientes tipos de travesías de agua de bajo costo: (a) vados; (b) badenes, puentes Irlandeses ó vados alcantarillados; (c) arrecifes ó puentes sumergibles; (d) puentes de madera con riostras de madera ó acero; (e) puentes Bailey; (f) balsas Uniflote; y (g) puentes flotantes. El compendio describe cada tipo de travesía. Presenta las técnicas de diseño y construcción y los problemas asociados con los varios tipos de travesías. Compara los usos y costos de cada tipo y recomienda que se establezcan pautas para la elección de un vado, balsa ó puente.

Presentación de los textos seleccionados

El primer texto es el segundo capítulo de *Handbook of Methods and Procedure for Low Cost Service Roads* (Manual de métodos y procedimientos para caminos de servicio de bajo volúmen, (Departamento Vial de Texas, 1946). Define un buén drenaje en términos simples. Se habla sobre el problema

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soient provisoires, autrement il y a des chances que le calcul soit fait hâtivement, ou que ces ouvrages soient mal construits. Si cela arrive, on pourra dire qu'ils sont vraiment provisoires, car ils seront emportés à la première grosse chute de pluie.

Les ouvrages de franchissement qui ne sont pas submersibles, comme les ponts et les bacs, constituent le deuxième stade de l'aménagement progressif d'une route à faible capacité. Cependant, une évaluation économique peut prouver qu'ils devraient être construits au premier stade. Le prix de revient de la construction d'un dalot peut être moindre que celui de la construction d'un radier quand le cours d'eau à franchir n'est pas large. L'amélioration des ouvrage non-submersibles peut être un stade du programme d'aménagement progressif, par éxemple l'élargissement d'un pont d'une à deux voies. Quelque soit le cas, le coût de l'ouvrage de franchissement devrait être évalué avant de commencer la construction. Chaque ouvrage de franchissement dont nous allons faire la description est correct pour certaines conditions. Cependant il y a des cas où ces conditions se chevauchent, et il n'est pas toujours très facile de déterminer quel genre d'ouvrage sera toujours le plus économique. Dans le doute, on devrait évaluer plusieurs ouvrages et construire le plus économique. Le vrai prix de revient d'un ouvrage comprend le coût de la construction, plus le coût le l'entretien de cet ouvrage durant sa vie utile.

Discussion of Selected Texts

The first text, the second chapter of *Handbook of Methods and Procedure for Low Cost Service Roads* (Texas Highway Department, 1946), defines good drainage simply and concisely. It also discusses the problem of determining runoff. Culvert problems are evaluated and practical reasons for the use of corrugated metal pipe culverts are presented. The economy of proper culvert location and length is stressed.

This text notes that the most durable type of bridge for a stream crossing is probably constructed of reinforced concrete. However, such construction is a highly technical operation. Inferior workmanship or poor mixing and placing of concrete can mean the loss of the entire investment in a reinforced concrete bridge. Unskilled workers may fail to realize that concrete bridges depend upon a solid foundation for stability. Failure to construct a proper foundation usually results in complete collapse of the bridge.

Unskilled workers are able to construct wood pile foundations with more success than they can construct concrete footings. The text describes practical methods for driving wood piles. It also describes in detail the methods used in the construction of bridges built on wood piles. Many common faults in timber bridge construction are noted. The proper construction

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de determinar agua de drenaje. Se evalúan problemas de alcantarillas y se presentan razones prácticas para el uso de alcantarillas de tubo de metal corrugado. Se subraya el ahorro de costo en la correcta ubicación y longitud de la alcantarilla.

El texto dice que el tipo más duradero de puente para una travesía de arroyo es probablemente la que se construye con hormigón reforzado. Sin embargo, tal construcción es una operación altamente técnica. La mano de obra inferior, ó mal mezcladura y colocación del hormigón pueden significar la pérdida de la inversión total en el puente de hormigón reforzado. Los operarios pueden no darse cuenta que los puentes de hormigón dependen para su estabilidad de un fundamento sólido. La falta de construir un fundamento correcto generalmente resulta en el derrumbamiento completo del puente.

Los operarios tienen más éxito en la construcción de fundamentos de pilotes de madera que en la de estribos de hormigón. El texto describe métodos prácticos para hincar pilotes de madera. También describe en detalle los métodos utilizados en la construcción de puentes colocados sobre pilotes de madera. Se toman nota de muchas faltas comunes en la construcción de puentes de madera. Se describen los métodos de construcción correctos para sobrellevar estas faltas. Se dá importancia al ahorro de costos en la correcta construcción de puentes a través del texto.

El segundo texto, *Use of Gabions for Low Water Crossings on Primitive or Secondary Forest Roads* (El uso de cestones para travesías de agua de bajo nivel en caminos forestales

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Les ouvrages de franchissement que nous allons discuter dans ce recueil sont: (a) les passages à gué, (b) les radiers, (c) les levées ou ponts submersibles, (d) les ponts de bois avec poutres longitudinales en bois ou en acier, (e) les ponts Bailey, (f) les bacs Uniflote, et (g) les ponts flottants. Chaque ouvrage de franchissement est décrit, et les techniques de construction et de dimensionnement, ainsi que les problèmes particuliers à chacun, sont discutés. L'emploi et le prix de revient de chaque genre d'ouvrage sont comparés. Finalement, nous recommandons qu'un guide soit établi pour aider à faire le choix d'un gué, d'un bac, ou d'un pont.

Discussion des textes choisis

Le premier texte, le second chapitre de *Handbook of Methods and Procedure for Low Cost Service Roads* (Manuel de méthodes et procédés pour routes latérales économiques) publié par le Texas Highway Department en 1946, donne une définition simple et concise d'un bon dispositif de drainage. Il discute aussi du problème du calcul du débit.

Les problèmes de construction des ponceaux sont évalués et les raisons pratiques pour l'utilisation de buses en tôle ondulée sont presentées. Les économies que l'on peut faire en choisissant convenablement la location et la longueur d'un ponceau sont soulignées. Ce texte remarque que le pont le plus durable methods to overcome these faults are described. The economy of proper bridge construction is stressed throughout the text.

The second text, *Use of Gabions for Low Water Crossings on Primitive or Secondary Forest Roads,* was taken from *Engineering Technical Information System: Field Notes* (Forest Service, U.S. Department of Agriculture, May-June 1973). It describes an economical method of constructing a ford in a stream where the grade of the road precludes the use of a culvert.

The third text, *Design and Construction of Low Water Dips,* was taken from *Construction and Maintenance Bulletin No. 6* (Texas Highway Department, May 1951). It describes a dip or Irish bridge constructed over a culvert. This type of dip provides for a dry crossing during periods of normal stream flow. It is submerged during periods of high flow.

The text develops a formula for determining the length of vertical curves at the approaches to a dip. It lists the field data necessary for the design of a dip. The proper grade difference between the stream bed and roadway is described. A method of protecting the embankment from erosion during periods of high flow is detailed. Flood gauge installation is noted.

Dips can be permanent parts of a low-volume road. The construction cost of a dip should be compared to the cost of a conventional structure. Dips will always be less expensive

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primitivos ó secundarios), se tomó de *Engineering Technical Information System: Field Notes* (Sistema de información técnica ingenieril: Notas de campaña, Servicio Forestal, U.S. Department of Agriculture, mayo-junio, 1973). Describe un método económico para la construcción de un vado en un arroyo donde la rasante del camino excluye el uso de una alcantarilla.

El tercer texto, *Design and Construction of Low Water Dips* (Diseño y construcción de badenes para bajos niveles de agua), se tomó de *Construction and Maintenance Bulletin No. 6* (Boletín no. 6 de construcción y manutención, Departamento Vial de Texas, mayo 1951). Describe un badén ó Puente Irlandés construído sobre una alcantarilla. Este tipo de badén permite una travesía seca durante períodos de flujo normal del arroyo. Se sumerge durante períodos de alto flujo.

El texto desarrolla una fórmula para fijar la longitud de curvas verticales en los accesos a un badén. Nombra los datos de campaña necesarios para el diseño de un badén. Se describe la correcta diferencia de pendiente entre el cauce del arroyo y el camino. Se detalla un método para proteger el terraplén de la erosión durante períodos de alto flujo. Se menciona la instalación de medidores del nivel de agua.

Los badenes pueden ser partes permanentes de un camino de bajo volúmen. El costo de construcción de un badén deberá compararse al costo de una estructura convencional. Los badenes siempre serán menos costosos para arroyos grandes pero las alcantarillas de cajón pueden costar menos para arroyos pequeños.

El cuarto texto es una publicación de

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est probablement celui construit en béton armé. Cependant, ce genre de construction est d'une technique très avancée. Une éxécution inférieure, un mauvais mélange, une mauvaise pose du béton peut signifier la perte de tout les capitaux investis dan un pont de béton armé. La manoeuvre non spécialisée peut ne pas se rendre compte que les ponts en béton doivent leur stabilité à une fondation solide. Si on ne construit pas une fondation correcte on est presque sûr que le pont s'effondrera complètement. Une manoeuvre non spécialisée peut construire une fondation de pieux en bois beaucoup mieux qu'une fondation de pieux en béton. Le texte présente des méthodes pratiques pour enfoncer les pieux en bois. Il explique aussi en détail les procédés de construction des ponts qui reposent sur une fondation en bois. Les erreurs les plus courantes commises lors de la construction de ponts en bois sont soulignées. Les méthodes correctes de construction pour prévenir ces erreurs sont expliquées. Le texte met l'emphase sur les économies réalisées par une construction correcte des ponts.

Le deuxième texte, *Use of Gabions for Low Water Crossings on Primitive or Secondary Forest Roads* (Emploi de gabions dans la construction d'ouvrages de franchissement de basses eaux pour chemins ruraux ou routes secondaires), est extrait de Engineering Technical Information System: Field Notes (Forest Service, U.S. Department of Agriculture, Mai-Juin 1973). Ce texte decrit une méthode for large streams, but box culverts may cost less for small streams.

The fourth text is a research publication, ***Causeways or Submersible Bridges,*** taken from the *Journal of the Indian Roads Congress* (Vol. XVI, No. 3, April 1952). It defines a causeway as a submersible road bridge across a stream, designed so that the normal dry weather river flow passes entirely through vents below the roadway. Occasional floods pass both through the vents and over the roadway to a depth that halts traffic. Causeways function like the dips described in the third Selected Text. They are designed to handle the much larger flows found in major rivers. The hydraulic problems due to such large flows led to several causeway failures in India. This research project investigated these failures. Any engineeer attempting to design a large submersible road bridge should study the conclusions drawn from this research.

The fifth text consists of Chapter 5 and Section 1 of Chapter 7 from ***FMS-34: Engineer Field Data*** (U.S. Army, 1976). Chapter 5 concerns the marking of bridges and vehicles. It is included because it defines the bridge class. The bridge class determines the design of the bridge. The design tables in Section 1 of Chapter 7 are based on the bridge class.

The excerpt from Chapter 7 describes the design of rectangular timber, round timber, or steel beam bridge superstructures. Bridge

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investigación, ***Causeways or Submersible Bridges,*** (Arrecifes ó puentes sumergibles), tomado del ***Journal of the Indian Roads Congress*** (Diario del congreso vial de la India, Vol. 16, No. 3, abril 1952). Define un arrecife como un puente de camino sumergible por sobre un arroyo diseñado para que el flujo normal de un río durante temporadas secas pasa totalmente a través de pasajes debajo del camino. Las ocasionales inundaciones pasan a través de las aberturas y por sobre el camino hasta una profundidad que detiene el tránsito. Los arrecifes funcionan como los badenes descriptos en el texto previo. Están diseñados para soportar los flujos mucho más grandes de los ríos mayores. Los problemas hidráulicos debidos a tales flujos tan grandes causaron varios fracasos de arrecifes en la India. Este proyecto de investigación estudió estos fracasos. Las conclusiones deberían ser estudiados por cualquier ingeniero que tiene intención de diseñar un puente de camino sumergible grande.

El quinto texto consiste en dos extractos de ***FM5-34: Engineer Field Data*** (FM5-34: Datos ingenieriles de campaña, U.S. Army, 1976). El primer extracto, capítulo 5, se concierne con señalación de puentes y vehículos. Se incluye porque define la clase de puente. Esta determina el diseño del puente. Las tablas de diseño en la segunda sección extraída se basan sobre la clase de puente.

El segundo extracto, del capítulo 7, describe el diseño de superestructuras de puente de madera rectangular, madera cilíndrica ó de vigas de acero. Se describe el diseño de

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économique pour construire un pasage à gué dans une rivière quand la pente de la route exclut l'emploi d'un ponceau.

Le troisième texte, ***Design and Construction of Low Water Dips*** (Conception et construction de radiers pour le franchissement de basses eaux), est extrait de ***Construction and Maintenance Bulletin No. 6*** (Texas Highway Department, Mai 1951). Il décrit un radier construit sur un ponceau. Ce genre de radier permet le franchissement à sec durant les périodes de débit normal et est submergé quand la rivière est en crue.

Le texte comprend aussi une formule pour calculer la longueur des courbes de profil en long de la route à l'accès des radiers. Les données nécessaires pour le dimensionnement d'un radier son énumérées. Les différences de niveau correctes entre la route et le fond du lit de la rivière sont données. Une méthode de protection contre l'affouillement durant les périodes de crue est expliquée en détail. L'installation de jauges pour mesurer les crues est décrite.

Les radiers peuvent constituer un élément permanent d'une route à faible capacité. Le coût de construction d'un radier devrait être comparé au coût de construction d'un ouvrage plus ordinaire. Les radiers sont toujours d'un coût plus modeste pour les rivières de grande largeur, mais pour une rivière étroite un dalot peut être plus économique.

Le quatrième texte est un résultat de recherches, *Causeways or Submersible* substructure design of timber bents, pile bents, or pile piers is described. The selection and design of each part are given step-by-step, using tabulations included in the text. In addition, graphs based on the bridge classes described in Chapter 5 simplify the design procedure. Abutment design is also included.

The sixth text consists of several excerpts from *The Bailey and Uniflote Handbook* (Acrow Press, Fifth Edition, 1974). The background of Bailey equipment is explained. Two examples are given to assist the engineer in the selection of a suitable Bailey bridge. The design tables for shear and bending needed to use the examples are included.

The seventh text is Chapter VII, *Potential Cost-Savings in the Design of Water Crossings,* from *Opportunities for Cost Reduction in the Design of Transport Facilities for Developing Regions* (Institute for Transportation and Traffic Engineering, 1970). It investigates the potential economies of many different water-crossing facilities. This text provides an economic evaluation of the data presented earlier in Compendium 3 and now in Compendium 4. The report offers economic guidelines which should help in the selection of the proper low-cost water crossing for various situations. The cost comparisons are based on 1979 prices. Therefore, the highway planner should update these prices to those in effect at the time and for the location under consideration.

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subestructuras de puente de entramados de madera, entramados de pilotes ó pilares de pilotes. La selección y diseño de cada parte se presenta en un procedimiento paso por paso utilizando tabulaciones incluídos en el texto. Gráficos que utilizan las clases de puentes descriptas en el capítulo 5 simplifican el procedimiento de diseño. Se incluye el diseño de estribos.

El sexto texto consiste en varios extractos de *The Bailey and Uniflote Handbook* (Manual del Bailey y Uniflote, Acrow Press, Quinta Edición, 1974). Se introduce los antecedentes del equipo Bailey. Se describe la selección de un Puente Bailey apropiado con dos ejemplos para asistir al ingeniero. Se incluyen las tablas de diseño para el esfuerzo cortante y combadura que se necesitan para utilizar los ejemplos.

El séptimo texto es el capítulo VII, *Potential Cost Savings in the Design of Water Crossings* (Ahorros de costo posibles en el diseño de travesías de agua, Institute for Transportation and Traffic Engineering, 1970). Investiga los ahorros posibles de muchas distintas clases de travesías de agua. Este texto provee una evaluación económica de los datos presentados en éste y el compendio 3, *Pequeñas Estructuras de Drenaje.* El informe ofrece pautas económicas que ayudarán en la selección de travesía de agua correcta de bajo costo para una gran variedad de circunstancias. Las comparasiones de costo se hacen con precios del año 1970. El planificador vial deberá actualizar los precios al momento y en la ubicación bajo consideración. El texto subraya la importancia de seleccionar la travesía más económica posible.

Bridges (Levées ou ponts submersibles). Il est extrait du Journal of the Indian Roads Congress, Vol. 16, No. 3, Avril 1952. La définition d'une levée est donnée: c'est un pont submersible qui traverse une rivière et qui est conçu de façon à ce que pendant la saison séche le cours d'eau passe entièrement sous le pont par des canalisations construites sous la route. A l'occasion, quand la rivière est haute, l'eau passe à la fois dans ces canalisations et submerge la route à une telle profondeur que le trafic routier est arrêté. Les levées fonctionnent comme les radiers dont nous avons parlé dans le texte no. 3 mais elles sont conçues pour les débits beaucoup plus importants de grands fleuves. Aux Indes, les problèmes hydrauliques occasionnés par ces grands volumes d'eau ont causé plusieurs fois la rupture de ces levées. Cet article a pour but l'étude de la cause de ces échecs. L'ingénieur qui doit dimensionner un pont submersible important devrait étudier avec soin les conclusions.

Le cinquième texte est le chapitre 5 et la section 1 du chapitre 7 du manuel *FM5-34: Engineer Field Data* (Donné es pour le Génie) (U.S. Army, 1976). Le chapitre 5 concerne la designation des ponts et des véhicules. Ce chapitre est inclus parce qu'il donne une définition de la classification des ponts. La classe d'un pont determine le calcul de cet ouvrage. Les tables de calcul dans la section 1 du chapitre 7 sont basées sur la classe du pont.

The text stresses the importance of selecting the most economical crossing.

The eighth text consists of an excerpt from Section 14,—*Bridges, Viaducts and Ramps*— of the *Handbook of Highway Engineering* (Van Nostrand Reinhold Co., Robert F. Baker, editor, 1975). It describes the differences between AASHO and other common bridge-loading criteria. It also mentions earthquake considerations and overloads. This text cautions the reader that all bridge-loading criteria are not the same. The timber and Bailey bridge designs presented in this compendium are basic, proven designs that can be safely used on low-volume roads. The subject of this selected text becomes more significant when major bridges are being considered. However, the low-volume road engineer should be aware that many different loading criteria for bridges are in use throughout the world. These criteria are described in detail in reference 9 (see Bibliography).

Bibliography

A brief bibliography containing reference data and abstracts for 16 publications follows the Selected Texts. The first seven describe the Selected Texts. The other eight describe publications that are closely related to the Selected Texts.

Although there are many other articles,

El octavo texto consiste en un extracto de la sección 14, *Bridges, Viaducts and Ramps* (Puentes, viaductos y rampas) del *Handbook of Highway Engineering* (Manual de Ingeniería, Vial Van Nostrand (Reinhold Co., Robert F. Baker, editor, 1975). Describe la diferencia entre los criterios de carga de puente de la AASHO y otros criterios comunes de carga de puente. También menciona consideraciones de terremotos y sobrecargas. Este texto se incluye para advertir al lector que no todos los criterios de carga de puente son iguales. Los diseños de puente de madera y Bailey presentados en este compendio son diseños básicos comprobados que pueden ser utilizados sin peligro en caminos de bajo volúmen. El tema de este texto seleccionado se vuelve más significante cuando se consideran puentes mayores. Sin embargo, el ingeniero del camino de bajo volúmen debe tener en cuenta de que hay muchos distintos criterios de carga para puentes utilizados en todo el mundo. Estos varios criterios de carga se describen en detalle en la referencia 9 de la bibliografía.

Bibliografía

Se sigue a los textos seleccionados con una breve bibliografía que contiene datos de referencia y abstractos para 16 publicaciones. Los primeros 8 describen los textos seleccionados. Los otros 7 describen publicaciones que se asocian intimamente con los textos seleccionados.

Aunque hay muchos artículos, informes, y libros que pudieron haber sido detallados en la bibliografía, no es el propósito de ésta contener todas las posibles referencias para

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Le passage du chapitre 7 décrit le calcul des superstructures de pont en bois (poutres rectangulaires ou circulaires) et des ponts en acier. Le calcul des infrastructures (palées en bois, palées de pieux, piles de pieux) est donné. La sélection et le calcul de ces élément sont éxpliqués pas à pas, en utilisant les tables incluses. En outre, des graphiques, basés sur les classes de ponts décrites dans le chapitre 5, simplifient le calcul. Le calcul des culées est aussi inclus.

Le sixième texte consiste en quelques passages du livre, *The Bailey and Uniflote Handbook* (Le guide des ponts Bailey and Uniflote), publié par Acrow Press, 5e édition, 1974. L'historique du matériel Bailey est expliqué. Pour aider l'ingénieur deux éxemples sont donnés qui justifient le choix du pont Bailey convenable. Les tables de calcul de cisaillement et de déflexion nécessaires pour utiliser les exemples donnés sont incluses.

Le septième texte est le chapitre VII, *Potential Cost-Savings in the Design of Water Crossings* (Economies potentielles dans le calcul des franchissements d'eau) du livre, *Opportunities for Cost Reduction in the Design of Transport Facilities for Developing Regions,* (Institute for Transportation and Traffic Engineering, 1970). Ce texte éxamine les differentes sortes d'ouvrages de franchissement d'un point de vue économique et présente une évaluation économique de toutes les données incluses dans les recueils 3 et 4. Des régles pour estimer le prix de revient de l'ouvrage d'art reports, and books that could have been listed, it is not the purpose of this bibliography to contain all references related to the subject. 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.

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el tema. La bibliografía contiene unicamente aquellas publicaciones de las cuales se seleccionó texto o las publicaciones básicas que hubieran sido seleccionadas si no hubiera un límite al número de páginas en este compendio.

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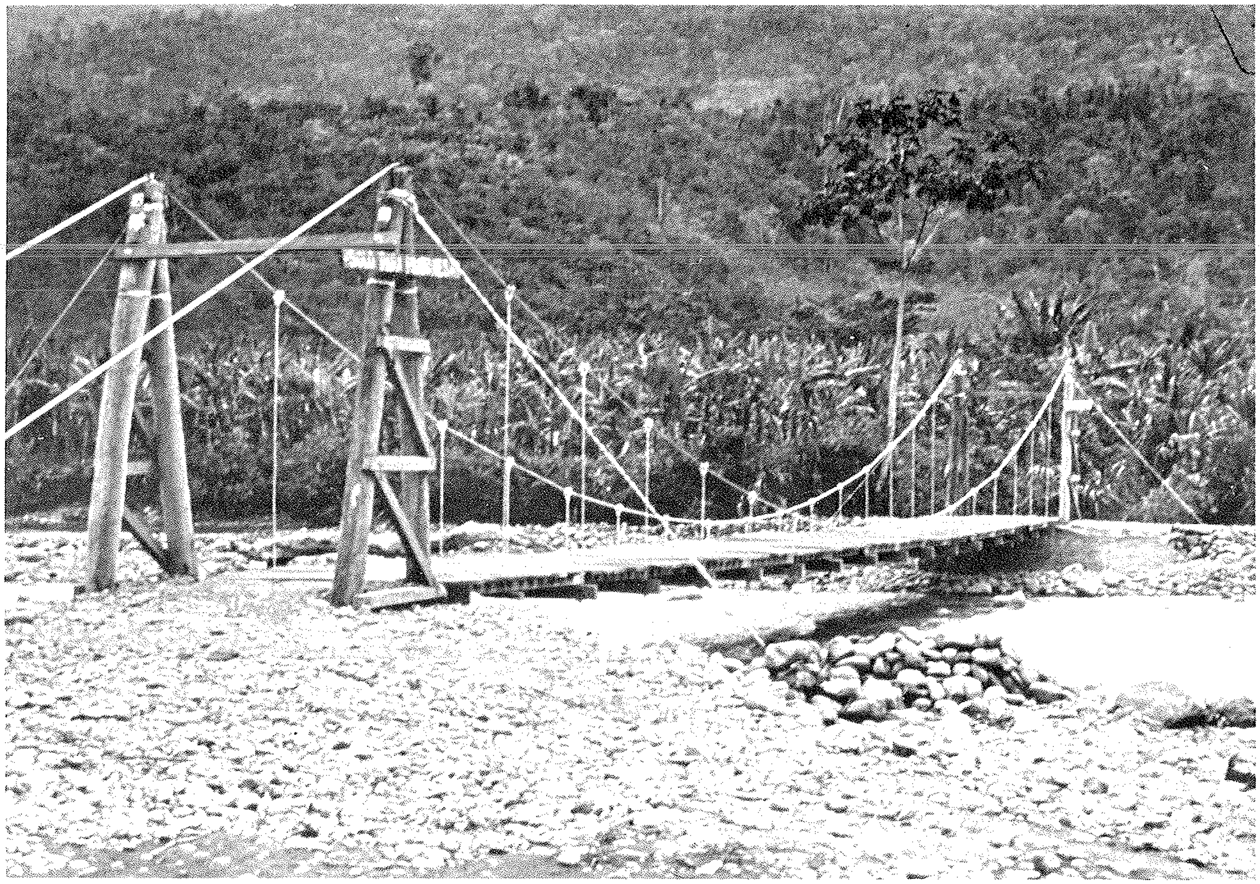
convenable pour un éventail de situations, sont offertes. Les comparaisons du coût sont basées sur les prix de 1970 et il faudra que ingénieur planificateur tienne compte de cela et utilise les prix en vigueur à l'époque et à l'endroit qu'il considéra. Le texte met l'emphase sur l'importance de choisir l'ouvrage de franchissement le plus économique.

Le huitième texte est extrait de la section 14 de ***Bridges, Viaducts and Ramps*** (Ponts, viaducs et rampes) de ***Handbook of Highway Engineering*** (Van Nostrand Reinhold Co., Robert F. Baker, editor, 1975). Ce texte explique les différences qui éxistent entre les critères de charges d'AASHO et les critères de charges d'autres systèmes communément adoptés. Mention est faite des tremblements de terre et des surcharges. Ce texte est inclus pour avertir le lecteur que les critères de charges ne sont pas tous les mêmes. Les ponts en bois et les ponts Bailey qui sont présentés dans ce recueil sont des ponts de base dont la valeur a été éprouvée, et ils peuvent être utilisés en toute sécurité dans les routes à faible capacité. L'étude de ce texte choisi devient encore plus importante quand on envisage de construire des ponts encore plus grands. Cependant, l'ingénieur routier, quand il conçoit une route à faible capacité, doit se souvenir qu'il existe un grand nombre de critères de charges dans le monde entier. Ces critères sont détaillés dans la référence no. 9 (voir la bibliographie).



This cable suspension foot bridge is located in Caranavi, Bolivia.

Bibliographie

Le brève bibliographie qui suit les textes choisis fournit les références et des analyses de 16 publications. Les 8 premières se rapportent aux textes choisis et les 7 autres à des publications dont le sujet est étroitement rattaché à celui des textes choisis.

Bien qu'il y ait beaucoup d'autres articles, rapports et livres qui pourraient être inclus, l'objectif de cette bibliographie n'est pas d'énumérer toutes les références possibles ayant rapport au sujet de ce recueil. Donc, notre bibliographie, telle quelle, se rapporte seulement aux publications dont nous avons choisi des extraits, ou aux textes de base que nous aurions choisi aussi s'il n'y avait pas de limites quant au nombre de pages de ce recueil.

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:

*Some pages (or parts of pages) in this part of

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Esta sección del compendio contiene páginas seleccionadas de cada texto que se catalogaron en la Tabla de Materias. Se utilizan recuadros rectangulares para encerrar las páginas que han sido reproducidas de la publicación original. Algunas de las páginas originales han sido reducidos para entrar en los recuadros. No se han hecho ningunos otros cambios en el material original exceptuando algunas notas aclaradoras que de vez en cuando han sido agregadas. De esta forma, cualquier error que hubiera existido en el texto seleccionado ha sido reproducido en el compendio mismo.

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

* Algunas páginas (o partes de páginas) en

Textes Choisis

Cette partie du recueil contient les pages sélectionnées de chaque texte qui est énuméré dans 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.

La pagination originale apparaît à l'intérieur de l'encadrement. La pagination du recueil est à l'extérieur de l'encadrement, soit à droite, soit à gauche de la marge extérieure des pages et est celle qui est citée dans la table des matières et dans l'index du recueil.

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:

* Certaines pages, ou portions des pages,

the original document appear in the selected text, but other pages (or parts of pages) in this part of the original publication have been omitted.

**All pages in this part of the original document appear in the selected text.

The selected texts therefore include only those parts of the original documents that are preceded by asterisks in the tables of contents of the respective publications.

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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esta parte del documento original aparecen en el texto original, pero otras páginas (o partes de páginas) 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 unicamente 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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dans cet extrait du document original sont 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 le personnel attaché à ce projet. Ces explications sont entourées d'un encadrement en pointillé et commencent toujours par le mot NOTE.

Handbook of

Methods and Procedure For Low Cost Service Roads

by JOHN E. BLAIR
District Engineer, Texas Highway Department

Published by Texas Highway Department for free distribution to local, county, and state road officials, pursuant to House Concurrent Resolution No. 15 of the 49th Texas Legislature.

TABLE OF CONTENTS

Chapter Two

DRAINAGE

Perhaps the thing that should be emphasized at this point is that the road supervisor should be careful to do first things first. No effort should be made to bring an earth road to final grade until drainage has been properly taken care of, and no start should be made toward placing any kind of surface until the graded road is ready for it.

It is commonplace to say that good drainage is the first essential of a good road, but it is important to know just what is meant by good drainage. To put this in simple terms, suppose we say that a road should be so graded and shaped that water falling on it, or reaching it by running down from higher ground, will drain away. The simplest arrangement that will secure this result is the best.

A culvert should be put in every natural drain that will lead water away from the road. There is always a temptation to economize by leaving out some of the culverts, leading water in the side ditches to another culvert lower down. This often results in great damage due to erosion by the running water, so that maintenance expenses are excessive, and even the road itself may be destroyed, and have to be moved over out of the gully that will finally be formed.

Erosion in a ditch depends entirely on three things: First, the slope of the ground; Second, the nature of the soil; and Third, the volume of water that the ditch carries. Nothing much can be done to change the natural slope of the ground, or to modify the soil type, but a great deal can be done to reduce the volume of water to be carried. Doubling the amount of water running down a certain ditch will much more than double the damage done, and it is worth a considerable expense to get as many extra culverts in the road as possible. In many cases landowners will insist on having water diverted from their property and carried to some other culvert elsewhere, that will discharge on land belonging to some one else. This is wrong, both legally and morally, and the road builder who tampers with the natural flow of water in the channels that nature has provided is on unsure ground.

No extreme precautions need be taken to see that every culvert is large enough to carry the water that comes to it under any and all conditions of rainfall. No great harm is done ordinarily if water flows over a local road now and then, and if culverts of a suitable type are used it is easy to replace one that has been found to be too small, or to put in another one alongside. The nature of rainfall is such that cloudburst rains are usually of small extent, covering only a limited area. For this reason small culverts must be larger in proportion to the area they drain than bridges which take care of larger streams.

There are several formulas which purport to give a means of calculating the size of culvert required from the size and kind of area to be drained, but it is to be questioned if such formulas have any value on farm roads. The runoff from a given area of land depends on a large number of variable factors, all of which have to be estimated, for example the shape of the area of land, its steepness, the kind of soil of which it is composed, whether terraced or not, whether pasture or plowed field. Small differences in the values assigned to any of these variable factors will give large differences in the result, and it is just about as accurate to determine the size of culvert needed by careful observation of conditions during and after rains.

Corrugated metal pipes will be found very satisfactory for use on the class of roads we are dealing with. These pipes are comparatively light in weight, and are easily handled and installed with inexperienced labor. They will stand rough handling without damage, and can readily be taken up and installed elsewhere if the occasion requires. They may be bought in sections of any convenient length, and can be connected into longer lengths by means of coupling bands made of the same material as the pipe. Various fittings, such as elbows, Ys, and Ts can be supplied, and these have many uses for special cases that may arise.

Other culverts may of course be used, and may be made of materials theoretically more durable than galvanized metal. Concrete pipe are excellent for small culverts, and as far as durability is concerned will far outlast pipe made of light metal. However, they are very heavy, and a crane or derrick of some kind will be needed to handle the larger sizes. Concrete or clay tile pipe are rather easily broken by rough handling, and must be laid on a solid foundation to prevent breakage due to possible settlement in the embankment.

There are some other practical considerations that must be taken into account when deciding what kind of culverts should be used. For instance, in our country where the hand of man has interfered so rudely with the balance of nature, erosion is constantly changing the surface of the land in an unpredictable way. Where the outlet channel below a culvert is fairly steep the tendency is for the channel to wash out, so that a culvert that was installed at the level of the stream bed may later be found to have a considerable drop at its outlet end. This results in a narrowing of the road at this point, and the culvert must be lengthened to offset it. The culvert may be taken up and relaid at a lower elevation, adding a section to allow for the greater height of fill over the pipe, or a

DRAINAGE

drop outlet arrangement may be added to it by means of elbows and coupling bands.

On the other hand, where the fall in the stream bed is slight, soil washed down from cultivated land above will tend to fill up the channel, resulting in stopping of the culvert. This means clean out the stream bed below the road, (not always possible, due to objection by the landowner) or take out the culvert and raise it to a higher grade. Again, the light weight pipe lends itself readily to any change needed. An expensive masonry culvert that has to be raised or lowered to compensate for changes brought about by erosion is a tough proposition to handle.

It is false economy to use culverts that are too short. Never put in a culvert so short that it causes a narrow place in the road. The few dollars saved by this are not worth saving. Be sure to add enough length to allow for the side slopes of the fill, and cover the pipe deep enough with earth or gravel so that it will be protected from contact with the wheels of vehicles. Headwalls will not be required if the pipe is long enough.

Small culverts are easily obstructed during rains by catching corn stalks, weeds, brush, and other such trash, and the upper end of all culverts should be inspected after every rain to see that they are open. Except for this, pipe culverts when correctly installed will need no attention or maintenance, and will last a long time.

Larger structures are one of the most troublesome features on the typical local road. Many of these are of untreated timber, requiring heavy expense for maintenance. Almost the entire revenues of some county road departments are consumed by the never-ending replacement of planks on such bridges. The case is similar to that of a man rowing a leaky boat; if the leak is big enough he will spend all his time bailing out the water, and will never get anywhere until he can get the leak stopped. Some means must be found to stop some of the expense of bridge repairs if poor country road districts are to get themselves out of the mud.

For the average small stream the best and most durable type of bridge that can be constructed probably is reinforced concrete. Such bridges, if properly built, will last forever, so far as we know. They do not decay, and are not subject to destruction by fire. However, this is another case where practical considerations must be taken into account.

Some local road authorities have embarked on an extensive program of concrete bridge and culvert construction, but the results in many cases have been very discouraging. Although good concrete will probably last forever, it does not necessarily follow that a structure built of concrete will last forever, or even for a few years.

The mixing and placing of concrete is not a hit or miss affair, but is a highly technical operation. The proportions of gravel, sand, cement, and water must be very carefully worked out. Building the forms is a job for highly skilled carpenters, and the steel must be properly proportioned to carry the loads, and must be securely held in its intended position while the concrete is placed. Thousands of concrete structures have been built in which poor materials were used, and on which the workmanship was so inferior that the entire investment was lost within a short time.

Concrete bridges which rest on piers depend for their stability on an extremely solid foundation, and it is very hard to get the untrained foreman to realize the importance of this. Piers are often set on poor material, and the general tendency is not to carry them deep enough below the stream bed. Foundation excavation must often be done in mud and water, with the result that the men give up too soon, and the foundation undermines, destroying the bridge. In case a structure undermines in the way described the whole thing is usually a total loss, or worse, since it is often expensive to get it out of the way. In case a concrete bridge is abandoned for any reason, such as a change in location, the salvage value of the bridge is exactly nothing. So unless you have an engineer experienced in this kind of work, you had better let this type of bridge alone.

Owing to the extreme difficulty of securing a solid foundation where expert supervision is not available, the pile type of foundation will prove simplest and cheapest to construct in the majority of cases. Many different kinds of superstructure can be put on piles, and bridges of this kind have many advantages that should recommend them highly for use on farm roads.

The construction of a pile driver is a very simple matter, and a good general rule is that piles should always be driven, never planted in post holes. Of course, in some cases, the formation in the bed of a stream is too hard to drive piles, and in such cases some other plan must be used. For the present, however, we will confine ourselves to a discussion of piles.

On the whole it will be found that the best piles for use in farm road bridges are of creosoted timber. Files of this kind have been known to last in railroad bridges, docks, etc. for as much as fifty years. If good piles are bought, and proper care taken in driving them, they can confidently be expected to last for not less than twenty years, and possibly for much longer. Local authorities should consult their State Highway Department or other qualified agency in regard to specifications under which creosoted timber should be bought, and should make their purchases accordingly. Good material costs only a trifle more than inferior stuff, and the cost of labor for erecting the bridge is the same in either case.

A pile hammer for driving piles should preferably weigh not less than 1,500 pounds, and the driver should be so constructed that the hammer can be allowed to drop at least fifteen feet on the pile at the time driving is concluded. With this kind of arrangement piles that are driven to refusal will bear any kind of load they will be called on to carry on this kind of bridge. More pile bridges fail because of the piles not being deep enough in the ground than from any other cause, so be sure to get them as deep in the ground as possible. Remember that a bridge usually restricts the channel to some extent, causing a swifter current under the bridge than at other places in the stream. This leads to scour, and piles that appeared to be deep enough are often undermined due to this cause.

It is not uncommon to find that the formation in the bed of a stream is too hard to drive piles to the depth considered advisable, and this situation poses a difficult problem. Unless the formation consists of solid ledge rock, concrete or masonry piers should not be used. Every effort should be made to get the piles down. Remember that even though the formation is too hard to drive piles, it may be easily scoured away by a swift current of water, even though the piles are below the existing bed of the stream. Some of the freakish things that a current of running water will do have to be seen to be believed.

In cases of this kind the piles can often be driven very easily to any desired depth by means of a water jet. A power driven pump capable of delivering a large volume of water at rather high pressure will be needed. The outlet of the pump is connected by means of a hose to a joint of pipe through which the water is forced. The point of this pipe is pushed vertically down into the ground at the point where it is desired to drive the pile, and the high speed stream of water will wash a hole into which the pile can be driven. Such a stream will cut heavy shale, hardpan, cemented gravel and similar substances. A section of railroad rail can be used to assist the jet, working the rail up and down in the same way as cable tools are used in drilling a well. The pile driver is very convenient for handling the jet or the drilling tool. Even a hole no more than four or six inches in diameter will often permit the pile to be driven.

Whatever trouble it takes, get the piles down deep enough to be safe against any possibility of undermining.

There are several ways of raising a pile hammer for securing the required drop. If a good deal of work is to be done a power driven winch is undoubtedly the best equipment. However, perfectly satisfactory work can be done with a truck, a tractor, or even a good team of mules. A cast iron follow block, made with slots on the sides to slide up and down in the leads, and recessed on the under side to hold the head of the pile, is a great convenience. This holds the pile in position, and saves a great deal of time and trouble.

For bridges with a roadway width of more than about fourteen feet, four piles should be used for each bent. For narrow bridges three will be enough.

In order to be sure that timber piles will give the maximum service life, certain care must be taken in handling and driving them. Creosote does not penetrate into the entire timber, but there is always an untreated heart or core. If the pile is cut or damaged in any way so as to expose this untreated core, rot will start at that point, and the life of the timber will be greatly reduced. In order to prevent this piles should be handled in a careful manner to avoid injury to the creosoted outer layer. Of course each pile will have to be cut off at the top after driving, and this point must be carefully protected. Soak the top of the pile with creasote oil, pour a heavy treatment of hot asphalt on it, and then cover the whole head of the stick with a sheet of galvanized metal, large enough to be bent down on all sides of the pile.

It is important that all the piles be cut off at the same level, so that the cap will bear equally and evenly on all the piles. Pull or jack the piles into a good line before cutting them off, then nail a good straight plank on each side of the row with the top of the plank at the level of the cut. The piles are then cut off with a cross-cut saw, using the guide planks to keep the saw straight and level. Where nails are driven into the pile in this way, they leave holes at which rot may start. These holes should be repaired by whittling a small peg out of creosoted wood, dipping it in hot asphalt, and driving it into the hole. In case bolt holes must be bored to attach sway bracing, the hole should be bored to the exact size of the bolt that is to be used. The bolt should be dipped in hot asphalt and driven into the hole with a hammer. This seals out the air and moisture, and will prevent rot from getting a start.

10 The cap, or timber which rests directly on the piles, will usually consist of a piece of creosoted wood, about 10"x12" in size, and long enough to bear on all the piles of a single bent. The same care should be used in handling these timbers as for piles. The cap is generally fastened to the piles by means of drift pins, which consist of a piece of iron rod, sharpened on one end. These pins should be not less than two feet long, in order to reach through the cap and well into the head of the pile. A hole is bored down vertically through the cap just over the center of each pile, and the pin driven with a heavy hammer down through the cap and into the pile. This hole should be slightly smaller than the size of the drift pin, which should be dipped in hot asphalt before being driven. If it is necessary to cut the timber for any reason, the cut should be treated with creosote and hot asphalt to keep out the air and water.

Where the bridge may be expected to be overtopped with water during flood rains, the fastening above described is often not enough to prevent the deck of the bridge from floating off the piles. In such cases a strap of iron should be used to fasten the cap down securely to each of the piles. The best way to attach these straps is with lag screws, which are similar to ordinary wood screws but much larger.

A very common fault that can be pointed out in many bridges is the inadequate size and spacing of stringers. It is not unusual to find stringers of nominal 3"x12" size used on spans of as much as twenty feet, and spaced as much as three feet apart across the bridge. Although such a bridge may never actually break down under a load, its effective life is very short. Such stringers deflect excessively under a load that will not break them. This causes the stringers to work up and down, resulting in considerable friction and wear at the point where they rest on the cap. Rot sets in at this point, and the timber is soon useless. It is also very hard to keep the floor plank tight on such limber stringers, and the floor plank pump up and down, wearing out the planks as well as the tops of the stringers.

A good general rule is to use bents about 17 feet apart, so that stringers 18 feet long can be used, with each stringer having full bearing on the cap at each end. Use timber 4"x14" size, and space them not more than about two feet apart. These stringers should be fastened to the caps with toe nails, and if there is danger from overflows washing the deck away, a few hook bolts or other fastenings should be used to attach the stringers solidly to the caps, which in turn are anchored to the piles.

It is important to see that all the stringers are at the same level on top, so that a floor plank will bear evenly on every stringer in a panel. If this is not done, the floor plank will be very hard to keep tight. If one stringer is a little higher than the rest, turn it over and trim it a little at the ends, where it rests on the cap. Don't cut it off on top all along its length. This makes a bad job, is more trouble, and may affect the life of the timber.

Any kind of floor plank may be used, or concrete, but there is a good deal to be said in favor of using 2"x4" plank, laid on edge to make a floor 4" thick. As each of these planks is laid it is nailed to the one next to it, so that we have, in effect, a solid slab of wood 4" thick instead of a number of individual planks. This makes a very stiff floor, and helps to keep down vibration and movement in the structure. Small lumber of this kind costs less per thousand board feet than wider plank, so that a 4" floor can be laid to cost no more than one 3" thick made of wider and more expensive plank. The floor plank need not be long enough to cover the full width of the bridge. Any lengths of more than about four feet will do. The floor should also be creosoted, for long life, and if it shows signs of unreasonably rapid wear, a cover of asphalt and sand, or crushed stone, can be placed to prevent traffic from wearing it out. When so protected, the floor should last as long as the rest of the bridge.

When spans longer than 17' are required, for some special reason, very good results can be had by using steel I beams for stringers instead of timber. For spans up to about 22 feet use 12" I beams spaced about three feet apart, and for spans up to about 30 feet use 15" beams. Spans up to 50 feet or more can be readily built by using larger beams, say up to 25" in depth, and splicing them together so that the beam is continuous over three or more spans. Before trying to construct a bridge like this, however, a qualified structural designer should be consulted.

The principal trouble noticed in steel beam bridges is that they rattle and vibrate excessively due to the fact that the beams are not attached to the caps, and the floor is not attached to the stringers. The stringers can be anchored to the wooden caps by means of lag screws driven through holes in the bottom of the beams and into the cap. These holes should be drilled in the steel at the shop where the beams are bought. For attaching the floor plank to the beams there is a simple little clip of steel which nails to the floor plank, and has a notch to fit over the top flange of the beam. These are worth the money, since they prolong the life of the floor, and keep down the noise and clatter.

Steel truss bridges must be used for extremely long spans, especially where floating drift is to be expected, but these should be constructed only under the supervision of a qualified engineer. Truss bridges require considerable expense to keep them painted, and are subject to being destroyed or damaged by collision from heavy trucks.

It is poor economy to construct a bridge too short, even though it may be large enough to take the water. As already mentioned, a bridge restricts the channel to some extent, causing the current at the bridge to flow faster than at other places in the stream. This increased velocity often leads to undermining the piles or the bulkheads which will fill at the ends of the bridge. It is always a hard job to make repairs on a washed out bulkhead, and it disturbs the road, so it is a good plan to make a bridge a little longer than seems to be necessary, and get the ends of the bridge back away from the current. The cost of constructing the longer bridge will be saved over a period of years in the cost of maintaining and replacing the bulkheads, the embankment, etc., and traffic will not be tied up so often due to these washouts.

Since bulkheads should be expected to last for the full life of the bridge, they should be very solidly constructed. Use creosoted plank at least 4" thick, and lay them as tight as possible, to prevent the backfill from getting out through the cracks. The bulkhead should go well down into the ground to avoid undermining, and the wings should extend far enough out to each side so that the fill will not be likely to slump off and make a narrow place at the end of the bridge.

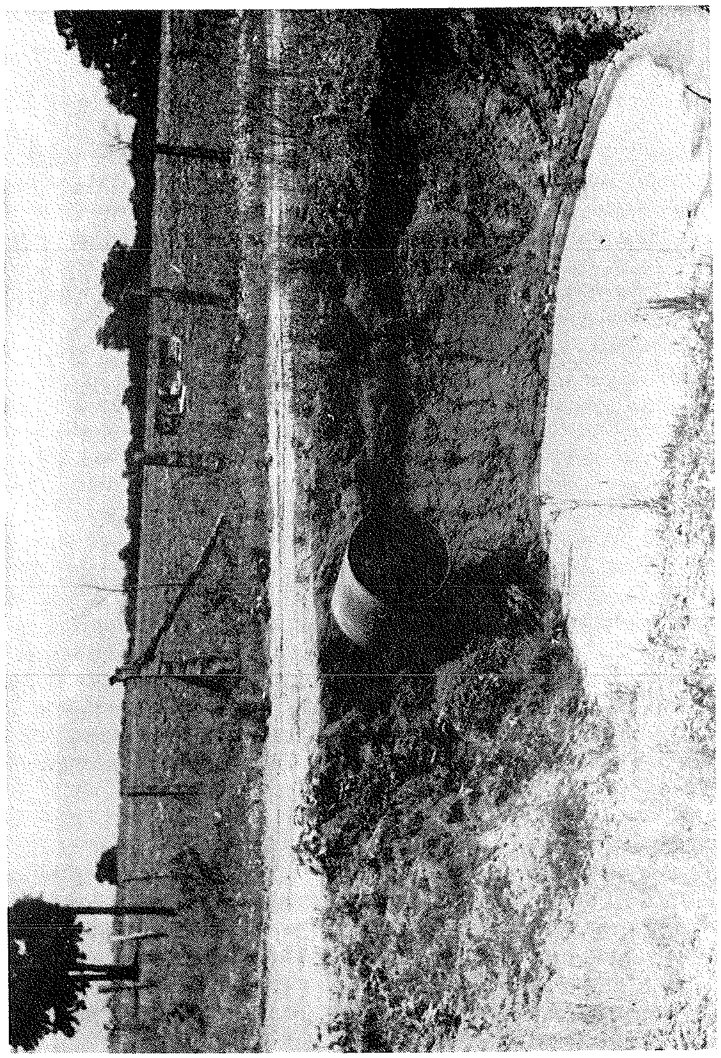
Keep in mind that in constructing a new bridge such as has been described, a good deal of money must be spent at one time. In order to justify this cost the bridge must last for at least twenty years, and to make sure of this all the work must be well and faithfully done. Slip-shod methods and "jerry building" will merely waste money.

Timber structures have one serious disadvantage. They are subject to destruction by fire, and care must be taken to see that weeds, driftwood, grass, etc., are not allowed to accumulate in such a way as to create a hazard.

DRAINAGE

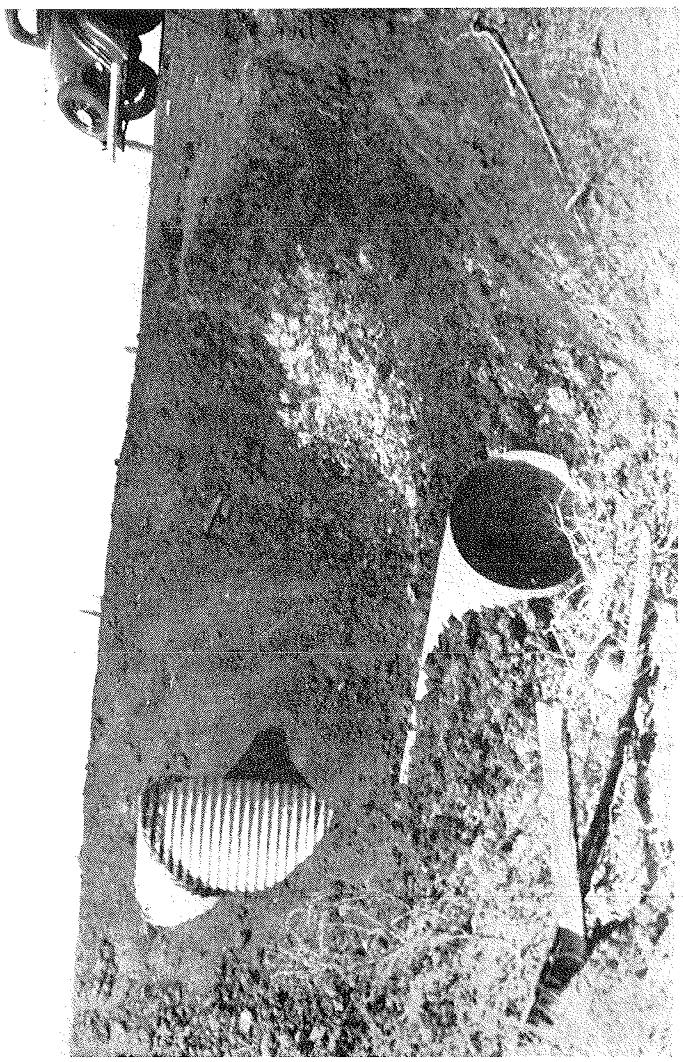
The arrow shows where a natural drain formerly crossed this road. In order to save the cost of a culvert the drain was filled in and the water carried ahead in the left ditch to another culvert lower down. Notice the large ditch that is forming. In the long run this ditch will cost more to deal with than was saved by leaving out the culvert.

DRAINAGE



This pipe culvert was set too high, causing a large hole to scour out at the lower end. It will be necessary either to lower the culvert, or to lengthen it, and provide a drop outlet at the lower end.

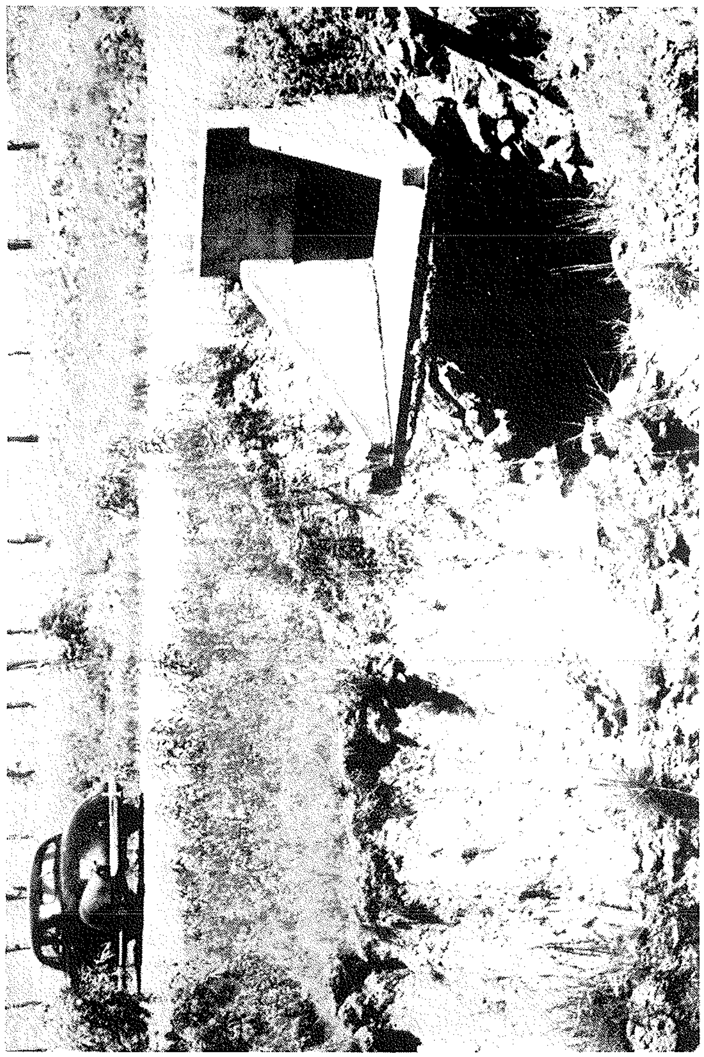
DRAINAGE



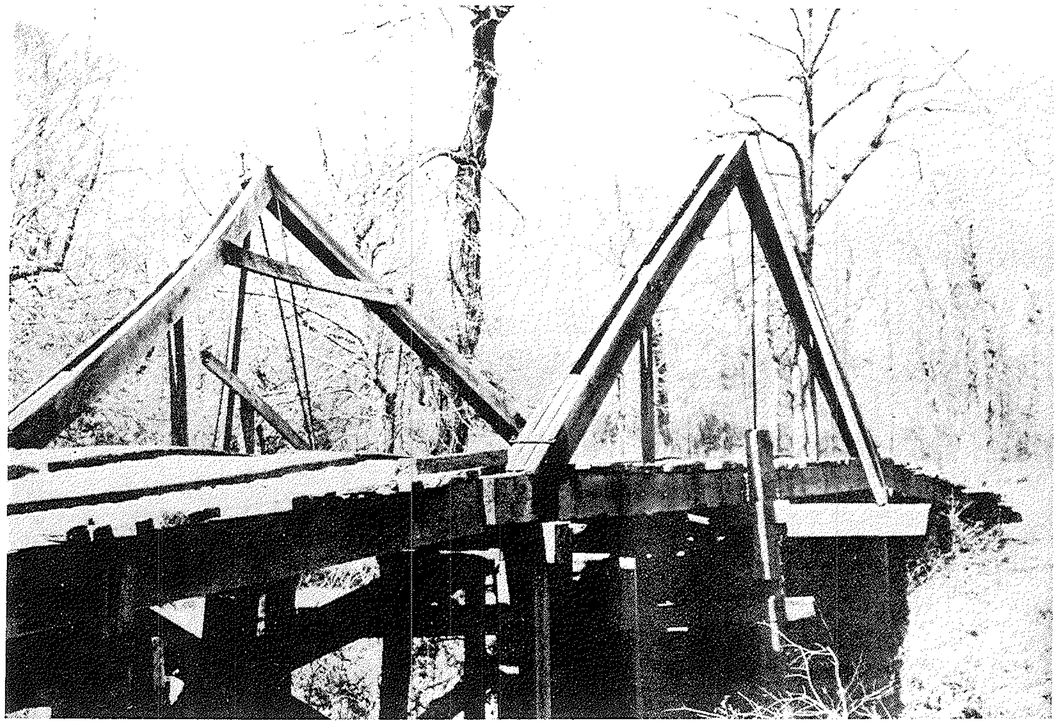
This pipe culvert shown here was originally installed too high, so that a large gully formed below, and left a narrow place in the road. An extension and drop outlet have been added, using pipe elbows and coupling bands, and the fill widened again to its original width.

16

DRAINAGE

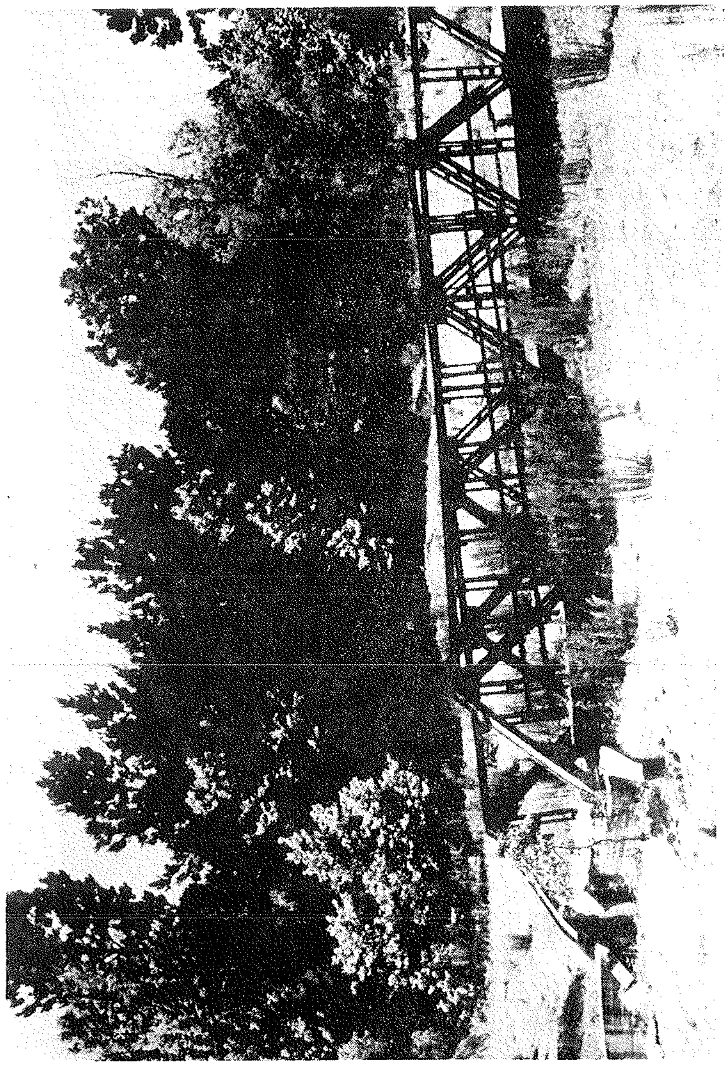


The lower end of this culvert has undermined due to the fact that the outlet ditch had a rather steep fall, and the culvert was set too high at the time it was constructed. To lower this culvert, or to construct a drop outlet on its lower end, would be quite a job.



This bridge is typical of thousands to be found on farm roads throughout the country. Made of untreated timber, and very poorly constructed, it is a source of constant trouble and expense.

DRAINAGE

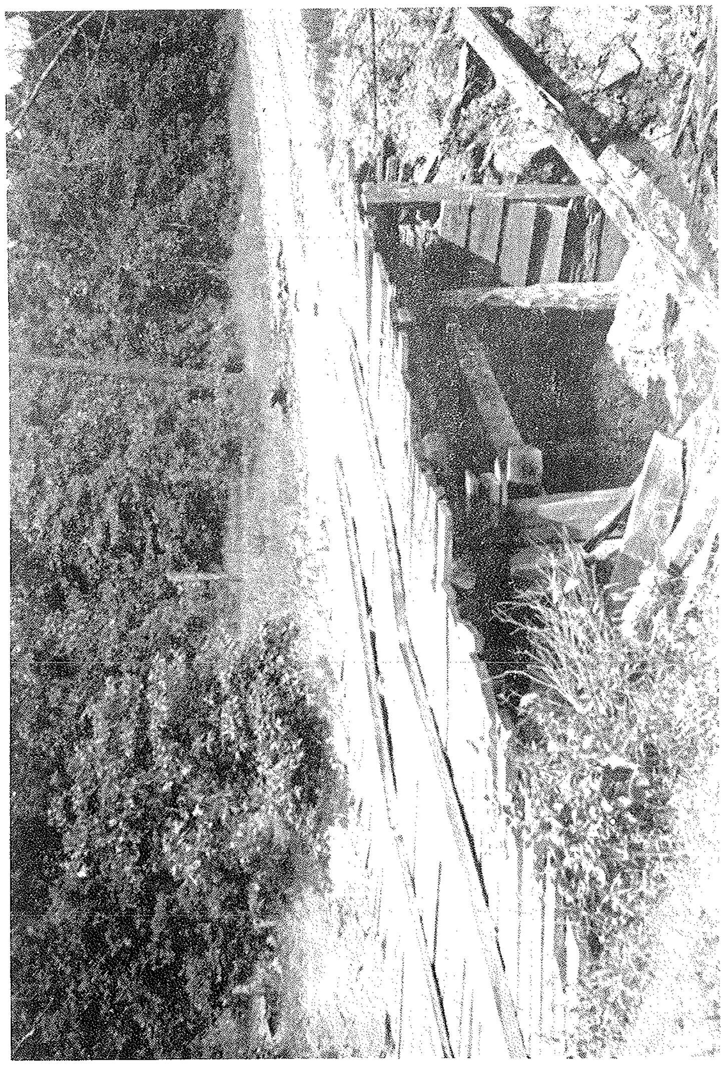


Showing a steel truss bridge with a concrete floor, resting on concrete abutments at each end. One abutment has failed by undermining, due to the fact that it was not set deep enough in the ground. Bridge is a total loss, and has been abandoned.

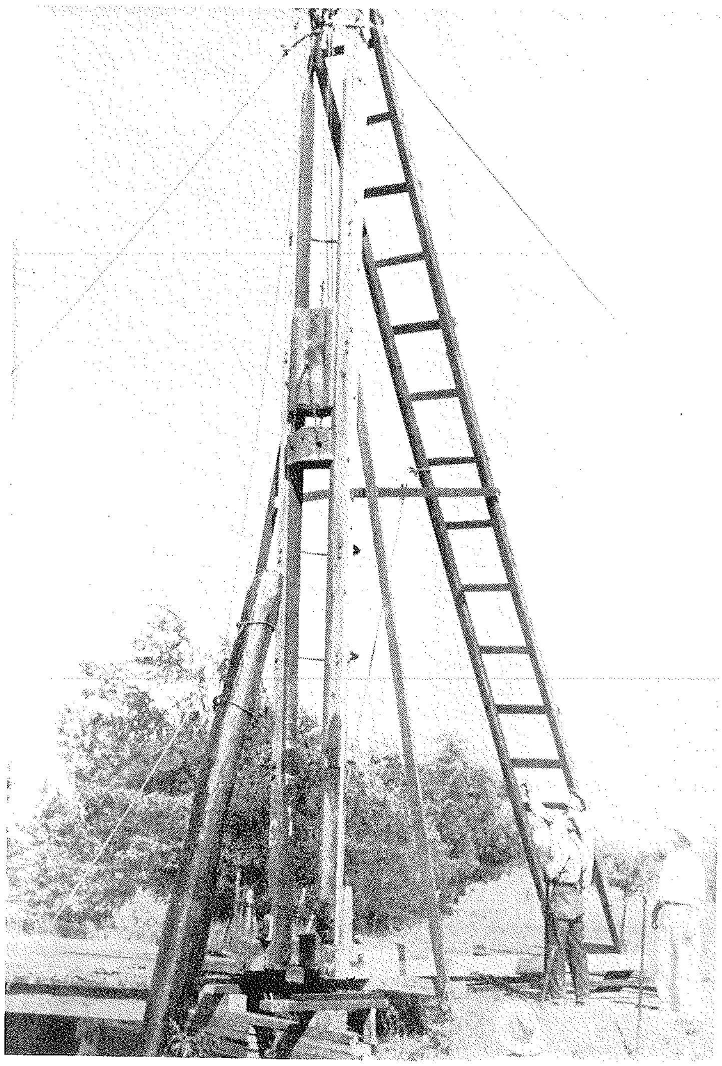
DRAINAGE

This is hardly a typical bridge, although there are many like it on farm roads.

DRAINAGE



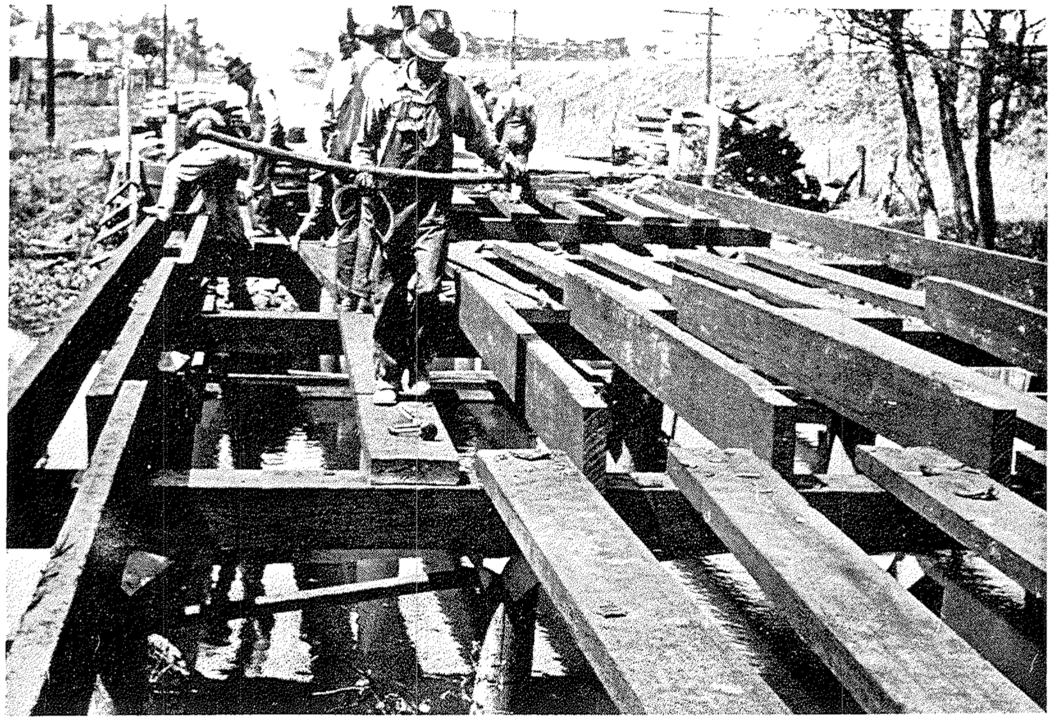
This is typical of thousands of bridges on farm roads. It is poor economy to try to get along with such bridges, since the upkeep cost is a constant drain on road funds.



A simple and easily constructed pile driver. A pile is being hoisted into position, while the hammer and follow block are held up out of the way. Almost any kind of suitable power may be used for raising the hammer. In this case a double drum winch, off to the left and not shown, is the power used. The line on one drum handles the hammer, and the other is used for picking up the pile.

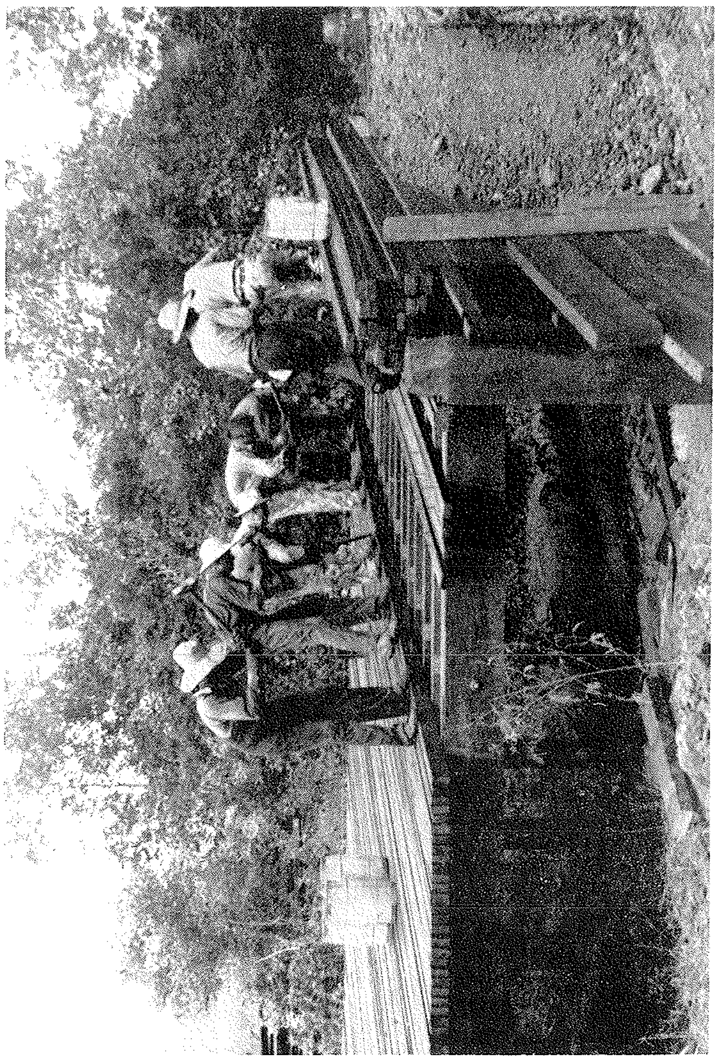
DRAINAGE

Small crain used as a Pile Driver.



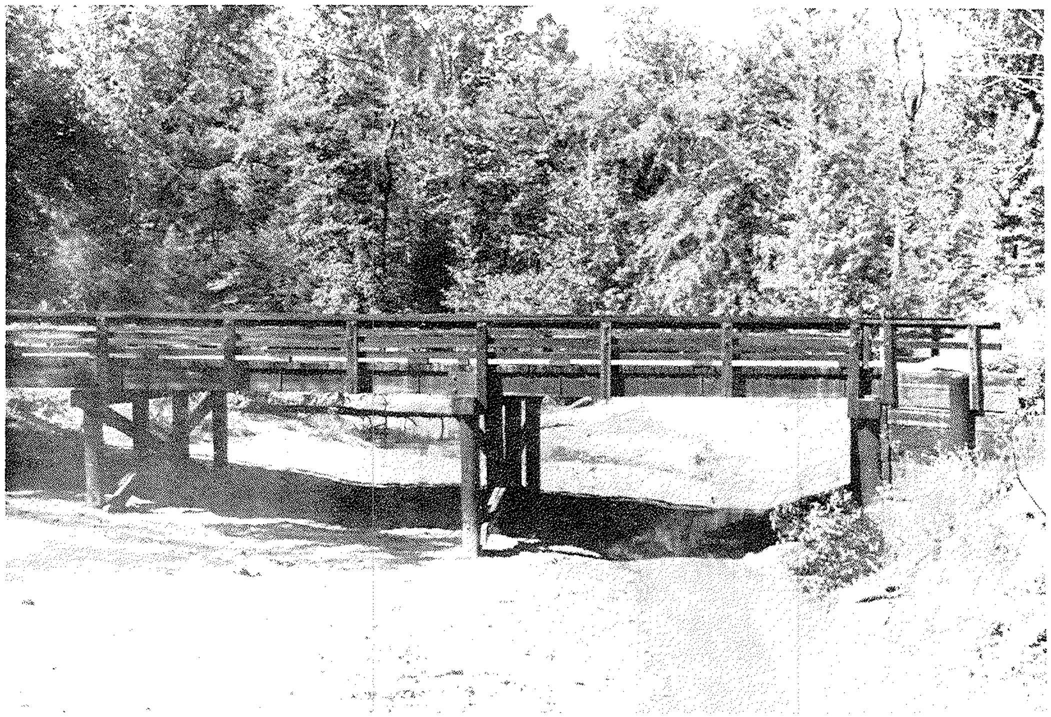
Placing the stringers on a creosoted timber bridge. Piles have been driven, cut off, and capped.

DRAINAGE



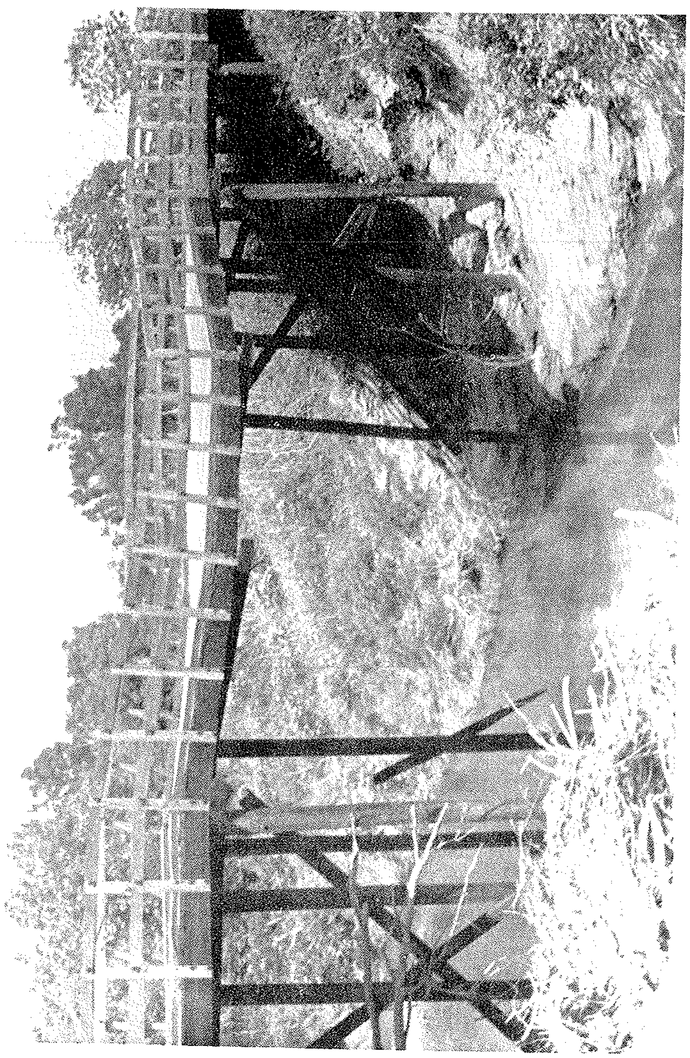
Construction of a creosoted timber bridge. Piles have been driven, caps and stringers placed, and the men are placing the 2''x4'' wooden floor plank. These planks are nailed to one another, and toenailed to the stringers, making a very strong and stiff floor. Bulkhead wall is not yet completed.

Showing what may happen to a steel truss span due to collision from a vehicle. This light car, driven at high speed, got out of control and struck one of the main members of this truss with great violence, causing collapse of the entire span. One life was lost, and a farm road was closed to all traffic for a long time.



A well constructed bridge of creosoted lumber, set on creosoted timber piles. The only suggestion here is that it would have been a good idea to add another span at the right, to get the bulkhead back further from the current. The deepest part of the channel is at the right, causing the swiftest part of the current to run near the right hand bulkhead, with danger of scour and undermining.

DRAINAGE



A well constructed bridge of creosoted timber which failed due to the fact that the piles were not driven deep enough below the stream bed. Two bents were undermined and destroyed.

28 Temporary drift (ford), East-West Highway, Nepal.
(Photo courtesy of TRRL, UK)

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Field Notes

Volume 5 Numbers 5 and 6
May-June 1973

A Method for Determining Riprap Specifications

Terrence R. Lejcher

**Use of Gabions for Low Water Crossings on Primitive or Secondary Forest Roads

Allen D. Leydecker

FOREST SERVICE ● U.S. DEPARTMENT OF AGRICULTURE

USE OF GABIONS FOR LOW WATER CROSSINGS ON PRIMITIVE OR SECONDARY FOREST ROADS

By Allen D. Leydecker
Civil Engineer, Modoc National Forest

During the past 3 years, the Modoc National Forest, in northern California, has been constructing gabion low water crossings with very satisfactory results.

One of these designs has proven to be both economical and aesthetically pleasing on our secondary and primitive roads. Basically, the road at the water crossing is designed to give good line and grade through the stream. The final elevation of the low point of the parabolic grade line is usually 6 to 12 inches above the stream bed elevation at the downstream edge of road. We use 6′-6″ X 3′-3″ X 3′-3″ gabions. These gabions are placed at the final grade line with the upstream edge of the gabion alongside the downstream edge of the road. The gabions are backfilled and stream gravel is pushed up behind the gabions to form the running surface (see fig. 1). Essentially, the gabions form a 6- to 12-inch high, porous dam which retains the stream gravel.

The major expense involved in this type of water crossing is in placing and filling the gabions. The wire baskets themselves cost only $15 to 20 each. We found that buying gabion rock and transporting it to the site is less expensive and time consuming than locating and using on-site rock.

Construction is usually straight forward. A 4-foot trench is dug along the downstream edge of the road. Bottom elevation of the trench should be final road elevation minus the depth of the gabion ±0.1 foot. The gabions are wired together on the surface then dropped into the trench. The center gabion is filled, usually with a front-end loader. Using this center gabion as an anchor, the line of gabions is pulled taught and straightened by a chain come-a-long attached to a truck. As shown in Figure 2, tension is kept on the gabions while filling. After all the gabions are filled, final adjustments are made in the top course of rock and the baskets are wired closed. Backfilling completes the job.

In about a year's time, fines transported by the stream cement the gravel backfill and construction scars heal, leaving a satisfactory stream crossing which, as shown in Figure 3, is practically invisible.

Figures 4 and 5 show a ford constructed in the spring of 1971. The pictures were taken the following summer. Flood flow at this site was calculated as 400 cfs. The crossing cost $3,000 and was done by force account. We found that as the crew gained experience the cost decreased sharply.

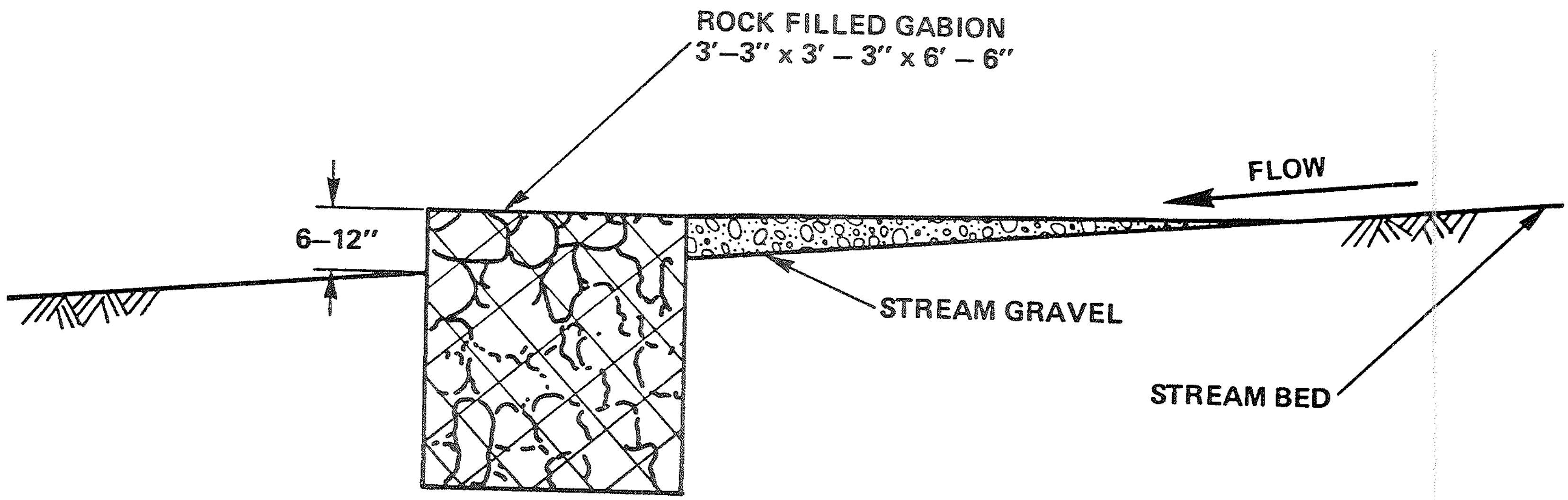

Figure 1. — Gabian Ford (not to scale).

Figure 2.—Gabions Filled Under Tension. Tension (supplied by come-along) lifts baskets off ground. As they are filled, they settle back straight and true.

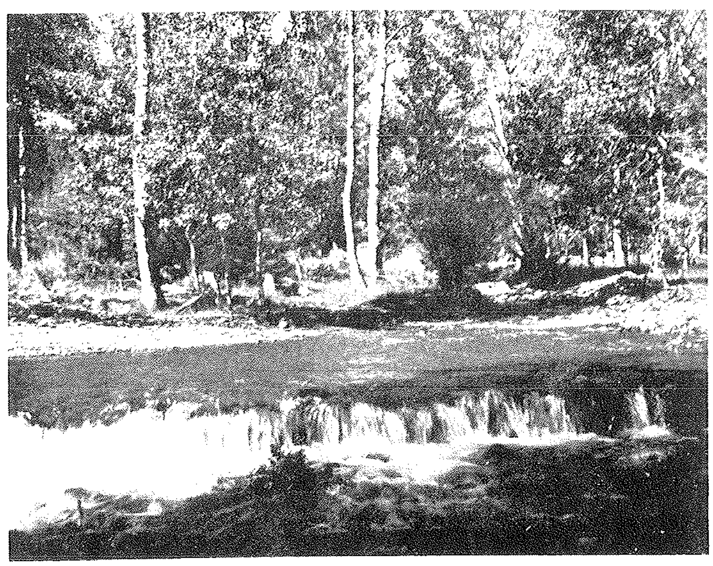

Figure 3.—View of Crossing Looking Upstream

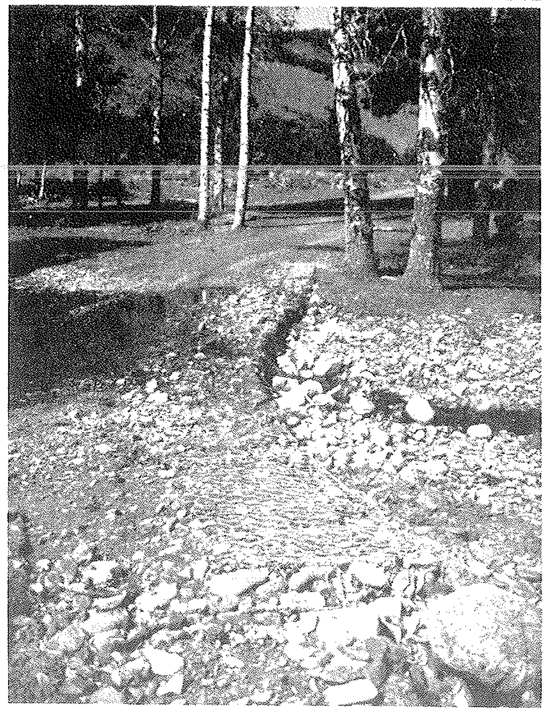

Figure 4.—Crossing During Late Summer. Gabions were placed on a 70-foot radius with a parabolic grade on tangents of ±9%.

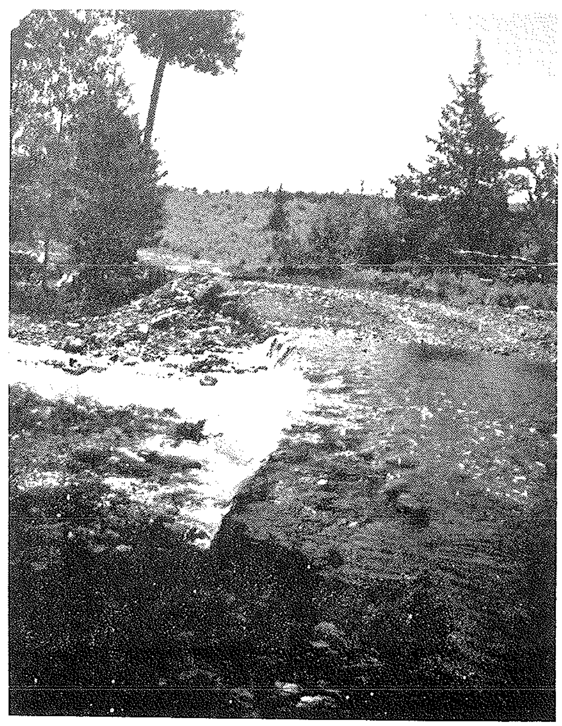

Figure 5.—View of Above Crossing During Early Summer. Roadbed remained firm. Note that the grade of the road precludes use of culvert.

All in all, we on the Modoc have been pleased with the low cost, durability and appearance of the gabion fords we have constructed. We feel that the use of gabions should be kept in mind as a design alternative for stream crossings on forest roads.

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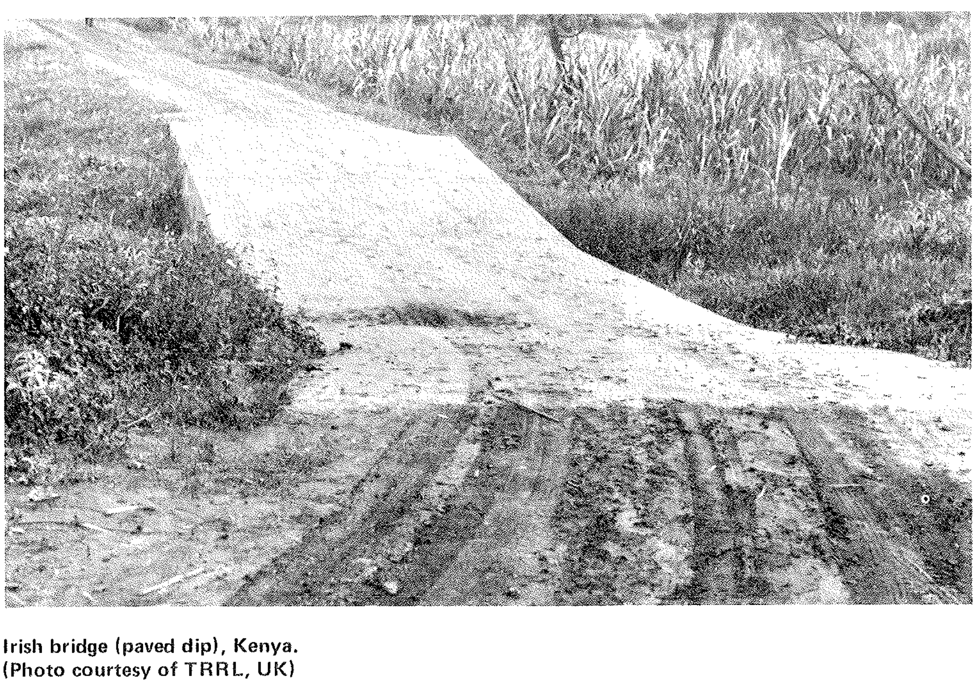
34



Irish bridge (paved dip), Kenya.
(Photo courtesy of TRRL, UK)

TEXAS HIGHWAY DEPARTMENT

Construction & Maintenance

BULLETIN No. 6
May, 1951

Highway Shortcourse Issue

This Bulletin is being used as a means of distributing the technical papers, presented at the Twenty-Fifth Annual Highway Short Course at A & M College, for the information of those of you who were unable to attend and for reference or review for you who were present. The material contained herein should prove interesting from the standpoint of highway engineering, construction and operation.

Transcripts on the many impromptu remarks and informal discussions, which contributed greatly to the success of the meeting, are not available.

—D. C. Greer

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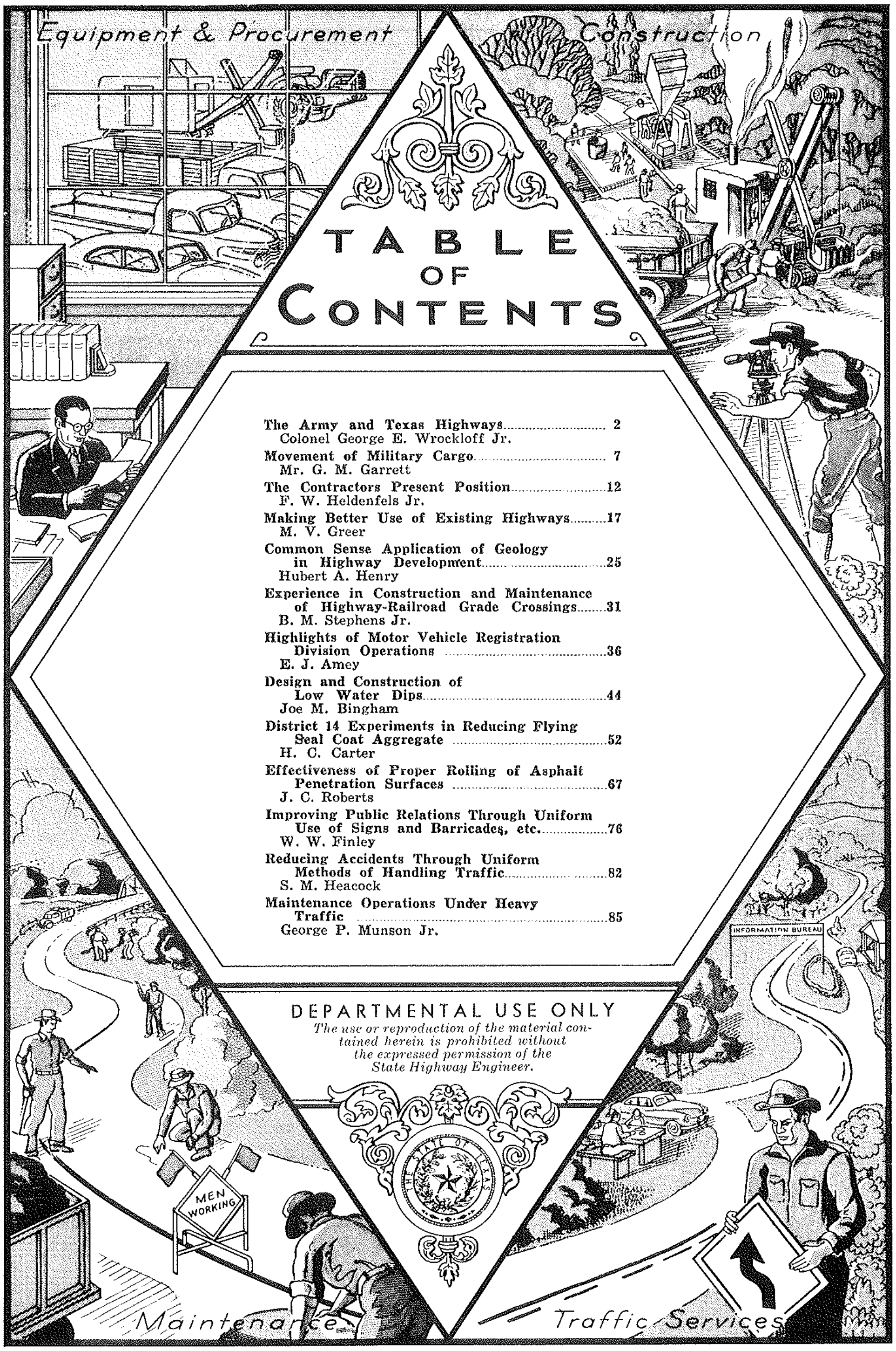


TABLE OF CONTENTS

Design and Construction

A few years ago when the Highway Commission elected to construct a network of low cost roads or Farm to Market Highways throughout the state, we highway employees were given a very big job to do. The job which I refer to was the designing and constructing of these roads. At the beginning of this program, we were reluctant to design these roads to low standards because it was a complete about-face from what we had done in past years. We all had visions of the low cost roads failing to stand up and were afraid of the criticism that we would get if they did fail. For this reason it took approximately three years for us to lose our fears and get the standards of design down as low as desired by the Austin Office. It required a lot of brow-beating, so to speak, by Mr. Greer, the Land Service Roads Department, and the District Offices to get us in line, but we finally made the transition, and I believe that with all things being considered, we have done a good job. I believe that in most instances, we are getting the best roads that can be constructed with the limited funds allocated for this work. It is my opinion, however, that there is still room for improvement, and my subject for today concerns one of the ways that we can improve these roads.

Before going too deeply into the subject matter of this paper, I would like to say a few words that I hope will dispel any thoughts from your minds that I am advocating the wholesale substitution of dips for bridges on our highways. I believe that bridges should be used wherever possible if the amount of traffic to be handled justifies a bridge and if sufficient funds are available for construction of the bridge. However, I will say that in special instances where the above mentioned conditions are not fully applicable, it would be better to construct a good dip than an inadequate bridge, and that the use of dips on our low type roads should be given due consideration.

JOE M. BINGHAM
Mineral Wells, Texas

Most of us have designed and constructed low-water dips be-

# of Low Water Dips

JOE M. BINGHAM, *Resident Engineer*
TEXAS HIGHWAY DEPARTMENT

cause we did not have the money in the job to build a structure of the usual type. I have seen all of the dips in my own district and a great number in the other districts, and I know that you have seen many of them around over the state. I feel sure that you will agree with me when I say that there are some good ones, some that are just fair, and some that are bad. The bad ones do not always fall in that category for the same reason, but for various reasons too numerous to mention. However, I believe that the chief reason is that we do not give them enough study in the design stage.

Evidently some of us are taking the attitude that our dips are only temporary structures, that they will be replaced with bridges within a year or two, and therefore are not of sufficient importance to warrant a thorough effort on our part. I cannot agree with this line of thought for the following reasons: (1) For reasons of safety any portion of our highways, be it Farm to Market or otherwise, which goes to make up the riding surface on which the public will travel is worthy of our very best engineering effort; (2) The highway pattern has been, and will probably continue to be for more and more miles of low cost roads -- roads that will require all our skill and ingenuity as engineers to assure maximum mileage on a minimum cost-per-mile basis. If this is true, then for financial reasons our dips will generally be permanent instead of temporary structures and will necessarily remain in service for a considerable length of time; (3) Due to the national emergency we are facing today, which we already know will bring shortages of skilled labor and critical materials to the construction field, we may be forced to use more low-water crossings in the future than we have in the years just past; and (4) Through the use of proper design and construction methods, dips can be built that will be adequate for certain types of roads from the standpoint of both traffic and drainage, which are essentially the basic requirements of any highway structure.

My first experience along this line came on a project where an existing dip was left in place to become a part of the completed project. I thought we got a good job on everything except the dip connections or approaches, and this fact alone ruined the job in my estimation. If you attempted to drive across the dip at a speed above twenty-five miles per hour, you were literally taking your life in your own hands. It would throw you to the top of the car at both ends of the dip, and you can imagine how many unfavorable comments I heard from the people who traveled the road. Here was some of that criticism that I mentioned a while ago and which we all prefer not to get, but which is sometimes exactly what is needed to move us to action. In my case, I resolved that the first dip I had to design would certainly receive some attention as to grade line. I did not want another twenty-five mile-per-hour dip on a road designed for a speed of forty-five miles per hour.

I was working in Hood and Somervell Counties and due to the rough terrain, had several opportunities to gain additional experience in designing dips. An improved method of design was set up through the experience mentioned, and I believe that it is worth your consideration. The method of design that I want to present to you now is not claimed to be the best, and I know that some of you probably have a method equally as good, or even better; but I do think that at least a part of it will be beneficial to some of you.

There are several items of field data that are needed for this method of design, and they have been set up in five separate groups. They are as follows:

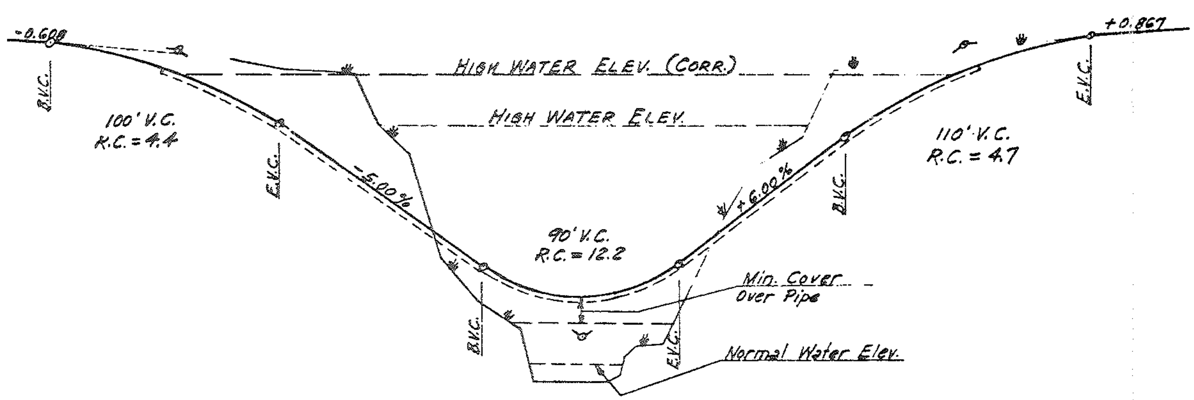
1. Stream Section and Roadway Cross Sections
2. Water Elevation at Normal Stage
3. Stream Meander, Profile and Topography
4. Highway Elevation
5. Drainage Area

Now we will go through the design procedure step by step, in order to give you a better understanding of the method's true value. (Graph Number 1) From the elevation of water in the stream at normal stage and the centerline profile as a section, you first determine the amount of opening necessary to handle normal drainage. This opening may be provided with one or more pipes and may be increased to handle a fairly large rain without overflow of the dip, if sufficient waterway opening is provided. From the stream profile, or cross sections, the flow-line elevations of the proposed pipe are determined, and then by providing minimum cover over the pipe, an approximate grade at the low point is found.

I want to take just a minute here to say a word about the low point in the grade line. On low water structures it is very important to hold the grade elevation to a minimum above the stream bed. This is particularly true of dips on account of the water pressure against the structure, and it will naturally become greater with each additional foot of height. This is also true for any type of low water structure because of the possibility of drift collection, the removal of which may sometimes

MAX. RATE OF CHANGE VALUES

	C.D.	C.U.
FARM HIGHWAYS (45 M.P.H.)	10	15
STATE HIGHWAYS (60 M.P.H.)	8	13



RATE OF CHANGE EQUATION

$$r = \frac{G_1 - G_2}{L}$$

EXAMPLE ~

$$r = \frac{-5.0 - (+6.0)}{0.9} = 12.2\ \%$$

GRAPH No. 1

LENGTH OF VERT. CURVE EQUATION

$$L = \frac{G_1 - G_2}{r}$$

EXAMPLE ~

$$L = \frac{-5.0 - (+6.0)}{10} = 1.1 \text{ Sta. or } 110' \text{ V.C.}$$

become a very costly maintenance operation. There appears to have been some disagreement in the past on the question of how high grade should be set above stream bed on low water bridges. You will occasionally see one that is too low for a high-water bridge and too high for a low-water bridge, which usually means that it is just right for the collection of drift. The utmost care should be taken in selecting the finished grade elevation for any type of low-water structure. And now to pick up where we left off with the design steps -- with the approximate grade at the low point and the roadway approach grades on each bank of the stream, we are now ready to work out the grade across the proposed dip. From what I have already said, I'm sure you know that this is one of the most important features of the dip because it is desirable to have an installation that will take traffic at the design speed of the highway, if possible. And too, we all know that John Q. Public is going to base his opinion of the structure almost entirely on the way it rides.

On the first dips not much attention was given to the grade line. We would build one and then see how it would ride. If it was rough, we would try for improvement on the next job. In other words, it was very much a method of cut and try, and we never quite knew just what we had until the dip was completed and we could ride over it for a test.

The lengths of vertical curves we use have much to do with the final result. This is dependent on three things; they are (1) the total change of grade between the two tangents, (2) the safe rate of change of grade per station, and (3) the necessary sight distance. The first two points are most important, while point number three is desirable, but must on occasion be sacrificed to some extent, and in rare cases overlooked almost entirely to fit the dip to the stream crossing. Ordinarily the curves should be made as long as conditions will permit for best results.

We have been using an equation for some time now to determine the "Rate of Change" on our dips and after continued use, together with some field tests, have found that the desired length of vertical curve to give the best riding dip can be predetermined through its use. It is, by definition, as follows:

$$r = \frac{G_1 - G_2}{L}$$

Where r is the rate of change in per cent per station,

G_1 and G_2 are the two given grades in per cent,

And L is the length of vertical curve in stations.

The grades G_1 and G_2 are considered positive when ascending and negative when descending and are used with their proper algebraic signs in this equation. They amount to the same thing that we commonly call the "Algebraic Difference" in the solution of vertical curves.

For example, if we have a descending grade of five per cent meeting an ascending grade of six per cent with a vertical curve length of 90 feet, the solution of the equation is as follows:

$$r = \frac{-5.0 - (+6.0)}{0.9} = 12.2\%$$

At first this equation was used to determine the "Rate of Change" on the dips already built, and then by driving over them in an automobile at varying rates of speed until the maximum safe speed was determined, a maximum "Rate of Change" was determined for Farm to Market Highways or a design speed of 45 miles per hour, and for State Highways or a design speed of 60 miles per hour. The maximum "Rate of Change" for Farm to Market Highways was set at 15. For roads designed for 60 miles per hour, the maximum "Rate of Change" was set at 12. Further experience revealed the fact that, due to the pull of gravity, weight of the vehicle, etc., we could not use as high a "Rate of Change" value on curves breaking downward as we could on those breaking upward. For that reason our original values were revised as follows:

With these maximum "Rate of Change" values known we can change the equation to solve for the length of curve, as follows:

$$L = \frac{G_1 - G_2}{r}$$

For example, if we have a descending grade of five per cent meeting an ascending grade of six per cent with a rate of change value of 10 desired, the solution of the equation is as follows:

$$L = \frac{-5.0 - (+6.0)}{10}$$

= 1.1 Stations or 110 feet vertical curve

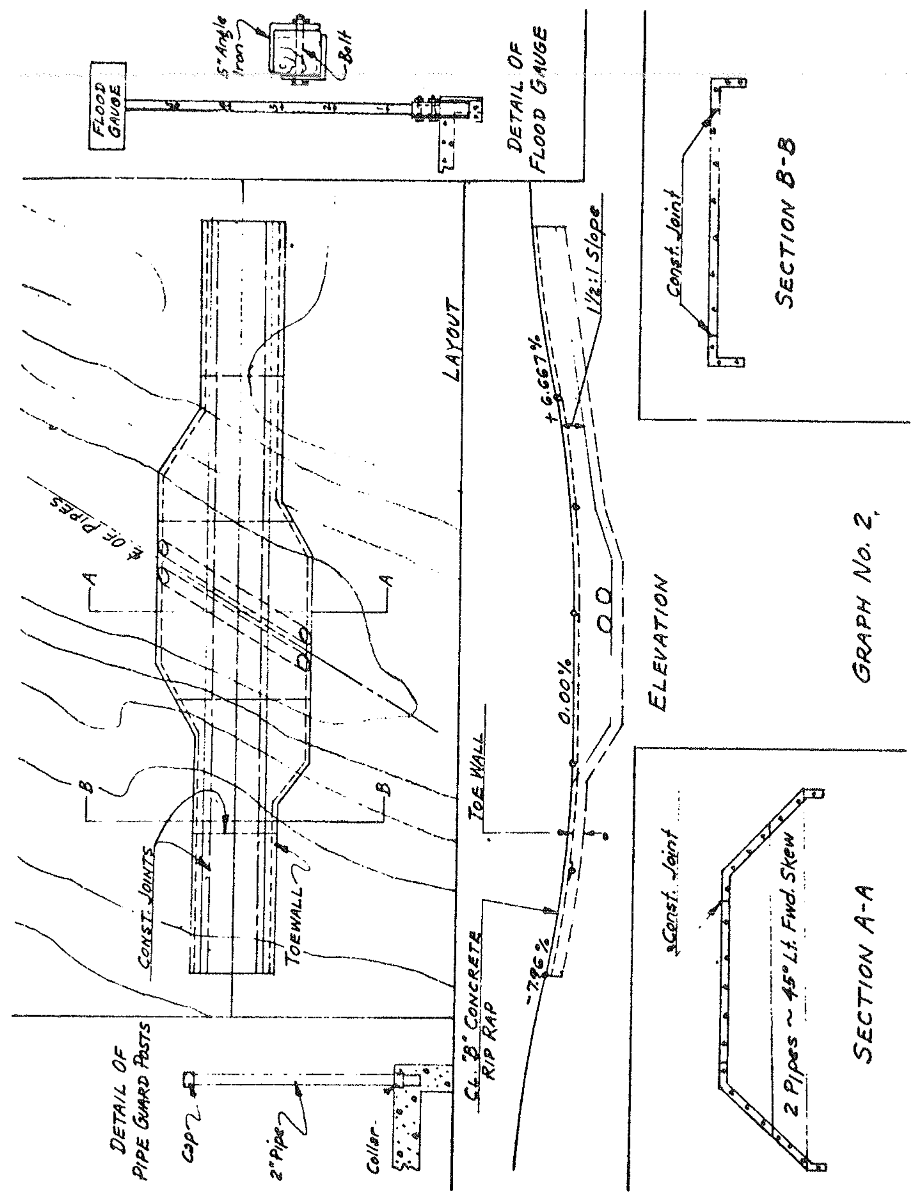
Through the proper use of this equation, I feel safe in saying that you can eliminate the rough riding dips completely.

The next step in design is to determine the length of the dip to be riprapped, or protected from flood waters. This is done by first calculating the area below high water in the natural stream. With this information a corrected high water elevation can be determined by taking into account the obstruction of the stream by the construction of the dip across it. If funds are available, the ends of the dip should be located at approximately the corrected high-water elevation. This gives maximum protection at flood stage. If, however, due to limited funds,

Maximum Rate of Change Values

	Curves Downward	Curves Upward
Farm Highways (45 M. P. H.)	10	15
State Highways (60 M. P. H.)	8	12

These are maximums and should not be exceeded, but the use of lower rates in both cases will naturally be better, and should always be used if the cost of the dip is not increased too much by so doing, or if the money is available in the project.


FLOOD GAUGE
5" Angle Iron
Bolt
DETAIL OF FLOOD GAUGE
LAYOUT
℄ OF PIPES
A
A
B
B
CONST. JOINTS
TOEWALL
Const. Joint
SECTION B-B
+6.667%
1½:1 Slope
0.00%
-7.96%
TOE WALL
ELEVATION
GRAPH No. 2
Cl. "B" CONCRETE RIP RAP
DETAIL OF PIPE GUARD POSTS
Cap
2" Pipe
Collar
Const. Joint
2 Pipes ~ 45° Lt. Fwd. Skew
SECTION A-A

it is necessary to cut down the length of the dip, it can be done in most cases without creating too much of a maintenance problem if care is taken in selecting the proper place to begin and end the concrete. The central dip area carries the main volume of water with the damaging velocities, and usually the drainage near the outer edges of the flood water will not cause too much damage to a base and surface if it does not stay up for prolonged periods of time.

We have been using five inch or six inch thicknesses of Class "B" Concrete Riprap reinforced with either wire mesh or bar steel for these dips and paving them completely -- across the roadway and down the slopes and with good deep toe walls all around. (Refer to Graph Number 2) This is placed on the compacted embankment previously placed over the pipe to handle normal drainage. The concrete pours have been broken down to average size by the use of construction joints placed both longitudinally and transversely. These joints are dowelled and painted with a heavy grade of oil asphalt prior to placement of the adjacent section.

A standard flood gauge, two dip signs, and enough two-inch pipe posts to effectively define the crown lines across the main channel have been installed on our dips as a part of the contract. The flood gauge is mounted in a bracket made by embedding two 5" x 5" x 18" angles in the concrete approximately nine inches. The post is anchored in the bracket with bolts, and if broken by drift or otherwise, it can be replaced without tearing into the dip concrete.

This, in effect, completes the design of the dip, but one more step should be taken to justify its use. The drainage area should be used to determine the size of conventional structure required in order that a comparative estimate of cost between the two can be made. For the larger streams the dip will always be considerably cheaper, but in the case of small streams where it is possible to handle the drainage with a large single or multiple box culvert, this is not always true. Therefore, it is good engineering to check on this feature before final selection is made.

In Somervell County on the Farm Road from Glen Rose to Lanham Mills, F. M. 205 I believe, we constructed a dip of this type across the Paluxy River about two years ago at a cost of slightly less than $10, 000. A bridge of sufficient length to span the river at this location would have cost in the neighborhood of $300, 000; so you can readily see that there is a place in our work where dips really pay off for us. The cost of a bridge at this crossing was prohibitive on the low type road, whereas the dip was economical and is serving traffic nicely and should continue to do so for a long time.

In closing, I would like to remind you again of the importance of a smooth and safe riding grade line across our dips. Give this feature of the work a little more study in the design stage, and I believe that in nearly all cases we can provide dips that can be traveled over at the design speed of the highway on which it is to be placed.

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CONTENTS

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RESEARCH PUBLICATION

"CAUSEWAYS OR SUBMERSIBLE BRIDGES.*"

By

S. P. Raju, F.N.I

Director, Engineering Research Laboratories,
Hyderabad-Deccan.

SYNOPSIS

A "Causeway" is a submersible road bridge across a stream with the double function of allowing the normal dry weather flow to pass through the vents below the roadway, and the occasional floods both through the vents and over the roadway, thus entailing a temporary cessation of traffic. On account of their dual function causeways present problems peculiar to themselves and unlike other hydraulic structures like spillways, sluices, barrages, lifting-weirs, and road bridges. This article deals with some hydraulic investigations in connection with causeways.

1. DEFINITION OF "CAUSEWAYS"

The word "Causeway", at least in India, denotes a submersible road bridge across a stream, which is designed and built in such a way that the normal dry weather flow of the river passes entirely through the vents below the roadway and the occasional floods pass both through the vents and over the roadway, thus entailing temporary cessation of traffic.

2. TYPES OF CAUSEWAYS

These causeways may have the roadway just a few feet above the river bed, say about the order of 5 ft when they are sometimes called LOW LEVEL CAUSEWAYS. Or, the roadway may be very high, up to say 25 or 30 ft above the bed, when they are called HIGH LEVEL CAUSEWAYS.

Secondly, the vents may consist of pipes or short-span culverts. Or, they may be constructed with arched vents of big spans, say of 25 or 30 feet.

Thirdly, the depth of water designed to flow over the road may be of the order of just a few feet or as high as 20 feet.

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*Reprinted from the Annual Report of the Hyderabad Engineering Research Laboratories for 1950.

3. PECULIARITIES OF CAUSEWAYS

Among the hydraulic structures built across rivers, causeways have a peculiarity of their own. Unlike irrigation dams, spillways, barrages, anicuts, (or lifting weirs) and road bridges, causeways have a double function of passing normal discharges through the vents below the roadway and the flood discharges both through the vents and over the roadway itself.

On account of this dual function causeways present hydraulic problems which are peculiar to this kind of structures. It is not known to what extent such submersible bridges are used in other parts of the world. At any rate, it has not been possible to get any information.

4. CAUSEWAYS INVESTIGATED AND THEIR HYDRAULIC FEATURES

The general problem of causeways was first brought to the notice of the Author in 1936, while he was Professor of Hydraulics in the Engineering College of the Osmania University. The Hyderabad Public Works Department had built several causeways in the State and during the rains of that year some failed in ways, the reasons for which could not be easily explained. The Chief Engineer for Roads and Buildings referred them to the Author for investigation in his Laboratory.

The first case taken up was the Aler Causeway typical of many, consisting of 2 ft diameter hume pipes concentrated in the centre of the river and built on sand foundation. The roadway was 4 ft above the bed and the depth of flood water above the causeway about $4\frac{1}{2}$ ft. The next causeway that came up for investigation was the proposed Tintiny submersible bridge across the river Krishna, with a maximum discharge of about 6,00,000 cusecs. This was proposed to consist of 56 arched vents of 30 feet span. The roadway was 30 feet above the bed and the depth of flood over the roadway was to be 20 feet.

In 1947 there were some failures of causeways which were investigated in the Hyderabad Engineering Research Laboratories. The Peddavagu Causeway had 25 vents of 8 ft span, the height of roadway above the bed being 8.26 ft and the flood 11.55 ft above the roadway. The other one so far investigated is the Shahbazpalli Causeway with vents of 4 ft span, the height of roadway above the bed about 4 ft and the depth of flood above the causeway over 8.58 feet. This was placed in a very acute bend of the river.

The following is a statement of the Causeways investigated and their **hydraulic features:**

Features	Causeways			
	Aler	Tintiny	Peddavagu	Shahbazpalli
1	2	3	4	5
Maximum discharge in cusecs	50,000	6,00,000	1,00,000	68,000
Nature of vents	Hume pipes 2 ft dia.	Arched vents 30 ft span	Arched culverts 8 ft span	Culverts of 4 ft span
Location of vents	Middle	All along	All along	Towards the side
Height of roadway above the bed in feet	4	30	8.26	4.00
Depth of flood water above roadway in ft	4.56	20	11.55	8.58
Total flood water in ft	8.56	50	19.81	12.58
Year of investigation	1937–38	1938–39	1948	1949

5. NATURE OF CAUSEWAY PROBLEMS

The experience gained from these investigations has indicated that the three factors that contribute towards the causation of problems in causeways are:—

(i) the design of the causeway,

(ii) the configuration of the river including bed and banks,

(iii) the conditions of flood flow.

Experience also indicates that the causeway problems for purpose of study may be classified as follows:—

(1) **Effects of the design of the causeway**:

(a) on the river upstream of the causeway;

(b) on the river downstream of the causeway ;

(c) on the river bed below the causeway ;

(d) on the flow of water inside the vents ;

(e) on the flow of water over the roadway ;

(2) **Effects of the conditions of flood flow:**

(a) when the flood is normal and rate of rise of flood is slow ;

(b) when the flood is abnormal and rate of rise of flood is rapid ;

(c) when the flood brings jungle trees and blocks the vents.

6. INVESTIGATIONS CARRIED OUT SO FAR

A resume of the investigations carried out so far will first be given before discussing the findings with respect to the problems as analysed above.

6.1. Investigations on Aler Causeway

6.1.1. **Problems.**—This causeway was built across the Aler river on the Hyderabad-Hanamkonda Road. The level portion of the causeway is 500 ft long and 4 ft above the bed. The openings for the dry weather flow consist of 20 hume pipes of 2 ft diameter, placed 2 ft 9 in. apart from centre to centre and with their bottoms at the bed level, so that the clear space between the top of the pipe and the road surface was 2 feet. The pipes occupying a total length of 61 ft were placed 169 ft from the right end, and 270 ft from the left end of the level portion. 49

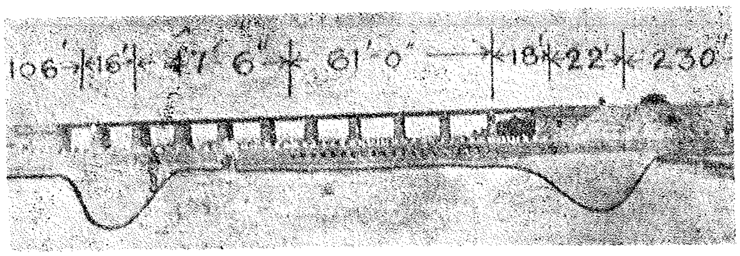
The bed consisted of pure sand, and the foundations for the retaining walls were taken to a depth of 4 ft on the upstream side and 6 ft on the downstream side.

In April and September of 1936 severe floods occurred, which according to observations rose to 8.56 ft upstream of the causeway and the flood level 500 ft downstream was 5.98 ft showing an afflux of 2.58 feet.

The significant features of the effects of the flood were :—

(1) On the upstream side of the causeway there was practically no scour.

(2) On the downstream side, while there was scour all along the causeway, it was significantly small immediately in front of the vents amounting to only 2 ft deep compared to 10 ft at some other places.



Photograph 1.
Aler Causeway—showing the approximate line of scour in black line.

(3) On either side of the vented portion the scours were more severe extending from 6 to 10 ft depth near the wall. Longitudinally they went up to about 100 ft on the right side and about 75 ft on the left. The deepest scours of 10 ft depth were spread over lengths of 16 and 22 ft on either side, and their distances from the end vents were 47 ft on the right and 18 feet on the left, that is to say, for 16 and 22 ft lengths the scour went down 4 ft below the foundation and the wall was overhanging in those places without any support (Photo 1).

6.1.2. **Analysis of the probable causes of the scour**:

The scours must have been caused either :

(1) by the subsoil flow, or

(2) by the surface flow, or

(3) by both.

The subsoil flow in permeable foundations may do damage to the structure in two ways : (1) by uplift, and (2) by the undermining of the soil.

Regarding uplift, no rift or raising of the floor has been observed either in Aler Causeway or in any other, so that this possibility may be left out of consideration. Regarding undermining the subsoil in the case of Aler Causeway is apparently homogeneous, and the structure in the foundations was symmetrical all along the level portion. It is, therefore, to be expected that the scour, if due to piping, must be uniform all along the downstream end of the causeway. But this was not the case, not only in this but also in other causeways of similar conditions. Severe scours did not occur all along, but only at the sides of the vented portion, the vented portion itself being significantly free from any high degree of scour.

It was, therefore, to be concluded that the scour was caused, not by the subsoil flow, but by the surface flow. This was confirmed by the preliminary investigations in which it was possible to reproduce in a model the conditions of scour corresponding to those in the prototype by means of surface flow only.

6.1.3. **Investigations.**—Investigations were made on a partial model of a causeway with three vents in the middle placed in a glass flume with sand up to the level of the bottom of the vents. Two rectangular vents were provided at the sides in such a way that the glass of the flume itself formed one of their sides and flow inside could be observed. These could be closed or opened as desired.

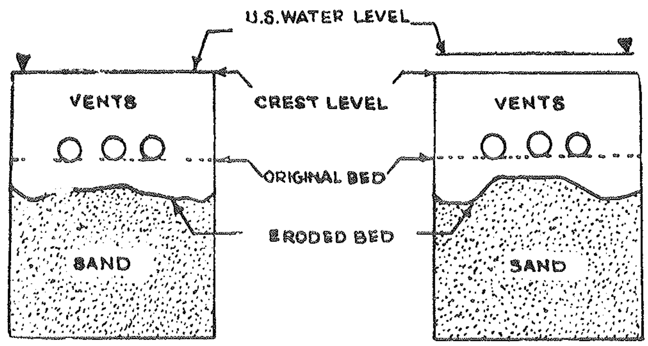
The water was made to flow first through the three vents only, the level upstream being just to the surface of the roadway. As shown in Fig. 1 (a), the experiment indicated that the scour at the sides was more than in front of the vents due to vortices formed by a high velocity jet from the vent flowing adjacent to region of still water at the side as shown in Fig. 1 (c).

When the water was made to flow through the vents and over the model, the character of the scour remained the same but only intensified in degree as shown in Fig. 1 (b). It will be noticed that this characteristic of the the scour bears a strong resemblance to the actual method of scour in the prototype as shown in Photo No. 1. These experiments showed that the greatest scour at the sides was due to dead-water region.

In the next experiment, the dead-water region was removed by opening one of the side vents and making water flow up to the level of the causeway. This showed that on the side where the vent was opened there was no scour, Fig. 2 (a). When the water was made to flow above the causeway also, the same trend continued, Fig. 2 (b). When next both the side vents were opened, the scour at the sides was removed entirely, Fig. 2 (c). These investigations have shown that the peculiar characteristic of scour in the Aler Causeway was due to the concentration of vents in the middle, the moral being, of course, that in the design of the causeways the vents should be distributed throughout the length of the causeways.

Further studies were made to investigate conditions of flow when the level of the water was gradully increased over the causeway. When the water began to flow over in the addition to passing through the vent, the flow became rather complicated. To begin with at low head, when the nappe clings to the downstream side of the causeway, there is a little burrowing into the sand bed immediately next to the wall. But as soon as the nappe springs clear and falls at an angle on the sand through the water, the impact breaks the nappe into two vortices of roller as shown in Fig. 2 (d).

(a) Water Flowing through the Vents only. (b) Water Flowing through the Vents and over the Model.



(c) Water Flowing through the Vents showing the formation of Vortices.

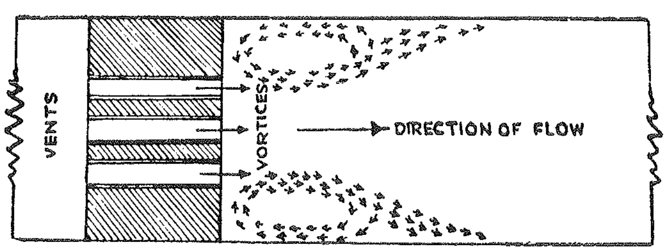


FIG. I – MODEL OF CAUSEWAY– *Side Vent Closed*

The forward roller lifts the sand at the line of impact and carries it forward, while the back roller tends to keep the sand up. As the sand is depleted from the zone of impact by the forward roller, the sand in the rear begins to fall down but is maintained in position for a while by the back roller moving upward till the sand surface become steeper and steeper and even gets beyond its angle of repose. There is a peculiar pulsation observed insuch movements, which seems to be periodic. There are movements at intervals at which the back roller seems to stop functioning immediately the sand slips down and is carried forward by the forward roller. Thus, there is a continual sinking of the sand level next to the causeway. It was observed that for a flow of 3 in. above the surface of the model the scour went deep down to 7 in. and exposed the foundation in about 20 minutes and thereafter remained stable even after running the water for 45 minutes. This simulates the scour going below the foundations in the prototype.

CONDITIONS OF SCOUR WITH DIFFERENT OPENINGS UNDER VARIED CONDITIONS OF FLOW

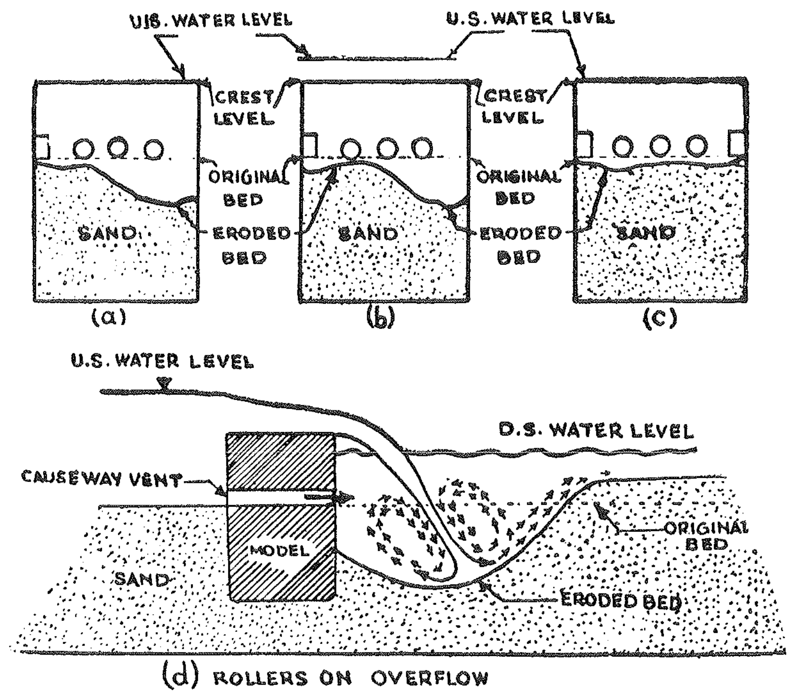


FIG. 2 — MODEL OF CAUSEWAY—*Side Vent Open.*

6.2. **Investigations for reducing the period of Submergence of the Causeway:**

In the rapid development of road construction in India the causeway or the submersible bridge is drawing increasingly greater attention of road engineers on account of its possibilities of providing a cheaper cross-drainage work than an insubmersible bridge. The period of submergence and the period of cessation of traffic over the bridge may not be a matter of great importance in out of the way places where time is not of much consequence. But on important roads some delay of traffic may be warranted by the savings effected by the construction of a submersible bridge but it behoves the road engineer to reduce this period as far as possible by suitable methods in the design of a causeway.

To ensure this what is desired to see that the expected flood passes through and over the causeway with as low an afflux as possible, leaving the road surface dry as quickly as possible for the passage of the traffic. In other words, it is necessary to devise methods by means of which the discharging capacity of the causeway for a given afflux is increased as much as possible. From this point of view the vent of the causeway may be looked upon as a short tube under submerged conditions and the top of the causeway or the road surface as a weir. On this basis, experiments were carried out to find methods of increasing the discharging capacity or the coefficient of discharge, both of the vent and the road surface.

54 6.2.1. **Increasing the coefficient of the vent.**— The coefficient of discharge of a vent of the kind used in causeways is of the order of about ·78 to ·80. The experiments have indicated that a provision of a bell-mouth on the upstream side increases the co-efficient to about ·88. In addition to this when a suitable divergence is given at the end of the pipe the coefficient rises to about 1·24.

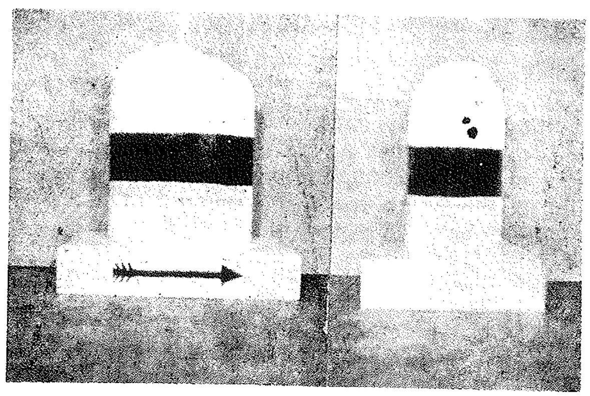
6.2.2. **Increasing the coefficient of discharge of the roadway.**— A broad crested weir with a sharp upstream edge corresponding to the top of the causeway has a coefficient of discharge of the order of about 2.94. Experiments in the Laboratories as well as elsewhere indicate that when upstream edge is rounded or bevelled the coefficient may be increased up to about 3.23.

6.2.3. **Streamlined Guardstone.**— At present guardstones that are used on causeways are rectangular in plan with sides vertical, the top portion being curved towards innerside of the causeway. This shape naturally offers a considerable resistance to flow and increases the afflux. This can be reduced by making guardstones streamlined (as indicated in Photo 2.)

6.2.4. **One-way camber of the causeway towards down-stream.**— A road generally is given a camber on both sides of the centre. Experiments have indicated that one-way camber towards the downstream have two advantages as shown in Fig. 3.

(a) The afflux is considerably reduced and there is no chance of a standing wave being formed, as in the case of a two-way camber.

(b) As this arrangement raises the level of the upstream edge, this contributes towards keeping the roadway dry up to a higher depth of causeway upstream.



Photograph 2.
" Streamlined " Guardstone.

6.3. Investigations on Tintiny Causeway

Studies on the model of the Tintiny causeway proved very revealing regarding the effects of slow and rapid raise of flood on the flow inside the vents.

The model was made to a scale of 1 : 36. In order to facilitate the observations of the character of flow inside the vents, the model was made to represent only half the pier, the vent side being fitted against a glass wall.

Manometric arrangements were made for the measurements of pressure at three sections, near the upstream, downstream and middle of the model.

For simulating normal floods with slow rise and abnormal floods with rapid rise the screw valve of the supplying pipe was given different number of turns to suit the flow determined after some trials.

To adjust the downstream levels accurately a special streamlined shutter was designed with vertical streamlined vanes with arrangements for adjusting them as in the case of guide blades in an inward flow turbine.

Observations of the rate of rise and for flow under both conditions are given in Figs. 4 and 5 respectively. The pressures obtained for different flows are shown in Fig. 6.

While model discharges of 0·93, 1·25, and 1·40 cusecs could be adjusted to give the same depth of water on the upstream measuring section, the discharge of 1·83 cusecs however could not be adjusted to the same level on account of want of sufficient height in the forebay. The results showed:

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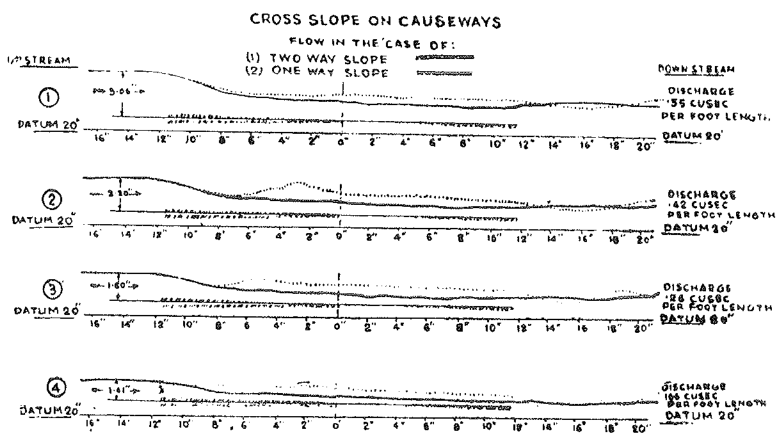

FIG. 3 - FLOW OVER CAUSEWAYS WITH ONE WAY & TWO WAY CAMBERS.

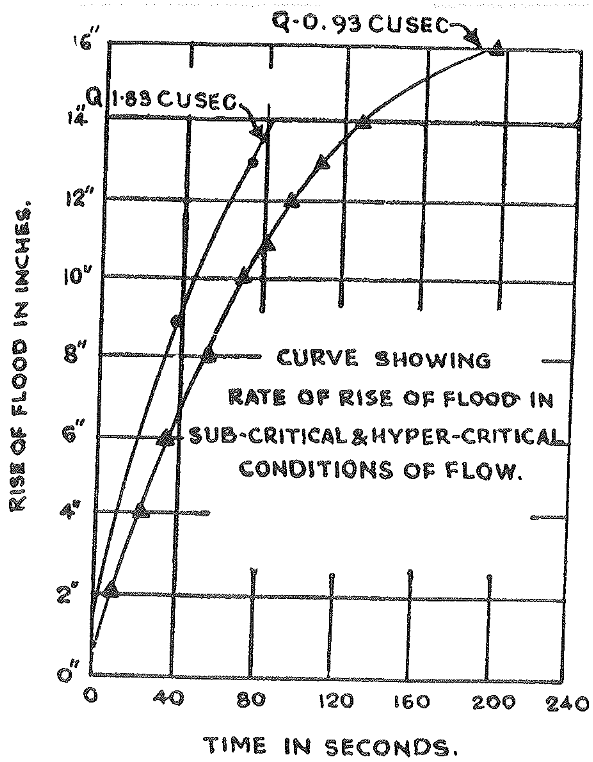

FIG. 4 - SUBMERSIBLE BRIDGE

57

(1) When the flood is normal and the rate of rise is slow the pressures inside the vents follow the hydrostatic pressure law. The velocities are below the critical.

(2) When the flood is heavy and the rate of rise is rapid, a standing wave is formed inside the vent. The velocities go above the critical and the pressures indicate that they do not follow the hydrostatic pressure law, but are considerably below. At very high floods, they go even below atmospheric pressure.

The consequence of the results of these investigations is, that for normal floods the arch has an upward hydrostatic thrust to compensate for the downward hydrostatic thrust above it. But in the hyper-critical stage the downward thrust may be far greater, in which case allowance has to be made in the design of

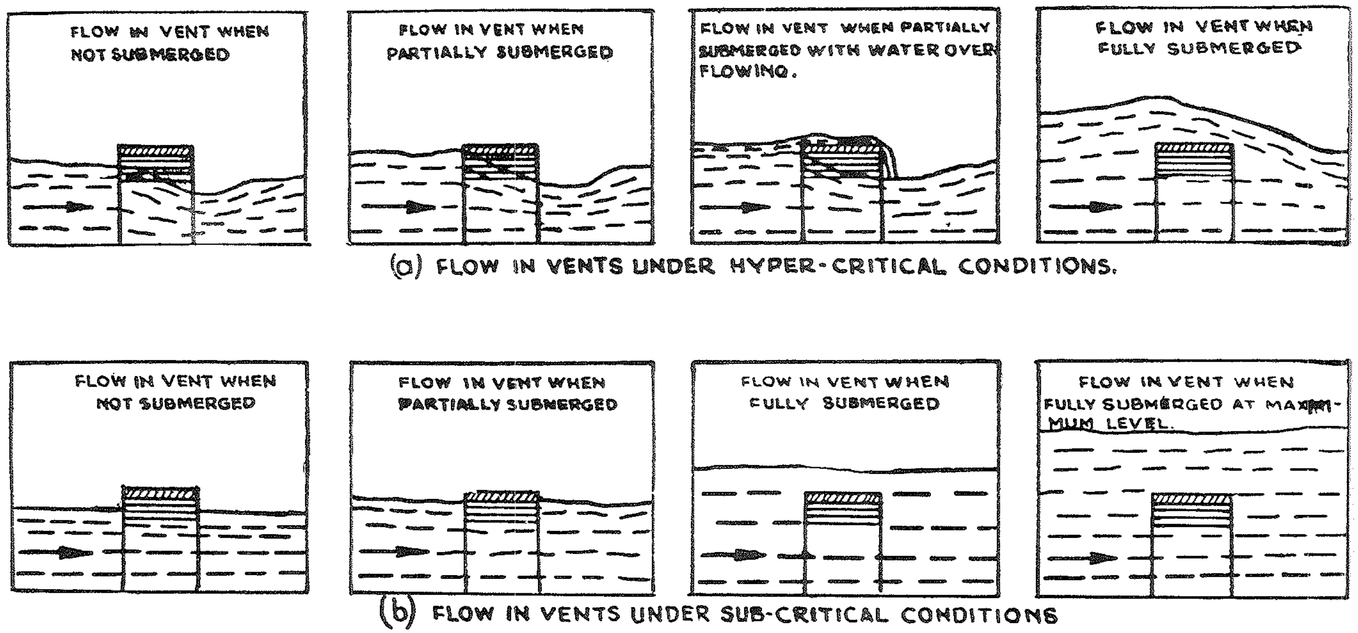

FIG. 5 - SUBMERSIBLE BRIDGE - *Flow under sub-critical & hyper-critical conditions.*

the arch and the piers. Each case may have to be determined by model experiments.

PRESSURES FOR
SUB-CRITICAL & HYPER-CRITICAL CONDITIONS
OF FLOW.

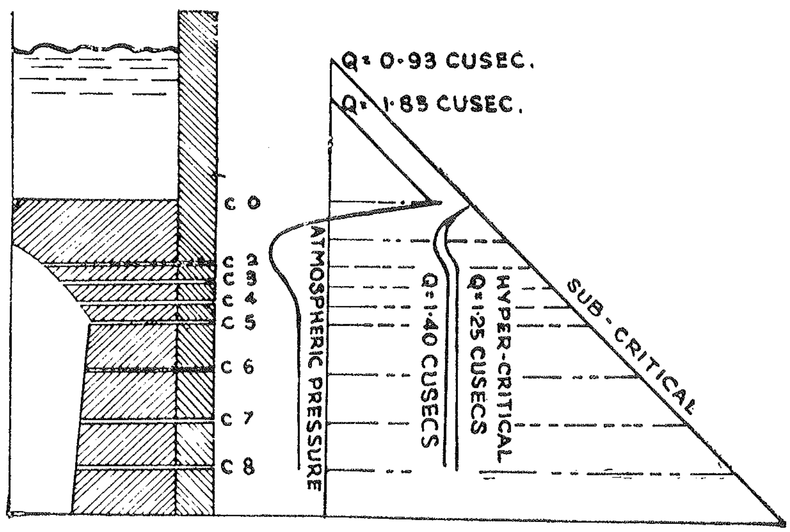

FIG. 6 - SUMERSIBLE BRIDGE - *Pressures for different flows.*

6.4. Investigations on Shahbazpalli Causeway

This causeway on the Karimnagar-Kamareddy Road in Hyderabad State had failed three times, since its construction about 40 years back and these failures are primarily due to the incorrect location of the causeway below an S-bend in the river.

The investigations of Mr. R. K. V. Narasimham show the importance of the effect of a bend on the upstream side of a causeway.

During heavy floods the high velocity jets would cling to the left concave bank due to centrifugal action and cause continuous erosion of the bank at the left approach ramp of the causeway. The presence of the causeway itself at this position is responsible for augmenting this erosive action. When the causeway failed in this manner in 1946 it was found that the river had cut into the bank to a distance of nearly 50 feet upstream of the causeway. The result of this erosion is that during heavy floods the foundations of the causeway and approach ramp get undermined and the causeways fail.

To safeguard this causeway from further failure, spurs had to be provided at the bend to deflect the flow. The location, length, and height of the spur were determined by investigations on scale models of the river and causeway. In the severe floods of September 1950 the spur has been effective in saving the causeway from further damage.

6.5. Investigations on Peddavagu Causeway

The Peddavagu Causeway on the Ramayanapet-Siddipet Road in the Hyderabad State is a case of failure of some of the central vents by getting blocked with trees and brushwood brought by the heavy floods.

This had an apron on the downstream side aud none on the upstream side. The extreme vents on one side were intact while some on the other side were partially damaged. But the central vents had failed by deep scours on the upstream side resulting in the sinking of the upstream retaining walls. Investigations of Mr. R. K. V. Narasimham have indicated that this may be due to a transverse flow along its upstream side of the blocked vents, creating a deep scour along its upstream side of the blocked vents, creating a deep trench extending at places below the foundation of the retaining walls.

This indicates that for the emergency of the choking of vents by brushwood, etc., an apron on the upstream side is also to be recommended.

7. CONCLUSIONS

The above investigations have led to the following conclusions about the effects of causeways on the regime of rivers and the effects of the conditions of flood flow on the causeways :—

(1) For sub-critical conditions of flow during normal flood and slow rate of rise, the pressures in the vents follow hydrostatic law. As this produces an upward thrust on the arch, there is no special precaution needed in the design of the arch.

(2) For hyper-critical conditions of flow during heavy floods and rapid rate of rise, the pressures in the vents are less than hydrostatic and in extreme cases could

be even sub-atmospheric. The consequent change in the resultant thrust over the bridge must be taken into account in the design.

(3) The blocking of vents may produce transverse flow along the upstream side and cause heavy scour. For protection against trees and brushwood blocking the vents, an upstream apron will be necessary.

(4) If vents are concentrated in the centre, there will be heavy scour at the sides due to high velocity jets reacting on still water regions. The vents should therefore be distributed all along the causeways. Also the jets through the vents act as cushions against the energy of the nappe of water flowing over the causeway and thereby reduce the scour. If soil is loose, an apron is needed.

(5) When the causeway is placed immediately below a bend in the river, the erosive action on the concave bank is intensified and the approach ramp of the causeway attacked, while the silting on the other side is increased.

(6) On the downstream side the effect of the causeway on the regime of the river is more or less local extending to a distance depending upon the local phenomena of hydraulic drop and hydraulic jump. 61

(7) The period of submergence may be reduced by decreasing the hydraulic resistance and thereby lowering the afflux by the following methods :-

(a) increasing the coefficient of discharge of the vent by bell-mouth on the upstream side and divergence on the downstream side.

(b) increasing the coefficient of discharge of the roadway by rounding or bevelling the upstream edge of the causeway,

c) giving one way slope to the road surface,

(d) making the guardstones streamlined.

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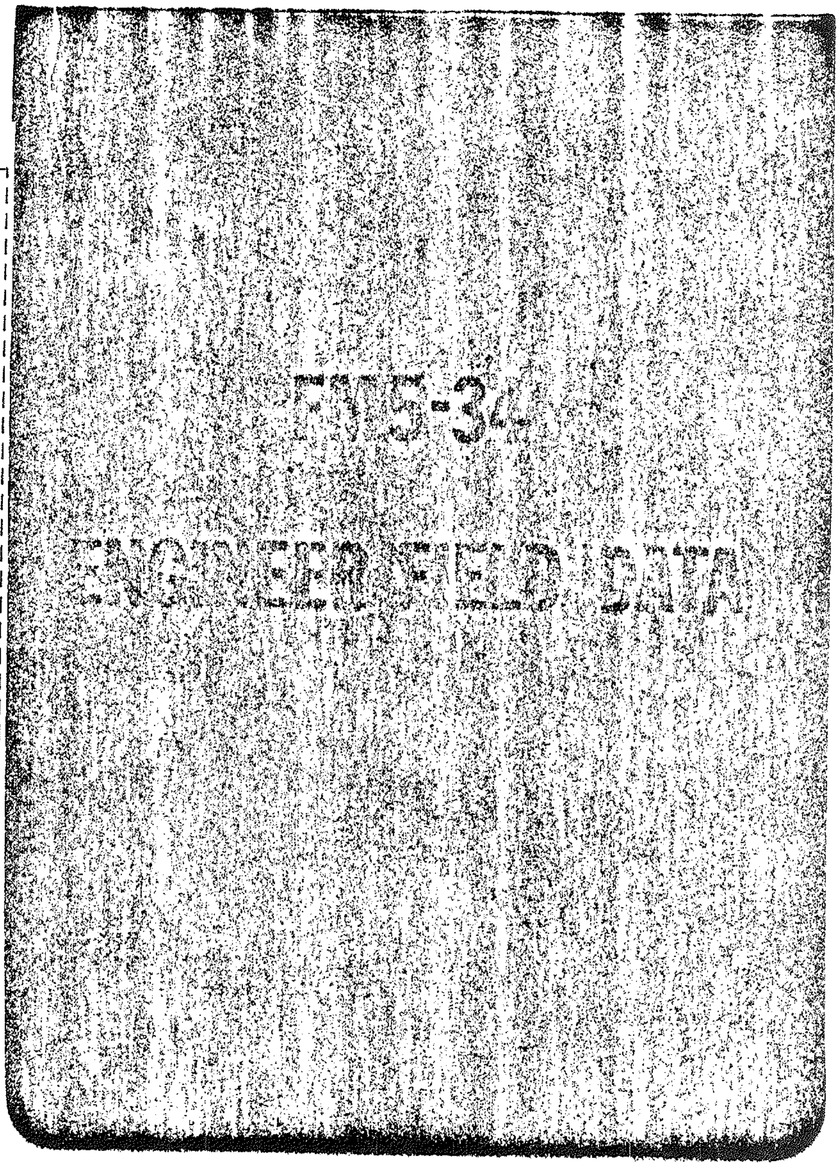


* FM 5–34

FIELD MANUAL
NO. 5–34

HEADQUARTERS
DEPARTMENT OF THE ARMY
Washington, D.C., 24 September 1976

ENGINEER FIELD DATA

*This manual supersedes FM 5–34, 12 December 1969, with all changes.

CHAPTER 5

MARKING OF BRIDGES AND VEHICLES

Section I. BRIDGES

5–1. MARKING OF BRIDGES

a. Classification.

(1) The class number of a bridge represents the safe load–carrying capacity of a single–lane bridge or a single lane of a multilane bridge under normal crossing conditions. The bridge class number may be a *single class* number, which will permit either wheeled or tracked vehicles to cross if the vehicle class number is equal to or less than the bridge class number, or it may be a *dual class* number, which indicates one normal class number for wheeled vehicles and another normal class number for tracked vehicles. Dual classification may be used for bridges with a capacity greater than class 30. For reconnaissance reports and tables, dual class numbers are written with the wheeled class number in parentheses above the tracked vehicle class number.

(2) The normal class number is the largest bridge class number (single or dual) which permits the normal crossing of vehicles whose vehicle class numbers are equal to or less than the bridge class number.

(3) A special class number represents the load–carrying capacity of a bridge under special crossing conditions. These numbers are not posted on standard bridge marking signs, but on supplementary signs.

(4) Width requirements. See table 5–1.

Table 5–1. Bridge Width Requirements – m (ft.).

Bridge class	4–12	13–30	31–60	61–100
One-lane width	2.74 (9)	3.35 (11)	4 (13'2")	4.5 (14'9")
Two-lane width	5.5 (18)	5.5 (18)	7.32 (24'	8.23 (27)

b. Bridge Signs.

(1) For prefabricated bridges and ferries, bridge signs indicate the class number as given in technical manuals. For bridges fixed in place or for nonstandard fixed bridges designed in the field, bridge signs shall indicate the class number as determined by methods shown in chapter 7 or TM 5–312.

(2) All single–lane bridge signs are a minimum of 16 inches in diameter. Multilane and dual class bridge signs are at least 20 inches in diameter. Numerals are black on a yellow background with a black border 1½ inches wide.

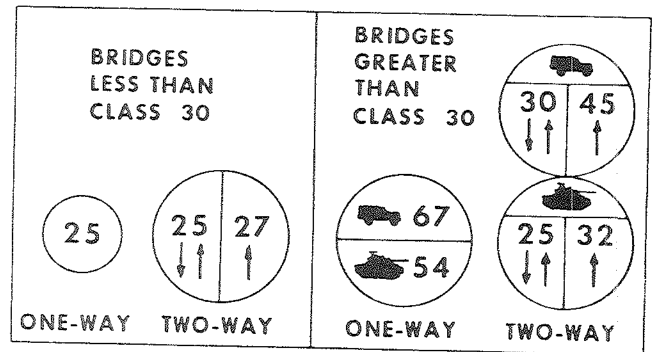


Figure 5–1. Bridge classification signs.

(3) A multilane bridge has a road way wide enough to carry at least two lanes of traffic simultaneously. If each lane has the same class, the signs are the same as for single–lane bridges. If the lanes are of different classes, each lane has a class sign. Two--lane bridges may carry a combination circular sign (fig. 5--1) which gives the normal two–way classification on the left and the computed one–way classification on the right.

(4) Dual classification is used for bridges with a capacity greater than class 30. Two numbers are then shown on the sign; the upper one for wheeled vehicles, the lower one for tracked vehicles (fig. 5–1). Dual class two–lane bridges may be designated by a composite sign indicating both dual class and combination classes (fig. 5–1).

c. *Traffic Control.* To expedite passage of vehicles and to prevent damage to the bridge, rigid control of bridge traffic must be maintained. This is done by the following control measures wherever possible.

(1) A traffic park is set up where vehicles can be halted and dispersed in order to avoid congestion. (fig. 5-2)

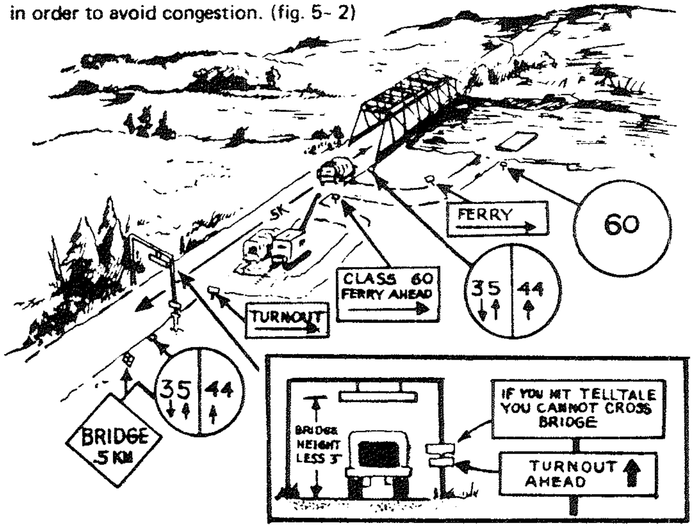


Figure 5–2. Example of telltale, turnout, and sign arrangement for single–lane bridges.

(2) A turnout area is provided for vehicles to turn off the road and out of the line of traffic. It is meant primarily for vehicles having mechanical troubles, but it can be used as a limited traffic park.

(3) Telltales are provided for bridges having overhead framing, trolley wires, or other features which limit overhead clearance.

(4) A normal crossing is defined as one in which the vehicle class number is equal to or less than the bridge classification number, where vehicles maintain 30.5–meter intervals, and where speed is restricted to 40 kph (25 mph). On floating bridge, sudden stopping or acceleration is forbidden.

(5) Special crossings are authorized by the local tactical commander, under exceptional operating conditions in the field. Special crossings permit a vehicle to cross a bridge (or other crossing means) whose class number is less than that of the vehicle. Special crossings are either caution crossings or risk crossings.

(a) In a caution crossing, vehicles with a classification exceeding the capacity of the bridge by 25 percent are allowed to cross under strict traffic control. Caution crossings require that the vehicle remain on the centerline, maintain a 50–meter distance from other vehicles, not exceed 12 kph (8 mph), not stop, not accelerate, and not shift gears on the bridge.

(b) A risk crossing may be made only on standard prefabricated fixed and floating bridges. Risk crossings are made only in the greatest emergencies. The vehicle moves on the centerline, is the only vehicle on the bridge, does not exceed 5 kph (3 mph), does not stop, does not accelerate, and does not shift gears on the bridge. The vehicle class number must not exceed the published risk class for the type bridge being crossed. After the crossing, and before other traffic is permitted, the engineer officer should reinspect the entire bridge for any damage.

Section II. VEHICLES

5–2. MARKING OF VEHICLES

a. *Weight Classification.* All vehicles with a gross weight over 3 tons and all trailers with rated payload over 1½ tons are assigned classification numbers. These numbers indicate a relationship between the load–carrying capacity of a bridge and the effect produced on it by a vehicle. The effect of the vehicle on the bridge depends upon the gross weight of the vehicle, the weight distribution to the axles, and the speed at which the vehicle crosses the bridge.

b. Vehicle Signs.

(1) *Classification.* Classification numbers assigned to vehicles are whole numbers ranging from 4 through 150. Front signs on a vehicle are 9 inches in diameter and the side signs are 6 inches in diameter. The signs have black numberals on a yellow background and the numerals are as large as the sign will permit. The fron sign goes above the bumper to the driver's right and below his line of vision, and the side sign on the right side of the vehicle in a place where normal use of the vehicle does not conceal it from view.

(2) *Combination Classification.* With a combination vehicle (two or more single vehicles spaced less than 30.5m apart), the front sign shows the normal vehicle class for the combination with the letter "C" in red above the class number. Each vehicle in the combination carries a side sign which shows its class as a single vehicle. If one vehicle is towing another, they are considered separate, unless they are both on the same span and the distance between them is less than 30.5m. Combination classes are determined as indicated in paragraph 5–3c below.

5–3. EXPEDIENT VEHICLE CLASSIFICATION

In an emergency, temporary vehicle classification can be accomplished by using expedient classification methods. The vehicle should be reclassified by the analytical method as outlined in TM 5–312 or by reference to FM 5–36 as soon as possible to obtain a permanent classification number.

a. Wheeled Vehicles. Expedient classification for wheeled vehicles may be accomplished by the following methods:

(1) Compare the wheel and axle loadings and spacings of the unclassified vehicle with those of a classified vehicle of similar design and then assign a temporary class number.

(2) Assign a temporary class number equal to 85 percent of the gross weight of the vehicle *in tons* as follows:

TEMPORARY CLASS (wheeled vehicles) = 0.85 W_T

where W_T = gross weight of vehicle in tons.

The gross weight of the vehicle may be estimated from the tire pressure and tire contact area if no other means are available.

$$W_T = \frac{A_T P_T N_T}{2000}$$

where,

W_T = Gross weight of vehicle in tons

A_T = Average tire contact area in square inches (tire in contact with hard surface)

P_T = Tire pressure in PSI

N_T = Number of tires

Note: The tire pressure may be assumed to be 75 psi for 2½-ton vehicles or larger if no tire gage is available. For vehicles having unusual load characteristics or odd axle spacings, a more deliberate vehicle classification procedure, as outlined in STANAG 2021, is required.

b. Tracked Vehicles. Expedient classification for tracked vehicles may be accomplished by the following methods:

(1) Compare the ground contact area of the unclassified tracked vehicle with that of a previously classified vehicle to obtain a temporary class number.

(2) Assign a temporary class number equal to the gross weight of the tracked vehicle in tons.

TEMPORARY CLASS (tracked vehicles) = W_T

where, W_T = gross weight in tons

Tracked vehicles can be assumed to be designed for approximately 2,000 pounds (one ton) per square foot of their bearing area (most heavy vehicles are slightly less than this). Thus, the gross weight of the tracked vehicle (W_T) can be estimated by measuring the total ground contact area of the tracks (square feet) and equating this to the gross weight in tons.

Example: An unclassified tracked vehicle has a ground contact area of 5,500 square inches. Therefore, the area is about 38.2 square feet, and the class of the vehicle is 38.2 or 39, since ground contact area is square feet equals approximate weight of a tracked vehicle in tons, which in turn is approximately equal to class number.

c. Nonstandard Combinations. The class number of nonstandard combinations of vehicles may be obtained expeditiously as follows:

Combination class = 0.9 (A + B) if A + B $\leqq$ 60
Combination class = A + B if A + B > 60
A = Class of first vehicle
B = Class of second vehicle

d. Adjustment for Other Than Rated Load. An expedient class may be given to overloaded or underloaded vehicles by adding to or subtracting the difference in loading, in tons, from the normally assigned vehicle class. The expedient classification number is marked with a standard vehicle class sign to indicate temporary classification as shown in figure 5—3.

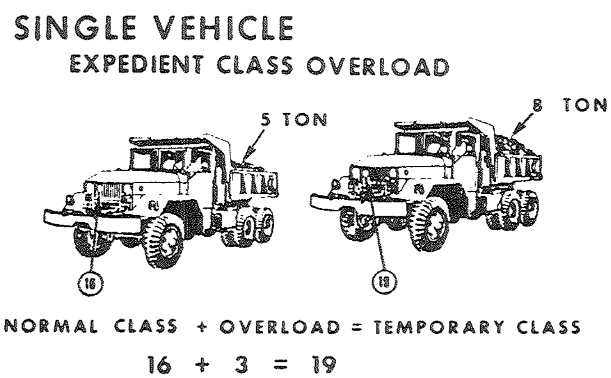


Figure 5—3. Expedient class overload.

CHAPTER 7

FIXED BRIDGES

Section I. NONSTANDARD BRIDGE DESIGN

7–1. NOMENCLATURE

a. Superstructure. The load--carrying component of the superstructure is the stringer system, which may be rectangular timber, round timber, or steel beams (figs. 7—1 and 7- 2).

b. Substructure. Intermediate supports for the superstructure may be timber bents, timber piers, pile bents, or pile piers, or a combination of these supports (fig. 7—1).

7–2. NOTATIONS

A = Area (in^2)
A_p = Bearing area of post or pile (in^2)
b = Width of stringer (in)
b_c = Width of corbel (in)
b_{cap} = Width of cap (in)
b_{sill} = Width of sill (in)
B_{PL} = Width of bearing plate (in)
d = Total depth of stringer (in)
d_c = Depth of corbel (in)
d_{cap} = Depth of cap (in)
D_p = Diameter of pile (in)
H = Height of timber bent post (ft)
H_p = Distance from fixed point to point of lowest bracing
H_m = Max hei' 'of post (ft)

kip = 1000 lbs
L = Span length (ft)
L_c = Effective corbel length (ft)
L_e = Effective span length (ft)
L_{ftg} = Length of footing (in)
L_m = Max span length (ft)
L_{PL} = Length of bearing plate (in)
M_{DL} = Dead load bending moment for entire span (kip–ft)
M_{LL} = Live load bending moment per lane (kip–ft)
m = Total bending moment per stringer (kip–ft)
M_c = Total moment acting on the corbels
m_{DL} = Dead load bending moment per stringer (kip–ft)
m_{LL} = Live load bending moment per stringer (kip–ft)
N_b = Number of braces
N_c = Number of corbels
N_L = Number of lanes
N_p = Number of posts or piles
N_{pr} = Theoretical number of piles required
N_s = Number of stringers
N_1 = Effective number of stringers per lane
N_2 = Effective number of stringers per lane for a 2–lane bridge
$\emptyset$ = Diameter of pile (in)
P_b = Capacity per pile based on end–bearing support
P_f = Capacity per pile for friction support
P_T = Total design load on substructure (kips)
S_b = Maximum spacing of bracing (ft)
S_x = Center to center spacing of component "x" (ft)
t_{PL} = Thickness of bearing plate (in)

V_c = Total shear acting on the corbels
v_c = Shear capacity of one corbel
V_{DL} = Dead load shear for entire span (kips)
V_{LL} = Live load shear per lane (kips)
v_{LL} = Total shear per stringer (kips)
v_{DL} = Dead load shear per stringer (kips)
v_{LL} = Live load shear per stringer (kips)
W_R = Width of roadway from inside curb to inside curb (ft)
W_S = Width of concrete slab (ft)

ROUND OFF RULE: Round the value down to the nearest whole number if the decimal is 0.09 or less, otherwise round up. Use this rule throughout where noted with an asterisk (*).

7–3. SUPERSTRUCTURE DESIGN (Timber and Steel Stringers)

a. Stringer Selection and Design.

(1) Step 1: Determine the maximum span length, L_m, of the stringers available from table 7–1 or table 7–2. Choose only those stringers with an L_m value $\geq$ the span length.

NOTE: Designs computed in this chapter are not conservative.

(2) Step 2: Determine the number of required stringers:

$$^{*}\ N_s = \frac{W_R}{6} + 1 \qquad \text{(Minimum } N_s = 4\text{)}$$

Determine the center-to-center stringer spacing:

$$S_s = \frac{W_R}{N_s - 1} \qquad \text{(Do not round off)}$$

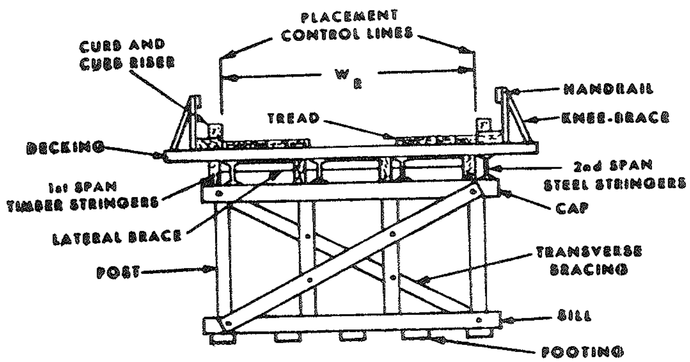


Figure 7–1. Timber trestle bridge.

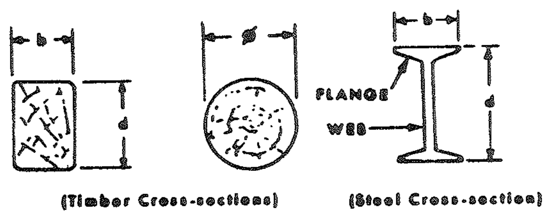


Figure 7–2. Stringer dimensions.

Table 7–1. Properties of Timber Stringers

ACTUAL SIZE (b x d) (in)	(a) MOMENT CAPACITY m (kip ft)	(b) SHEAR CAPACITY v (kips)	(c) MAXIMUM SPAN LENGTH (L_m) (ft)	ACTUAL SIZE (b x d) (in)	(a) MOMENT CAPACITY m (kip-ft)	(b) SHEAR CAPACITY v (kips)	(c) MAXIMUM SPAN LENGTH (L_m) (ft)
4 x 8	8.53	3.2	9.5	12 x 20	160.0	24.0	23.8
* 4 x 10	13.33	4.0	11.9	12 x 22	193.6	26.4	26.2
* 4 x 12	19.20	4.8	14.3	12 x 24	230	28.8	28.6
6 x 8	12.80	4.8	9.5	14 x 14	91.5	19.6	16.7
6 x 10	20.0	6.0	11.9	14 x 16	119.5	22.4	19.1
6 x 12	28.8	7.2	14.3	14 x 18	151.2	25.2	21.5
* 6 x 14	39.2	8.4	16.7	14 x 20	186.7	28.0	23.8
* 6 x 16	51.2	9.6	19.1	14 x 22	226	30.8	26.2
* 6 x 18	64.8	10.8	21.5	14 x 24	268	33.6	28.8
8 x 8	17.07	6.4	9.5	16 x 16	136.5	25.6	19.1
8 x 10	26.7	8.0	11.9	16 x 18	172.8	28.8	21.5
8 x 12	38.4	9.6	14.3	16 x 20	213	32.0	23.8
8 x 14	52.3	11.2	16.7	16 x 22	258	35.2	26.2
8 x 16	68.3	12.8	19.1	16 x 24	307	38.4	28.6
* 8 x 18	86.4	14.4	21.5	18 x 18	194.4	32.4	21.5
* 8 x 20	106.7	16.4	23.8	18 x 20	240	36.0	23.8
* 8 x 22	129.1	17.6	26.2	18 x 22	290	39.6	26.2
* 8 x 24	153.6	19.2	28.6	18 x 24	346	43.2	28.6
10 x 10	33.3	10.0	11.9	8φ	10.06	5.7	9.5
10 x 12	48.0	12.0	14.3	9φ	14.31	7.2	10.7
10 x 14	65.3	14.0	16.7	10φ	19.63	8.8	11.9
10 x 16	85.3	16.0	19.1	11φ	26.1	10.6	13.1
10 x 18	108.0	18.0	21.5	12φ	33.9	12.7	14.3
10 x 20	133.3	20.0	23.8	13φ	43.1	15.0	15.5
*10 x 22	161.3	22.0	26.2	14φ	53.9	17.4	16.7
*10 x 24	192.0	24.0	28.6	16φ	80.4	22.6	19.1
12 x 12	57.6	14.4	14.3	18φ	114.5	28.6	21.5

KEY TO SYMBOLS:

- φ DIAMETER
- * LATERAL BRACING REQUIRED AT MID-POINT AND ENDS OF SPAN.
- (a) FOR RECTANGULAR STRINGER NOT LISTED, $m = \frac{bd^2}{30}$. FOR ROUND STRINGER NOT LISTED, $m = .02d^3$
- (b) FOR RECTANGULAR STRINGER NOT LISTED, $v = \frac{bd}{10}$. FOR ROUND STRINGER NOT LISTED, $v = .09d^2$
- (c) FOR STRINGER NOT LISTED, $L_m = 1.19d$

Table 7–2. *Properties of Steel Stringers*

NOMINAL SIZE	ACTUAL DEPTH (d) (in)	ACTUAL WIDTH (b) (in)	FLANGE THICKNESS (t_f) (in)	WEB THICKNESS (t_w) (in)	MOMENT CAPACITY m (kip-ft)	MOMENT CAPACITY v (kips)	MAX SPAN LENGTH (L_m) (ft)	MAX BRACING SPACING (S_b) (ft)
51BU278	51 1/4	14	1 5/8	3/4	3067	594	133	15
*39WF211	39 1/4	11 3/4	1 7/16	3/4	1770	450	100	15
*37WF206	37 1/4	11 3/4	1 7/16	3/4	1656	425	95	16
36WF300	36 3/4	16 5/8	1 11/16	15/16	2486	520	94	25.5
36WF194	36 1/2	12 1/8	1 1/4	13/16	1482	431	93	14
36WF182	36 3/8	12 1/8	1 3/16-	3/4	1397	406	93	13
36WF170	36 1/8	12	1 1/8	1 1/16	1302	381	92	12
36WF160	36	12	1	11/16	1217	365	92	11.5
36WF230	35 7/8	16 1/2	1 1/4	3/4	1879	421	91	19.5
36WF150	35 7/8	12	15/16	5/8	1131	350	91	10.5
*36WF201	35 3/8	11 3/4	1 7/16	3/4	1545	402	90	16
33WF196	33 3/8	11 3/4	1 7/16	3/4	1433	377	86	17
33WF220	33 1/4	15 3/4	1 1/4	13/16	1661	392	86	20
33WF141	33 1/4	11 1/2	15/16	5/8	1005	313	85	11
33WF130	33 1/8	11 1/2	7/8	9/16	911	300	85	10
33WF200	33	15 3/4	1 1/8	3/4	1506	362	84	18.5
*31WF180	31 1/2	11 3/4	1 5/16	11/16	1327	327	80	16.5
30WF124	30 1/8	10 1/2	15/16	5/8	797	273	77	11
30WF116	30	10 1/2	7/8	9/16	738	263	76	10
30WF108	29 7/8	10 1/2	3/4	9/16	672	255	76	9
*30WF175	29 1/2	11 3/4	1 5/16	11/16	1156	304	75	17.5
*27WF171	27 1/2	11 3/4	1 5/16	11/16	1058	282	70	18.5
27WF102	27 1/8	10	13/16	1/2	598	217	69	10
27WF94	26 7/8	10	3/4	1/2	546	205	68	9
*26WF157	25 1/2	11 3/4	1 1/4	5/8	915	237	65	19

Table 7–2. *Properties of Steel Stringers (Con't)*

NOMINAL SIZE	ACTUAL DEPTH (d) (in)	ACTUAL WIDTH (b) (in)	FLANGE THICKNESS (t_f) (in)	WEB THICKNESS (t_w) (in)	MOMENT CAPACITY m (kip ft)	MOMENT CAPACITY v (kips)	MAX SPAN LENGTH (L_m) (ft)	MAX BRACING SPACING (S_b) (ft)
24WF94	24 1/4	9	7/8	1/2	497	191	62	11
24WF84	24 1/8	9	3/4	1/2	442	174	61	9.5
24WF100	24	12	3/4	1/2	560	173	61	13
24I120	24	8	1 1/8	1 3/16	564	286	61	12.5
24I106	24	7 7/8	1 1/8	5/8	527	224	61	12
24I80	24	7	7/8	1/2	391	183	61	8.5
24WF76	23 7/8	9	11/16	7/16	394	163	61	8.5
*24WF153	23 5/8	11 3/4	1 1/4	5/8	828	217	60	20.5
*24I134	23 5/8	8 1/2	1 1/4	13/16	634	283	60	15
*22I75	22	7	13/16	1/2	308	168	56	8.5
*21WF39	21 5/8	11 3/4	1 3/16	5/8	699	198	55	24.5
*21I112	21 5/8	7 7/8	1 3/16	3/4	495	238	55	14.5
21WF73	21 1/4	8 1/4	3/4	1/2	338	148	54	9.5
21WF68	21 1/8	8 1/4	11/16	7/16	315	140	54	9
21WF62	21	8 1/4	5/8	3/8	284	130	53	8
20I85	20	7 1/8	15/16	11/16	337	195	51	11
*20I65	20	6 1/2	13/16	7/16	245	132	51	9
*20WF134	19 5/8	11 3/4	1 3/16	5/8	621	177	50	23.5
18WF60	18 1/4	7 1/2	11/16	11/16	243	115	46	9.5
*18I86	18 1/4	7	1	11/16	326	184	46	13
18WF55	18 1/8	7 1/2	5/8	3/8	220	108	46	8.5
*18I80	18	8	15/16	1/2	292	133	46	14
18WF50	18	7 1/2	9/16	3/8	200	99	46	8
18I55	18	6	11/16	1/2	199	126	46	7.5
*18WF122	17 3/4	11 3/4	1 1/16	9/16	648	145	45	23.5

Table 7–2. Properties of Steel Stringers (Con't)

NOMINAL SIZE	ACTUAL DEPTH (d) (in)	ACTUAL WIDTH (b) (in)	FLANGE THICKNESS (t_f) (in)	WEB THICKNESS (t_w) (in)	MOMENT CAPACITY m (kips-ft)	MOMENT CAPACITY v (kips)	MAX SPAN LENGTH (L_m) (ft)	MAX BRACING SPACING (S_b) (ft)
°18162	17 3/4	6 7/8	3/4	3/8	238	100	45	9.5
°18177	17 3/4	6 5/8	15/16	5/8	281	163	45	11.5
18WF112	18 3/4	11 3/4	1	9/16	460	136	42	23.5
°18170	18 3/4	8 1/2	15/16	5/8	238	146	42	12
18WF60	18 1/4	7 1/8	5/8	3/8	181	84	41	9
16WF45	16 1/8	7	9/16	3/8	163	85	41	8
16WF64	16	8 1/2	11/16	7/16	234	106	40	12.5
16WF40	16	7	1/2	5/16	145	75	40	7.5
°16150	16	6	11/16	7/16	155	105	40	8.5
16WF36	15 7/8	7	7/16	5/16	127	74	40	6.5
°16WF110	16 3/4	11 3/4	1	9/16	345	127	40	25
°16162	15 3/4	6 1/8	7/8	9/16	200	128	40	11.5
°16145	15 3/4	5 5/8	5/8	7/16	150	104	40	7.5
°16WF103	16	11 3/4	15/16	9/16	389	121	38	24.5
16156	16	5 7/8	13/16	1/2	173	110	38	10.5
16143	16	5 1/2	5/8	7/16	132	93	38	7.5
°14WF101	14 1/4	11 3/4	15/16	9/16	344	114	36	26
°14140	14 1/4	5 3/8	3/8	3/8	119	83	36	8
14151	14 1/8	5 5/8	3/4	1/2	150	104	36	10
14170	14	8	15/16	7/16	204	87	36	18
°14157	14	6	7/8	1/2	153	101	35	12.5
°14140	14	5 1/2	5/8	3/8	121	78	35	8
14WF34	14	6 3/4	7/16	5/16	109	61	35	7.5
14WF30	13 7/8	6 3/4	3/8	1/4	94	58	35	6
°14WF82	13 3/8	11 3/4	7/8	1/2	287	88	34	26.5

Table 7–2. Properties of Steel Stringers (Con't)

NOMINAL SIZE	ACTUAL DEPTH (d) (in)	ACTUAL WIDTH (b) (in)	FLANGE THICHNESS (t_f) (in)	WEB THICKNESS (t_w) (in)	MOMENT CAPACITY m (kips-ft)	MOMENT CAPACITY v (kips)	MAX SPAN LENGTH (L_m) (ft)	MAX BRACING SPACING (S_b) (ft)
°14146	13 3/8	5 3/8	11/16	1/2	126	99	34	9
°13135	13	5	5/8	3/8	86	72	33	8
°13141	12 5/8	5 1/8	11/16	9/16	108	104	32	9.5
12WF36	12 1/4	6 5/8	9/16	5/16	103	56	31	9.5
°12165	12	8	15/16	7/16	182	73	30	21
12WF27	12	6 1/2	3/8	1/4	76	44	30	7
12150	12	5 1/2	11/16	11/16	113	120	30	10
12132	12	5	9/16	3/8	81	62	30	7.5
°12134	11 1/4	4 3/4	5/8	7/16	81	72	28	8.5
°11WF76	11	11	13/16	1/2	202	77	28	27
°10129	10 5/8	4 3/4	9/16	5/16	67	48	27	8.5
10WF25	10 1/8	5 3/4	7/16	1/4	59	38	25	8
°10140	10	6	11/16	3/8	92	53	25	14
10135	10	5	1/2	5/8	65	88	25	8
10125	10	4 5/8	1/2	5/16	55	46	25	7.5
10WF21	9 7/8	5 3/4	5/16	1/4	48	36	25	6.5
°10WF59	9 1/4	9 1/2	11/16	7/16	132	56	23	23
°9125	9 1/2	4 1/2	1/2	5/16	51	43	24	8
°9150	9	7	13/16	3/8	103	45	23	21
°8135	8	6	5/8	5/16	65	34	20	15.5
°8128	8	5	9/16	5/16	49	35	20	11.5
8WF31	8	8	7/16	5/16	61	33	20	14.5
°8WF44	7 7/8	7 7/8	5/8	3/8	81	40	20	21
°7WF35	7 1/8	7 1/8	9/16	3/8	58	37	18	18.5
°6WF31	6 1/4	6 1/4	9/16	3/8	45	31	16	18.5

°THESE NOMINAL SIZES HAVE NO U.S. EQUIVALENT.
FOR STRINGERS NOT LISTED:

$m = 2.26d_i(bt_f + d_it_w/6)$

$v = 16.5(d_i \times t_w)$

(3) Step 3: Determine the effective number of stringers for one way (N_1) and two- way (N_2) traffic: (For a one—way bridge compute only N_1.)

$N_1 = \frac{5}{S_s} + 1$ (Do not round off)

$N_2 = {}^{3}/_{8}\ N_s$ (Do not round off)

Use smaller of N_1 or N_2 for all further calculations.

(4) Step 4: Determine the live load moment per lane, M_{LL}, from figure 7-3.

Calculate the live load moment per stringer, m_{LL}:

Timber Stringer : $m_{LL} = \frac{M_{LL}}{N_1 \text{ or } N_2}$

Steel Stringer : $m_{LL} = \frac{1.15\ (M_{LL})}{N_1 \text{ or } N_2}$

(5) Step 5: Determine the dead load moment, M_{DL}, for the entire span from figure 7- 4.

Calculate the dead load moment per stringer (m_{DL}):

$m_{DL} = \frac{M_{DL}}{N_s}$

(6) Step 6: Calculate the total moment required (m_{REQD}) per stringer:

$m_{REQD} = m_{LL} + m_{DL}$

Compare the total required moment (m_{REQD}) with the moment capacity (m) of the desired stringer found in table 7—1 or table 7- 2.

(a) If the moment capacity (m) is greater than the total required moment (m_{REQD}), a moment failure will not occur. Proceed to Step 7.

(b) If the moment capacity (m) is less than the total required moment (m_{REQD}), add one stringer and return to Step 2 or select a stringer with a moment capacity greater than the required moment.

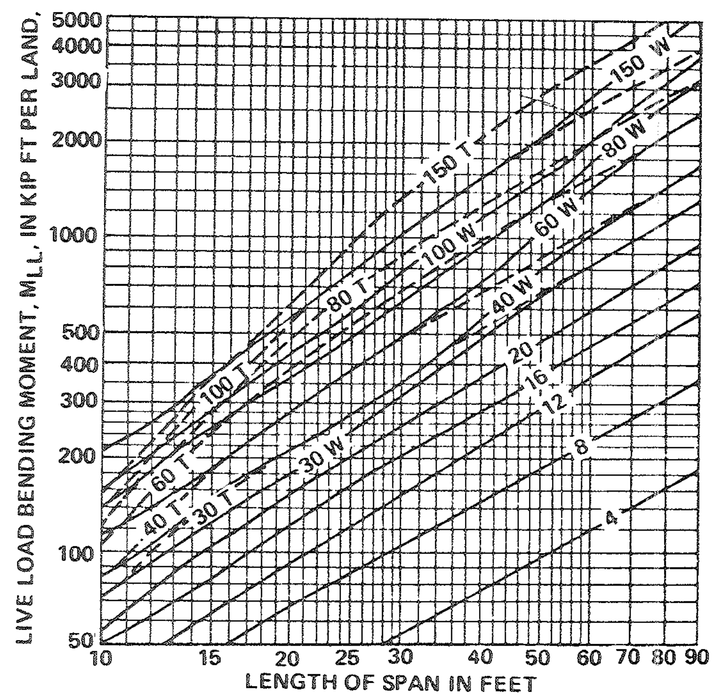


Figure 7–3. Live load moment graph.

L (FEET)	Timber stringer – timber deck, one lane M_{DL}	V_{DL}	Timber stringer – timber deck, two lane M_{DL}	V_{DL}	Steel stringer – timber deck, one lane M_{DL}	V_{DL}	Steel stringer – timber deck, two lane M_{DL}	V_{DL}	L (FEET)
70					640.25	37.10	1133.13	64.75	70
65					538.88	33.15	937.42	57.60	65
60					441.00	29.40	765.00	51.00	60
55					356.44	25.85	614.45	44.69	55
50					281.25	22.50	484.38	38.75	50
45					217.69	19.35	373.36	33.19	45
40					164.00	16.40	280.00	28.00	40
38					146.12	15.28	247.86	26.03	38
36					127.08	14.18	217.08	24.12	36
34					111.86	13.12	189.30	22.27	34
32					96.77	12.10	163.84	20.48	32
30	91.13	12.15	160.88	21.45	83.25	11.10	140.63	18.75	30
28	76.24	10.89	134.06	19.16	70.86	10.14	119.56	17.08	28
26	63.04	9.70	110.36	16.98	59.83	9.20	100.56	15.47	26
24	51.41	8.57	89.57	14.93	49.82	8.30	83.52	13.92	24
22	41.26	7.50	71.51	13.00	40.80	7.44	68.37	12.43	22
20	32.60	6.50	56.00	11.20	33.00	6.60	56.00	11.00	20
18	25.03	5.56	42.86	9.52	26.10	5.80	43.34	9.63	18
16	18.75	4.69	31.87	7.97	20.10	5.02	33.28	8.32	16
14	13.57	3.88	22.88	6.54	14.99	4.28	24.75	7.07	14
12	9.40	3.13	15.70	5.23	10.73	3.58	17.04	5.68	12
10	6.13	2.45	10.13	4.05	7.25	2.90	11.88	4.75	10
9	4.80	2.13	7.89	3.51					9
8	3.66	1.83	5.90	2.80					8

(M_{DL} IS IN KIP–FEET; V_{DL} IS IN KIPS)

SPAN IN FEET — TIMBER STRINGER – TIMBER DECK ONE LANE — TIMBER STRINGER – TIMBER DECK TWO LANE — STEEL STRINGER – TIMBER DECK ONE LANE — STEEL STRINGER – TIMBER DECK TWO LANE — SPAN IN FEET

Figure 7–4. Dead load moment and shear.

For an unlisted steel stringer:

$$m = 2.25\, d_i\, (bt_f + \frac{d_i t_w}{6})$$

For an unlisted timber stringer:

$$m = \frac{b\,d^2}{30}$$

d_i = depth of web
t_w = thickness of web
t_f = thickness of flange
b = width of stringer
d = depth of stringer

(7) Step 7: Determine the live load shear per lane (V_{LL}) from figure 7–5.
Calculate the live load shear per stringer (v_{LL}):

$$\text{Timber Stringer}: v_{LL} = \frac{3V_{LL}}{16}\left[\frac{N_1 \text{ or } N_2 + 1}{N_1 \text{ or } N_2}\right]$$

$$\text{Steel Stringer}: v_{LL} = \frac{1.15\, V_{LL}}{2}$$

(8) Step 8: Determine the dead load shear per span (V_{DL}) from figure 7–4.
Calculate the dead load shear per stringer (v_{DL}):

$$v_{DL} = \frac{V_{DL}}{N_s}$$

(9) Step 9: Calculate the total shear required (v_{REQD}) per stringer:

$$v_{REQD} = v_{LL} + v_{DL}$$

Compare the total required shear (v_{REQD}) with the shear capacity (v) of the desired stringer found in table 7–1 or table 7–2.

(a) If the shear capacity (v) is greater than the total required shear (v_{REQD}), a shear failure will not occur. Proceed to Step 10.

(b) If the shear capacity (v) is less than the total required shear (v_{REQD}), select a different stringer with a s capacity greater than the total requ hear.

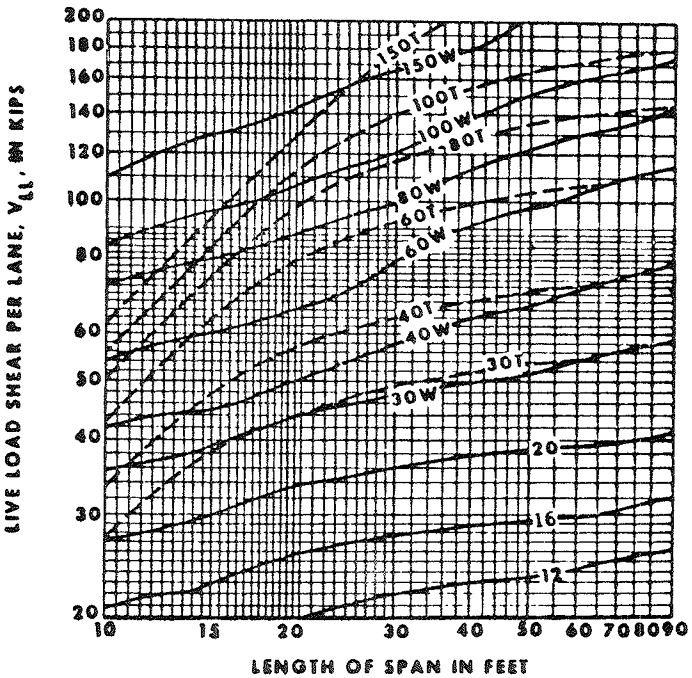


Figure 7–5. Live load shear graph.

For an unlisted steel stringer:

$v = 16.5(d_i t_w)$

For an unlisted timber stringer:

$v = \frac{bd}{10}$

Where:

d = depth of stringer

b = width of stringer

t_w = thickness of web

(10) Step 10: Determine the number of lateral braces required between adjacent stringers:

Timber: Determine if braces are required from table 7–1. Minimum lateral bracing material is 3" by ½d of the stringer.

Steel: Lateral braces are always required with steel stringers. Space braces along span length evenly. Minimum bracing materials is ³/₈" by ½d of stringer.

number braces: $N_b = \frac{L}{S_b} + 1$

(11) Step 11: Bearing plate design (fig. 7–6) required for all steel stringers (not required for timber).

$L_{PL} = b_{cap}$

$B_{PL} = \frac{2(v_{REQD})}{L_{PL}}$ (Round up to nearest whole inch.)

NOTE: Minimum B_{PL} = stringer flange width

$t_{PL} = \frac{B_{PL} - 2.5}{8.48}$ (Round up to nearest ¹/₈")

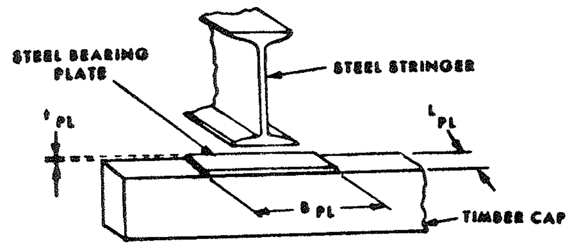


Figure 7–6. Bearing plate.

b. Decking, Treadway, Curbing, and Handrail Design.

Step 12: Determine the required decking thickness from the decking chart, figure 7–7, using the design class and the stringer spacing in inches. Add two inches to the required thickness if two or more layers of plank decking are required. (Two inches is added only ONCE regardless of number of layers stacked.) Absolute minimum decking thickness is 3 inches. For treadway, use at least 2–inch material. For curb and handrail design, see figure 7–8.

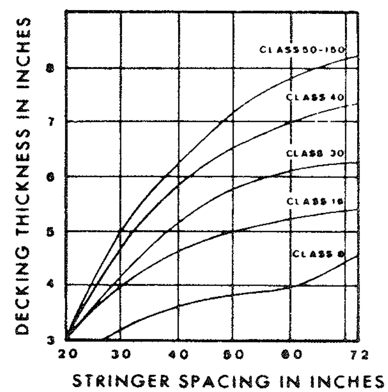


Figure 7–7. Decking chart.

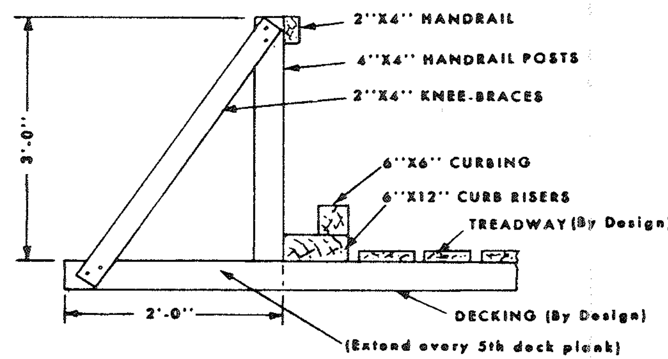


Figure 7–8. Handrail and curbing.

7-4. SUBSTRUCTURE DESIGN (intermediate Supports)

a. Timber Trestle Bent Design (fig. 7-9).

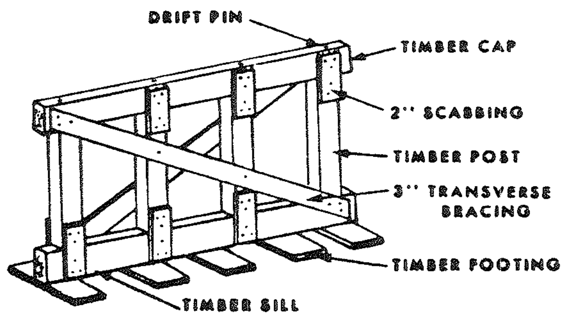


Figure 7-9. Timber trestle bent.

(1) **Step 1:** Determine critical support by finding the effective span length (L_e) for each intermediate support:
$L_e = L_1 + L_2$ (sum of adjacent span lengths)
The support for which L_e is the greatest will be the critical support, which must be designed.

(2) **Step 2:** Check the post height (H) of the tallest support against buckling. Post must be chosen from materials available (minimum post size is (6 in. x 6 in.) Find the maximum post height (H_m) in table 7-3.
If $H_m > H$, buckling will not occur. Use horizontal braces at midpoint, or select a larger post if $H_m \leq H$.

NOTE: All bracing on intermediate supports should be bolted to posts, cap, and sill.

Table 7-3. Properties of Timber Posts

Size of Post (in)	Capacity per Post (kips)	Max. Height (ft)	Size of Pile (in)	Capacity Per Pile (kips)	Max. Height (ft)
6 x 6	18	15	8φ	25	18
6 x 8	24	15	9φ	32	20
8 x 8	32	20	10φ	40	22
8 x 10	40	20	11φ	47	25
10 x 10	50	25	12φ	56	27
10 x 12	60	25	13φ	66	29
12 x 12	72	30	14φ	76	31

(3) Step 3: Determine the design load acting on the critical support:
(a) Using the design class and L_e, determine the live load shear per lane (V_{LL}) from figure 7-5.
(b) Using the adjacent span lengths, L_1 and L_2 separately, and the type of superstructure involved, determine the dead load shear (V_{DL}) from figure 7-4.
(c) Using the number of lanes (N_L), the live load shear per lane (V_{LL}), and the dead load shear (V_{DL}), compute the total design load, P_T:
$P_T = V_{LL}(N_L) + V_{DL}$ (in kips)

(4) Step 4: Determine the maximum load that one post can support, "capacity per post", from table 7-3.

(5) Step 5: Determine the number of posts required (N_p) and the center-to- center post spacing (S_p):

$$^*N_p = \frac{P_T}{\text{capacity/post}}$$ *(Note: For a pier use $\frac{1}{2}P_T$.)

$$S_p = \frac{W_R \times 12}{N_p - 1}$$ (inches)

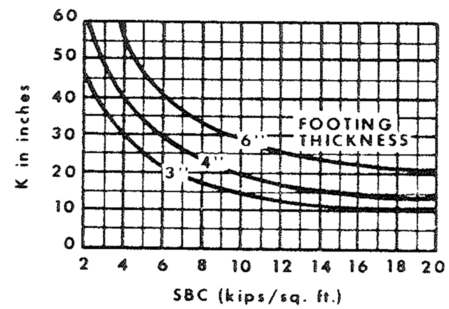
(6) **Step 6**: Check maximum allowable center-to-center spacing of posts:
max $S_p = 5\,(d_{cap})$ (inches)
If max $S_p < S_p$, add posts until max $S_p \geq S_p$ or use a cap with a larger d_{cap} dimension.

NOTE: Absolute minimum size cap and sill is 6 inches by 8 inches.

(7) **Step 7**: Using the available footing material thickness in inches and the soil-bearing capacity of the soil on which the footing is to rest (table 7-4), determine the "K" value from figure 7–10. Then calculate the maximum allowable footing length, max L_{ftg}:
max $L_{ftg} = k + b_{sill}$ (inches)

Table 7-4. Soil-Bearing Capacity

TYPE SOIL -- SBC (kips/sqft)	
Hardpan overlaying rock	24
Very compact sandy gravel	20
Loose gravel and sandy gravel compact sand and gravelly sand; very compact sand in organic silt soils	12
Hard dry consolidated clay	10
Loose coarse to medium sand, medium compact fine sand	8
Compact sand clay	6
Loose fine sand, medium compact sand-inorganic silt soils	4
Firm or stiff clay	3
Loose saturated sand–clay soils, medium soft clay	2



Max $L_{FTG} = K + b_{SILL}$

MINIMUM WIDTH OF FOOTING 12"

Figure 7-10. Footing chart.

(8) Step 8: Using the soil–bearing capacity, (SBC in kips/sq ft) and the ground contact area of one footing (GCA in sq ft), compute the capacity of one footing.
Capacity/footing = (GCA)(SBC) (kips)

(9) Step 9: Determine the number of footings required (N_{ftg}) and the center–to–center footing spacing (S_{ftg}):

$$* \; N_{ftg} = \frac{P_T}{\text{capacity/footing}}$$

NOTE: For a pier use ½P_T

$$S_{FTG} = \frac{W_R(12)}{(N_{FTG} - 1)} \quad \text{(inches)}$$

NOTE: Minimum number of footings is equal to the number of posts.

b. Timber Trestle Pier Design. Design of a timber trestle pier is identical to the design of a timber trestle bent EXCEPT that each bent is designed for one–half the total load. Therefore, use $\frac{1}{2}P_T$ in paragraph a, step 5, and step 9. A timber trestle pier, as shown in figure 7–11, will be used when loads are too great to be carried by a single bent or span lengths are greater than 25 feet. In addition to the nine design steps followed for the design of each bent, a common cap and corbel design must be made for a pier.

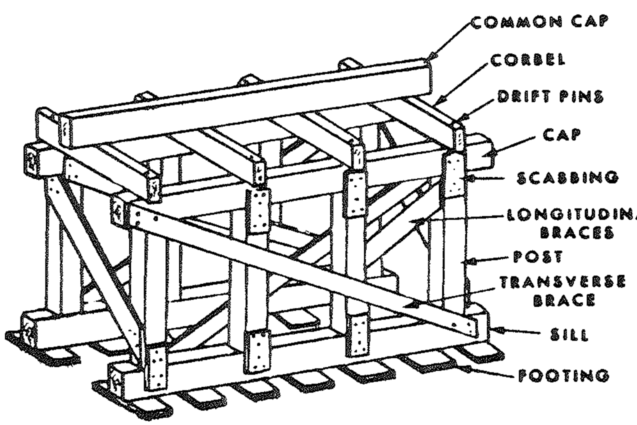


Figure 7–11. Timber trestle pier.

(1) Step 1 through Step 9: For cap, sill, posts, and footing design for bents, see paragraph a.

(2) Step 10: Determine the effective corbel length (L_c):
L_c = effective corbel length

NOTE: Minimum $L_c = 1/6H_p$ or $1/6\ H$

(3) Step 11: For design of corbels, check ratio of corbel length (L_c) to depth of corbel (d_c) to determine if moment or shear governs.

If $\frac{L_c}{d_c} \leq 12$, shear governs, proceed to step 13

If $\frac{L_c}{d_c} > 12$, moment governs, proceed to Step 12

(4) Step 12: Determine the number of corbels (N_c) required for moment by finding the total moment acting on the corbels (M_c) and the moment capacity of one corbel (m_c):

$$M_c = \frac{P_T(L_c)}{4} \quad \text{(ft-kips)}$$

Determine m_c for one corbel from table 7–1.

$$N_c = \frac{M_c}{m_c}$$ Proceed to Step 14

(5) Step 13: Determine the number of corbels (N_c) required for shear by finding the total shear acting on the corbels (V_c) and the shear capacity of one corbel (v_c):

$$V_c = \frac{P_T}{2} \quad \text{(kips)}$$

Determine v_c for one corbel from table 7–1.

$$N_c = \frac{V_c}{v_c}$$

(6) Step 14: Determine the center- to center spacing of the corbels based on the required number of corbels (N_c) as determined in Steps 12 or 13:

$$S_c = \frac{W_R(12)}{N_c - 1} \quad \text{(inches)}$$

(7) Step 15: Determine the minimum depth of the common cap (d_{cap}) and the minimum width of the common cap (b_{cap})

$$\min d_{cap} = \frac{S_c}{5}$$

$$\min b_{cap} = \frac{2 P_T}{N_c b_c}$$

NOTE: Absolute minimum size common cap is 6" x 8".

c. *Pile Bent Design (fig. 7–12).*

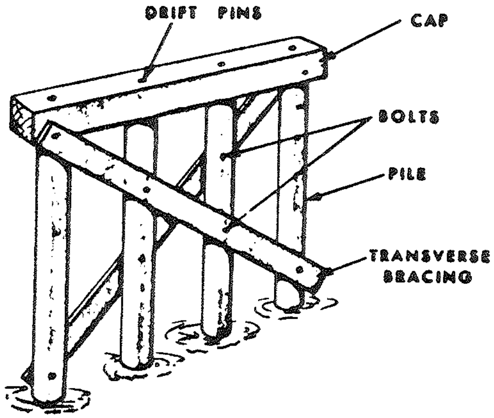


Figure 7–12. Pile bent.

NOTE: Pile type supports should be used instead of footing type supports when site conditions are affected by deep water or swift current causing scour, low capacity soil over-laying rock, or unconsolidated soil with low soil--bearing capacity.

(1) Step 1 through Step 3: Determine total load (P_T) on critical support (para a).

(2) Step 4: Determine the capacity per pile (P_b) based on end--bearing support from table 7–3.

(3) Step 5: Determine the capacity per pile (P_f) for friction support from one of the following dynamic formulas for timber piles (formulas based on test pile data or static formula – use lowest value)

Drophammer $P_f = \frac{2(W_d)(h)}{(S + 1.0)}$

Single- Acting Pneumatic or Diesel $P_f = \frac{2(W_d)(h)}{(S + 0.1)}$

Double- Acting Pneumatic or Diesel $P_f = \frac{2E}{(s + 0.1)}$

Static Formula $P_f = \Sigma f(\pi D_p L_g)$

W_d = weight of drophammer (kips)
h = average height of fall (ft)
E = work energy of hammer (ft/kip)
S = penetration of pile per blow for last 6 blows (inches/blow)
f = friction coefficient from TM 5–312
L_g = length of pile in soil layer

(4) Step 6: Using the smaller of the two values obtained from Step 4 and Step 5 for the capacity per pile, determine the effective number of piles required (N_{pr}):

$$N_{pr} = \frac{P_T}{\text{Allowable capacity pile}}$$ (Do not round off)

(5) Step 7: Determine the spacing to diameter of pile ratio (S_p/D_p) to minimize a possible overlapping of pressure bulbs which can reduce the capacity of the piles:

$$\frac{S_p}{D_p} = \frac{W_R(12)}{\frac{(N_{pr}-1)D_p}{N_R}}$$

NOTE: For a pile PIER, substitute $\frac{N_{pr}}{2}$ for N_{pr}.

If: $\frac{S_p}{D/p} > 10$ — Each pile develops full capacity. Round N_{pr} off and continue to Step 9.

$\frac{S_p}{D_p} < 3$ — Use a pile pier design.

$3 \leq \frac{S_p}{D_p} \leq 10$ — Capacity is reduced due to pressure bulb overlap. Continue to Step 8.

(6) Step 8: Determine the actual number of piles per row (N_p) from the appropriate chart in figure 7–14, using N_{pr} obtained in Step 6 and S_p/D_p Ratio obtained in Step 7.

NOTE: Minimum $N_p = 4$.

(7) Step 9: Calculate actual center--to- center spacing of piles and check spacing limitations.

Actual $S_p = \frac{W_R \times 12}{(N_p - 1)}$ (inches)

Minimum $S_p = 3(D_p)$ (inches)

Maximum $S_p = 5(d_{cap})$ (inches)

IF: Actual $S_p < 3(D_p)$ Return to Step 7 and design a pile pier.

IF: Actual $S_p > 5(d_{caps})$ Add more piles and check max and min spacing or increase depth of cap.
Calculate new S_p/D_p ratio based on N_p. Use appropriate pile chart to obtain N_{pe} using reverse procedure used for N_p.

$$\frac{S_p}{D_p} = \frac{W_r(12)}{(N_p - 1)D_p}$$

If $N_{pe} \geq N_{pr}$ – OK
If $N_{pe} < N_{pr}$ add 1 pile/row and repeat step 9 until $N_{pe} \geq N_{pr}$

d. Pile Pier Design (fig. 7–13).

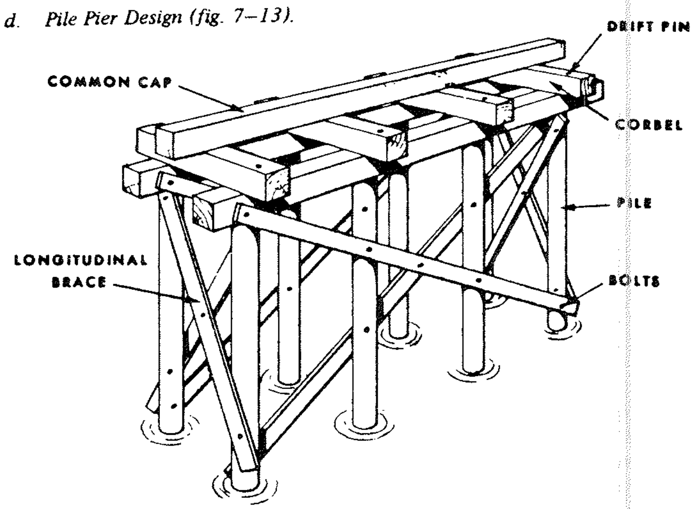


Figure 7–13. Pile pier.

(1) Step 1 through Step 3: Determine total load (P_t) acting on the critical support (see para a).

(2) Step 4 through Step 9 (pile design based on spacing criteria): In Step 7 substitute $\frac{1}{2}N_{pr}$ for N_{pr} and in Step 8 use the two-bent pile pier chart in figure 7-14 to determine the actual number of piles required per row (see para c).

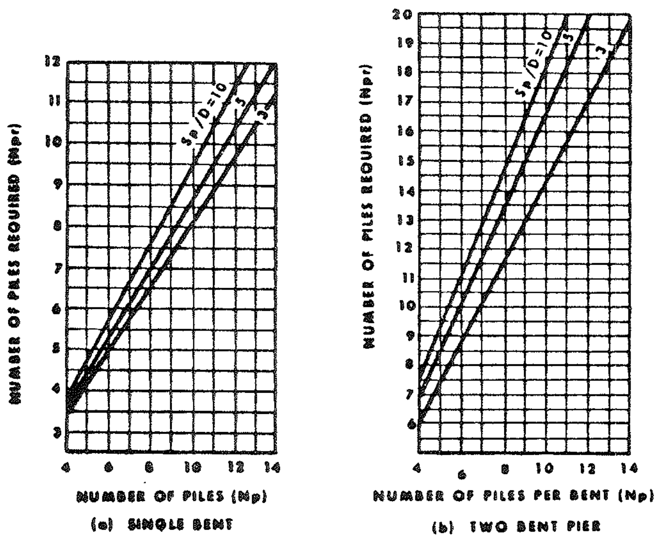


Figure 7–14. Pile charts.

(3) Step 10 through Step 15: Design common cap and corbel system (para b).

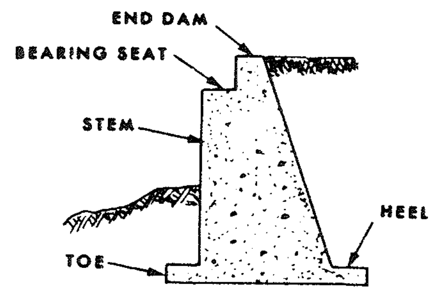
NOTE: Pile piers should be used in low capacity soils where pile bents do not give the required support or in situations requiring greater stability due to span lengths, support heights, or available material size.

'–5. SUBSTRUCTURE DESIGN

a. See figures 7–15 through 7–18 and table 7–5 for selection of butments.

b. Deadman Design. For deadman design, see TM 5–312.

NOTE: If time does not permit a detailed deadman design, use at least 4" diameter deadman at least as long as the roadway width. It should be ttached to the abutment with at least ten ³/₈" diameter cables. The leadman should be buried 4' deep and placed 20' from the abutment.



'igure 7–15. Concrete abutment.

Table 7–5. Abutment Selection Guide

TYPE	HEIGHT	SITE CONDITIONS	DESIGN REMARKS
CONCRETE ABUTMENT	TO 20'	MOST PERMANENT TYPE. USE ON FIRM BANKS WITH GOOD SOIL.	FOR DESIGN, SEE TM 5- 312.
TIMBER SILL ABUTMENT	TO 3'	MOST ECONOMICAL AND EASILY CONSTRUCTED. USE ON HIGH, FIRM BANKS WITH GOOD SOIL.	DESIGN IS IDENTICAL TO TIMBER TRESTLE BENT WITHOUT POSTS. L_e CONSISTS OF SUPPORTED SPAN ONLY (PAR a).
TIMBER BENT	TO 6'	USE ON FIRM BANKS WITH GOOD SOIL.	DESIGN IS IDENTICAL TO TIMBER TRESTLE BENT. L_e CONSISTS OF SUPPORTED SPAN ONLY (PARA a). TO PREVENT OVERTURNING, USE DEADMAN.
PILE ABUTMENT	TO 10'	USE ON GENERALLY SLOPING BANKS WITH POOR SOIL CONDITIONS, WHEN STABILITY IS DESIRED, OR WHEN BANKS FLOOD FREQUENTLY.	DESIGN IS IDENTICAL TO PILE BENT. L_e CONSISTS OF SUPPORTED SPAN ONLY (PARA c). TO PREVENT OVERTURNING, USE DEADMAN.

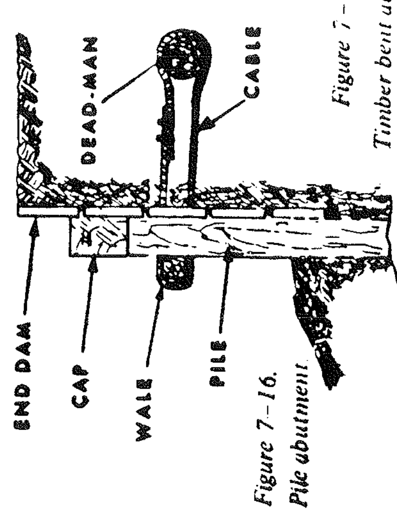


Figure 7–16. Pile abutment.

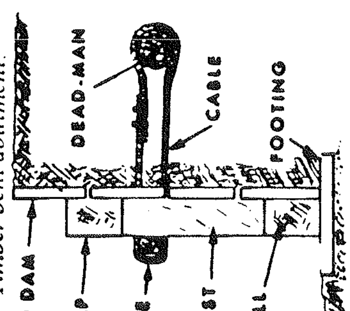


Figure 7–18. Timber bent abutment.

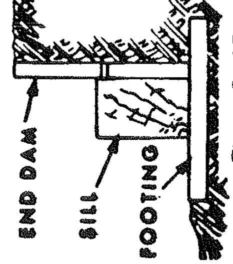
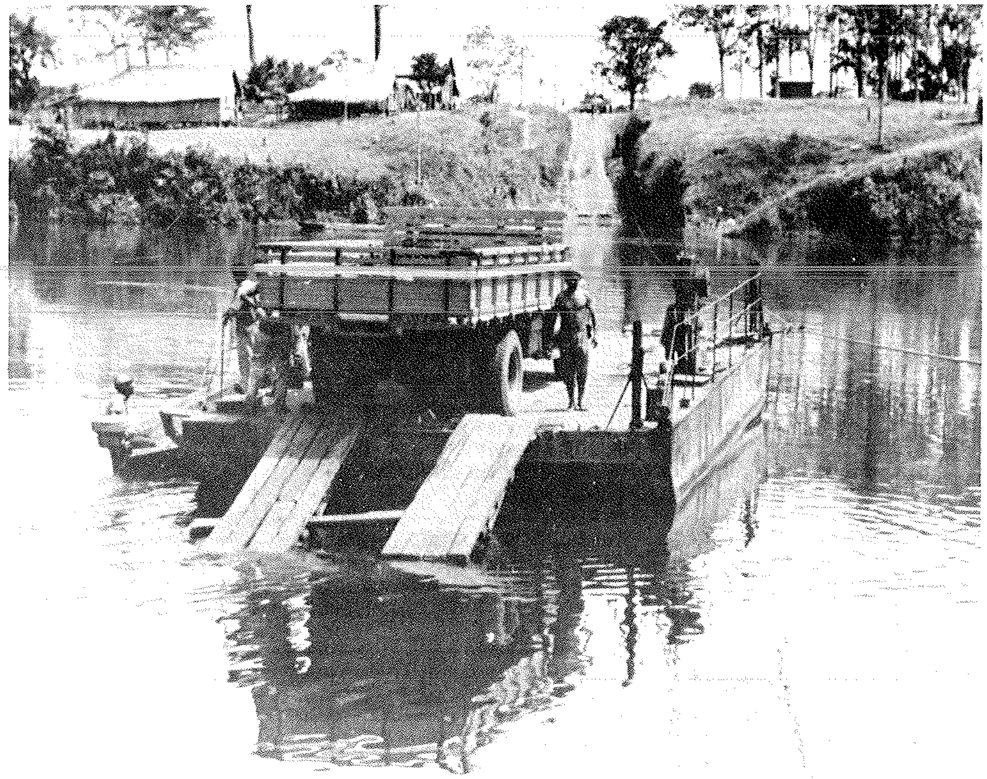


Figure 7–17. Timber sill abutment.



Ferry crossing, Rio Condeias, Brazil.

THE BAILEY AND UNIFLOTE HANDBOOK

Edited by Major J. A. E. Hathrell (R.E. Retd.)

and a Director of

THOS. STOREY (ENGINEERS) LIMITED
LONDON

One of the Acrow Group of Companies

Group Office U.S.A.
ACROW CORPORATION OF AMERICA
231 WASHINGTON AVENUE
CARLSTADT, NEW JERSEY

Contents

PART II—DESIGNING WITH BAILEY

87

PART III—THE UNIFLOTE

Introduction

The original Bailey equipment was designed to form a simple through type bridge. That is to say, the roadway is carried between two main load-carrying girders.

The main girders are composed of a number of identical Bailey Panels pinned together, end to end, and connected where necessary side to side, to form continuous stiff girders from bank to bank.

Road bearers, called transoms, are laid across the bottom chords of the Bailey panels, connecting and spacing the main girders apart, at the same time carrying the subsidiary steelwork supporting the roadway. Various bracing members and decking units complete the structure. The Bailey System includes several alternative decking systems. While timber decking is used for temporary bridges, a steel deck unit system allows Bailey equipment to be used for the construction of permanent bridges. These steel decked bridges are designed to take a road surface such as asphalt.

Bailey equipment can also be used vertically with equal facility to form piers and towers.

A considerable expansion in the range of components enables all types of bridges to be constructed. Deck type bridges, multi-lane bridges, suspension bridges, bow string, and arched bridges can now be constructed using Bailey equipment.

The same equipment is successfully employed throughout the world for all types of engineering structures where in the past normal steelwork has been used.

All components are jig manufactured to precise tolerances and all units can be reasonably handled both by hand and crane. The speed of erection for Bailey equipment allows for rapid construction in all types of structures, with a guarantee that all parts will fit together easily and are interchangeable. Bailey equipment now gives a comprehensive unit construction system.

In all types of structures the Bailey panel is the basic component, and the manner in which the panels are grouped together determines the load which the structure will carry.

The unit construction principle allows for the rapid construction of temporary support work which may be required in the construction of the Bailey structure itself. In the case of beams (bridges, centering work) a false "nose" constructed of the same Bailey panels is added to the main structure, and allows the beam to be rolled or launched from one support to the next, with the nose acting as a cantilever. Cantilevers up to 260 ft. (80 metres) have been achieved. The range of Bailey components covers the rollers and erection tools required.

Part I of this book covers the general techniques and construction detail for the various types of Bailey bridges.

Part II of the book covers general principles of design for various types of Bailey structures, and is laid out to enable the engineer to design with speed and accuracy for any type of construction. This section also gives tabulated data for easy reference.

Part III of this book covers the Uniflote equipment which has been introduced by Thos. Storey (Engineers) Ltd., one of the Acrow Group of Companies. This unit flotation system can be used both alone and in conjunction with Bailey equipment to give economic and speedy erection for many types of marine engineering works. The Uniflote has been adopted by Public Works Authorities, Civil Engineering Contractors and Armies throughout the world. Uniflote equipment is used for the construction of ferries, lighters, drilling platforms and for the flotation of land-based engineering plant, allowing the equipment to give the same performance over water that would normally be expected on land. The need for specialised floating plant is, therefore, reduced.

How to Select a Suitable Bailey Bridge

Selection of the most suitable type of Bailey Bridge to solve any particular problem depends primarily upon two factors:

1. The length of span required.
2. The weight and size of the load to be carried.

1. Can always be determined quite accurately and is the width of the gap to be bridged plus a suitable distance each end to allow the loads from the bridge foundations to spread into the subsoil.

2. Is sometimes known specifically, at other times has to be estimated. The former is the case where a bridge has to be designed to conform with some standard bridge loading of a national or local authority; it is also the case where a bridge is to be built to carry some specific heavy load which an existing bridge is not strong enough to support.

Very often, however, a bridge is required for a secondary or minor road, to deal with local traffic of a mixed character. In this case, some decision has to be taken as to the most economical maximum load for which the bridge should be designed. Signboards are then erected limiting the loads which may cross, and the occasional heavy load has to be re-routed.

The actual load must be known in detail as to the number and spacing of axles, the load on each axle and the maximum wheel load. The latter will be required to determine both the maximum stresses in the main girder and the type of decking system to be employed. It will also determine what width of roadway is required.

Bailey timber deck is designed for a maximum wheel load of 6 tons.

The steel deck is designed for a maximum wheel load of $11\frac{1}{4}$ tons.

These loads are based upon the normal size of road wheel; some types of modern heavy contractors plant are fitted with giant pneumatic-tyred wheels and it can happen that such a wheel, carrying say, 12 tons, will have a less severe effect on the deck than a normal six ton wheel, owing to the very large area of contact obtained with giant tyres.

Bridges fitted with two transoms per bay will carry a maximum single axle load of $12\frac{1}{2}$ tons, or double axles (at not less than 4 ft. (1·22 m.) centres) sharing a load of 20 tons.

Where axle loads in excess of the above figures have to be carried, then the bridge must have four transoms per bay. In this case the maximum single axle is 20 tons, and such axles must not occur at less than 4 ft. (1·22 m.) centres.

Once this loading—referred to as the "live" load—has been determined, it must be applied to the bridge span in two ways:

1. To determine the maximum shear it induces at the ends of the bridge.
2. To determine the maximum bending moment it induces at, or near, the centre of the span.

Dependent upon the span and load involved, one or other of these two cases will determine the arrangement of the side girders—the number of trusses, the number of storeys and whether or not chord reinforcement is required.

Since the loads carried on a bridge are moving, their actual static weights must be increased by a factor—normally termed the "impact factor"—to cover the additional stresses set up in the bridge structure due to vibrations set up by the speed at which the load is applied, bounce of wheels, the effects of braking and accelerating, etc.

Where bridges are designed to the standard loading of a Highway Authority, the percentage addition to the static live load to allow for impact, will be stated in the regulations.

Where no such guidance is available, the following general rules may be applied:

For normal, rubber-tyred traffic .. .. 25% impact
92 For vehicles, such as cranes, excavators
and bulldozers which run on tracks 10% impact

The above figures are for vehicles proceeding under their own power. Where a heavy load (on wheels) is being pulled slowly over a bridge by a winch sited beyond the end of the bridge 10% impact may be allowed.

NOTE: that the figure given above for cranes, is only for the vehicle driving across the bridge. Where a crane is *working* on a bridge—possibly picking up loads over the side of the bridge—eccentric loads are transmitted into the bridge girders and a much higher impact factor must be used to allow for the effect of the load on the crane hook, etc. This calls for a detailed analysis outside the scope of the present handbook.

The live load determined and the maximum shears and bending moment calculated and the appropriate impact percentage added, one additional factor has to be considered. The effect upon the bridge of its own "dead" weight. Fortunately, with Bailey, this is no great problem, since the dead weights of all the constructions for various spans can be tabulated, and in fact, tables have been prepared and included in this book, which render the calculation of the dead load unnecessary. This will be explained below.

Once the total effect of live load, impact and dead load has been determined, the construction required for the main girders may be found, observing the following design criteria:

The maximum allowable shear, per truss, at the end of the bridge (with end post fitted) is:

*15 tons for single storey trusses

*25 tons for double, or triple, storey trusses.

The maximum stress, due to the bending moment, near the centre of the span, should not exceed basic permissible figures for steel to BS.968.

In Table 6 the figures for the self weight of each type of bridge, for each span, have already been calculated and subtracted from the maximum figures given above. The tabulated figures are therefore the nett figures available for live load and impact in every case. Since bridges with steel deck and an asphalt surface are considerably heavier than their timber decked counterparts, separate tables are given for the two types. Thus, once the shear and bending moment figures for live load and impact have been calculated, it is only necessary to look along the line for the particular span in the appropriate table to determine what is the most suitable construction for main girders.

For every bridge it is necessary to consult two tables, one for shear, the other for bending, and the one which requires the heavier construction will decide the form the bridge is to take. Generally speaking, short spans carrying heavy loads are governed by shear, long spans carrying light loads are governed by bending.

Some examples follow to illustrate the above.

Example 1.

A bridge is required to carry a truck of 25 tons gross laden weight over a gap of 50 feet. It has been determined that a 60 ft. span bridge will suffice. The truck is eight feet overall width and has two axles. The front axle carries eight tons and the rear axle, which has double wheels carried 17 tons. The axles are spaced 10 ft. apart.

1. A roadway width of 10 ft. 9 in. will suffice for this vehicle, therefore use Standard Bailey.
2. No wheel load is greater than six tons; thus timber deck may be used.
3. The maximum axle load is 17 tons, requiring the bridge to have four transoms per bay.

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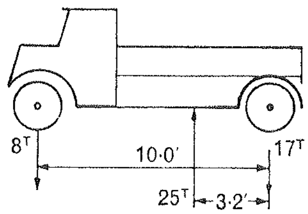
*For Standard and Standard Widened bridges of Triple Truss construction, since the trusses are not equally spaced, the *total* allowable shear at the end of bridge has to be reduced to allow for mal-distribution. See Chap. 2, page 171.

Calculations for Shear and Bending.

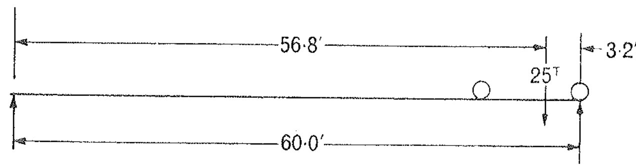
1. Calculate the centre of gravity of the load, by taking moments about the 17 ton axle. Then the total moment, divided by the total load gives the distance of the centre of gravity from the 17 ton axle.



17 × 0 = 0
8 × 10 = 80

25 tons 80 tons ft.
80 tons ft. ÷ 25 tons = 3·2 ft.

2. Position of load for maximum shear is when rear axle has just entered on to the bridge.

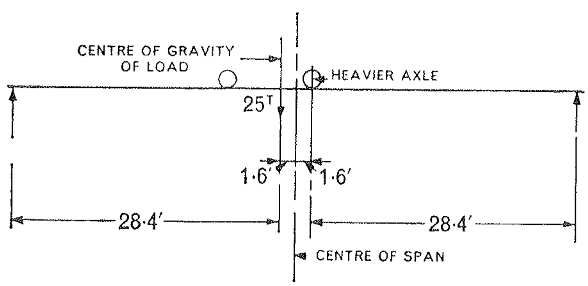


$$\text{Max. shear at Right-hand end} = \frac{25 \times 56{\cdot}8}{60} = 23{\cdot}7 \text{ tons}$$

Add for impact, 25% = 5·9 tons

Total live load and impact shear 29·6 tons

3. Position of load for maximum bending moment is when the centre line of the span is halfway between the centre of gravity of the load and the heavier axle. The point of maximum bending is under the heavier axle.



94

Right-hand reaction $= 25 \times \frac{28{\cdot}4}{60}$ = 11·83 tons

B.M. under heavier axle $= 11{\cdot}83 \times 28{\cdot}4$ = 336 tons ft.
Add for impact 25% = 84

Total Bending Moment, Live Load and Impact 420 tons ft.

From Table 6b
On a 60 ft. span, Single Single will take 24 tons shear
Double Single will take 51 tons shear
Single Single Reinforced will take 22 tons shear

From Table 6a
On a 60 ft. span, Single Single will take 319 tons ft. bending moment
Double Single will take 683 tons ft. bending moment
Single Single Reinforced will take 720 tons ft. bending moment

Neither Single Single, nor Single Single Reinforced has sufficient capacity to take 29·6 tons shear. Therefore Double Single must be used: this is also adequate for bending. Therefore specification of Bridge is: Standard Bailey, of 60 ft. span Double Single construction, four transoms per bay, timber decked.

NOTE: that in this particular case, the minimum construction which could be used is Double Single, since four transoms per bay cannot be fitted to Single Single or Single Single Reinforced constructions, without the use of Transom Clamp Mk IV with attachment (TSBB. 665 & 666). 95

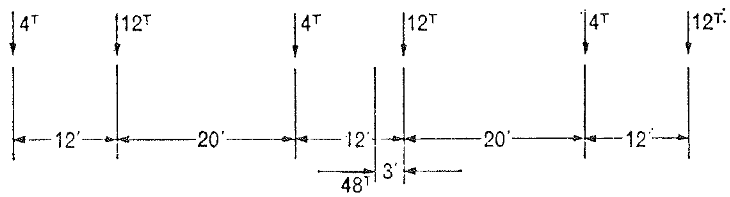
Example 2.

A permanent bridge with an asphalt road surface has to span 160 ft. and to carry a train of three trucks. Each truck will have a gross laden weight of 16 tons and its load will be 14 ft. wide and will stand 16 ft. above road level. A clear distance of 20 ft. will be maintained between trucks while crossing the bridge. Each truck has a front axle carrying four tons and a rear axle carrying 12 tons, the two axles being at 12 ft. centres.

1. The width of 14 ft. requires the bridge to be Extra Wide Bailey with a clearance between side girders 15 ft. 8 in.
2. Since this is a permanent bridge, with an asphalt surface, steel deck will be used and it is considered advisable to stagger the ends of the units to avoid any tendency of cracks developing in the asphalt.
3. According to the axle loading, only two transoms per bay are required, but if the ends of the deck units are to be staggered, two transoms are required at the junction of each bay. Only one transom need be placed at the centre vertical—therefore use three transoms per bay.

Calculations for Shear and Bending.

1. Calculate the centre of gravity of the load.



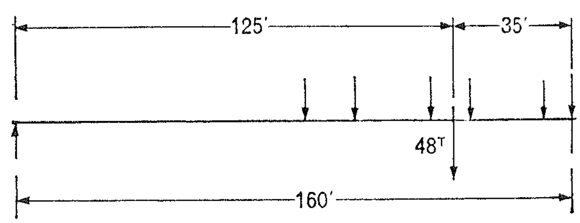
C.G. from left-hand end:

$$\begin{aligned} 4 \times 0 &= 0 \\ 12 \times 12 &= 144 \\ 4 \times 32 &= 128 \\ 12 \times 44 &= 528 \\ 4 \times 64 &= 256 \\ 12 \times 76 &= 912 \\ \hline 48 \qquad & \quad 1968 \end{aligned}$$

$1968 \div 48 = 41$ ft.

This is 3 ft. from the nearest heavy (12 ton) axle in the central position.

96 2. Position for maximum shear.



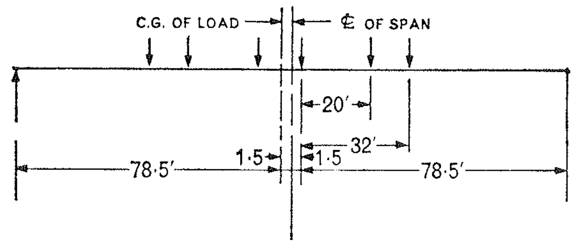
Shear is a maximum at the right-hand end as the last 12 ton axle enters the bridge.

$48 \times \frac{125}{160} =$ 37·5 tons

Add for impact 25% = 9·4 tons

46·9 tons

3. **Position for maximum bending.**



This occurs when the centre of gravity and the nearest heavy axle are equally disposed about the centre line and is a maximum under this heavy axle (at x).

Right-hand reaction $= 48 \times \dfrac{78{\cdot}5}{160} \quad = \quad 23{\cdot}6$ tons

B.M. at $\times = 23{\cdot}6 \times 78{\cdot}5 \quad = \quad 1852$ tons ft.

$-(4 \times 20 + 12 \times 32) \quad = \quad -467$,, ,,

1388

Add for impact 25% = 347 ,, ,,

1735 ,, ,,

In Table 8c against 160 ft. span, either Triple Triple or Triple Double Reinforced have a sufficient reserve of bending moment. Checking the shear for these two constructions against 160 ft. span in Table 8d shows they have an ample reserve of shear strength.

If Triple Triple is used, the top chords must be tied together with Overhead Bracing. This will restrict the headroom to 14 ft. 6 in. This construction is therefore not suitable for loads 16 ft. high.

Therefore, specification of bridge is: Extra Wide Bailey, of 160 ft. span Triple Double Reinforced construction, three transoms per bay, with steel deck suitable for asphalting.

TABLE 6a

TABLE OF BENDING MOMENTS AVAILABLE FOR LIVE LOAD. TONS, FEET.
STANDARD BAILEY. TIMBER DECK.

Feet	S.S.	D.S.	SSR	T.S.	D.S.R.	D.D.	T.S.R.	T.D.	D.T.	D.D.R.	T.T.	T.D.R.
10	407	—	—	—	—	—	—	—	—	—	—	—
20	400	—	—	—	—	—	—	—	—	—	—	—
30	387	785	802	—	—	—	—	—	—	—	—	—
40	370	759	781	—	—	—	—	—	—	—	—	—
50	347	725	754	1116	—	—	—	—	—	—	—	—
60	319	683	720	1067	1484	—	—	—	—	—	—	—
70	286	633	680	1008	1420	1493	2188	2299	—	—	—	—
80	249	576	634	940	1347	1414	2096	2198	—	—	—	—
90	206	511	582	863	1264	1323	1991	2083	—	—	—	—
100	158	439	524	777	1170	1223	1875	1956	2583	2881	4025	4443
110	105	359	460	681	1068	1112	1745	1815	2430	2747	3827	4268
120	47	271	390	577	956	990	1604	1660	2263	2601	3610	4076
130	—	176	313	464	833	858	1450	1492	2081	2442	3375	3868
140	—	—	—	342	701	716	1284	1311	1885	2270	3122	3642
150	—	—	—	210	560	562	1106	1116	1674	2086	2849	3400
160	—	—	—	70	408	398	915	907	1448	1888	2557	3142
170	—	—	—	—	—	224	712	686	1218	1678	2257	2867
180	—	—	—	—	—	40	496	450	954	1455	1918	2575
190	—	—	—	—	—	—	—	202	685	1220	1567	2266
200	—	—	—	—	—	—	—	—	402	972	1203	1941
210	—	—	—	—	—	—	—	—	103	700	817	1598
220	—	—	—	—	—	—	—	—	—	—	463	1240
230	—	—	—	—	—	—	—	—	—	—	—	855
240	—	—	—	—	—	—	—	—	—	—	—	473
250	—	—	—	—	—	—	—	—	—	—	—	—

TABLE 6b

TABLE OF SHEAR FORCES AVAILABLE FOR LIVE LOAD. TONS.

STANDARD BAILEY. TIMBER DECK.

Feet	S.S.	D.S.	S.S.R.	T.S.	D.S.R.	D.D.	T.S.R.	T.D.	D.T.	D.D.R.	T.T.	T.D.R.
10	29	—	—	—	—	—	—	—	—	—	—	—
20	28	—	—	—	—	—	—	—	—	—	—	—
30	27	55	26	—	—	—	—	—	—	—	—	—
40	26	54	25	—	—	—	—	—	—	—	—	—
50	25	52	24	71	—	—	—	—	—	—	—	—
60	24	51	22	69	48	87	65	—	—	—	—	—
70	23	49	21	67	46	85	63	—	—	—	—	—
80	22	48	20	65	44	83	60	—	—	—	—	—
90	21	46	19	63	42	81	58	111	—	—	—	—
100	20	45	18	62	40	79	55	108	71	74	97	102
110	19	43	17	60	38	77	53	105	68	72	93	98
120	18	42	15	58	36	75	50	103	65	69	90	95
130	17	40	14	56	34	73	48	100	62	67	86	92
140	—	—	—	55	32	70	45	97	59	64	82	88
150	—	—	—	53	30	68	43	95	56	62	78	85
160	—	—	—	51	28	66	40	92	53	59	75	82
170	—	—	—	—	26	64	38	89	50	57	71	78
180	—	—	—	—	—	62	36	86	47	54	67	75
190	—	—	—	—	—	—	—	84	45	51	63	71
200	—	—	—	—	—	—	—	—	42	49	60	68
210	—	—	—	—	—	—	—	—	39	46	56	65
220	—	—	—	—	—	—	—	—	—	—	52	61
230	—	—	—	—	—	—	—	—	—	—	—	58
240	—	—	—	—	—	—	—	—	—	—	—	55
250	—	—	—	—	—	—	—	—	—	—	—	—

TABLE 8c

TABLE OF BENDING MOMENTS AVAILABLE FOR LIVE LOAD. TONS, FEET.
EXTRA WIDE BAILEY. STEEL DECK AND ASPHALT.

Feet	S.S.	D.S.	S.S.R.	T.S.	D.S.R.	D.D.	T.S.R.	T.D.	D.T.	D.D.R.	T.T.	T.D.R.
10	402	—	—	—	—	—	—	—	—	—	—	—
20	395	—	—	—	—	—	—	—	—	—	—	—
30	376	772	—	—	—	—	—	—	—	—	—	—
40	349	735	760	—	—	—	—	—	—	—	—	—
50	315	688	722	1080	—	—	—	—	—	—	—	—
60	245	630	659	1014	1431	—	2215	—	—	—	—	—
70	224	560	610	936	1348	1421	2115	2223	—	—	—	—
80	167	480	502	846	1253	1320	2002	2100	—	—	—	—
90	102	393	480	745	1143	1206	1872	1958	—	—	—	—
100	30	290	397	555	949	1077	1728	1800	2420	2745	3855	4302
110	—	180	306	505	890	937	1570	1628	2235	2582	3620	4092
120	—	60	150	366	745	672	1291	1323	2035	2401	3365	3864
130	—	—	65	210	580	612	1200	1228	1810	2203	3090	3617
140	—	—	—	—	410	432	990	1003	1570	1998	2795	3352
150	—	—	—	—	225	232	775	768	1310	1768	2465	3067
160	—	—	—	—	—	—	538	506	850	1380	1925	2584
170	—	—	—	—	—	—	280	228	740	1258	1755	2422
180	—	—	—	—	—	—	—	—	235	998	1365	2082
190	—	—	—	—	—	—	—	—	110	708	965	1720
200	—	—	—	—	—	—	—	—	—	403	525	1330

TABLE 8d

TABLE OF SHEAR FORCES AVAILABLE FOR LIVE LOAD. TONS.
EXTRA WIDE BAILEY. STEEL DECK AND ASPHALT.

Feet	S.S.	D.S.	S.S.R.	T.S.	D.S.R.	D.D.	T.S.R.	T.D.	D.T.	D.D.R.	T.T.	T.D.R.
10	28	—	—	—	—	—	—	—	—	—	—	—
20	27	—	—	—	—	—	—	—	—	—	—	—
30	25	54	—	—	—	—	—	—	—	—	—	—
40	24	51	23	—	—	—	—	—	—	—	—	—
50	22	49	21	66	—	—	—	—	—	—	—	—
60	21	47	19	63	45	—	59	—	—	—	—	—
70	19	45	18	61	42	81	56	110	—	—	—	—
80	18	43	17	58	40	78	52	106	—	—	—	—
90	16	41	14	55	37	76	49	103	—	—	—	—
100	15	39	13	53	35	73	46	99	65	69	106	92
110	—	37	11	49	32	70	42	95	61	66	101	87
120	—	34	7	47	29	68	39	91	57	63	97	83
130	—	—	6	44	27	65	36	88	54	59	92	79
140	—	—	—	—	24	62	33	84	50	56	88	75
150	—	—	—	—	21	59	29	80	47	53	83	70
160	—	—	—	—	—	—	26	77	43	50	79	66
170	—	—	—	—	—	—	23	73	40	47	75	63
180	—	—	—	—	—	—	—	—	36	44	70	58
190	—	—	—	—	—	—	—	—	33	41	66	54
200	—	—	—	—	—	—	—	—	—	37	61	50

Part III

The Uniflote

Introduction to The Storey Uniflote

The Uniflote was conceived as a flotation system based on "unit construction" principles, whereby numbers of identical flotation units could be assembled together to form rafts of various sizes according to the load carrying capacity and usage required. It had to be equally applicable in the fields of both Military and Civil Engineering In the former it had to be suitable to support the various bridging equipments of armies throughout the world, to enable them to be used as floating bridges or ferries and it had to be capable of being used as a ferry without any such bridging superstructure or as a ship-to-shore causeway.

Many of these applications, of course, overlap into requirements for the civilian field. Additionally here it had to be equally suitable for permanent installations, such as landing stages, and for temporary rafts. In the latter case it could be used to carry normally land-based plant, such as cranes, excavators and pile driving equipment for use on marine works.

Therefore, in order to prepare a design for the Uniflote, the following criteria were laid down:

(i) It must be capable of supporting, by easy attachment, the three current types of Bailey Bridging, "standard", "widened", and "extra wide" and their American equivalents, M I, II and III, the 50/60 and 55/65 Raft superstructures and the Heavy Girder Bridge in both its standard and narrow forms. It must also be capable of supporting wheel and track loads anywhere on its deck.

(ii) The various flotation units must be capable of being connected together *in the water* from deck level and such connexions must not interfere with the water-tightness of the units.

(iii) Each unit to be capable of supporting a load of 10 tons whilst maintaining a reasonable freeboard, in the region of 9 in. (0·23 m.). It should still be capable of bearing this load where a receding tide leaves the unit grounded.

(iv) The units to be capable of being transported on a vehicle which is common all over the world, a three ton truck.

A study of Article (i) revealed that the most suitable length was 17 ft. 9 in. (5·41 m.) (this was also complying with the requirements of Article (iv)).

Article (iv) required the unit not to exceed 8 ft. 9 in. (2·67 m.) in width and three tons in weight.

These dimensions taken in conjunction with Article (iii), established the depth at 4 ft. (1·219 m.).

To comply with Article (ii), all couplings were designed to work outside the main water-tight body of the unit. Top couplings took the same form as those of the Bailey and Heavy Girder panels, a male lug and a female jaw locked in engagement by a horizontal pin. The bottom couplings were designed as up and downturned hooks. The assembly crew using only their own weight can tilt the units in the water sufficiently to enable the noses of the hooks to over-ride each other. As soon as the units are allowed to resume their normal horizontal trim the hooks engage fully, and the top lugs come into register, enabling the locking pin to be inserted.

Once the top couplers are pinned, the bottom hooks cannot come out of engagement.

These couplings require a space of 5 in. between the units and so the final dimensions of the Uniflote become:

17 ft. 4 in. long (5·283 m.) (17 ft. 9 in. (5·41 m.) centre-to-centre of couplings).

8 ft. (2·438 m.) wide (8 ft. 5 in. (2·565 m.) centre-to-centre of couplings).

4 ft. (1·219 m.) deep. 103

Later, a 6 ft. (1·829 m.) deep Uniflote was also developed, principally for the civilian market.

Along the deck at each side gunwales were fitted, with a series of holes to which saddles could be pinned. By this means, all the bridging equipments listed in Article (i) can be simply and effectively attached.

For greater safety it was decided to make the Uniflote with three water-tight compartments by incorporating two bulkheads at roughly the third points of its length. These bulkheads also serve to increase considerably the stiffness and rigidity of the Uniflote. Each compartment is served by a water-tight hatch in the deck. In each hatch are two tube connectors, one with a tube extending almost to the bottom of the Uniflote. By this means each compartment can be individually flooded and, in reverse, water may be ejected by the application of compressed air.

To complete the equipment of the Uniflote, runners were attached to the bottom to assist in skidding operations on shore, and four lifting shackles fitted to the deck for craning purposes.

The Uniflote, as described above, is available in two types. Type 1 has the deck set approximately 3 in. (0·076 m.) below gunwale level so that a replaceable timber deck may be fitted if required. Type II (a special military version) has an integral steel deck set level with the top of the gunwales over which traffic may drive direct.

Twelve sets of couplers are fitted to each Uniflote. A "set" comprises either (a) a male top coupler and an upturned bottom hook, or (b) a female top coupler and a downturned bottom hook. Each female top coupler has a locking pin chained to it.

Four sets of couplers are ranged along each side, and two sets at each end, those on one side and end being "male" and on the other side and end being "female". By this means Uniflotes can be coupled together not only side-to-side and end-to-end, but each side of one Uniflote can be coupled to the ends of two other Uniflotes.

When applied to floating bridges of the Bailey or Heavy Girder type the ability of Uniflotes to be side-coupled shows an enormous saving in stores on such items as the Landing Bay Pier, since the Landing Bay Transom and the Distributing Girder system is no longer required.

Selection of the most suitable material was decided by two principal factors, strength and economy. Both factors are of equally vital interest to the intending purchaser, whether military or civilian. Investigation showed that the Uniflotes were most highly stressed when used as pontoons under floating bridges; the whole of the load being concentrated at the two points of application of the bridge side girders. Various plastics, including fibre glass were considered, but rejected for the following reason:

104 1. By themselves their strength was insufficient.
2. They could not be used for the couplings.
3. Inclusion of a stiffening frame raised the price above the economic limit.
4. In case of damage (such as would be incurred under war conditions) repair either required returning units to a base depot (where special equipment was available) or proved to be impracticable.

Two metals were investigated, steel and aluminium. The latter suffers from most of the disadvantages associated with plastics even using a high duty alloy. There is no great saving in weight over a steel structure; the required extrusions and plates are more expensive than the equivalent rolled steel sections and plates. Since units could not be satisfactorily manufactured by riveting, specialised welding plant would be required. This, in turn, means that units damaged in action would have to be taken out of service and returned to a base depot where such plant (and skilled operators) is available. The unit was very liable to damage when grounded and carrying full load (as required under Article (iii)).

On the other hand, a steel unit complied with all the original requirements laid down.

Operation of Shore-loading Ferries

Uniflote shore-loading ferries may be either captive or free ranging.

The captive ferry can only normally be used where it is required to range between two fixed stations on either side of a river having a current flowing in one constant direction. In operation, it requires to have a cable slung across the river upstream of the ferry, of sufficient strength and suitably anchored. From a running block on this cable, two lines are taken to two winches mounted as far apart as possible at opposite ends of the ferry. 105

The winch at the leading end of the ferry takes in some of its line, swinging the ferry at an angle to the current; the resultant force drives the ferry across the river. As the other bank is approached, the same winch pays out its line, taking way off the ferry and bringing it in at the correct angle. For the return journey the same drill is repeated with the other winch.

On a river with a fast-flowing current this calls for some skill and experience on the part of the operators.

On streams with little current it may be necessary to sling a supplementary cable across the river, looped around a power windlass on the ferry, to provide the necessary motive power.

Alternatively, two chains may be laid across the bed of the river, anchored at each bank. The ferry then hauls itself across by picking the chains up over two power-driven sprockets.

Where normal up-and-down-stream navigation has to be maintained on a river, these schemes are not usually very practicable. The ferry then has to be free ranging, i.e., powered and navigated like any other vessel. Motive power is usually provided by internal combustion engines driving screw-type propellers; direction is controlled either by rudders or by varying the thrust or direction of the propellers. Alternatively motor tugs can be used, either lashed alongside, or pushing astern.

The Uniflote ferry may be operated as a captive ferry by the simple expedient of fixing two suitable winches, where there is sufficient current to drive the ferry, and adding a supplementary powered windlass where the current is ineffective.

To operate as a free-ranging ferry, the Uniflote ferry is fitted with propulsion units. Such units normally comprise internal combustion engines, mounted either directly on the deck or outboard, from which vertical shafts project downwards to drive, through suitable bevel gearing, normal screw-type propellers. The direction of the propellers can be varied by rotation about the vertical drive shafts, and the ferry can thus be driven in any direction. An arrangement is incorporated in each vertical drive shaft to enable the propeller to be raised clear of the water for inspection and maintenance.

The number and power output of the propulsion units will of course be decided by the size of the ferry and the conditions under under which it has to operate. Except in certain special cases, the numbers of units will not be less than two, nor more than four. Where two units are employed they should be positioned as far apart as possible, i.e. at opposite sides and opposite ends of the ferry. This layout gives the greatest degree of manoeuvrability. Where four units are employed, they are positioned, two on either side, as near the ends of the ferry as conditions will allow.

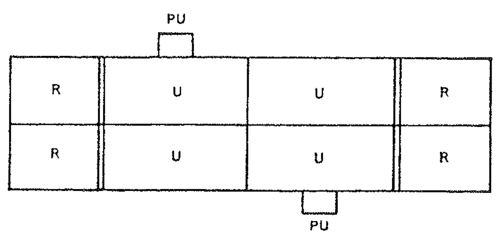
Care must be taken, however, not to set power units too near the ends of the ferry, since there would then be a danger of the propellers fouling the bottom as the ferry runs on to the shore or river bank. The slope of the shore at the intended landing stations must therefore be carefully ascertained.

(b) Centrally over the *junction* between two Bow or Stern units.
(c) Centrally over the end of a Uniflote.
(d) Centrally over the junction between two Uniflotes.
(e) On Ramp Units (in exceptional circumstances).
(f) On an Outrigger (fitted to the side of a Uniflote).

In the latter case, the whole unit is mounted outboard, leaving the deck space clear for vehicle and passengers. Details of these various saddles, for winches, power units, and other equipment, can be obtained from Thos. Storey (Engineers) Ltd.

TYPICAL UNIFLOTE FERRIES

Five of the most frequently used sizes of Uniflote ferry will be described, in order to demonstrate as simply as possible, the scope of the Uniflote in this application.



U = Uniflote R = Ramp *Type A*
P.U. = Propulsion Unit

Ferry Type A

This is a simple type, consisting of only four Uniflotes coupled together in pairs to form a basic raft two Uniflotes long by two Uniflotes wide. To each end of this raft are fitted two ramp unit assemblies; i.e. each of the four Uniflotes has a ramp unit attached at one of its ends. This provides a ferry 63 ft. 1 in. (19·2 m.) long and 16 ft. 5 ins. (5·00 m.) wide. The whole of this deck area may be occupied by vehicles and passengers. At 12 in. (0·305 m.) freeboard, this ferry has a carrying capacity of 32 tons (71,680 lb.).

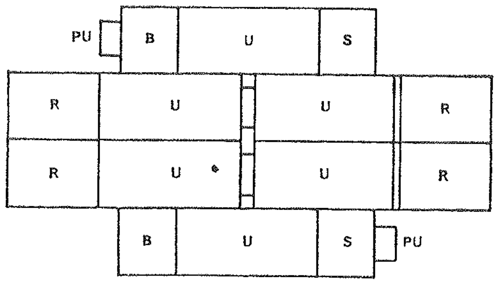
Motive power is provided by two 42 H.P. diesel units mounted outboard on cantilever saddles, and drives the ferry at speeds up to 7 knots (12·5 km./h.).

The unladen draught is approximately 18 in. (0·46 m.) according to the position of the ramps (since these provide more buoyancy in their lower positions and less in their raised positions), representing a dead weight of some 29 tons (64,960 lb.).

Ferry Type B

This is composed of six Uniflotes. Four Uniflotes are coupled in pairs side-by-side, and then, with the insertion of four 11 in.

interflote connectors, end-to-end. The interflote connectors are necessary in order to arrange the outside couplers of these Uniflotes at the correct centres to attach to them the two further outrigger Uniflotes. Two Ramp assemblies are fitted at each end, and each outrigger Uniflote has a Bow Unit and Stern Unit attached.



U = Uniflote. B = Bow. S = Stern.
R = Ramp. PU = Propulsion Unit.

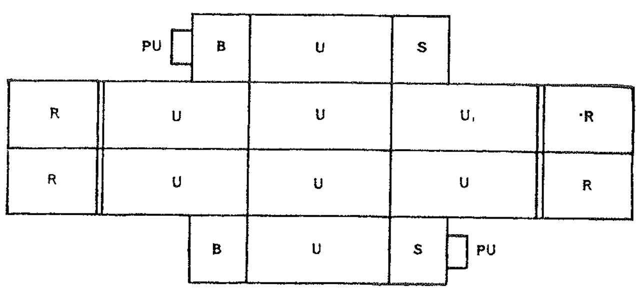
Type B

The ferry is 64 ft. 5 ins. (19·6 m.) long and 33 ft. 3 ins. (10·1 m.) wide. Vehicles are normally restricted to the deck area formed by the central four Uniflotes and the four Ramps. The "roadway" width is therefore 16 ft. 5 ins. (5·00 m.). The outrigger Uniflotes can then be reserved for foot passengers. At 12 in. (0·305 m.) freeboard, the ferry has a carrying capacity of 48 tons (107,520 lb.).

108 Motive power, consisting of two 42 H.P. diesel units, can conveniently be mounted on the Bow and Stern Units, at diagonally opposite ends of the ferry. With the propulsion units in these positions, a minimum depth of water of 3 ft. (0·91 m.) is required, 12 ft. (3·66 m.) from the bank. The dead weight of this ferry is approximately 39 tons (87,360 lb.).

Ferry Type C

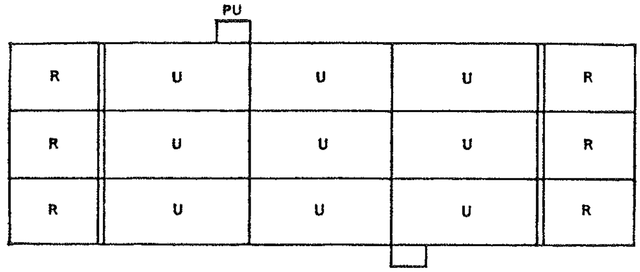
This is an eight Uniflote ferry, being three Uniflotes long by two Uniflotes wide, with two outrigger Uniflotes. Two Ramp assemblies are provided each end, and each outrigger Uniflote is complete with Bow and Stern units.



Type C

The overall length is 80 ft. 10 in. (24·6 m.), the overall width 33 ft. 3 in. (10·1 m.). The width normally occupied by vehicles (on the six central Uniflotes) is 16 ft. 5 ins. (5·00 m.). At 12 in. (0·305 m.) freeboard, the ferry will carry 64 tons (143,360 lb.).

Two propulsion units of either 42 H.P. or 60 H.P. (as required by local conditions) are best mounted on the Bow and Stern Units at diagonally opposite ends of the ferry. The dead weight of this ferry is approximately 47 tons (105,280 lb.).



Ferry Type D *Type D*

This ferry composed of nine Uniflotes, is rectangular, being three Uniflotes long by three Uniflotes wide, with three Ramp assemblies each end. The whole of the deck space may be occupied by vehicular traffic.

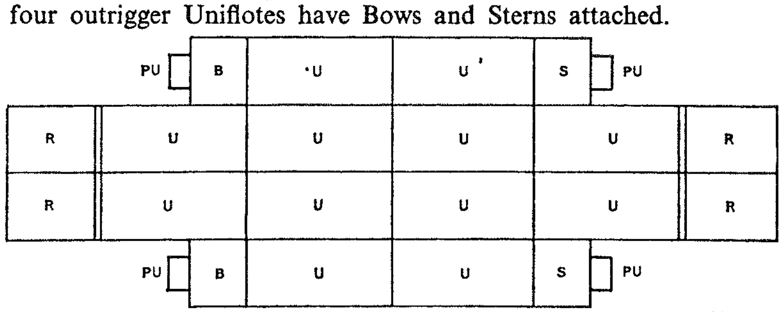
The overall length is 80 ft. 10 in. (24·6 m.), the overall width is 24 ft. 10 in. (7·60 m.). At 12 in. (0·305 m.) freeboard, this ferry has a carrying capacity of 72 tons (161,280 lb.). 109

In order to maintain all deck space clear for traffic, power units should be mounted outboard on cantilever saddles, two units of either 42 H.P. or 60 H.P. being used, as required by local conditions. These units should be mounted at diagonally opposite ends of the ferry.

The approximate dead weight of this ferry is 50 tons (112,000 lb.).

Ferry Type E

This ferry is composed of twelve Uniflotes, being four Uniflotes long and two Uniflotes wide plus two Uniflotes as outriggers on each side. Two Ramp assemblies are fitted at each end and the four outrigger Uniflotes have Bows and Sterns attached.



Type E

The overall length is 98 ft. 7 in. (30·0 m.); the overall width is 33 ft. 3 in. (10·1 m.) this width being reduced to 16 ft. 5 in. (5·00 m.) at each end. At 12 in. (0·305 m.) freeboard, the capacity of this ferry of 96 tons (215,340 lb.).

Propulsion units are best mounted on the Bow and Stern Units; their number and horse power will be determined by conditions prevailing at the ferry site.

Summarising the above examples gives the following table:

Ferry Type	*Load Tons*	*Capacity lb.*	*Overall Sizes Feet*	*Overall Sizes Metres*	*Available Deck Area Sq. Feet*	*Available Deck Area Sq. Metres*
A	32	71,680	63 × 17	19·2 × 5·2	1,008	9·35
B	48	107,520	64·5 × 33·5	19·6 × 10·3	1,209	112
C	64	143,360	80·8 × 33·5	24·6 × 10·3	1,470	136
D	72	161,280	80·8 × 24·8	24·6 × 7·8	1,981	183
E	96	215,340	98·5 × 33·5	30·0 × 10·3	2,136	198

Double-ended Ferries have been described in the examples on pages 220 to 222. Single-ended Ferries of identical load carrying capacity are often advantageous. In these cases the Ramps are omitted at one end. Scow Ends (Bow or Stern Units) are substituted. With Single-ended Ferries it is an advantage to fit the propulsion units on these Scow Ends.

110 **Designing a Uniflote Ferry**

1. Determine the total load the ferry will have to carry, obtain full information regarding the type and numbers of vehicles to be handled (together with their gross laden weight, spacing of axles, width and length).

2. Estimate the approximate distance the ferry will have to travel at each crossing.

3. Calculate the density of traffic with which the ferry will have to cope (2 and 3 will determine not only the size of the ferry, but also whether it is more economical to operate one large ferry or two small ferries).

4. Investigate the nature of the crossing (whether river, estuary or open sea).

5. (a) Obtain details of speed of current (whether constant in speed and direction, and any seasonal variations).

(b) Investigate any tidal conditions, the current speed in both directions, the normal high and low water levels, and any seasonal variations. Determine limit (if any) of these conditions under which the ferry will be expected to continue in operation.

(c) Investigate the maximum wave formation likely to be encountered on the crossing.

6. (a) If the ferry has to load and unload on to shore or river banks, obtain a rough section to show gradients and distances from the shore to an offshore point where there is a minimum of 3 ft. (0·0914 m.) of water. Investigate the nature of the shore (sand, rock, concrete, etc.).

(b) If the ferry is to work from a fixed landing stage, obtain full details of the landing stage, with particular reference to the height of the landing stage above water level if it is floating, and the variation in height of the water level if it is fixed.

7. Determine the best means of propulsion,

either

(a) Winch;

or

(b) Propulsion Units (outboard);

or

(c) Motor Tug.

DESIGNING A BAILEY/UNIFLOTE FLOATING BRIDGE

1. These calculations have been prepared for a 24 tons load.

2. In this case the "tracked vehicle" type of load has been used as this gives the nearest approximation to a point load and therefore has the most severe effect on the bridge.

3. On fully floating bays, no allowance is made for impact (dynamic effects) on live load. On landing bays, 50% of the normal impact factor is used.

4. All calculations are based on the use of "Double Truss" construction and the dead weights appertaining to the Standard Widened type of Bailey Bridge have been used.

All floating bay piers consist of "triflotes", i.e. three Uniflotes coupled end-to-end with bow and stern units added. The dead weight of bow and stern units has been allowed for, but their effect on the buoyancy of the triflote has been ignored. Each triflote will support one ton per inch of draught. Landing Bay piers comprise a number of triflote piers connected together side-to-side to form a solid raft.

5. Each end of each Double Single floating bay has Connecting Posts fitted to the Bailey girders, by which the various floating bays are connected together. These Posts are pin-connected at the bottom chord level only. At the top chord level, these Posts are fitted with striker plates, between which there is a gap of $1\frac{1}{8}$ in. when adjacent floating bays are both floating level.

When a load is applied at the junction of two floating bays the triflote piers will sink until these striker plates contact. The depth to which the triflote piers must sink to cause this closure depends upon the length of the floating bays and can be tabulated as follows:

100 feet floating bays—12 in. sinkage
90 „ „ „ —$10\frac{1}{2}$ in. sinkage
80 „ „ „ — $9\frac{1}{2}$ in. sinkage
70 „ „ „ — 8 in. sinkage
60 „ „ „ — 7 in. sinkage
50 „ „ „ — 6 in. sinkage

Note: For quick calculation take 1 in. per 10 ft. bay of bridge, + 1 in.

i.e. 70 ft. bays = 7 × 1 in. + 1 in. = 8 in.

This junction is then said to be "locked". Any further load applied at this point will cause the two floating bays to sink deeper in the water as one solid unit, at the same time pulling down the ends of the adjacent floating bays. This further load is therefore shared by a larger number of triflote piers. The resultant upthrust from these piers engenders a bending moment in the bridge girders which is a maximum at the locked joint. For Double Single construction, this bending moment should not exceed 800 tons ft.

6. The junction of the Landing Bay to the End Floating Bay is arranged for free articulation by fitted Span Junction Posts in this position only. A junction link pinned into the bottom of each pair of Span Junction Posts transmits the load through a distributing bearing to the gunwales of the Uniflotes comprising the Landing Bay pier. Since all these Uniflotes are coupled together, end-to-end and side-to-side, into a solid raft, no system of distributing girders (as used with the original Bailey Floating Bridge equipment) is required.

The load must always be applied at the exact centre of the Landing Bay Pier. Where this is composed of an even number of triflotes, the bearings are immediately above the junction of two triflotes and the "Distributing Bearing, Short" is used. Where the Landing Bay pier is composed of an odd number of triflotes, the bearings are over the centre of a triflote and the "Distributing Bearing, Long" must be used.

Due to the use of these Distributing Bearings, the end of the End Floating Bay which is supported on the Landing Bay Pier is at a higher level than its off-shore end. With the Distributing Bearing, Short, this difference in height is 12 in.; with the Distributing Bearing, Long, it is 20 in. The resultant slope on the End Floating Bay reduces the clearance between the striker plates of the connecting posts at its junction to the first floating bay, so that this junction in some cases is almost "locked" before any live load is applied. Not only does this cause difficulties in erection, but the application of live load in the higher classifications causes serious over-stressing of this locked junction. In such cases a special 10 ft. floating bay, supported on a triflote, is introduced between the end floating bay and the first (normal) floating bay. Not only does this simplify erection, but the two sets of connecting posts (at each end of the 10 ft. bay) give twice the clearance before locking and the additional buoyancy of the extra triflote obviates any over-stressing of the Bailey girders. 113

7. It is realised that these calculations do not constitute an exact analysis, but for practical purposes they give results as accurate as can be actually measured in still water.

A more exact analysis, based on Professor Southwell's "Relaxation Methods" was put forward in a paper read before the British Institute of Civil Engineers by Sir Donald Bailey in June, 1947.

STANDARD WIDENED BAILEY
FLOATING BRIDGE FOR 24 TON LOADS

1. Floating Bays

Overall length (centre to centre of junctions) = 92 ft.

One triflote pier each end of bay located centrally under the end 10 ft. bay of bridge. The piers are therefore at 80 ft. centres.

Using Standard Widened Double Single Bailey Bridging, check strength of girders with 24 tons load at centre of 80 ft. span.

Dead weight of 80 ft. span	= 26 tons.
Length of live load	= 9 ft.

Bending Moment

Due to dead load—$26 \times \frac{80}{8}$ .. .. = 260 tons ft.

Due to live load—$\frac{24}{2}\left(\frac{80}{2} - \frac{9}{4}\right)$ .. = 450 tons ft.

Total .. .. .. = 710 tons ft.

Section modulus for Double Single .. = 892 in.^{3}

Stress due to bending = $\frac{710 \times 12}{892}$ .. = 9·5 tons/sq. in.

Allowable stress in bending .. .. = 11 tons/sq. in.

Flotation

Dead weight: 92 ft. Double Single bridge = 28·8 tons

2 Triflotes each 11 tons .. = 22·0 tons

= 50·8 tons

Displacement factor for two triflotes = 2 tons per in.

Dead Load Draught = $\frac{50 \cdot 8}{2}$ = 25½ in.

114

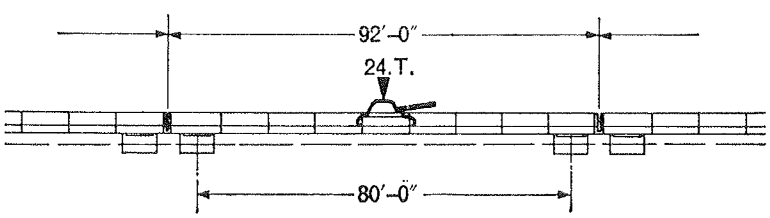


Fig. i

Load Case 1 (See Fig. i)

With Live Load at centre of bay.—Load is shared by four triflotes—the two supporting the 92 ft. floating bay plus one each end of the adjoining floating bays.

Additional draught due to live load = $\frac{24}{4}$ = 6 in.

Total draught for this load case = 25½ + 6 = 31½ in.

Freeboard = 48 in. − 31½ in. = 16½ in.

Load Case 2 (See Fig. ii)

Live Load at Junction of Two Floating Bays. Joint has to be depressed 10½ in. to lock. Therefore two triflotes must have increased draught of 10½ in.

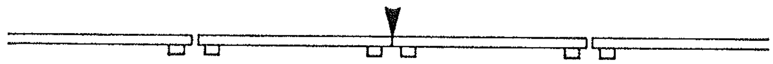


Fig. ii

Load to effect this = 2 × 10½ = 21 tons.

Remaining Live Load (24 − 21 = 3 tons) is shared by the four triflotes of the two locked bays plus one triflote each end of the adjacent floating bays.

Therefore 3 ton load is shared by six triflotes.

Increase in draught $= \frac{3}{6} = \frac{1}{2}$ in.

Total draughts for this load case

At locked joint: Due to dead load ..	..	= 25½ in.
Due to joint locking	..	= 10½ in.
Due to remaining load	..	= ½ in.
		36½ in.
Freeboard = 48 − 36½	..	= 11½ in.
At outer end of locked bays:		
Due to dead load	..	= 25½ in.
Due to live load	..	= ½ in.
		26 in.
Freeboard = 48 − 26 ..	..	= 22 in.

Bending moment at locked joint, due to upthrust of piers =

Pier adjacent to locked join 11 tons × 5 ft. ..	=	55 tons ft.
Pier at distant end of floating bay ½ ton × 87 ft.	=	43·5 tons ft.
Reaction from adjacent floating bay ½ ton × 92 ft.	=	46·0 tons ft.
		144·5 tons ft.
Allowable	=	800 tons ft.

Load Case 3 (See Fig. iii)

Full Convoy Loading. 100 ft. clear space between vehicles. Each 24 ton load is 9 ft. long; therefore loads at 109 ft. centres. Calculation for 24 ton load at C has already been made in Case 2 above. Therefore superimpose on this, the effects of 24 ton load on AB and DE.

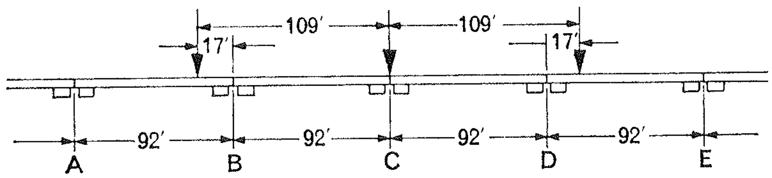


Fig. iii

Load on B (and D) $= 24 \times \frac{75}{92}$ .. .. $= 19\frac{1}{2}$ tons

Load on A (and E) $= 24 \times \frac{17}{92}$ .. .. $= 4\frac{1}{2}$ tons

Load at B (and D) shared by two triflotes

Draught $= \frac{19\frac{1}{2}}{2}$ .. .. $= 9\frac{3}{4}$ in.

Add dead load draught .. .. .. $= 25\frac{1}{2}$ in.

116 $35\frac{1}{4}$ in.

Load at A (and E) shared by two triflotes

Draught $= \frac{4\frac{1}{2}}{2}$ .. .. $= 2\frac{1}{4}$ in.

Add dead load draught .. .. .. $= 25\frac{1}{2}$ in.

$27\frac{3}{4}$

Summation of two cases to find final draughts

	A	*B*	*C*	*D*	*E*
	in.	in.	in.	in.	in.
Due to load at C	$25\frac{1}{2}$	26	$36\frac{1}{2}$	26	$25\frac{1}{2}$
Due to load on AB and DE ..	$2\frac{1}{4}$	$9\frac{3}{4}$	—	$9\frac{3}{4}$	$2\frac{1}{4}$
	$27\frac{3}{4}$	$35\frac{3}{4}$	$36\frac{1}{2}$	$35\frac{3}{4}$	$27\frac{3}{4}$

Difference in draught .. .. .. 8 $\frac{3}{4}$ $\frac{3}{4}$ 8
Difference in draught to lock joint .. .. $= 10\frac{1}{2}$ in.
Therefore no joints locked.

2. Landing Bay

Maximum length = 180 ft. Standard Widened, Double Double Reinforced.

Dead weight of this span (18 × 5·22) .. .. = 94 tons

Bending Moment in span, with live load at centre:

Due to Dead Load $= 94 \times \frac{180}{8}$ .. .. = 2,115 tons ft.

Due to Live Load $= 24 \times \frac{180}{4}$ .. .. = 1,080 tons ft.

Impact on Live Load = ½ of 25% = 12½% .. = 135 tons ft.

3,230 tons ft.

Section modulus for Double Double Reinforced = 3,838 in.^{3};

Stress due to bending $= \frac{3{,}230 \times 12}{3{,}838} = 10{\cdot}4$ tons/sq. in.

Max. shear per end post $= \frac{47 + (24 \times 1{\cdot}125)}{4} = 18{\cdot}5$ tons

3. Landing Bay Pier

Dead Load from 180 ft. Landing Bay $= \frac{94}{2}$ .. = 47·0 tons

Dead Load from End Floating Bay $= \frac{29{\cdot}0}{2}$ .. = 14·5 tons

61·5 tons

Assume Landing Bay Pier comprises three triflotes, then its dead load (allowing for distributing bearings) .. .. = 35 tons

96·5 tons

Displacement factor .. .. = 3 tons/in.

Dead load draught $= \frac{96{\cdot}5}{3}$ .. .. .. = 32·2 in.

Freeboard .. .. = 15¾ in.

Live Load .. .. = 24 tons

Loaded draught $= \frac{96{\cdot}5 + 24}{3}$ .. .. = 40¼ in.

Freeboard .. .. = 7¾ in.

Though somewhat less than normal minimum freeboard of 9 in. this is satisfactory for still water conditions.

Any buoyancy from Bow and Stern (Scow End) units has been ignored but, will give in practice, increase to calculated freeboard.

4. End Floating Bay

92 ft. Double Single bridge.

One triflote at off-shore end.

Draught of triflote at off-shore end is same as for normal floating bay .. .. .. = $25\frac{1}{2}$ in.

Freeboard .. .. = $22\frac{1}{2}$ in.

Slope of End Floating Bay

Dead load condition only.

Height to underside of bridge above Water Level:—

1. At Landing Bay Pier = 16·0 in. + 20 in. = 36 in.
2. At off-shore end .. .. = $22\frac{1}{2}$ in.

Slope = $13\frac{1}{2}$ in. in 92 ft.

Partial closure of connecting posts at off-shore end due to slope of end floating bay =

$$13\tfrac{1}{2} \text{ in.} \times \frac{4 \text{ ft. } 9 \text{ in.}}{92 \text{ ft.}} \qquad = \tfrac{3}{4} \text{ in.}$$

Normal gap, with both bays level .. .. = $1\frac{1}{8}$ in.

Remaining gap = $1\frac{1}{8}$ in. − $\frac{3}{4}$ in. .. .. = $\frac{3}{8}$ in.

Sinkage to lock joint = $\dfrac{\frac{3}{8}}{2}$ in. × $\dfrac{92 \text{ ft. } 0 \text{ in.}}{4 \text{ ft. } 9 \text{ in.}}$ .. = 3·6 in.

Load on two triflote to cause 3 in. sinkage .. = 7·2 tons

Remaining live load (24 − 7 = 17 tons) shared by seven triflotes, therefore further sinkage $\dfrac{17}{7}$ .. .. = $2\frac{1}{2}$ in.

118

Bending moment at locked joint (due to upthrust of Landing Bay Pier) = 3 × $2\frac{1}{2}$ tons × 92 ft. .. .. = 690 tons ft.

Note: With "convoy" loading, this joint will not lock.

Institute of Transportation
and Traffic Engineering

OPPORTUNITIES FOR COST REDUCTION IN THE DESIGN OF TRANSPORT FACILITIES FOR DEVELOPING REGIONS

VOLUME 1

A Study Conducted under Contract No. DOT-OS-A9-004

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CONTENTS

VOLUME 1

VOLUME 2

CHAPTER VII

POTENTIAL COST-SAVINGS IN THE DESIGN OF WATER CROSSINGS

by

Peter M. Hall

TABLE OF CONTENTS

Introduction

When one is examining roads for potential economies, it is worthwhile to look at the whole problem of water crossing facilities. The facilities include culverts, surface drains, fords, and bridges. Additionally, in this discussion, we shall look at ferries, a vehicle system that can substitute for bridging.

Why should we look at these facilities? First, they account for a substantial percentage of the construction cost of nearly every road system. For example, it has been estimated that approximately 25% of the U.S. highway construction costs are spent for water crossing purposes: 10% for bridges and 15% for culverts.[1] Culverts are defined as any conduit under the roadway up to 20 ft in total span; bridges, as crossings exceeding 20 ft. This estimate probably applies, with minor variation, to most road systems in developing regions.

Second, water crossings facilities usually are the weak links in a road system. Severe flooding or intense rainfall will concentrate damaging effects at these points, leading not only to replacement costs but also to the costs of delay and inconvenience to the road users.

Third, it has been said that "...high maintenance costs usually reflect poor drainage (for low volume roads). Therefore, we are justified in a material addition to construction costs for adequate drainage if by doing so we can secure lower maintenance charges."[2] In other words, mere reduction of investment in initial facilities is no solution to long-run cost savings. At some point, however, high costs of capital (high discount rates) may necessitate stage construction of facilities to avoid excessive initial costs.

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[1] Kenneth B. Woods. Highway Engineering Handbook, p. 12-13.

[2] U. S. Forest Service. Drainage Practice in the California Region, p. 3.

Fourth, bridge replacement often represents the principal cost, and sometimes the entire cost, in upgrading the level of service for an existing roadway. In some cases, new bridges can replace existing bridges to improve (1) capacity (more lanes), (2) live-load limits, and (3) alignment. Sometimes, new bridges can dramatically decrease route distance.

I. Culverts and Short Bridges

Culverts are an integral part of any roadway, unless the roadway happens to coincide with a ridgeline -- an unlikely event. We have already defined a culvert as any conduit under a roadway up to 20 ft in total span. This is not a strict definition; in fact, many countries and jurisdictions restrict culverts to lesser spans. "Short bridge" refers only to those structures exceeding culvert dimensions but short enough in total span to allow standard design. In most cases these structures would be 30 ft or less in total span.

There are no dramatic ways to reduce the long-term costs of culverts. It is easy, however, to bring on unnecessary costs -- and they can become large -- by slighting fundamental requirements. It is most important to:

1. Obtain sufficient hydraulic data to anticipate the range of runoff intensities and the frequency of these events.
2. Properly select size and type of culvert.
3. Locate the culvert properly with respect to alignment and slope.
4. Use adequate earth fills below and above culvert pipe.
5. Provide appropriate entrances and headwalls.
6. Provide appropriate debris control devices to prevent clogging.
7. Provide appropriate outlets and endwalls.
8. Perform required periodic maintenance services.

Their careful consideration in the design, construction, and operation of all roads, particularly those in developing regions, is certain to pay off in reduced long-term road costs.

An excellent reference on the subject is California Culvert Practice (see bibliography), but it should be supplemented by consideration of opportunities for keeping costs in line with the planned level of road service.

An approach to minimizing initial costs for culverts is described in Pritchett's Application of the Principles of Engineering Economy to the Selection of Highway Culverts (Ref. 25). He maintains that the high standards advocated by the California Division of Highways are not necessarily applicable to rural, low-volume roads. The problem of determining the trade-off between smaller culverts with predictable flooding and higher-standard culverts with less flooding is discussed therein.

One should also observe that culverts can be designed in many sizes and shapes to conform to natural surroundings. There is often a tendency to sterotype culvert design around a limited set of patterns. The result is a lack of flexibility and originality in design that can be excessively costly. This subject is especially well treated in the U.S. Forest Service publication, Drainage Practice in the California Region (Ref. 31). The Handbook of Steel Drainage and Highway Construction Products, published in 1967 by the American Iron and Steel Institute, is an excellent reference for steel culvert pipe (Ref. 2).

It should be mentioned that concrete and steel culvert pipe lend themselves to mass production within developing economies. Even though such production may not reduce road costs, it may be desirable as a contribution to overall development objectives.

Short-bridge costs can be reduced by standardized designs, utilizing a maximum of local materials. Figs. 4 through 7 of the above mentioned U.S. Forest Service Drainage Practice in the California Region present some basic designs of short bridges. Additionally, the following U.S. Army reference manuals contain numerous examples of standard abutments, piers, and superstructures for heavy military bridging which could be adapted for less heavy civilian requirements:

(1) TM 5-302, Construction in the Theater of Operations, October 1958, change 1, pp. 824-876.30.

(2) TM 5-303 Bills of Materials and Equipment of the Engineering Functional Components System, July 1960, change 6, pp. 715-859.

It should be observed that cross-drainage facilities of short total span -- 20 ft and under -- should usually be designed for two-way traffic. The justification for this conclusion will be found in the attached paper, The Economics of One-Way Bridging.

II. Fords

Traditionally, natural fords have been employed as stream crossing sites. In the days of horses and foot traffic, one could tolerate fording depths up to 40 in. (1 meter) and more. The present day motor vehicle is restricted to shallower depths, however. Medium trucks should not ford depths over 24 in., and fording depths for other vehicle sizes should be adjusted accordingly. Due to restricted fording depths, and to roadway surface requirements, most of today's fords are improved.

It is recommended that fords be considered only for the following situations:

1. Roads in arid regions where flooding in stream beds is infrequent and of short duration.
2. Links in a network for which bypasses are available during periods of unfordable depths.
3. Very short crossings, sometimes called "dips," where water depth will seldom exceed fordable limits.

Use of fords in any other situation runs the risk of creating uneconomical delays. Any improved ford is susceptible to damage and washout. In fact, one should never install fords with the idea of permanency.

Table 1 present some cost estimates for several types of ford construction. Roadway widths are 20 ft, and amounts of capital and labor are measured per unit length. Culverted fords[3] are designed with pipe diameters of at least 24 in. in order to avoid clogging. The Gabion wall ford (type 2, Table 1) is constructed with rock-filled, wire-mesh baskets called Gabions. These devices can also be used for bridge piers, abutments, and wing walls. See Fig. 1A for more details.

Fig. 1 is a comparison of various representative fords to a timber bridge in terms of the present value of construction and replacements costs over a 20-year period. In this comparison, it is anticipated that the life of a ford (5 years) would be half the life of a timber bridge (10 years). The comparison favors the ford, but does not consider the cost of delay and additional vehicle maintenance associated with a ford. Both of these costs should be considered in each case where a ford is proposed.

When fords and dips are used in a road system, the following points should be considered for cost saving:

1. Construct them flush with the stream bed in areas of high stream velocity to minimize washout.

2. Keep design standards at a bare minimum and avoid "permanent" structures.

3. Consider simple techniques such as Gabion construction.

4. For culverted fords, use large enough diameter pipe to prevent clogging by debris, sediment, or rocks.

5. Make maximum use of local materials (sand, aggregate, rocks).

A useful reference for short fords (dips) is the U. S. Forest Service pamphlet, Drainage Practice in the California Region, Figs. 18, 19, and 20 (Ref. 31)

III. Ferries

A ferry, being a vehicle, differs considerably in characteristics from other

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[3] A submergible causeway designed with culverts for cross-drainage during periods of low flow.

facilities we are examining. We shall define a ferry as any floating device that operates between two terminal points of a road network interrupted by a water barrier.

Ferries raise the following considerations. First, they should normally be considered only for crossing sites that are navigable year-round. Second, the need for terminal facilities makes it difficult to design a system for sites with large seasonal fluctuations in water level and widths. Third, ferries have greatly reduced capacities compared to continuous roadway devices, such as bridges and fords. Fourth, ferries necessitate delayed crossing of vehicles and passengers. The average delay per vehicle per crossing will be one-half the ferry cycle time. Fifth, ferries require continuous labor expenses that become significant in present-value calculations.

Table 2 outlines some typical ferry types and the associated cost information. The Bailey U4 Uniflote ferries deserve particular mention. These ferries are modular-assembly vessels, whose "building blocks" are basic Bailey Uniflote components, marketed by Acrow Corporation of America, 231 Washington Avenue, Carlstadt, New Jersey. The following characteristics make them particularly suited to the needs of developing countries:

1. Easily transportable.
2. Minimum terminal requirements.
3. Easily maintainable.
4. Relatively low cost.
5. Simple assembly by unskilled labor.

In comparing ferry costs, it is helpful to convert the various recurring costs to present values so that they may be summed. Total cost then becomes:

$$\text{Total Ferry Cost} = C_0 + C\ (\text{maint}) + C\ (\text{Labor}) + C\ (\text{power}) \qquad (1)$$

where,

C_0 is initial ferry and terminal cost,

C (maint) is maintenance cost less engine repairs,

C (labor) is labor cost,

C (power) is cost of fuel, lubricants, and engine repairs.

Once the design and selection of equipment for a given crossing are determined, all of the cost elements except C(power) are essentially fixed. C (power) on the other hand, will vary with traffic. However the variance of C (power) caused by changes in traffic flow considered in this paper is minimal.

Fig. 2 compares ferry costs and float-bridge costs, in present value terms, as functions of the crossing gap. One can see that the float bridge is unquestionably cheaper for distances less than 400 ft.

At any distance, however, the ferry necessitates an average delay per vehicle equal to half the cycle time of the ferry. This delay cost is likely to be substantial enough to call for its inclusion as an additional element in total cost comparisons. It can be computed in the following manner:

$$\text{Ferry cycle time} = 2(d/s + k) \qquad (2)$$

where,

d = width of crossing site in feet,

s = average speed of ferry in fpm,

k = average terminal time of ferry in minutes.

$$\text{Average delay per vehicle} = 1/2 \text{ ferry cycle time} = \frac{d}{s} + k.$$

$$\text{Total delay per hour} = \alpha(d/s + k)$$

where,

α = constant average arrival rate for both directions, assuming equal flow in each direction.

Assuming 12 hours of operation per day:

$$\text{Total annual delay} = \alpha(d/s + k) \times 12 \text{ hrs/day} \times 365 \text{ days/yr} \qquad (5)$$

$$\text{Annual delay cost} = (\text{vehicle delay cost/hr})\ \alpha(d/s + k)\ 12 \times 365 \qquad (6)$$

If we specify constant values for vehicle delay cost per hr, and s and k in equation (6), then annual delay costs are linear with respect to d, for each value we assign to α.

Rather obviously, the foregoing relations hold only as long as α is less than the maximum service rate of the ferry. Otherwise delays will be infinite. The maximum service rate, counting in both direction, and expressing the result in vehicles per hour, develops from equation (2) and the vehicular capacity of the vessel as:

$$\text{Max. Service Rate,vph} = (\text{vessel capacity}) \left(\frac{60}{d/s + k}\right) \qquad (7)$$

Using equation (6), delay costs in present value terms were calculated for a Uniflote Type C ferry of 6-vehicle capacity, using several values of α. The results are shown in App. E. In Fig. 3 these costs are compared, as a function of ferry distance, with the Bailey float bridge, which is a reasonable alternative in most situations.[4]

From the information in Fig. 3, the feasible domain of the ferry as a function of both crossing distance and traffic volume is determined, as shown in Fig. 4. To avoid the infinite delays associated with a traffic intensity (degree of saturation) of 1, the feasible limits of the ferry have been arbitrarily drawn so that the degree of saturation will never exceed 0.9. Also shown are average delays per vehicle from equation (3). These are purely a function of the crossing distance because it has been assumed that s and t are constant.

[4] Navigation requirements may restrict the use of float bridging. However, Bailey float bridging can be elevated between bays to allow passage of limited size vessels.

It must be pointed out that the float bridge is a one-way structure and must also experience some delay cost. For extremely low volumes of traffic, however, this cost is not of great significance, as demonstrated in the paper, The Economics of One-Way Bridging, which accompanies this report.

Points deserving special consideration with regard to keeping down the costs of ferries are:

1. Terminal facilities can be simplified to the bare minimum required to load and unload.
2. A vehicle that does not require terminal facilities, such as an air-cushion vehicle, ACV, may be usable. This vehicle would also be useful on crossings having water obstacles subject to considerable variation of water level and width.
3. Uniflote ferry systems may be applicable. They are particularly useful for one-time rafting operations to move heavy machinery or construction equipment.

One of the few references on rafting techniques is the U. S. Army TM 5-210, Military Floating Bridge Equipment (Ref. 10). It describes all of the available military rafting equipment which is usually constructed from floating bridge components.

IV. Float Bridges

Float bridges are usually a temporary means of crossing a water barrier. A float bridge can be defined as a bridge which has the superstructure on floating intermediate supports. A natural floating bridge exists in the form of the ice bridge, in which the entire structure floats on the surface. In many less-developed areas of extreme latitude, ice bridges are a cheap and practical means of crossing water barriers in the winter months.

Most float bridging is prefabricated in standard design for military purposes. Cost is almost purely a function of length for each design. The variation in costs arise from differing anchorage requirements due to tidal action or stream velocity. Virtually all existing float bridging is single lane. Table 3 lists types of available float bridging with potential for use in developing regions. Each type listed can be constructed by unskilled labor, but supplemental equipment is needed to assemble types 3 and 4.

Fig. 5 gives an idea how the costs of various types compare for various lengths, indicating that the Bailey float bridge is considerably less expensive than other types. Fig. 4, as previously discussed, shows conditions under which a ferry is more economical than a float bridge.

Float bridges should be employed only in the following situations:

1. Sites that require temporary bridging, where a raft or ferry is not economically or technically feasible.
2. Sites with difficult bottom conditions that make fixed bridging uneconomical.

When float bridging is being considered, delay costs to any existing or proposed water traffic must be evaluated and included with the cost of the bridge.

Opportunities for cost reduction in float bridges are practically nil, except by giving careful attention to the design of the anchorage system. Here, the important consideration is to provide an anchorage system that will prevent the high cost of loss of the bridge.

The following references on floating bridges will be useful:

1. U. S. Army, TM 5-210, Military Floating Bridge Equipment, August 1965 (Ref. 10).
2. Thomas Storey (Engineers, Ltd.) The Bailey and Uniflote Handbook, pp. 234-246 (Ref. 30).

V. Fixed Bridges

Fixed bridges are composed of three main elements: (1) superstructure, (2) substructure, and (3) decking. Fixed bridges differ from float bridges by having substructures (piers and abutments) that are fixed in place. In this discussion fixed bridges are divided into three types: (1) prefabricated, (2) standard, and (3) non-standard.

Prefabricated Fixed Bridges

Prefabricated fixed bridges are defined as semipermanent bridges constructed from interchangeable component parts, principally the superstructure parts, although some pier assemblies are available. Many of these bridges are hand-erectable, and virtually all can be assembled by unskilled labor. Most have military origins, but there are numerous examples of civilian applications.

Standard fixed bridges have the following unique characteristics:

1) All are steel or aluminum.
2) Most are single-lane.
3) Component parts allow flexible design of span lengths and live-load limits.
4) Assembly time is rapid.
5) Man-hours for construction are low.
6) Unskilled labor can do all the construction with a minimum of skilled supervision.
7) Design and engineering costs are held to an absolute minimum.
8) Salvage value is usually considerable.

Table 4 is a list of currently available standard fixed bridges, with references, cost data, and important characteristics included. With the exception of the first three entries, all of these bridges are currently in the U. S. military supply system. Should any be declared surplus, they would have potential application in developing countries for railway and highway projects. This discussion, however, is limited to the first three bridge types, which are commercially available.

AH Bridge is a 2-lane, Warren truss bridge developed by Thomas Storey (Engineers) Ltd., England, for Acrow Corporation of America. It is a unit-construction design, suitable for permanent or temporary use. It is assembled in 30 ft sections, up to 300 ft clear span for AASHO H-20 loading. The bridge can be assembled by unskilled labor, using two 6-ton cranes.

The Eiffel Bridge is a 1-lane, semipermanent steel truss bridge, manufactured in France. It has been extensively used in former French colonial areas of Southeast Asia and Africa. It is hand-erectable by unskilled labor but is somewhat more difficult to construct than the Bailey bridge. Seventeen types of Eiffel bridges exist, the three most common ones being: 2 RES, 2 REL, 3 NES. See reference 26 for more details.

The Bailey Bridge is a component assembly, hand-erectable, steel-truss girder bridge. It was developed by Sir Thomas BAiley in England for use in World War II. Since that time the bridge components have found a wide range of civilian application, not restricted to bridging. Practically any form of bridge can be constructed with Bailey components: truss girder (through or deck design), arch, suspension, lift bridge, float bridge and pier assemblies. Two references describe the uses in detail:

1. Thomas Storey (Engineers) Ltd. The Bailey and Uniflote Handbook, 1968.
2. Dept. of the Army, TMS-277, Bailev Bridge, August 1966.

Bailey Bridges can be built in four widths by changing the transoms and sway bracing. The cost of the greatest width, Double Wide Bailey, is more than twice the cost of two standard Widened Bailey Bridges. For this reason, and the fact that one-way (one-lane) bridging seems to have wide application for developing areas,[5]

[5] See supplemental paper, The Economics of One-Way Bridging.

it is recommended that the single-lane Bailey Bridge be used. It is available in three sizes:

Type	Roadway Width	Truss Clearance
Standard	10'9"	12'4"
Standard Widened	12'6"	14'3"
Extra Wide	13'9"	15'8"

The popularity of the Bailey Bridge is attested by the fact that more tonnage was manufactured in 1968 than in all of World War II! The bridge has recently been purchased in significant quantities by Panama and Peru. It is expected that it will be extensively used in the Alaskan North slope.

The high cost of prefabricated fixed bridges may be justified in certain developing areas for the following reasons:

1. Local, unskilled labor can be utilized.
2. Low engineering and design costs may be achieved.
3. High salvage values may be realized.
4. Great flexibility may be attained, including "leapfrogging" prefabricated bridges into wilderness areas through replacement by permanent structures at specified staging intervals.

Disadvantages of prefabricated fixed bridges include:

1. High initial cost.
2. High transportation costs to interior sites.

Thus prefabricated bridging appears to be suited for use in the following situations:

1. Bridge programs where speed of assembly is important (flood relief, special government civil works projects.)
2. Planned bridge programs which look forward to later replacement with permanent bridging in more developed areas.

3. Situations where the cost of skilled labor is prohibitive, or where skilled labor is unavailable.

4. Situations where severe seasonal flooding requires bridging to be removed at these times.

5. Situations where only temporary bridging is required. (Construction projects, military maneuvers).

NOTE: It is recommended that deck design be considered for all but the most temporary installations of prefabricated bridging. This procedure will minimize width restrictions on these structures by placing the trusses under the roadway and out of the way of overhanging loads, and extra-wide vehicles.

Standardized Fixed Bridges

Standardized fixed bridges are bridges that follow predesigned standards and specifications, almost to the detail. Most short bridges, trestles, and many medium-length bridges fit this category. Too often, packages of standard designs are assembled ad hoc by road planners, without careful economic analysis. Of course, virtually every bridge design borrows ideas from established designs, but the present discussion is confined to bridges that are essentially a carbon copy of existing bridges.

It should come as no surprise that bridges for one geographical area are not necessarily suitable for another. Likewise, bridges for one given set of traffic conditions (traffic volumes, vehicle sizes and weights, etc.) may not be suitable for another route with difference conditions. The point is simply that over-reliance on a set of standard bridge designs can be uneconomical in many cases. This is especially true for developing areas and capital-scarce economies, in which the designs used by more developed regions may be quite inappropriate.

On the other hand, there may be opportunities for significant cost saving by standardizing a hitherto laissez-faire bridge design policy. Certainly there is a trade-off between over-standardization and under-standardization that should be carefully studied to achieve least long-run costs in a particular region.

Following are some detailed references on standardized bridge designs, including both substructures and superstructures:

1. Dept. of the Army, TM5-286, Semipermanent Highway and Railway Trestle Bridges, April 1945.
2. Dept. of the Army, TM5-303, Bills of Materials and Equipment of the Engineer Functional Components System, changes 1 - 7.
3. Dept. of the Army, TM5-302, Construction in the Theater of Operations,Z changes 1-2.

Non-Standard Fixed Bridges

Non-standard fixed bridges are those designed for a specific site. The final design will be influenced by the following factors: (1) approaches, (2) water characteristics, (3) bottom conditions, (4) distance, (5) on-site materials, (6) cost of alternative materials, and (7) navigation requirements. Design of non-standard fixed bridging should be undertaken only by qualified and competent structural engineers. Waddell's Bridge Engineering (Ref. 33) and Robinson's Piers; Abutments and Formwork for Bridges (Ref. 26) are references for basic principles of design which can lead to economies. A good rule-of-thumb is that the minimum cost design is achieved when:

Cost of substructure = Cost of superstructure (less the decking)[6]

Thus, it is evident that, as bridge height increases, span length must increase. Furthermore, it has been estimated that:

Cost of bridge/ft ≈ 10 x cost of paved approaches/ft[7]

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[6] Reference 31, p. 1188

[7] Reference 23, p. 124

The latter relationship indicates that one can often reduce initial costs by lengthening approaches to shorten the required bridge. It is important, however, to include delay costs in present value comparisons of alternative plans which affect approaches.

Cost functions for non-standard bridges are almost impossible to estimate, except for low-water bridges such as a timber pile trestle. As a result, comparisons of alternatives must be undertaken on a basis suitable to the site, but may be broken down into six types:

Type 1. Comparison of costs using different types of construction.

Type 2. Comparison of a bridge with a ford (for seasonally fordable rivers.)

Type 3. Comparison of a bridge with a ferry (for unfordable navigable rivers).

Type 4. Comparison of a high bridge and a submersible bridge.

Type 5. Comparison of a short bridge with long approaches and a long bridge with short approaches.

Type 6. Comparison of one-way and two-way bridges

So far, we have discussed types 2, 3, and 5.

Table 5 is an attempt to provide a crude approach for type 1 comparisons. Materials are listed in the order of logical consideration to achieve minimum capital expense. Reference sources are provided for those who wish to investigate the subject in detail.

Type 4 comparisons are described in reference 21. This reference also contains some designs for submersible bridges. The conclusion of the author is that submersible bridges are relatively uneconomical, except for bridges over 200 ft long on unimportant routes when the cost of a submersible design is 60 per cent or less of the high-bridge alternative. As this event is unlikely, we conclude that submerged bridges are seldom an attractive design alternative.

Type 6 comparisons are common for prefabricated and standard fixed bridges but are rare for non-standard designs. The subject is covered fully in the attached paper, The Economics of One-Way Bridging.

Cost reduction in the design of non-standard bridging can be achieved in the following ways:

1. Maximize use of local materials, especially where the cost of capital is high (high discount rates).
2. Lengthen approaches to reduce bridge length.
3. Avoid overdesign for unnecessarily high speed limits or excessive live-load limits. This is especially applicable to bridges in developing regions.
4. Beware of cutting corners in initial engineering costs (design, foundation tests); corner cutting can too often result in a costly over-design or a wasteful bridge failure.

VI. An Example of Staged Development

Historically, initial stream crossing methods, and subsequent upgrading of facilities, have followed a predictable pattern. The State of California offers one of the best examples in modern history of staged development of stream crossing techniques.[8] In 1850 there were essentially no bridges of any consequence in the new state. The fast-growing horse and wagon traffic relied on fords and ferries. A century later, 30,000 bridges had been built of every size and description.

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[8] Panhorst, "Century of Bridge Progress", California Highways and Public Works, p. 114.

Fords were simply natural sites which allowed passage of man or beast with head above water. Ferries were initially crude devices, unpowered and propelled by current or manpower. However, very soon after the Gold Rush, powered ferries were common in San Francisco Bay and along the Sacramento River.

Bridges followed a predictable pattern of development. The initial bridges were crude structures of log or timbers. Truss designs were limited to, (1) A-frame, (2) king or queen post designs. Trestle designs were also tried, but many were unsuited for the hazards of a water crossing. Indeed many initial bridges of every type of design failed because of hasty, over economical construction. Soon more elaborate timber trusses were used, but they were economical only because of the huge supply of natural timber in the Mother Lode country. More noteworthy was the use of suspension bridges on a fairly large scale to achieve longer spans at least cost. Some of these suspension bridges were still standing in 1950. Steel bridging did not come into widespread use until after the arrival of the railroads, which could deliver steel bridge at a price competitive with local materials. Until the 1870's, most of the significant bridges in the state were private toll facilities. Stone masonry arch bridges were apparently not constructed until the latter part of the century due to, (1) availability of stonemasons, (2) desire for permanent bridges. Other improvements in California bridge design closely paralleled the technical advancements of the turn-of-the-century with respect to steel and concrete.

VII. Summary

This report has tried to relate the importance of proper design of cross drainage and water crossing facilities to the need for cost reduction of roads in developing areas. We have considered culverts, fords, ferries, float bridges, submergible bridges, prefabricated fixed bridges, and standard and non-standard fixed bridges. In most cases, the cost comparisons of alternative facilities have been in present value terms. This has provided a reasonably accurate view of long terms costs. Little mention has been made of maintenance for 2 reasons:

1. Expected lives of facilities for present value calculations are adjusted to absorb normal maintenance costs.
2. Maintenance costs for adequately designed structures are only a small proportion of invested capital. Ferries are an exception and expected maintenance costs have been included in all cost data.

A second subject that has been avoided is that of bridge specifications. This is an important subject with respect to design for cost saving. The point requiring emphasis, however, is that the specifications for bridge design (live load limits, lateral and vertical clearances, approaches) are a function of the vehicles which use the bridge. This is a subject deserving separate attention, although some mention is made in Chapter VIII dealing with vehicles.

An important addendum to this subject is Chapter VI, The Economics of One-Way Bridging.

VIII. Conclusions

The following general conclusions seen to be warranted:

1. Culverts and short bridges account for a significant proportion of initial and long-term roadway system costs. Most cost savings will be preventive: adequate initial design and construction will prevent costly delays, repairs, and replacements.
2. Fords and ferries are at best suited only for the initial stage in provision of stream crossing facilities, to be replaced by bridges in later stages of development. Exceptions would be ferry sites where bridge costs are prohibitive, and fords in arid climates or where bypasses are available.
3. Ferry costs (present value) for short and medium crossings in most cases are far in excess of bridge costs. This is true even when the cost of labor is relatively low.

4. Submerged bridges have little, or no potential for cost saving over conventional high bridges. (See Ref. 21).

5. Float bridging is limited to temporary purposes, or specialized use on rivers without major water traffic. Cost of float bridging is very high.

6. Prefabricated bridging components, for example the Bailey Bridge and Uniflote, seem to have valuable characteristics for use in developing regions, in spite of the high initial cost and exported capital.

7. Standardized bridging has conflicting potentials for significantly increasing or lowering costs, potentials which deserve careful study in relation to conditions in each region.

IX. Recommendations

1) It seems advisable to do more research into the proper design specifications of initial bridging for penetration roads and low-volume roads in developing regions. These specifications (live load limits, clearances, approaches) must be related to the vehicles which use the bridge. Prefabricated bridging, in particular the Bailey Bridge, has the property of in-place staging of allowable loads simply by adding more panels and reinforcement chords, or by adding a parallel bridge.

2) Guidelines should be established for the choosing of a ford, ferry or bridge at specific sites of a penetration or low volume road. This set of guidelines can assist planners in cost reduction. These guidelines should consider both present value comparisons and stream-of-cost comparisons of fords, ferries and bridges. This information will assist planners to meet staging objectives for water crossings, in establishing and upgrading low volume penetration roads.

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APPENDIX A

2-WAY LOW TIMBER BRIDGE

Reference: See Bills of Materials and Equipment of the Engineer Functional Components System, TM 5-303

Width: 24'

Span Length: 20' (Maximum bending moment for 14', 50 ton = maximum bending moment for 20', 20 ton).

Useful Life: 10 years for wooden bridge and piers

20 years for abutments

Cost Data (20 yr. Present Value, 10%, 1969 $):

2 ea. Abutments/raised approaches (zero-intercept)	Est. $2,000
Superstructure[1], facility no. 85202, p. 853	$1,782
Superstructure, 10 yr. replacement	687
Timber pile pier[2], facility no. 851062, p. 716	868
Timber pile pier, 10 yr. replacement	334
Total cost per 20' span (slope)	$3,671

1. Estimated cost of materials in reference are increased 25% for inflation. Labor cost is included and is $ .75 per man-hour.

2. Cost of 20 ton, double lane pier approximates cost of single lane, 50 ton pier.

APPENDIX B

FORD COST ESTIMATES

Reference: See Table 1, Fords

Width: 20 feet

Useful Life: 5 years for all types

Cost Data (20 yr. Present Value, 10%, 1969 $):

	Plain Gabion	Plain Concrete	Culverted[2]
Material Cost, 100 m	$1,000	$3,800	$13,500
Labor Cost[1], 100 m	1,875	1,875	4,500
Sub total	$2,875	$5,675	$18,000
Replacement Cost for 5, 10, 15 years.			
(Subtotal × 1.2457)	$3,585	$7,080	$22,400
Present Value/100 m	$6,460	$12,755	$40,400

1. Labor cost is $.75 per man-hour.
2. Cost represents Gabion or concrete construction using 36" dia. pipe.

APPENDIX C

UNIFLOTE FERRY COST ESTIMATES

Reference: See Table 2, Ferries

Useful Life: 20 years for all types. Operating cost includes normal maintenance costs

Cost Data (20 yr. Present Value, 10%, 1969 $):

		Type A	Type B	Type C
1)	Crew size	2	2	2
2)	Annual man-hours[1]	13,130	13,130	19,700
3)	Annual wage cost[2]	($6,570)	($6,570)	($9,850)
4)	Daily operating cost	$20.00	$22.50	$45.50
5)	Annual Operating cost	($7,300)	($8,220)	($16,600)
6)	Subtotal (3 + 5)	$13,870	$14,790	$26,450
	Present Value, 20 yrs.			
	(Subtotal × 9.3640)	$130,000	$138,500	$248,000
	Capital Cost	31,000	47,000	66,000
	Grand Present Value	$161,000	$185,500	$314,000

1. Assuming ferry operates 18 hr./day, from 0600 to 2400 hours.

2. Wage rate = $0.50 per man-hour.

Appendix D

FLOAT BAILEY

Description: See reference 3, p. 242, "Standard Widened Bailey Floating Bridge for 24-Ton Loads."

Width: 12' 6"

Length per bay: 92'

Useful life: 20 years

Cost Data[1] (Present value, 10%, 1969 $):

Landing bays / Landing bay piers (zero intercept)	$ 5,000 est.
Cost per bay (slope):	
2 ea. triflotes	$15,800
2 ea. endscows	1,630
Anchorage	500
90' double-single, standard widened	16,900
Decking, wooden	1,580
Decking, 10 year replacement	670
Labor costs (700 man-hours, $ .50 per hour)	350
Total cost per bay (slope)	$37,430

[1] Figures reflect 1 January 1969 U. S. retail prices, F.O.B. USA Port of Entry, Duty Paid. Price list supplied by Acrow Corporation of America, 231 Washington Avenue, Carlstadt, New Jersey.

Appendix E
PRESENT VALUE OF FERRY DELAY

Type of Ferry: Uniflote Raft, Type C, 6 vehicle capacity.

Average Speed, s: 440 fpm (5 mph)

Average Terminal Time, K: 5 minutes

Value of Time Lost: $0.50 per vehicle-hour.

Cost Data (20 yr. present value, 10%, 1969 $).

		d = 200'	d = 1,000'
1)	d/s	0.445	2.25
2)	d/s + K (Ave. delay per veh.)	5.445	7.25
3)	ferries per hour	11.0	8.28
4)	peak load capacity	66 vph	50 vph
	Computation for α = 10 vph		
5)	veh. delay per hour	54.45 min	72.5 min
6)	hrs. of veh. delay per year*	3,970	5,280
7)	annual delay cost	$1,985	$2,660
8)	20 yrs. present value 9.35 × annual delay cost	$18,600	$24,800
9)	20 yr. present value for α = 20 vph	$37,200	$49,600
10)	20 yr. present value for α = 30 vph	$55,800	$74,400
11)	20 yr. present value for α = 40 vph	$74,500	$98,200
12)	20 yr. present value for α = 50 vph	$93,000	$124,000

*Assuming 12-hour per day operation at constant traffic flow. Service at other times would be at much reduced volumes.

150

COMPARISON OF FORD AND
LOW BRIDGE COSTS

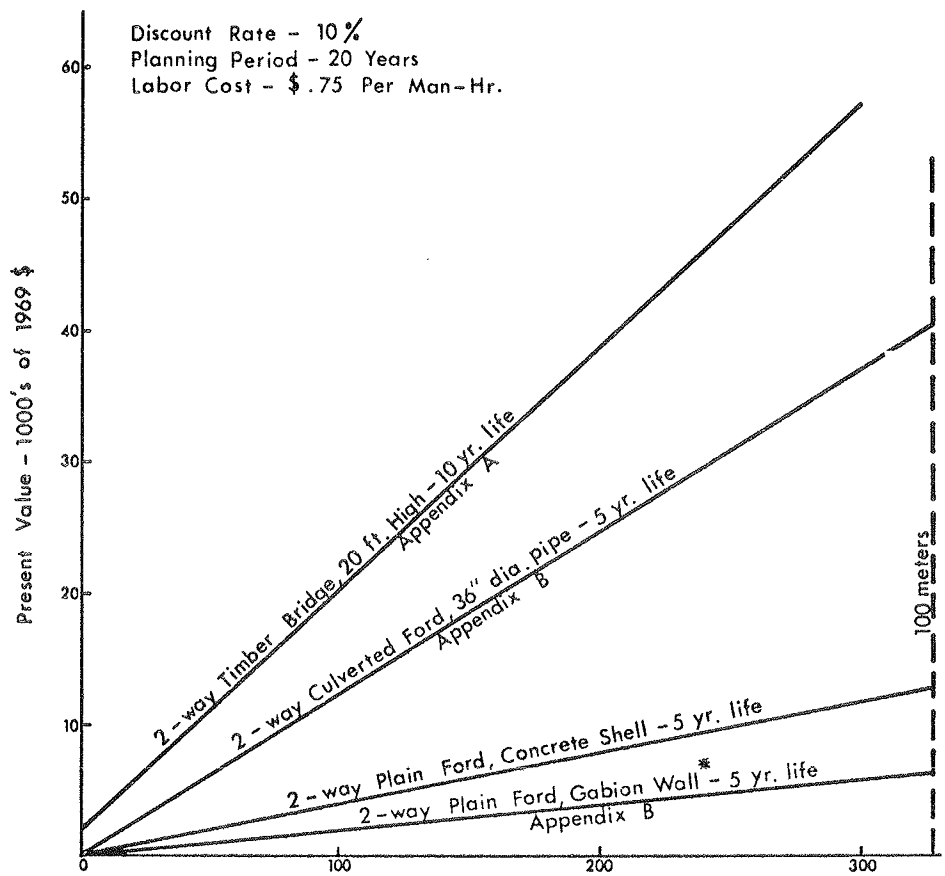


Fig. 1

*See fig. 1A for more details about the gabion ford.

Fig. 1A

LOW WATER BRIDGES OR FORDS

It often becomes necessary to install a permanent, light traffic, low water bridge or ford on access roadways in forest or farmland areas. Normal scour action, increased during periods of flood and swift velocities originally necessitated a high cost installation for a permanent structure.

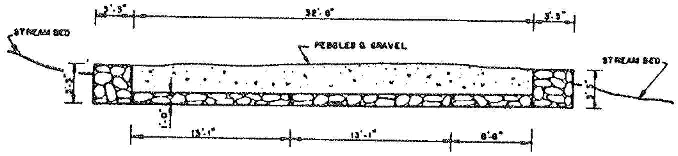
The use of Maccaferri gabions, however, has made permanent low cost structures of this type possible.

USEFUL HINTS:

1. The Maccaferri gabion structure adds the feature of harmony because it blends with the surrounding natural beauty.
2. A properly installed gabion ford will require little or no maintenance year after year.
3. If the walls of the structure are built **on** instead of **below** the existing stream bed, the additional requirement of a gabion apron must be incorporated.

Fig. 47A — Low water bridge installed in federal forest land was built with gabions and gravel. Post marks roadway at time of high water.

Fig. 47B — Cross-section of project.



Extracted from Maccaferri Gabions Technical Handbook
Maccaferri Gabions of America Inc.

PRESENT VALUE COMPARISONS OF
FERRY AND FLOAT BRIDGE COSTS

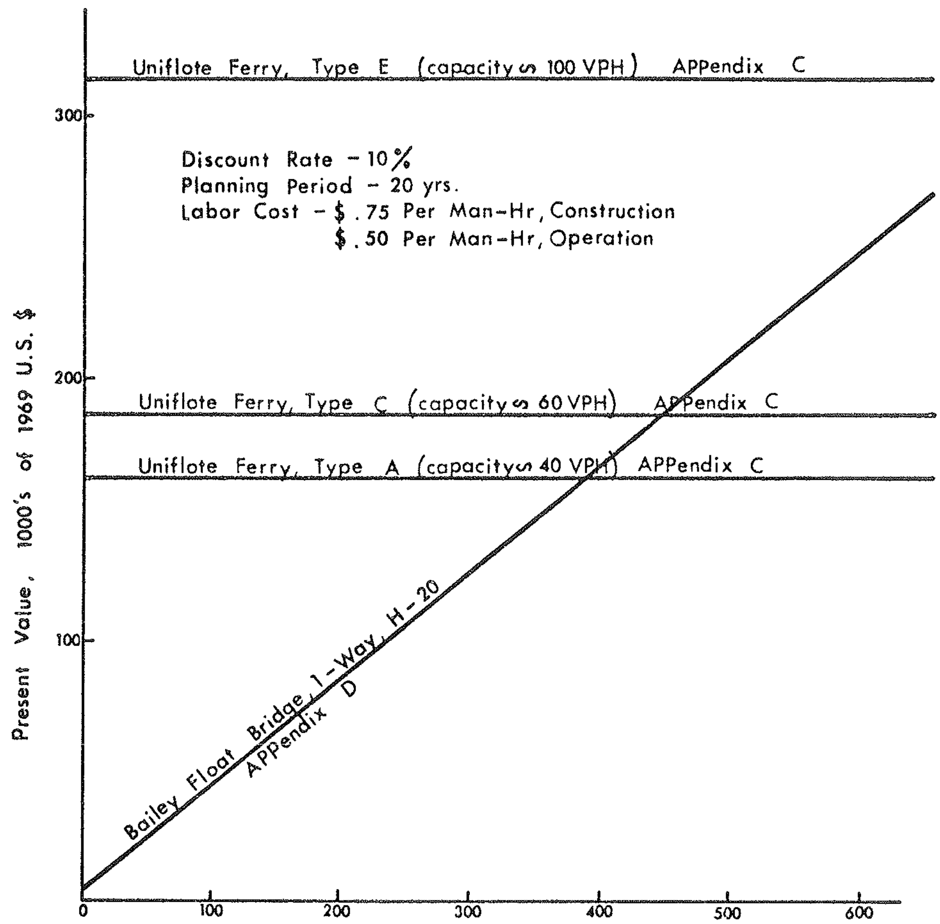


Fig. 2

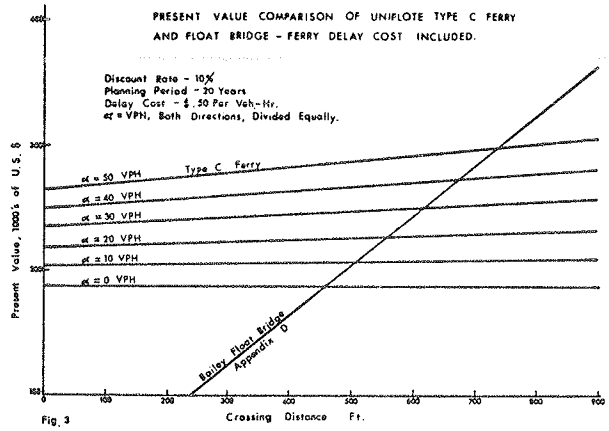


Fig. 3

LIMITS OF FEASIBILITY FOR UNIFLOTE TYPE C
FERRY AND BAILEY FLOAT BRIDGE

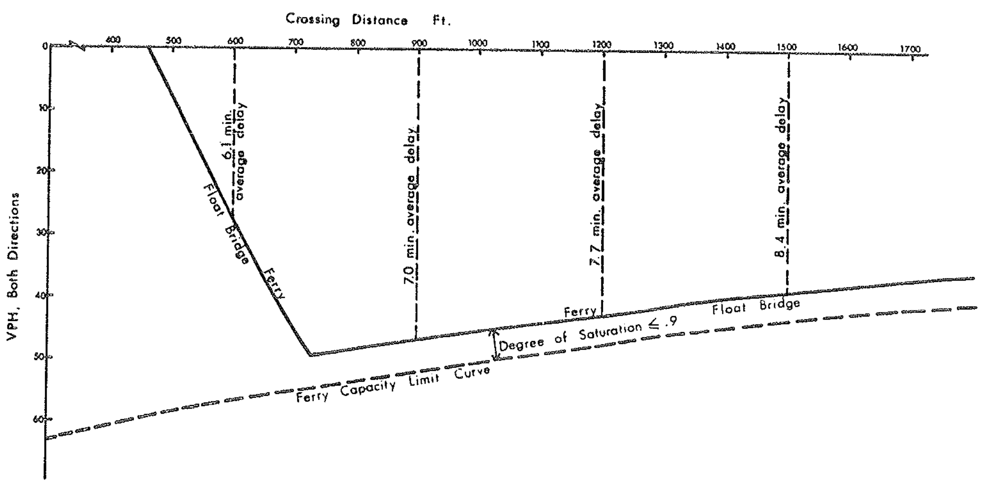


Fig. 4

COMPARISON OF FLOAT BRIDGE COSTS

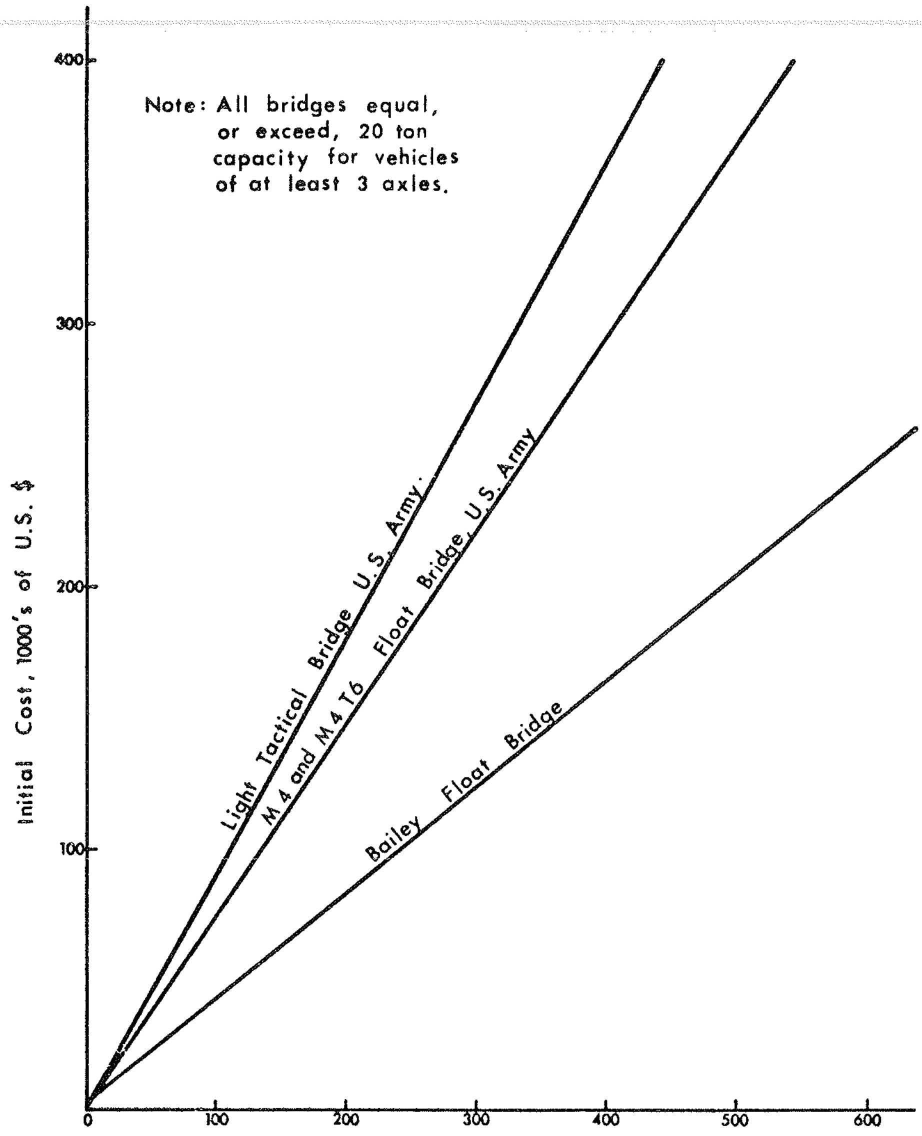


Fig. 5

TABLE 1 - FORDS

	Roadway Width ft/m	Roadway Height ft/m	Culvert Size in.	Maximum Flow Rate f^3/m*	Required Material/Meter of Length	Cost of Material Per M	Man-Hrs. Per M (No Equip)	Equip.	Man-Hrs. Per M (W/Equip.)	Expected Useful Life	Material Cost Per f^3/sec/M
1) Natural Ford	20/6.1	0	None	20	Variable amount of on-site material	None	5	Bulldozer	0.5	6 mo.-1 yr	None
2) Gabion Ford** Gravel Center	20/6.1	1.6/0.5	None	20	2.6 yd^3 of rock-filled gabion 8 yd^3 of river-run fill	$ 10.00	25	Bulldozer	5.5	5 yr	$0.50
3) " "	20/6.1	3.25/1.0	24	37	2.6 yd^3 of rock-filled gabion 6 yd^3 of river-run fill 27 ft of steel culvert pipe	$130.00	25	Bulldozer	12	5 yr	$3.52
4) " "	20/6.1	5.0/1.55	36	49	3.8 yd^3 of rock-filled gabion 10 yd^3 of river-run fill 13.5 ft of steel culvert pipe	$130.00	60	Bulldozer Frontloader Dump Trucks	20	5 yr	$2.65
5) Concrete Ford, 6" Shell	20/6.1	2.0/0.51	None	20	1.5 yd^3 of concrete 4.8 yd^3 of river-run fill 26' × 4' wire mesh reinforcement	$ 38.00	25	Bulldozer Concrete-mixer	8	5-10 yr	$1.90
6) "	20/6.1	3.25/1.0	24	37	1.6 yd^3 of concrete 6.0 yd^3 of fill 30' × 4' wire mesh reinforcement 22 ft of steel culvert pipe	$142.00	25	Bulldozer Concrete-mixer	10	5-10 yr	$3.84
7) "	20/6.1	5.0/1.55	36	49	1.8 yd^3 of concrete 10 yd^3 of fill 34' × 4' wire mesh 11 ft of steel culvert pipe	$143.00	60	Bulldozer Frontloader Dump Trucks Mixer	15	5-10 yr	$2.92
8) "	20/6.1	7.5/2.3	54	55	1.9 yd^3 of concrete 19 yd^3 of fill 40' × 4' wire mesh 9.5 ft of steel culvert pipe	$200.00	Impractical	(Same as above)	20	5-10 yr	$3.64

*Maximum flow rate for fordable conditions is estimated to be one foot depth, 6 feet per sec velocity.

**Maccaferri Gabions of America, Inc., 55 West 42nd Street, New York, New York. See Figure 1A for more details.

TABLE 2 - FERRIES AND RAFTS

	DIMENSIONS				PERFORMANCE									COST ESTIMATORS				
	Length ft/m	Beam ft/m	Above Water Height ft/m	Draft ft/m	Pass.	Autos	Short Tons (less crew and fuel)	Average Speed km/hr	Typical Route Length	Terminal Time	H.P. per Gross Ton	Power Type	Crew Size	Vessel Weight Short Ton	Vessel Cost Thous. $	Terminal Cost Thous. $	Operating Maintenance Cost/12 hr day (Less Crew)
1) 55-gal. Drum Raft	30/9.2	25/7.6	8/2.5	4/1.25	6	1	3	1	50-100 m	5 min	None	Poles w/cable guide	2	5	2	1	Nominal
2) Light Tactical Raft, U. S. Army (4 pontoon)	18.5/5.6	58/17.7	8/2.5	2.5/0.76	10	2	10	12	100 m - 2 km	5 min	3.12	Outboard 2 ea. 25 h.p.	2	6	44	1	$ 15.00
3) M 4 Raft, U. S. Army (4 pontoon, alum.)	37/11.3	87/26.5	8/2.5	2.5/0.76	20	3	50	8	100 m - 2 km	5 min	1.23	Outboard 2 ea. 40 h.p.	2	15	58	1	$ 20.00
4) Bailey U4 Uniflote*																	
Type A	63/19.2	17/5.2	8/2.5	3/0.92	12	4	35	10	100 m - 2 km	5 min	1.25	Diesel 2 ea. 42 h.p.	2	32	29	2	$ 20.00
Type B	65/19.6	34/10.3	8/2.5	3/0.92	20	4	53	8	100 m - 4 km	5 min	0.87	Diesel 2 ea. 42 h.p.	2	44	38	2	$ 20.25
Type C	81/24.6	34/10.3	8/2.5	3/0.92	25	6	71	8	150 m - 4 km	5 min	0.97	Diesel 2 ea. 60 h.p.	2	53	45	2	$ 22.50
Type D	81/24.6	25/7.8	8/2.5	3/0.92	25	9	80	8	150 m - 4 km	8 min	0.88	Diesel 2 ea. 60 h.p.	2	56	50	2	$ 22.60
Type E	99/30.0	34/10.3	8/2.5	3/0.92	30	10	107	8	200 km - 4 km	8 min	1.32	Diesel 4 ea. 60 h.p.	3	75	64	2	$ 45.50
5) Small Ferry, Ryer Island Cable Ferry, California	62/18.9	39/11.8	16/4.9	3/0.92	12	6	24	9.3	123 m	3 min	0.62	Diesel - Hydro Drive	2	110	100	20	$ 90.00
6) Medium Ferry, "HIYU" Wash. St. Hwy. Comm.	160/49.0	64/19.5	42/12.8	10/3.05	50	40	100	18	.5-12 km	5 min	1.25	Diesel	6	400	1,000	60	$215.00
7) Large Ferry "HYAK" Wash. St. Hwy. Comm.	382/116.5	73/22.3	80/24.4	18/5.5	1,650	160	500	29	2-32 km	10 min.	2.96	Diesel Electric	10	2,100	6,000	1,500	$590.00
8) ACV Ferry, SRN4	130/39.68	77/23.46	43/12.95	Nominal	250	30	56	113	2-40 km	15 min	20	Gas Turbine	8	114	1,400	60	$300.00

* Source of information is reference 28, p. 220.

TABLE 3 - FLOAT BRIDGES (20-TON, 3-AXLE, SAFE LOAD LIMIT)

	Deck	Pontoon	Length of Bay ft/m	Pontoons Per Bay	Roadway Width ft/m	Maxi-mum Current fps	Material Per Bay	Cost Per Bay	Man-Hrs Per Bay (No Equip)	Equip-ment	Man-Hrs Per Day (w/equip)	Maint. Crew Size	Reference
1) Light Tactical Bridge, U. S. Army	Alumi-num	Alumi-num	12/3.7	1	9/2.8	5	2,735 lbs per bay plus anchorage	$11,000	6	Crane, Bridge Boat	4	2	TM 5-210
2) M4 Float Bridge U. S. Army	Alumi-num	Alumi-num	30/9.1	1	13/4.0	7	8,700 lbs per bay plus anchorage	$23,000	35	Crane, Bridge Boat	30	4	TM 5-210
3) M 4T6 Float Bridge U. S. Army	Alumi-num	Inflat-able	30/9.1	1	10.2/3.1	7	7,000 lbs per bay plus anchorage	$22,000	Im-practi-cal	Crane, Air Compressor Bridge Boat	30	4	TM 5-210
4) Bailey Bridge on Uniflotes	Bailey, double-single	Tri-flote Pier (steel)	92/28.1	2	10.75/3.3	7	51 tons of steel plus anchorage	$35,100	Im-practi-cal	Crane, Bridge Boat	360	2	<u>The Bailey and Uni-flote Handbook</u>, p. 240

TABLE 4 - PREFABRICATED BRIDGES

Description	Reference	Span Range	Live Load Range	Width	Weight, lbs	Cube ft^3	Unit Price	Federal Stock Number, FSN	Comments
1) A. H. Bridge	Acrow Corporation of America	90' - 300'	20 tons, each direction	24'	(Up to 490 tons)	No data	$260,000 for 300' bridge	N/A	See main text
2) Eiffel Bridge	Eiffel Bridge Co. 23 Rue Dumont-D'Urville Paris 16, FRANCE	20' - 80'	30 - 15 tons	10'6" - 13'3"	No data	No data	No data	N/A	See text
3) Bailey Bridge, Civilian market	Acrow Corporation of America	30' to 210'	50 - 15 tons	10'9" - 24'6"	(Up to 200 tons)	No data	Dependent on span length & load limit	N/A	See text
4) Bailey Bridge Set, U. S. Army	TM 5-277 SC 5420-93-CL-E39	2 ea 80' D-S or 1 ea 130' D-D	35 - 50 tons	12'6"	216,785	No data	$ 35,391	5420-530-3784	See text
5) Panel Bridge, Aluminum	TB 5-268-1 SC 5420-93-CL-E37	2 ea 135' S-S or 1 ea 150' D-S	50 tons	13'6"	No data	No data	$175,000	5420-530-3783	Similar to Bailey Bridge
6) Highway Bridge, Steel, I-beam	TM 5-285 SC 5420-93-CL-#10	30'	50 tons	12'6"	12,920	302	$ 1,918	5420-267-0041	Pre-cut & drilled I-beam assembly
7) Highway Bridge, Steel, I-beam	TM 5-285 SC 5420-93-CL-E11	60'	50 tons	12'6"	45,800	892	$ 7,440	5420-267-0042	Same as above
8) Highway, Bridge, Steel, Truss	TM 5-285 SC 5420-93-CL-E12	90'	50 tons	12'6"	61,600	1,944	$ 15,914	5420-267-0043	Same as above
9) Railroad, Unit Construction, Deck Type	TM 5-372 SC 5420-93-CL-E24	55' - 85'	E45 - E40 Cooper's Rating	Track Width	145,338	1,797	$ 20,339	5420-267-0052	Unskilled labor, w/limited skilled supervision small # basic parts - interchangeable parts. Drift pin connectors, launchable
10) Railroad, Unit Construction, Through Type	TM 5-372 SC 5420-93-CL-E25	55' - 85'	E45 - E40	11'0"	97,361	1,321	$ 26,706	5420-267-0053	Same as above
11) Railway Bridge, Through Truss	TM 5-373 SC 5420-93-CL-E18	90' - 150'	E45 - E40	15'8"	273,324	5,240	$ 45,811	5420-267-0051	To be stocked indefinitely, same char. as above
12) Railway Bridge, I-beam	TM 5-371 SC 5420-93-CL-E13	17'	E45 - E40	Track Width	5,104	67	$ 849	5420-267-0046	Pre-cut and drilled I-beam assembly
13) Railway Bridge, I-beam	TM 5-371 SC 5420-93-CL-E14	21'	E45 - E40	Track Width	No data	No data	$ 1,346	5420-267-0047	Same as above
14) Railway Bridge, I-beam	TM 5-371 SC 5420-93-CL-E15	27'	E45 - E40	Track Width	11,518	205	$ 1,396	5420-267-0048	Same as above
15) Railway Bridge, I-beam	TM 5-371 SC 5420-93-CL-E16	31' 35'	E45 - E40	Track Width	18,668 20,835	340 382	$ 2,166	5420-267-0049	Same as above
16) Trestle, Railway, Steel, T-Type	TM 5-374 SC 5420-93-CL-E34	N/A	For 55' - 150' span Through-Truss	N/A	No data	No data	$ 35,545	5420-267-0037	For through truss RR bridge (11)
17) Trestle, Railway, Steel, L-Type, U-Type	TM 5-374 SC 5420-93-CL-E33	N/A	For 15' - 85' span, I-beam & unit const. bridge	N/A	No data	No data	$ 29,!28	5420-267-0036	For unit construction, RR bridges (9, 10)

TABLE 5 - COMPARISON OF BRIDGING MATERIALS

	Type of Material	Economical Span Range	Live Load Range	Design Difficulty	Labor Skills	Labor Intensity	Material Cost	Transport of Materials	Expected Life Range	Equipment Requirements	Reference Sources
1)	Log	20' - 70'	30 tons - 1 ton	Simple	Unskilled	Low (w/equip) High (w/out equip)	Minimal	Must use local materials	2 yr - 5 yr	Crane, bulldozer, chain saw	See (Hansen)
2)	Timber Stringer, Timber Pile	20' - 30'	20 tons - 1 ton	Simple	Semi-Skilled	Medium	Low to Medium	Expensive for long distances	5 yr - 10 yr	Pile driver, skill saw	1) TM 5-312 2) TM 5-258
3)	Timber, Simple Truss (Pony, King Post, Queen Post)	20' - 50'	30 tons - 1 ton	Simple to Medium	Semi-Skilled	Medium	Low to Medium	Expensive for long distances	5 yr - 10 yr	Pile driver, skill saw, power drill	See (Gaebel)
4)	Suspension, Wooden Deck	50' - 300'	10 tons - 1 ton	Medium	Semi-Skilled	Low	Medium	Economical for long distances	10 yr - 15 yr	Skill saw, concrete mixer for anchors	1) See (Weinert) 2) Roebling, p. 93 3) TM 5-270 4) TM 5-303, c 6, p. 819
5)	Masonry Arch, Earth Fill	20' - 50'	50 tons - 10 tons	Medium	Skilled	High	Low	Must use local materials	10 yr - 50 yrs	Bracing Material	1) See (Robinson) 2) TM 5-312
6)	Bailey Bridge	30' - 210'	30 tons - 16 tons	Simple	Unskilled	Low	High	Expensive for long distances	20 yr - 30 yrs	None	1) <u>Bailey and Unifloto Handbook</u> 2) TM 5-277
7)	Concrete Slab, Reinforced	20' - 40'	30 tons - 10 tons	Simple	Semi-Skilled	Medium	Medium	Expensive for long distances	10 yr - 30 yrs	Concrete mixer, skillsaw for framework	1) TM 5-312 2) See (Kadiyali)
8)	Concrete Beam Prestressed	30' - 105'	30 tons - 10 tons	Difficult	Skilled	Medium	Medium	Expensive for long distances	10 yr - 30 yrs	Special forms, concrete mixer, crane	See (Hall, Endebrock)
9)	Parabolic Pipe Truss	50' - 120'	30 tons - 10 tons	Medium to Difficult	Skilled	Low	Medium	Expensive for long distances	20 yrs - 50 yrs	Welder, crane	See (Lenz)

160

Luwu rural development, Sulawesi Island, Indonesia.
(Photo courtesy of USAID)

HANDBOOK OF HIGHWAY ENGINEERING

Robert F. Baker, Editor
L. G. Byrd D. Grant Mickle
Associate Editors

VNR VAN NOSTRAND REINHOLD COMPANY
NEW YORK CINCINNATI TORONTO LONDON MELBOURNE

CONTENTS

PART I

PART II

PART III

Loadings

AASHO Loadings

The AASHO loadings have gradually increased over the years. From 1927 when the loading was adopted, until 1944, the H-15 loading was used. This was a 15-ton truck with two axles spaced at 14 ft (4.2 m), with 80 per cent of the load on the rear axle and 20 per cent on the front. From 1944 until 1963, the H20-S16-44 designation was used, which since 1963 has been termed HS20-44. This is a three-axle truck with 20 tons on the two leading axles spaced at 14 ft (4.2 m), with the load divided 20 per cent and 80 per cent, followed by an additional trailing axle loaded with 16 tons and at a variable spacing. Certain uniform lane loadings are also permitted. One difficulty with these loads is that they represent trucks which are seldom if ever seen on the highway. However, experience has shown that structures designed for these loads will successfully carry any of the legal loads on the state highways in the early 1970's.

Foreign Loadings

It should be noted that the AASHO loadings are much lighter than those used in many foreign countries. A tabulation of design loadings in the early 1970's shows the AASHO loadings near the bottom while those of Great Britain and Germany are at the top. Direct comparisons of design loadings of Great Britain, Germany, and France can be misleading because the loads applied are quite different. However, an analysis of the moment and shear effects of these loads will give some indication of their relative severity. It is probably a fair statement to say that the design loadings of Great Britain, Germany, and France are about 1.85 times as severe as the AASHO loadings. The difference is not so much in the individual trucks or loads as it is in the number or sequence of the loads. The European loadings anticipate trains of trucks while the AASHO loading generally places only one heavy truck in each span.

The difference comes in part from a different philosophy in connection with the railroads. In the United States, when the load becomes too heavy for the highway, it is carried on a railroad. In Europe, when loads become too heavy the railroads will reject them and then they must be moved on the highways. The philosophical observation can be made that a country will develop a loading which best fits its economy. The present loading standards in the United States permit loads upon the highways which are a compromise between greater load-carrying capacity and the maintenance and safety problems which heavier trucks would generate. Political pressure for heavier legal loads can be anticipated, and a designer must ever keep this in mind.

Railroad Loadings

The railroads have long operated under a system of standard loads designated by the maximum weight of the locomotive such as E-60 or E-72. The weight is distributed over a standardized system of wheels. Many bridge design handbooks have tables for an E-10 loading from which the moments and shears under various wheels may be picked and used with a multiplier (E-60 = 6 X E-10).

Earthquake Considerations

There are few places in the United States entirely free from the threat of earthquakes. Many areas have not had a serious earthquake for some years, but the record will show that in the not too distant past severe earthquakes have occurred. Earthquake design involves a deep consideration of the philosophy of relative risk. Certain areas of the country have been accepted as low-risk areas while others are regarded as very vulnerable to earthquakes. Designing a moderate earthquake resistance into a bridge is not overly expensive and the designer would do well to consider putting in a few minimum safeguards to hold his structure together should it be subjected to an earthquake.

In high-risk areas, a reasonable philosophy must be developed. It is not feasible to design all bridges to withstand, without damage, the maximum rigors of an earthquake should it happen to be in the center of the disturbance. However, to prevent collapse and possible loss of life, every effort should be made to tie the structure together so it cannot pull apart and fall. Bridge failures in an earthquake are almost entirely failures of details and connections.

Some specific recommendations for earthquake-resistant design of bridges are worth noting. Bear in mind that concrete members rigidly attached to the ground will probably disintegrate under a maximum earthquake exposure. This completely eliminates all bond to the bars and lap splices of any sort become useless. Therefore to protect the stability of a structure and prevent its collapse, the following measures should be taken: (1) All columns should have closely spaced spiral reinforcement (e.g. No. 5 bars at 4-in (1.0 cm) centers, minimum). (2) The practice of doweling columns into footings should be avoided (in columns less than about 30 ft (9 m) in height, the main column bars should run from a good anchorage in the footing to an equally good anchorage in the cap without any lap splices). (3) Expansion joints should have ties across the gap which will permit normal expansion and contraction but will resist any major movement. Similar restrainers should also be placed in the abutments. Joint restrainers for earthquake forces are designed to resist a force equivalent to 25 per cent of the dead load of the lighter of the two sections of superstructure terminating at the joint, less the shear resistance of the columns supporting that section. Restrainers may be large high-strength rods or ¾-in (1.9 cm) prestressing cables which have a capacity of about 30 kips (15,500 kg) per cable. The cables may be grouped in clusters to reduce the number of restrainers to about two per cell of a box girder or per span between T-beams. (4) Special attention should be given to adequately anchoring footings to piles. (5) If static design factors are used, they should range between 10 per cent G and 30 per cent G in an earthquake prone area. The variation depends upon the foundation material, the lower values being used for rock foundations and the higher values being used for poor material and pile foundations. (6) Connecting members like footings and caps should have extra bars added top and bottom merely to try to keep the concrete blocks intact. (7) In an earthquake area, enough structures should be given a dynamic analysis to get a feel for the limits within which the design must fall to be safe dynamically. Certainly any major structure or one which would form an essential lifeline should be individually analyzed dynamically.

Other Loads

The AASHO Specifications list all of the other loads which can come onto bridge structures. These are grouped together so the designer can choose those loading combinations which will apply to his structure.

Overloads

There is a common misconception that most bridges are only occasionally subjected to overloads. However, a check with those who grant overload permits will prove startling to a designer. Some states issue over 200,000 overload permits each year (1972), and probably most of these overloads are concentrated on a small percentage of the state's highways. Other states issue blanket permits each year. These entitle a holder to haul his overloads as often as he wants. As a result, some bridges find overloading more the rule than the exception. Overloads take their toll in accelerated fatigue cracking and disintegrated decks. Hence, the designer would do well to include a considerable number of overloads in his design loading.

NOTE: This section is included to describe various loading criteria for bridges. See Reference 9 for more detailed comparison of highway bridge loading standards for different countries.

Paved dip near Oaxaca, Mexico.

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

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 de referencias a publicaciones adicionales que fueron mencionadas en los textos seleccionados o que se asocian intimamente con el material que se presentó en la Vista General y los Textos Seleccionados. Cada referencia tiene cinco partes que se explican e ilustran abajo

(a) Número de referencia: Este número dá la posición de la referencia dentro de este bibliografía en particular. Se utiliza en el índice del compendio pero ***no*** deberá utilizarse al pedir publicaciones.

(b) Título: Este es 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 parágrafo dá los nombres de autores personales o organizacionales (si hay alguno), el nombre del editor y su direccion, la fecha de publicacion, y el numero de paginas representadas por el título en la parte (b). En algunas referencias el parágrafo termina con

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 with an order number for the publication in parentheses.

(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, 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).

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un número de pedido para la publicación en paréntesis.

(d) Disponibilidad de la información: Este parágrafo explica que la publicación referenciada está disponible al lector en una de dos formas como sigue. (1) La publicación esta agotada pero puede ser consultada en la biblioteca indicada donde se sabe que se posee una copia. (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 parágrafo es un resúmen de la publicación cuyo título se dió en la parte (b).

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références se terminent par un numéro entre parenthèses qui indique le numéro de commande.

(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 bibliothèque 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 Ilustración Illustration

(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 8
HANDBOOK OF HIGHWAY ENGINEERING

Baker, Robert F.; Byrd, L. G.; Mickle, D. Grant, eds. New York: Van Nostrand Reinhold Company; 1975. 894 p.

Order from: Van Nostrand Reinhold Company, 450 West 33rd Street, New York, New York 10001.

This handbook is designed to provide a simple, comprehensive reference book of the principles, processes and data of current highway engineering technology. The topics which are concisely treated include standard topics such as planning, geometric design, soils and materials, as well as sections concerned with policy, management, quality, and environmental factors. Part I of this 4-part book covers highway policies, administration, economics, planning and programming, urban transportation planning, environmental engineering, and highway safety. The second part covers route location, geometric design standards, intersections, traffic control, electronic communication and control, right of way acquisition, and computer applications. Drainage, subgrades, foundations, embankments and cutslopes are covered in part 3. Part 3 also discusses pavement design, construction and reconstruction, bridges, viaducts and ramps, tunnels, roadway lighting, and landscape development. Part 4 outlines specifications, cost estimation, construction management, maintenance procedures and management, and snow and ice control. Each section discusses applicable principles, relevant data, and formulas and examples where appropriate. Example solutions are incorporated for the typical problems. References to detailed theory and data are also provided.

SELECTED TEXT REFERENCES

Reference 1
HANDBOOK OF METHODS AND PROCEDURE FOR LOW COST SERVICE ROADS

Blair, John E. Austin, Texas: Texas Highway Department; 1946. 61 p.

Out-of-print; may be consulted at U.S. Department of Transportation, Library Services Division, Room 2200, 400 Seventh Street, S.W., Washington, DC 20590.

The necessity for having culverts to insure proper drainage is described. Although there are several formulas which attempt to give a means of calculating the size of culvert required, it is noted that small differences in assigned values can lead to large differences in the results. Practical reasons for the use of corrugated metal pipe culverts are presented. It is noted that the best and most durable type of bridge for a stream crossing is one that is constructed of reinforced concrete. The mixing and placing of concrete is a highly technical operation. Many structures built with poor materials and inferior workmanship have not lasted long. It is noted that the best piles for use in farm road bridges are of creosoted timber. If good piles are used and proper care is taken in driving, they can be expected to last for twenty years or more. Practical methods for driving wood piles are described in the text. It also describes in detail the methods used in the construction of bridges built on wood piles. Steel truss bridges must be used for very long spans, especially where floating drift is to be expected. Because of the costly nature of this investment, all work must be carefully done.

Reference 2
USE OF GABIONS FOR LOW WATER CROSSINGS ON PRIMITIVE OR SECONDARY FOREST ROADS

Leydecker, Allen D. U.S. Forest Service Field Notes, Volume 5, Numbers 5 and 6, 1973 May-June; pp. 13-16.

May be consulted at or ordered from: U.S. National Agricultural Library, Route 1, Beltsville, Maryland 20705.

An economical and esthetically pleasing method of constructing a gabion low water crossing is described. The road at the water crossing is designed to give good line and grade through the stream. Gabions are placed at the final grade line with the upstream edge of the gabion alongside the downstream edge of the road. The gabions are backfilled and stream gravel is pushed up behind the gabions to form the running surface. The only major expense noted is in placing and filling the gabions. Constructing the gabions is briefly described. It is noted that in about a year's time, fines from the stream will cement the gravel backfill and cover all signs of construction leaving a satisfactory stream crossing which is practically invisible.

Reference 3
DESIGN AND CONSTRUCTION OF LOW WATER DIPS

Bingham, Joe M. Texas Highway Department Construction and Maintenance Bulletin, Number 6, 1951 May; pp. 45-51. (Proceedings of the 25th Annual Short Course in Highway Engineering, Agricultural and Mechanical College of Texas, College Station, Texas, 1951).

Out-of-print; may be consulted at U.S. Department of Transportation, Library Services Division, Room 2200, 400 Seventh Street, S.W. , Washington, DC 20590.

The consecutive steps of a design procedure for constructing low-water dips are described. The several items of field data needed for this method include data on stream section and roadway cross sections, water elevation at normal stage, stream meander, profile and topography, highway elevation, and drainage area. The amount of opening necessary to handle normal drainage may be determined from the elevation of water in the stream at normal stage and the centerline profile as a section. On low water structures it is very important to hold the grade elevation to a minimum above the streambed. The lengths of vertical curves have much to do with the final result. This is dependent on the following: the total change of grade between the two tangents, the safe rate of change of grade per station, and the necessary sight distance. An equation to determine the "rate of change" is given: $r= (G1-G2)/L$ where r is the rate of change in per cent per station; G1 and G2 are the two given grades in per cent; and L is the length of vertical curve in stations. The next step in design is to determine the length of the dip to be riprapped or protected from flood waters. This is done by first calculating the area below high water in the natural stream, and then determining a corrected high water elevation by taking into account the obstruction of the stream by the construction of the dip across it. Experience in the use of 5- or 6-inch-thicknesses of Class "B" concrete Riprap reinforced with either wire mesh or bar steel and completely paving them is outlined. The use of a standard flood gauge, 2 dip signs and enough 2-inch pipe posts to effectively define the crown lines across the main channels is also described.

Reference 4
CAUSEWAYS OR SUBMERSIBLE BRIDGES

Raju, S. P. Indian Roads Congress Journal, Volume 16, Number 3, 1952 April; pp. 354-369.

Order from: Indian Roads Congress, Jamnagar House, Shahjahan Road, New Delhi 110011, India.

A "causeway" is a submersible road bridge across a stream with the double function of allowing the normal dry weather flow to pass through the vents below the roadway, and the occasional floods both through the vents and over the roadway, thus entailing a temporary cessation of traffic. On account of their dual function, causeways present problems peculiar to themselves and unlike other hydraulic structures like spillways, sluices, barrages, lifting weirs, and road bridges. This article deals with some hydraulic investigations in connection with causeways.

Reference 5
ENGINEER FIELD DATA

U.S. Department of the Army. Washington, DC; 1976 September. 435 p. (Field Manual 5-34).

Order from: U.S. Department of the Army, Army AG Publications Center, 2800 Eastern Boulevard, Baltimore, Maryland 21220.

In this manual, data on a wide variety of pertinent subjects have been covered in a convenient format. The chapter on explosives and demolitions gives details of charge calculations, rock breaking, ditching and stumping. Minefield installation, reporting and recording relating to landmine warfare, and the removal of mines are described, as well as types of field fortifications, barbed wire entanglements, and expedient obstacles. Bridging and rafting equipment, and anchorage systems are further detailed, as well as concrete construction, military road construction, army airfields, helipads and heliports, rigging, and utilization of heavy equipment. The chapter on the marking of bridges and vehicles defines bridge class. The chapter on fixed bridges outlines nonstandard bridge design, bridge classification, standard bridges (Bailey and MGB) and miscellaneous bridging. This chapter describes the design of rectangular timber, round timber or steel beam bridge superstructures. Bridge substructure design of timber bents, and pile bents or pile piers are also covered. A step by step procedure together with tabulations is used to describe the selection and design of each part. Graphs are used to simplify the design procedure. Information is also provided on field sanitation, reconnaissance, communications and other miscellaneous field data.

Reference 6
THE BAILEY AND UNIFLOTE HANDBOOK

5th ed. Hathrell, J. A. E., ed. London: Acrow Press; 1974. 271 p.

Order from: Acrow Press, 8 South Wharf Road, London W2, U.K.

A brief background review of Bailey equipment is presented. Selecting the most suitable type of Bailey Bridge to solve any particular problem depends on two factors: The length of span required, and the weight and size of the load to be carried. Two examples are included to assist the engineer in selecting a suitable type of Bailey Bridge. The Storey Uniflote is a floating system using numbers of identical floating units assembled together to form rafts of various sizes. These units are then used for either floating bridges or ferries. In order to prepare a design for the Uniflote certain criteria are needed: It must be capable of supporting the Bailey Bridging; the flotation units must be capable of being connected in the water from deck level; each unit must be capable of supporting a load of 10 tons; the unit should be capable of being transported in a 3 ton truck. The operation of Uniflote shore-loading ferries is outlined. Five most frequently used sizes of Uniflote ferry are described in order to demonstrate its scope of application. Finally, a section on the design of a Bailey/Uniflote floating bridge is described. An example using a) the live load at the center of the bay, b) the live load at the junction of two floating buoys and c) full convoy loading shows the engineer the proper evaluation of floating bridge design.

Reference 7
OPPORTUNITIES FOR COST REDUCTION IN THE DESIGN OF TRANSPORT FACILITIES FOR DEVELOPING REGIONS

University of California, Institute of Transportation and Traffic Engineering. Berkeley, California; 1970. 406 p. (Sponsored by the U.S. Department of Transportation, Office of the Assistant Secretary for Policy and International Affairs and the U.S. Agency for International Development; report #PB-207520).

Order from: National Technical Information Service, 5285 Port Royal Road, Springfield, Virginia 22161.

The document provides the results of an examination of traditional designs of transport facilities in the developing countries with a view to reducing total initial and/or operating costs, or to reducing costs devoted to the imported elements. The topics include: Road cost analysis and design standards; road construction cost model; a road maintenance cost model; opportunities for cost savings in highway engineering design; economics of one-way bridging; potential cost savings in the design of water crossings; potential cost savings in the design and use of ground vehicles; opportunities for cost reductions in aircraft, airways, and airports; potential cost savings in the selection of waterway and harbor techniques; harbors and associated facilities; economic models for choice of transport techniques in developing countries;tradeoffs between construction costs and maintenance costs.

Reference 8
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ADDITIONAL REFERENCES

Reference 9
A COMPARATIVE STUDY OF HIGHWAY BRIDGE LOADINGS IN DIFFERENT COUNTRIES

Thomas, P. K. Crowthorne, U.K.: Great Britain Transport and Road Research Laboratory, Structures Department, Bridge Design Division; 1975. 47 p. (TRRL Supplementary Report 135UC).

Order from: Transport and Road Research Laboratory, Crowthorne, Berkshire RG11 6AU, U. K.

This report compares the highway bridge loadings of different countries. The historical background of highway bridge loadings is given and the studies so far carried out are reviewed. The loading standards in 18 countries are then compared in terms of the maximum bending moment and shear force for simply supported spans up to 100 metres. It is concluded that there is a very wide variation in the loading standards of different countries and the implications of some of these variations are emphasized.

Reference 10
MILITARY FIXED BRIDGES

U.S. Department of the Army. Washington, DC; 1968 December 1. Various paging. (Technical Manual 5-32).

Order from: U. S. Department of the Army, Army AG Publications Center, 1655 Woodson Road, St. Louis, Missouri 63114.

Preliminary investigations, reconnaissance of existing bridges, potential sites for new bridges, site surveys, construction techniques, and selection guides for standard bridges are discussed, and highway bridge and vehicle classification and nonstandard highway bridge design are presented. Details of bridge superstructure and substructure design, timber and steel (bolted and welded) connections as well as reinforcement and repair are discussed. Construction planning, supervision, inspection and maintenance are covered and comments are made on special bridging operations related to extreme cold, bridge foundations, substructures, superstructures and ice crossings. Reference is made to the Engineer Functional Components (EFCS) and related technical manuals. This manual is intended as a training guide and reference text for engineers responsible for the design, construction, classification, reinforcement and repair of nonstandard fixed highway and railway bridges for military use.

Reference 11
STANDARD SPECIFICATIONS FOR HIGHWAY BRIDGES

12th ed. American Association of State Highway and Transportation Officials, Operating Sub-Committee on Bridges and Structures. Washington, DC: American Association of State Highway and Transportation Officials; 1977. 496 p.

Order from: American Association of State Highway and Transportation Officials, 444 North Capitol Street, N.W., Suite 225, Washington, DC 20001.

Specifications related to general features of design and construction are presented. Design features relating to the following are covered: bridge locations and waterways, piers, culverts, roadway and sidewalks, clearances (navigational, vehicular or other), railings, roadway drainage, superelevation, floor surfaces, blast protection, utilities and underpasses. Aspects related to loads and the distribution of loads are covered as well as the various aspects of substructures and retaining walls. Reinforced concrete design features, allowable stress design and load factor design features are described. The characteristics of prestressed concrete and structural steel design (service load design method and strength design method) are reviewed. Other design aspects covered include heat-curved rolled beams and welded plate girders, load factor design, orthotropic deck-deck bridges, corrugated metal and structural plate pipes and pipe-arches, structural plate arches, timber structures, load capacity rating of existing bridges, elastomeric bearings, and steel tunnel liner plates. The construction features covered here include the following: excavation and fill, sheet piles, bearing piles, concrete masonry, concrete surfaces, reinforcement, Ashlar masonry, mortable rubble masonry, dry rubble masonry, brick masonry, steel structures fabrication, erection, bronze or copper-alloy bearing and expansion plates, steel grid flooring, railings (metal, concrete, stove and brick, wood) painting metal structures, protection of embankments and slopes, concrete cribbing, water-proofing, damp proofing, name plates, timber structures and preservative treatments, timber cribbing, construction and installation of soil metal plate structure interaction systems,wearing surfaces, elastomeric bearings, and the construction of tunnels using steel tunnel liner plates.

Reference 12
ADMINISTRATION OF BRIDGE INSPECTION

Campbell, Joe L. Washington, DC: National Association of Counties, Research Foundation; 1972 July. 33 p. (National Association of County Engineers Action Guide Series Volume XI).

Order from: National Association of Counties, 1735 New York Avenue, N.W., Washington, DC 20006.

This manual shows county officials where to find pertinent laws, regulations and guide manuals and how to comment on the legal and public responsibilities associated with the ownership of bridges and other highway structures. Federal, State and local regulations are reviewed, and state and federal highway programs are discussed. Tort liability, and engineers statutory responsibility are examined, and comments are made on the responsibility to the public, and on preventive maintenance. Bridge inventory is discussed in relation to federal requirements and the elements of an inventory. Various aspects of bridge inspection are covered including qualification of inspectors and inspection by technicians. Bridge rating is reviewed with reference to structural capacity determination, change of loading, posting-reduced load or speed, and public education.

Reference 13
MINOR MAINTENANCE OF COUNTY BRIDGES

Shurig, D.G. Lafayette, Indiana: Purdue University; 1964 August. 44 p. (Highway Extension and Research Project for Indiana Counties Engineering Bulletin, Engineering Experiment Station County Highway Series Number 7).

Order from: Highway Extension and Research Project for Indiana Counties, Engineering Experiment Station, Purdue University, West Lafayette, Indiana 47907.

This bulletin covers routine maintenance of the substructure, superstructure, approaches, channels, and bridge signs and markings. Cleaning and inspections, the maintenance of expansion bearings and joints and deck maintenance are considered, as well as weed and brush control around bridges. Patching abutments, piers, and wingwalls, cracking wingwalls, steel tubular piers, temporary reinforcements, and acid water attacks on foundations are examined. The minor maintenance of stringers and floor beams, decks, guardrails and posts, fences on bridges, stream silting and channel changes and the legal aspects of bridge and ditch cleaning are reviewed. The maintaining of the approach at deck level and the protection of approach slopes are also reviewed. The bulletin also covers sign selection, sign locations, bridge end markers, reflector markers, and signing and marking underpasses.

Reference 14
GUIDE TO BRIDGE HYDRAULICS

Roads and Transportation Association of Canada, Project Committee on Bridge Hydraulics; Neill, C. R., ed. Toronto: University of Toronto Press; 1973. 191 p.

Order from: University of Toronto Press, 33 East Tupper Street, Buffalo, New York 14208.

This guide outlines hydraulic factors to be considered in the layout and design of the bridges, and suggests tentative criteria and procedures to assist the bridge designer. General comments are made on economic aspects, the use of culverts as alternaives to bridges and on some organizational aspects. Details are given of flood frequency analysis for gauging stations, extensions of such analysis, flood envelope curves, runoff formulas, and unit hydrographs as well as hydraulic methods of estimating flood discharges, estimation of high-water levels and the special consideration of very rare floods. The design of waterway opening for scour and backwater is described and scour protection and channel training works are discussed. The guide also reviews special problems such as tidal crossings, inland basin crossings, waves and wave protection and the application of hydraulic models to bridge problems.

Reference 15
HYDRAULICS OF BRIDGE WATERWAYS

2nd ed. Bradley, Joseph N.; U.S. Federal Highway Administration, Office of Engineering, Bridge Division, Hydraulics Branch. Washington, DC: U.S. Federal Highway Administration; 1978 March. 111 p. (Hydraulic Design Series Number 1; stock number 050-001-00133-1).

Order from: Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20402.

This publication is based principally on the results of hydraulic model tests which have been evaluated on the basis of field data. The field data have been used to determine the actual limits of application and to complete the design curves. The computation of backwater, difference in water level across approach embankments and the configuration of backwater are discussed, as well as aspects relating to dual bridges, and the abnormal stage-discharge condition. The effects of scour on backwater, the partially inundated superstructure, spur dikes at bridge abutments, and supercritical flow under a bridge are also covered. Preliminary field and design procedures and illustrative examples are presented. The development of expressions for bridge backwater and the development of charts for determining the length of spur dikes are described in appendices.

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 may 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 or name ap-

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 el Vista General, Textos Seleccionados, o Bibliografía. Los vocablos del tema que se listean són aquellos básicos 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 están listeados como apellido seguido por las iniciales. Las organizaciones nombradas son las que han producido información sobre la materia del compendio y que siguen siendo una fuente de información sobre alguna parte o el alcance total del compendio. Por esta razón se dan las direcciones postales para cada organización listeada.

Los números que siguen a un vocablo del tema, nombre personal, o nombre de organización son los números de página del com-

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 cités 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 de personnes identifiées avec les sujets de ce recueil. Le nom de famille est suivi des initiales des prénoms. Les organisations citées sont celles qui ont écrit sur le sujet de ce recueil et qui continueront d'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 écrits en chiffres romains se rapporpears. Roman numerals refer to pages in the Overview, Arabic numerals refer to pages in the Selected Texts, and reference numbers (e.g., Ref.12) 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 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 números de referencia (por ejemplo, Ref. 12) 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 compendio 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 indicadas bajo los términos que siguen a las palabras *see also.*

La explicación anterior esta subsiguientemente ilustrada.

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tent 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. 12) 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, les références qui les touchent se trouveront citées après les mots-clés qui suivent la notation *see also.*

Ces explications sont illustrées ci-dessous.