NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM REPORT **1**

EVALUATION OF METHODS OF REPLACEMENT OF DETERIORATED CONCRETE IN STRUCTURES

HIGHWAY RESEARCH BOARD   NATIONAL ACADEMY OF SCIENCES - NATIONAL RESEARCH COUNCIL

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EVALUATION OF METHODS OF REPLACEMENT OF DETERIORATED CONCRETE IN STRUCTURES

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HIGHWAY RESEARCH BOARD OF THE DIVISION OF ENGINEERING AND INDUSTRIAL RESEARCH
NATIONAL ACADEMY OF SCIENCES - NATIONAL RESEARCH COUNCIL

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

Systematic, well-designed research provides the most effective approach to the solution of many problems facing highway administrators and engineers. Often, highway problems are of local interest and can best be studied by highway departments individually or in cooperation with their state universities and others. However, the accelerating growth of highway transportation develops increasingly complex problems of wide interest to highway authorities. These problems are best studied through a coordinated program of cooperative research.

In recognition of these needs the highway administrators of the American Association of State Highway Officials initiated in 1962, an objective national highway research program employing modern scientific techniques. This program is supported on a continuing basis by Highway Planning and Research funds from participating member states of the Association and it receives the full cooperation and support of the Bureau of Public Roads, United States Department of Commerce.

The Highway Research Board of the National Academy of Sciences-National Research Council was requested by the Association to administer the research program because of the Board's recognized objectivity and understanding of modern research practices. The Board is uniquely suited for this purpose as: it maintains an extensive committee structure from which authorities on any highway transportation subject may be drawn; it possesses avenues of communications and cooperation with federal, state, and local governmental agencies, universities, and industry; its relationship to its parent organization, the National Academy of Sciences, a private, non-profit institution, is an insurance of objectivity; it maintains a full-time research correlation staff of specialists in highway transportation matters to bring the findings of research directly to those who are in a position to use them.

The program is developed on the basis of research needs identified by chief administrators of the highway departments and by committees of AASHO. Each year, specific areas of research needs to be included in the program are proposed to the Academy and the Board by the American Association of State Highway Officials. Research projects to fulfill these needs are defined by the Board, and qualified research agencies are selected from those that have submitted proposals. Administration and surveillance of research contracts are responsibilities of the Academy and its Highway Research Board.

The needs for highway research are many, and the National Cooperative Highway Research Program can make significant contributions to the solution of highway transportation problems of mutual concern to many responsible groups. The program, however, is intended to complement rather than to substitute for or duplicate other highway research programs.

This report is one of a series of reports issuing from a continuing research program conducted under a three-way agreement entered into in June 1962 by and among the National Academy of Sciences-National Research Council, the American Association of State Highway Officials, and the U. S. Bureau of Public Roads. Individual fiscal agreements are executed annually by the Academy-Research Council, the Bureau of Public Roads, and participating state highway departments, members of the American Association of State Highway Officials.

This report was prepared by the contracting research agency. It has been reviewed by the Advisory Panel for clarity, documentation, and fulfillment of the contract. It has been accepted by the Highway Research Board and published in the interest of an effectual dissemination of findings and their application in the formulation of policies, procedures, and practices in the subject problem area.

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FOREWORD

By Staff
Highway Research Board

The findings of this study will be of particular interest and use to state maintenance engineers. Information contained herein describes techniques for repair of deteriorated concrete bridge decks. The discussions on utilization of various materials and the listing of source of their manufacture will be helpful in planning structure repairs. Cost data, even though broad, provide a basis of departure for the study of different repair techniques.

As a consequence of the "bare pavement practice" in winter maintenance operations, concrete highway structures have suffered substantial deterioration. Not only is the concrete physically and chemically damaged, but corrosion of reinforcing steel has led to structural weakness. In recognition of this problem, highway administrators have initiated research to bring fuller understanding of the causes for this deterioration and suitable methods of rehabilitation.

The immediate approach to the study of this deterioration has been to authorize research on the problem from the viewpoints of cause, effect, and correction. Under the National Cooperative Highway Research Program, research is under way in Highway Structure Protection and Snow and Ice Removal and includes studies directed towards developing non-chemical deicing agents, quality control in concrete placement, repair techniques for deteriorated concrete, and protective methods for future structures. The first research was begun in 1963 and final reports are being received.

This report issues from an after-the-fact study involving an appraisal of many methods of replacement of deteriorated concrete. Various facets of the problem were investigated and discussions held with agencies throughout the country. While this report does not recommend specific procedures, it discusses current practices in depth In the conduct of the study, 238 project sites were inspected during field visits to 28 states and the District of Columbia. Following the visits and additional contacts by mail, it was concluded that geographical distribution of the deterioration problem is directly related to the climate and, as would be expected, it becomes progressively worse in colder areas. Deterioration is not a problem of consequence in the southeastern part of the country. The report covers materials, equipment, and procedures used in concrete repair along with limited cost data.

Of the several materials encountered in repair operations, those predominately in use include portland cement mortars, epoxy-resin bonding agents, and coal-tar pitch emulsions. Equipment used during the repairs was varied, but all projects required considerable hand labor in preparing and cleaning areas to be patched. Several successful repair procedures were suggested. One of the most practicable procedures was the "stay-in-place" deck form used in the District of Columbia for undersides of decks where access is restricted. On other projects, removable forms framed from the lower flange of floor beams were successful.

Of the many repair plans studied, all showed a need for carefully established repair techniques. It was consistently apparent that successful projects were those in which high quality materials were used under carefully controlled workmanship. It was also noted that complete record keeping was associated with those projects which showed consistent success. The study revealed no special material or short-cut method as a substitute for proper construction practices.

The study pointed up areas requiring further research. These include the effect of smoothness on bridge-deck deterioration, factors influencing depth of concrete over reinforcing steel, techniques and devices for measuring the degree of soundness of hardened concrete, longitudinal movement of pavement approach slabs abutting structures, design of epoxy patching mortars, and the design of joints on bridge decks.

CONTENTS

EVALUATION OF METHODS OF REPLACEMENT OF DETERIORATED CONCRETE IN STRUCTURES

INTRODUCTION

As a part of the National Cooperative Highway Research Program sponsored by the American Association of State Highway Officials, this study gives attention to the major problem of deterioration of concrete in highway structures faced by maintenance and bridge engineers in many sections of the country today.

The problem is accentuated by a number of factors. First, there is an increasing number of structures in the highway system. Modern highway design, as exemplified by Interstate highways or urban expressways, calls for many more structures than did the typical highway route of a decade ago. In Michigan, for example, 942 structures have been added to the highway system within the last 6 years. Over 1,900 contracts for bridge construction were awarded by the Illinois Division of Highways between 1951 and 1961. The New York State Department of Public Works let 320 bridge construction contracts in 1961 alone—more than one for each working day in the year. For the same year, 137 new structures were completed on the Los Angeles freeway system and 372 others were under construction.

The maintenance and operational standards required for the present-day highway system also have a bearing on the problem. In northern climates, the growing use of snow and ice control chemicals to meet the year-round demands of highway users shows a definite relationship to the growing incidence of bridge concrete deterioration.

Regardless of the nature of the relationship, many problems of concrete deterioration appear to be directly related to the action of freeze-thaw cycles, particularly in the presence of deicing chemicals.

Field samples have been analyzed which show the sodium chloride content in snow slush on bridge pavements varying between 1 and 10 percent (*1*). Laboratory tests have shown that a 2 percent sodium chloride solution is more corrosive than higher concentrations.

In addition, it is believed that salt solutions may increase the number of freeze-thaw cycles to which the concrete is subjected during the winter months. Where cracks in the concrete permit brine solutions to penetrate to the reinforcement, corrosion is promoted and ultimately brings about spalling (Fig. 1) as the oxidized steel expands within the concrete.

One theory holds that brine, admitted to the pores and hairline cracks in the concrete surface, recrystallizes during periods of drying, thus causing internal pressure and promoting scaling and disintegration.

The osmotic pressure theory is based on the assumption that there is a difference in the percent concentration of brine at various depths within the concrete. The osmotic pressure resulting from this difference in concentration of solution is assumed to create internal stresses in the concrete.

It is known that deterioration takes place when concrete is subjected to repeated freezing and thawing in the presence of plain water. This is caused by the internal stresses resulting from expansion of ice crystals within the capillaries of the concrete during freezing.

Deterioration has been caused or increased by many other factors, including the materials and procedures employed in construction and maintenance, the elements of design, and the loads and other stresses to which the structure is subjected. A British engineer, Champion (*2*), suggests a number of common causes of failure of concrete: (1) Permeability of the cover concrete leading to rusting of the steel and spalling; (2) freeze-thaw effects on the surface; (3) mechanical obstruction to free expansion and contraction of the structures leading to thermal shrinkage cracks; (4) differential settlement beneath the structure leading to excessive strain on joints; (5) absence of drainage gradients on the horizontal surfaces leading to moisture collection; (6) redistribution of chemicals and crystal growth; (7) diurnal thermal stresses in times of hot sun; (8) fatigue due to thermal stresses or load stresses; (9) shock waves; and (10) bad workmanship.

Although this report gives recognition to repair procedures followed for all types of concrete failure, a great majority of the repairs inspected and considered in the study were occasioned by the action of moisture, chlorides and freeze-thaw cycles on the structural concrete.

In general, the geographical distribution of the problem of bridge deck deterioration is directly related to the climate, as indicated by the general information survey. These results substantiate the findings reported by Larson concerning a bridge deck condition survey conducted by the U.S. Bureau of Public Roads in January 1961 (*3*). Larson stated . . . "disintegration was generally not a problem in the southeastern part of the country but became progressively more serious in the colder areas with one notable exception. The report indicated that Alaska did not have a problem of disintegration of concrete decks. Salt had not been extensively used in Alaska and possibly the number of freeze-thaw cycles was less there than in this middle-Atlantic area."

Industry, also, has become increasingly aware of this problem. A wide variety of materials for repairing or preventing concrete deterioration have been studied and developed to one degree or another. In some instances, companies have been guilty of premature marketing of materials not fully developed. In other instances, field application procedures have not been given the same careful, technical attention used in developing the materials. At the same time, individual highway agencies in states and other local governments have engaged in a wide variety of experimental installations under diversified conditions with and without documentation and control of the experiments.

Figure 1. Complete failure of bridge deck concrete requiring expensive full-depth replacement of slab.

Concurrently, many data have been published on the subject of concrete repair and protection, often referring to the newly-developed materials being used in experimental programs. Frequently the articles, particularly those appearing in the trade press, are based on very early evaluations of these experiments and sometimes give premature conclusions as to the serviceability of the material or procedure.

In recognition of the growing problem of structure maintenance and the voluminous, often uncorrelated, information being developed on the subject, this study was undertaken.

CHAPTER ONE

OBJECTIVES AND PROCEDURES

This study had three basic objectives. The first was to make a comprehensive search of existing literature on the subject of repair of deteriorated concrete to bring together in a single report the essence of the useful information. A survey of existing repair procedures followed by state highway departments and other bridge maintenance agencies was also conducted so that unpublished information on current methods and materials could be included.

The second objective was to develop, through field inspection, information on the ability of these procedures and materials to restore structures to their original design state and to study and report on the economic aspect of the methods and materials.

The third objective was to explore the scope and adequacy of the information currently available and to prepare recommendations concerning areas in which further study could prove most productive and useful to the highway industry.

LITERATURE SEARCH

As an initial phase of the study, a comprehensive search was made of association and trade periodicals, conference proceedings, bulletins, special reports, abstracts and textbooks. Major publication sources in the concrete and related fields were searched. Volumes published over a period of the last 3 years were reviewed to encompass current work pertinent to the study. The literature search was conducted as the initial phase of the study, and it was continued during the general information survey and field inspections in order that special reports and studies of value to the project, suggested by representatives of the public and private organizations with whom contacts were made, could be included in the report.

Digests were prepared of 70 different articles and texts (Appendix B). Data were extracted on specifications of materials used in the reported projects, procedures and practices employed in performing the work, and costs of the various phases of the work. Evaluations of construction methods, quality of work, accomplishment of objectives, and actual or potential service life of the repairs were also recorded.

Currently, the Portland Cement Association is conducting a comprehensive study of concrete bridge deck deterioration. The study is incomplete, however, and was not included in the literature review. Conferences have been held with PCA representatives, and this report reflects the benefit of such information as has been made available to date.

Although the published data on methods of replacement of deteriorated concrete are somewhat incomplete, the literature search did indicate current repair projects. The agencies and individuals conducting these programs were contacted and their work was inspected. Published data also indicated manufacturers of materials and equipment used in the removal and replacement of deteriorated concrete, and these were contacted for more complete information when required.

Since it is the responsibility of the trade press to report on new and unusual approaches to this problem, a casual reader might misinterpret such presentations as a reflection

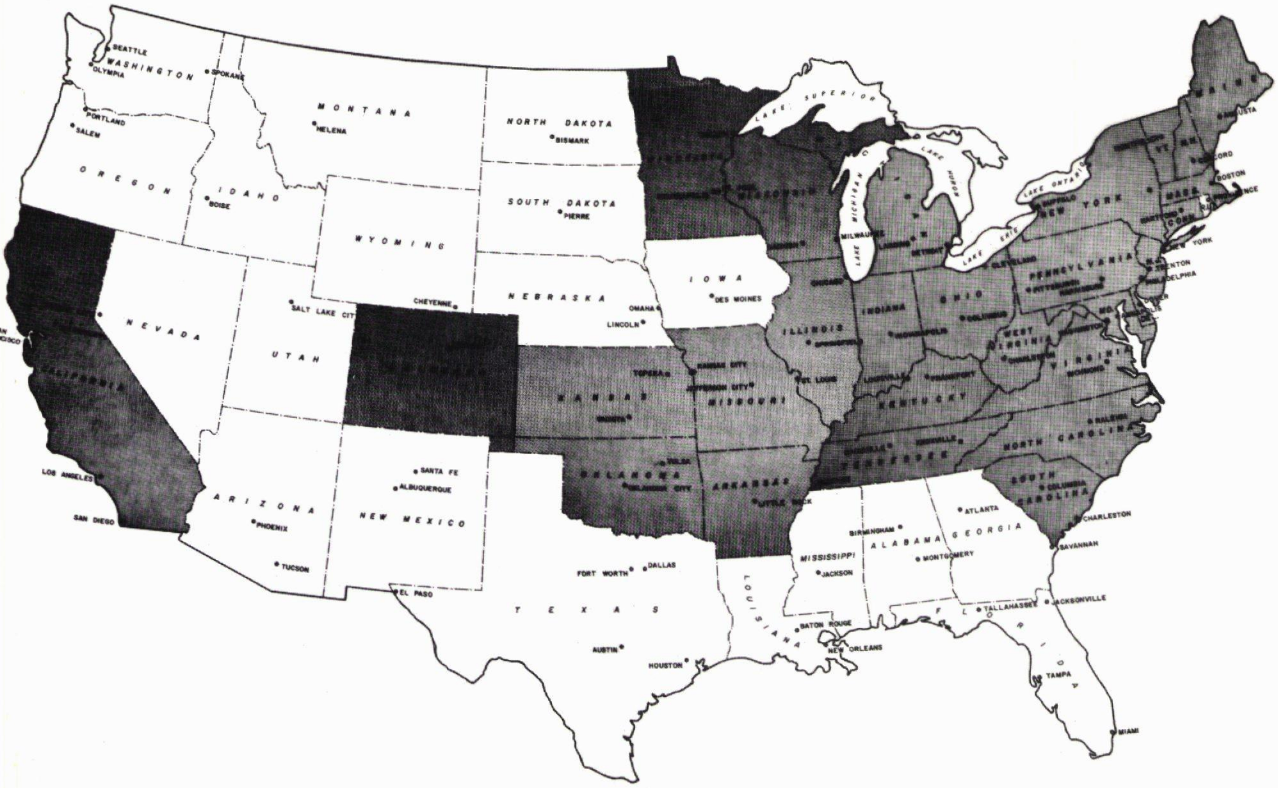


Figure 2. States where field inspections of bridges were made.

of general practice and current trends based on successful achievement over a period of time. Because they lack news value, procedures that have been used successfully over a period of time are seldom published (outside of internal directives or manuals) and may fail to receive the attention of other engineers and maintenance staffs.

In view of the preceding, the literature phase of this study, in itself, was not considered to be a valid basis for determining trends or drawing significant conclusions about methods of replacement of deteriorated concrete in structures.

INFORMATION SURVEY

Letters of inquiry were sent to each of the 50 state highway departments, the District of Columbia, bridge and toll road commissions, university research sections, and several city, county and foreign highway organizations. The department was requested to furnish information on methods, equipment, and materials used by that agency for the removal and replacement of deteriorated concrete. Information was also solicited on procedures and materials used in the reconstruction and waterproofing of expansion joints. Agencies were asked to provide unit cost data where available and to give observations and evaluations of the effectiveness of various types of repair work. Information on typical projects that might be included in the field inspection phase of the study was also requested.

Inquiries were sent to industry representatives to obtain information about materials and equipment used in concrete replacement. Because the formulations for many of the materials studied are apparently proprietary information which the manufacturers are unwilling to release, brochures and specifications furnished by manufacturers or material suppliers often dealt with performance data rather than with composition of the materials.

From the information developed through the literature search and the correspondence survey, an itinerary of field inspections was developed to cover those areas (Fig. 2) and agencies where work had been performed which appeared to be of significant value to the study.

FIELD INSPECTIONS

Visits were scheduled to include state highway departments, bridge and toll road commissions and others. A total of 238 project sites were visited and inspected (Appendix A).

Field visits were arranged by prior correspondence. Visits generally included a discussion of the structure repair program in the offices of the agency and on-site inspections of representative projects under the jurisdiction of that highway authority. Where possible, project sites included ones on which work had been completed and the structure returned to service for an extended period of time, as well as projects currently under way or recently completed.

The inspection usually included a visual survey of surface conditions, sounding the patch and surrounding area with a hammer or steel rod to detect evidence of bond failure or other weaknesses, and checking the underside of the structure for signs of moisture or deterioration. The inspector observed the condition of the repair work, the type and extent of repair failure where such failure was evident, and the degree to which the repair was accomplishing the intended work. These observations were recorded and the elements of the project rated to show the success of the repair as estimated by the inspector.

Where work was currently under way, equipment used in the repair program was observed and inspected. Equipment specifications and cost data were obtained when available. Materials and methods used in forming and supporting the repair area during placing and curing were also studied.

CHAPTER TWO

MATERIALS USED IN CONCRETE REPAIR

Before discussing concrete repair procedures in detail, it is necessary to identify and describe the many types of materials that were encountered. Mix designs and other quantitative discussions are covered in subsequent chapters. Specific materials and manufacturers encountered are given in Appendix C.

PORTLAND CEMENT

Because repair programs often followed original construction techniques, most of the commonly-used types of portland cement (*4*) were employed. These included Type I, general purpose cement; Type II, modified portland cement with a lower heat of hydration and greater resistance to sulfate attack; and Type III, high early strength cement. Air-entraining portland cement, Types IA, IIA, and IIIA were also employed in repair projects.

Additives and admixtures for portland cement concrete were found to be in frequent use in concrete repair projects. Those encountered in this study included the seven classifications listed by the Bureau of Public Roads (*5*), as follows:

1. Accelerators shorten the setting time of the concrete permitting earlier removal of the forms and use of the concrete. Calcium chloride is widely used as an accelerator.
2. Retarders delay the setting of concrete, a quality that may be useful in such applications as continuous pours of large concrete components. Sometimes called dispersing agents, organic retarders may include sugars, starches, and certain other compounds.
3. Air-entraining agents entrain large numbers of very small, separate air bubbles in the concrete. The entrained air improves resistance to damage from freezing and thawing, improves the workability of the fresh concrete, and permits lower water-cement ratios. Air-entraining admixtures are widely used and are produced by a number of different manufacturers. Classified with respect to major constituents, these agents fall into seven groups: salts of wood resins, synthetic detergents, salts of sulfonated lignin, salts of petroleum acids, salts of proteinaceous materials, fatty resinous acids and their salts, and organic salts of sulfonated hydrocarbons. (To this list can be added certain silicone compounds.)
4. Grouting agents are used as lubricants to provide a more flowable grout for penetrating seams, cracks and pockets when the grout is applied under pressure. Materials include bentonite, pumicite, fly ash, and various proprietary materials.
5. Workability agents improve the handling and placing qualities of concrete. Items include powdered or finely ground materials such as hydrated lime, bentonite, pumicite, fly ash and diatomaceous earth.
6. Pozzolans react with the lime freed by the hydration of portland cement to form additional cementitious compounds that improve the strength of hardened concrete. Agents include natural volcanic ash, fly ash, and a number of proprietary products.
7. Dampproofing agents are intended to reduce the penetration of moisture through hardened concrete. These materials include air-entraining agents, which have been used in moderate-to-high-cement-content concrete, and soap stearates and asphalt emulsions, which have been used for concretes of low cement content.

Other admixtures have been developed or are being developed for special requirements. These include gas-forming agents that create small gas bubbles in the concrete, and agents used to increase the strength and durability of the concrete.

A type of manufactured aggregate (used more in the nature of an admixture) is metallic fine aggregate, such as iron filings. Such aggregates oxidize and expand to counteract the shrinkage of the concrete while curing, thus reducing the tendency to pull away from the edges or perimeter of the patch.

AGGREGATES

The aggregates commonly encountered in concrete mortars for structural repair met the specifications adopted by the agency for new construction. They included trap rock, limestone, dolomite, gravel, slag, and lightweight aggregates.

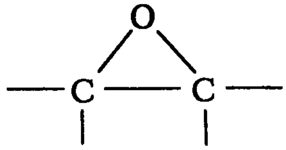
Natural, hard, clean sands, predominately silica, also meeting standard construction specifications, were used along with manufactured rock sands and lightweight fine aggregates.

Often processed or manufactured lightweight aggregates were used where additional dead load on a structure was critical or where easier application was believed to be available by their use. Many of these weighed one-third less than natural stone or gravel.

Another special type of fine aggregate employed in concrete repair work was an extremely hard, wear-resistant material such as emery or aluminum oxide, used as a topping to impart skid resistance and wearing qualities to repair projects on deck surfaces.

EPOXY RESINS

Derived from the Latin word *epi* meaning "on the outside of," and from "oxygen," epoxy resins are a family of chemicals containing the epoxide ring (*6*). Diagramatically the epoxide ring may be indicated as



These rings react readily with a number of compounds, including amines, phenols, thiols, acids, and alcohols (*7*).

Commercial epoxy resins are made by reacting, in the presence of a caustic, bisphenol-A and epichlorohydrin, compounds derived from natural gas or cokeing by-products. The chemistry of the epoxy compounds is complex and beyond the scope of this report, but when activated with a curing agent, the epoxy resin polymerizes to form a solid material with special adhesive qualities. The curing or polymerizing process is caused by the use of a catalyst or a reactive hardener. In the reaction, no by-products are formed and no large volume change is experienced.

Curing Agents

The basic types of curing agents used in epoxy resin compounds include the amines, acid anhydrides, and boron trifluorides. The amine curing agents are the most widely used. The resultant mixtures have low viscosity (before curing), are rapid curing at room temperatures, are relatively tough and readily mixable. Being nonhygroscopic, they are useful in fresh concrete. The acid anhydrides require high temperatures (120° to 200°C) for proper curing. The acid anhydride-cured epoxies have high resistance to heat and chemicals but are hygroscopic. The boron trifluoride compound is a highly corrosive gas and impractical for use under normal handling conditions.

Flexibilizers

To overcome the inherent brittle qualities of cured epoxy resins, flexibilizing modifiers are used. These modifiers react chemically with the epoxides to form more elastic molecules. Modifiers commonly used include the liquid polysulfides, the polyamides and the aliphatic amines. The liquid polysulfides are colorless, viscous materials which take part in the chemical reaction. When they are used, a compatible curing agent, such as the tertiary amine, dimethylaminomethyl phenol, is used. The polyamides are viscous brown liquids that also act as a curing agent for the epoxy. The aliphatic amines are low viscosity hardeners that react readily at room temperatures.

Thickeners and Fillers

In addition to the curing agents and modifiers that react chemically with the epoxy resins, other materials may be added that react mechanically to change the properties of the resulting product.

Thixotropic agents consist of finely-divided materials which form a cell-like structure and hold the liquid resin in a relatively immobile position until curing and hardening has occurred. Materials used for this purpose include chopped glass fiber, expanded silica bentonite, and mica platelets.

Inert solids, such as sand, aluminum oxide, calcium carbonate, and other aggregates and metals, are used to fill the mixture and displace, and thus reduce, the amount of resin required. Fillers may be used to alter the strength characteristics of the resin compound.

Epoxy resins have coefficients of expansion that are three to five times greater than portland cement concrete. To prevent shearing failure in the concrete to which they are bonded when temperature changes occur, some epoxy formulations include tar additives which impart stress-releasing qualities to the material. For applications of epoxy mortars, the proper sizes and quantities of aggregate in the mix can bring the coefficient of expansion of the mortar closer to that of concrete.

Generally, epoxy resins have characteristics which include rapid hardening at normal temperatures, a high degree of adhesion to most surfaces, durability and resistance to cracking, and chemical resistance to most acids, alkalis and solvents. Epoxy resins, being both exothermic and thermosetting, have a relatively short pot life. The heat released during the reaction of the epoxy resin and curing agent acts to increase the reaction, thus the longer the epoxy mixture remains in the batch container, where the heat cannot be released, the faster the curing action. Furthermore, the larger the batch mixture, the greater is the release of heat and the faster the reaction.

LATEX MORTARS AND LATEX BONDING AGENTS

A number of synthetic rubber latexes have been developed for use with portland cements. Such latexes are usually produced in the form of water emulsions. Thus, when added to portland cement mixes, the water in the emulsion reacts with the cement to cause hydration, while the particles of latex influence the strength and characteristics of the resulting mortar. Compressive strengths of latex mortars are decreased, but flexural and tensile strengths increase generally over those of plain portland cement mortars. Latex mortars also increase initial adhesive qualities on most surfaces.

Among those latex formulations currently available are the styrene-butadiene co-polymer particles in a water dispersion, the neoprene elastomer particles in a cationic water dispersion, and the saran type particles in a water dispersion. Polyvinyl acetate compounds have been used under several different trade names as bonding agents and as admixtures for concrete mortars. These materials are odorless latex liquids with a viscosity of heavy cream. They are air-cured and are thermoplastic.

POLYESTER RESINS

Polyester two-component resinous systems have several characteristics similar to those of epoxy resin formulations. Polyester resins are rapid curing at normal temperatures and have high corrosion resistance, high compressive strength and good bond to properly prepared concrete surfaces. The polyesters differ from most epoxy resins in that they do not adhere well to nonporous surfaces, such as metal or glass, and are not compatible with wet or damp surfaces, such as freshly-placed concrete.

The polyester component is somewhat unstable and cannot be stored very long before use. Polyester compounds employ a peroxide as the catalyst.

BITUMINOUS MATERIALS

Asphalts and tars have been used to varying degrees in concrete structure repair work. Where asphalt cements or liquid asphalts and tars are used, they generally conform to specifications for new construction as adopted by the responsible agency.

Coal tar pitch emulsions have been used in a number of concrete repair programs as protective coatings on repaired decks and other horizontal surfaces. Most coal tar pitch emulsions employed in this work meet Interim Federal Specification R-P-00355B. The material consists of a coal tar pitch dispersed in water by means of a combination of mineral colloids to form a suspension which, when dried, will not be redispersed by water.

The material is usually furnished in a creamy consistency suitable for undiluted application as a heavy film using a squeegee, brush or mechanical spray.

Work is being done by several agencies in the development of asphaltic-concrete mixes employing additives to improved impermeability, density, stability, and durability. Asbestos fibers have been used in a number of experimental asphaltic concrete mixes (*41*) and are reported to permit an increased asphalt-cement content without loss of stability or danger of bleeding of the mix. This, in turn, provides for increased density and reduced permeability of the asphaltic concrete. The asbestos fibers also appear to contribute some modest reinforcement to the asphaltic-concrete mix which may have structural benefits as well.

Hydrated lime has been used as an additive in hot mixes with particular benefit where marginally acceptable aggregates have been employed. The lime is reported (*10*) to react chemically with the free silica in the aggregate to form a gelantinous mass that seals cracks and openings in the aggregate and prevents the aggregate from disintegrating. The highly alkaline lime also neutralizes the acid properties of the asphalt and permits better coating of the aggregate.

Rubber and synthetic latex materials have also been used as additives in bituminous-concrete mixes. Other additives employed in asphaltic-concrete mixes include anti-stripping materials and materials employed as emulsifiers.

Some use has been made in concrete repair programs of the recently developed, colorless binders which are pigmented and used with aggregates of the same natural color to provide a full-depth color paving material. These binders are polymeric hydrocarbons, derived from petroleum products. The paving concretes, which consist of binder, plasticizer, pigment, and aggregate, are handled much like asphalt concrete.

SURFACE PENETRATING SEALANTS

To protect newly-repaired surface areas from moisture and chemicals, various penetrating sealants were being used by agencies contacted in this study. Linseed oil has been used for treating concrete surfaces, generally as boiled linseed oil and petroleum spirits mixture. A number of other penetrating sealants and coatings of a proprietary nature were also encountered.

A discussion of the uses of the materials described in this chapter, evaluations of their application in concrete repair work, and the economics of such materials, are covered in detail in subsequent chapters of the report.

CHAPTER THREE

EQUIPMENT USED IN CONCRETE REPAIR

A brief description is offered here of some of the basic types of equipment, especially applicable to concrete repair work, that were encountered in this study. The specific units and manufacturers are listed in Appendix C. No attempt is made to cover many types of equipment of a more general construction nature or to describe numerous hand tools and small equipment units which were a part of most repair projects. The selection of the proper types and sizes of tools and equipment for specific applications is discussed in following sections of the report.

SHOTCRETE EQUIPMENT

Gunned or pneumatically applied concrete has been employed for structural repair work for a number of years. The process, although often referred to by proprietary names, is called "shotcrete" by the Portland Cement Association and this terminology is generally accepted by the highway industry today.

There are currently two basic types of shotcrete. Dry-mix shotcrete is concrete or mortar in which the portland cement and aggregate are mixed in a dry state and conveyed to the nozzle where water is added as the mixture is ejected by air pressure. Wet-mix shotcrete is concrete or mortar in which the portland cement, aggregate, and water are all mixed in a mixing chamber and the plastic mass conveyed to the nozzle and ejected by air pressure. In both types of shotcrete, the equipment nozzle is held about 5 ft from the repair surface and in such a position that the shotcrete mortar strikes the surface at a right angle. A discussion of specific shotcrete repairs in representative programs appears at a later point in this report.

CONCRETE REMOVAL AND CLEANING EQUIPMENT

Saws

Tools useful in preparing areas of deteriorated concrete for repair are concrete masonry saws. They are available in either gasoline or electrically-powered models. Some self-propelled models are capable of cutting horizontal surfaces at a rate of up to 10 ft per min with a depth of cut of as much as 6½ in., depending on the hardness of the concrete. Concrete saws usually employ diamond-tipped, circular steel blades for cutting cured, hardened concrete. Abrasive saw blades are often employed in cutting green concrete. Several instances were encountered in this survey where repair crews had employed powered circular hand saws, such as are used by carpenters, equipped with abrasive blades to make cuts in vertical and sloping faces of concrete structures where repairs were required.

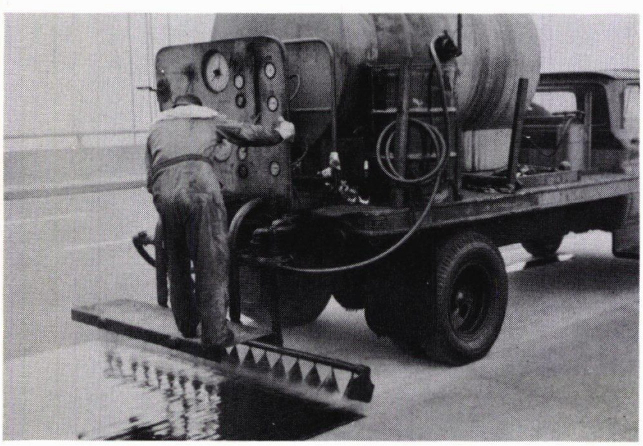


Figure 3. Special distributor unit used for application of two-component epoxy resin compounds.

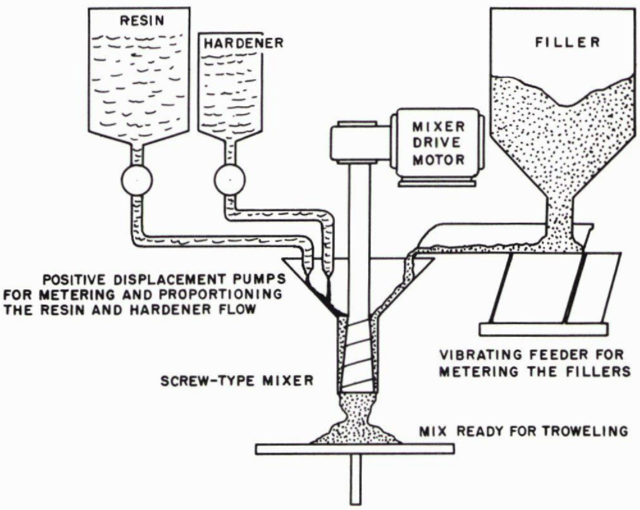


Figure 4. Schematic of continuous-type resinous patching mortar mixer system (11).

Grinding Devices

Grinding devices are used in surfacing and finishing applications on cured concrete. They usually employ an abrasive grinding wheel which can be applied to the concrete surface to remove high spots and other irregularities.

Routing Tools

For shallow routing or scarification of concrete surfaces, equipment is available which employs a hammermill type of unit in which a series of steel cutting knives revolves on a cylindrical shaft to remove a shallow section of concrete on impact. Other units have been devised for use in cleaning cracks and joints in preparation for resealing. One type employs a vertical rotating drill bit that can be moved horizontally along an irregular crack or a joint opening to cut a V-shaped groove in its path.

Pavement Breakers and Pneumatic Hammers

Pavement breakers and pneumatic hammers or chisels are effective working tools for cutting into concrete. Various shapes of blades or chisels are available for use with power tools. Paving breakers range in size from about 35 to 90 lb.

Sandblasting Equipment

Sandblasting equipment is used extensively as a final cleaning and mechanical etching preparation for surfaces to be patched or repaired. A wide range of sizes and types is

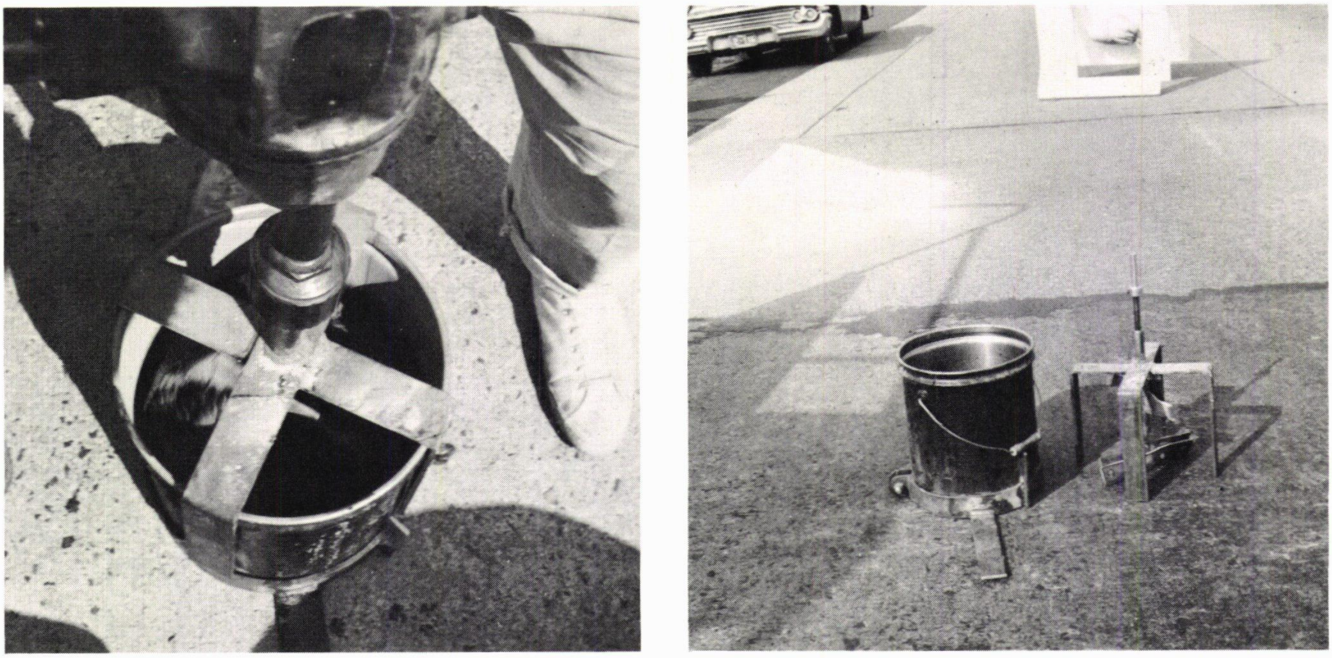


Figure 5. Electric drill-powered mixing apparatus for epoxy mortars, Connecticut State Highway Department.

available. Most manufacturers of shotcrete equipment offer special interchangeable nozzles that permit the equipment to be employed for sandblasting also.

Needle Guns

Another type of mechanical cleaning and etching equipment available on the market is the needle gun. This unit employs a cluster of long slender steel rods or needles mounted in a common holder in such a manner that each needle will reciprocate approximately one-fourth inch independently of the others. Compressed air drives the hardened steel needles against the work surface and the repeated impact cleans and etches the surface. Most of the needle guns permit the needle assembly to be interchanged with conventional chipping hammers, chisels, and other blades.

CONCRETE FORMS

Aside from manufactured forms used in several large-scale programs, forming for concrete repair work was custom made for the projects encountered. A description of several special forms is included in the repair procedure section of this report.

SPECIAL EQUIPMENT

The use of the two-component thermosetting bonding agents and sealants required several special types of equipment for handling. One unit was a truck distributor, similar to a conventional asphalt distributor, but specifically designed to handle the two-component epoxy resin compounds. It has separate tanks and circulating hoses for the two components which are concurrently pumped, each at a metered rate, into the distributor spray bar where they are thoroughly mixed in a mixing chamber immediately before being ejected through the spray nozzles onto the concrete surface (Fig. 3). The mixing chamber and spray bar assembly is readily removable so that it can be quickly placed in a solvent-filled cleaning tank at the completion of the material application run, to prevent the mixed components from hardening and plugging the unit.

Small manual spray units that mix the components while incorporating glass fibers, silica sand, or other inert materials have been developed for use with two-component resins and similar materials.

For mixing of resinous patching mortars, there is equipment that stores the components in separate compartments from which they are fed to a screw-type mixing chamber and ejected in a continuous operation (Fig. 4). Other small batch-type mixers for the two-component materials consist of power-driven mixing paddles that can be fastened into disposable 5-gal drums (Fig. 5).

Several types of mixing nozzles have been developed for mixing two-component joint-sealing material immediately before extrusion from joint-sealing machines. Again, the machines employ separate containers and hose systems for each component with a quickly disengaged mixer chamber and nozzle that can be promptly flushed with solvent at the completion of the work period.

A special unit of equipment developed by the Research Department of the Kansas State Highway Commission (Fig. 6) was being used to explore bridge decks in order to locate areas of concrete deterioration or weakness not indicated by visual inspections. Called the "thumper" by the Kansas engineers, it operates on the same principle by which a concrete surface is sounded with a tapping hammer. The thumper has the advantage of covering a 3-ft wide area and proceeding at the steady rate of a slow walk. The device consists of a series of six wooden hammer blocks mounted side-by-side along an axle fastened between two small-diameter tricycle wheels. Each hammer is alternately raised and dropped by a cam which turns

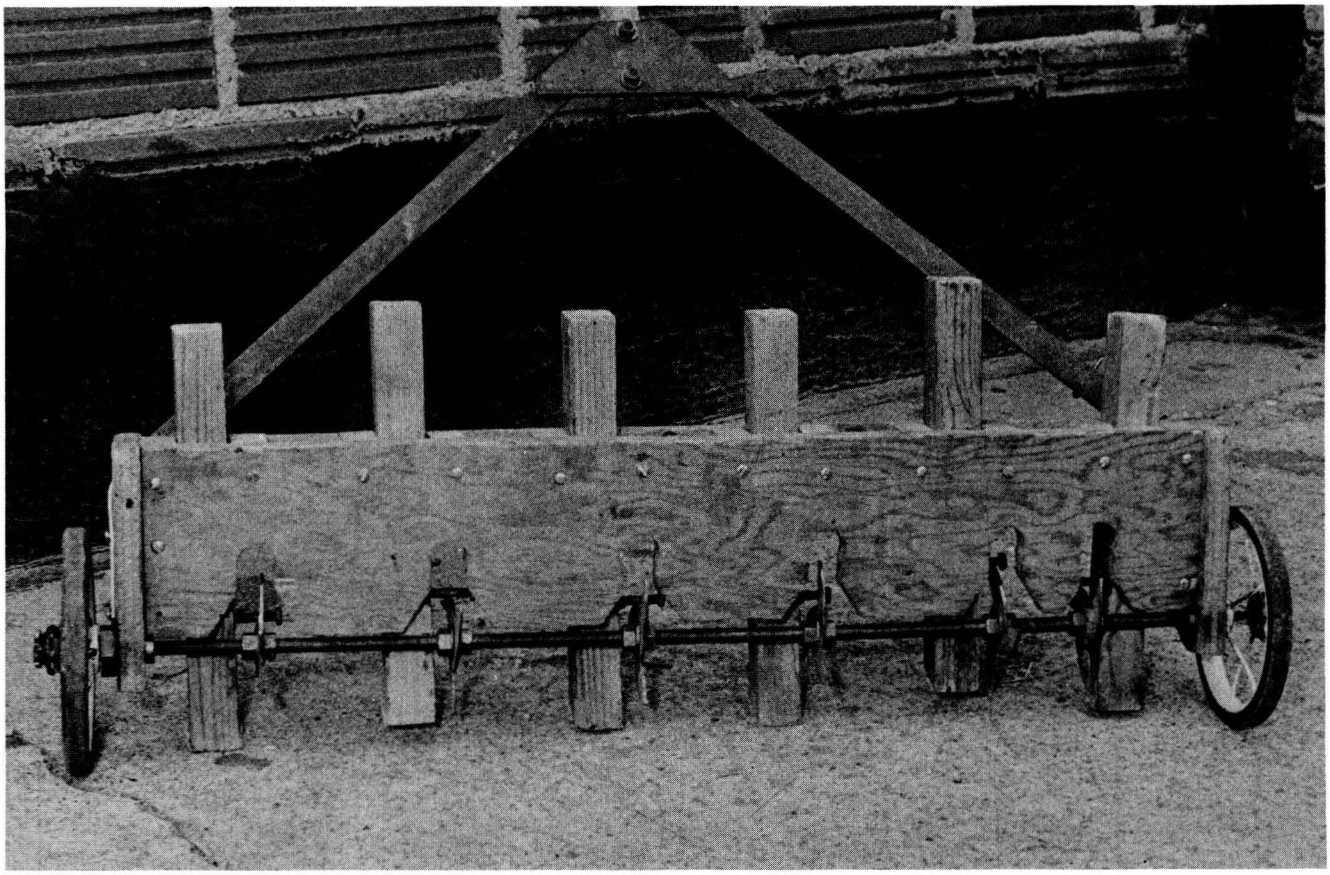


Figure 6. Specially built sounding device to locate unsound concrete on bridge decks, Kansas State Highway Commission.

on the revolving axle of the device. As the device is moved forward the hammers sound the concrete and reveal areas of weakness or failure. The operator or an assistant can readily mark out areas of weakened concrete that can then be inspected more closely by manual sounding with a hammer to outline the area for removal and repair.

CHAPTER FOUR

CONCRETE DECK REPAIR PROCEDURES

PREPARATION OF REPAIR AREA

The determination of the dimensions of the area of unsound concrete to be removed was reported to be one of the most difficult parts of concrete repair projects. At best, this was a step-by-step procedure which at some ultimate point depended on the experience, judgment, and concern of the engineer in charge of the project.

Location of Areas of Unsound Concrete

Location of areas of unsound concrete usually started with a visual inspection of the site. Cracking, scaling, spalling, raveling and other manifestations of weakness frequently were apparent to the inspector. Often, localized areas of discoloration or dampness were indicative of porosity and progressive weakening of the concrete. The appearance of effervescence and leaching stains on the concrete's surface indicated the penetration of moisture and potential, if not actual, disintegration. The brown discoloration and stain caused by reinforcing steel corrosion was often apparent to the inspector.

The lack of such evidence on the top surface was no assurance that disintegration was not under way. An inspection of the underside of concrete bridge decks often revealed evidence of weakness or failure. Where moisture had penetrated the full depth of the deck slab, discoloration and staining were generally apparent. Where the moisture had penetrated the deck over a long period of time, the deposits of calcium and sodium salts and other chemicals frequently formed stalactites along the underface of the structure.

Sounding of the concrete with a metal hammer or other sounding device was a popular and proven method of detecting many weak areas. Where the surface concrete was in some stage of disintegration and had lost its structural integrity, the hammer would strike it with a dull thud rather than the sharp vibrant ring that resulted from striking sound concrete. Where a plane of weakness or failure existed below the surface, a hammer blow would bring a hollow ring readily distinguishable to the inspector.

Removal of Concrete

This study indicated that many repair failures were occasioned by the removal of too little rather than too much concrete. However, complete removal was most effectively done using techniques and equipment that offered the maximum protection to areas of sound concrete on the perimeter of the patch. Where unnecessarily heavy equip-

Figure 7. Final cleaning of patch area on concrete deck after removal of old bituminous surface, Goethals Bridge, Port of New York Authority.

ment was used, it sometimes damaged the surrounding concrete and created additional areas of potential failure. Where partial-depth patching was done on bridge decks, several agencies restricted the weight of air hammers to a 25-lb maximum and gave special instructions to crew members about the use of the equipment to avoid breaking through the underside of the deck or fracturing the concrete below the partial-depth patch area.

To prevent damage to surrounding areas and to prevent loss of bond with the reinforcing steel imbedded in the remaining sound concrete, many programs required the exercise of special care in cleaning out old, unsound concrete around reinforcing steel. Some agencies did not permit air hammers and chisels to vibrate on the reinforcing steel.

For shallow-depth removal (less than ½ in.) or for surface scarification to provide good bond, routing or scarifying tools, such as impact hammers and grinding tools, were employed. For greater depths, removal was generally accomplished with air hammers.

Saw cutting around the perimeter of the patch area to a 1- or 1½-in. depth was a part of many projects and appeared to contribute to the success of the repair in several ways. The saw cut provided a clean, vertical face against which the patching material could be placed for maximum contact and bond, free of feather edges (Fig. 7). A simple technique that provided a slight "keying" action for the patch involved tilting the saw blade (by riding one wheel on a plank) to undercut the edge of the repair area at a slight angle. This helped to lock the patch in place and supplemented the bonding strength along its edge.

For special cases requiring a minimum of vibration and impact to the structural concrete, a removal system was employed whereby the entire area of concrete to be removed was crisscrossed with a series of saw cuts spaced at intervals of 1 in. or less. The saw-cut sections of concrete were then dislodged with a very lightweight chipping hammer requiring a minimum impact to accomplish the removal.

Wetting revealed cracks and breaks in concrete, particularly after the major portion of the unsound concrete was removed from a repair area. A fine spray of moisture applied to the dry surface of the old concrete would quickly evaporate from the sound surfaces but would penetrate and delineate cracks and breaks that remained. The workman doing the final cleaning in the patch area could quickly spot and remove any fragments of concrete that remained locked in place after the major concrete removal by heavy equipment.

Final Preparation of Patch Area

After removal of the unsound concrete, patch areas were thoroughly cleaned and freed of all dust and deposits before placing the repair material. Most areas were cleaned in preliminary fashion by blowing with an air jet from an air compressor or by thoroughly flushing with clean water under pressure. One department (*12*) did not recommend the use of compressed air. The department engineers expressed concern over the fine mist of lubricating oil that might be carried in the air from the compressor and would be deposited on the surface when the air stream struck. To prevent this oil film deposit, the department employs water pressure for final cleaning instead of air (Fig. 8).

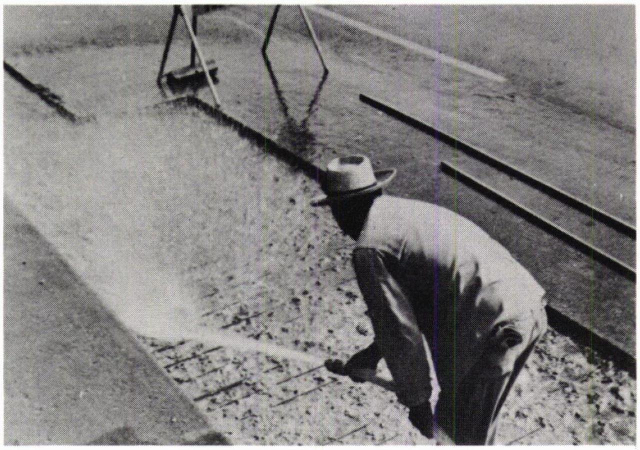


Figure 8. Final cleaning of patch area with water pressure, Rawson-Howell overhead, Wisconsin State Highway Commission.

Where reinforcing steel was exposed by the removal of deteriorated concrete, it was usually thoroughly cleaned before completing the project. Sandblasting or wire brushing was frequently used to remove corrosion and scale.

Improperly positioned or displaced reinforcing steel was repositioned by bending where practical. In other instances it was removed by saw or cutting torch and replaced with new steel in proper position. In such replacement, it was necessary to cut the patch area back sufficiently to allow the existing steel to extend into the patch for a proper length to permit lapping or welding new steel to the old.

In areas where the repair procedure did not require the removal of old concrete and the surface was contaminated with grease, oil or other deposits, most agencies scoured the concrete with strong soap or detergent compounds to lift and flush away the oily deposits. The scouring was followed by thorough flushing with water pressure.

When the surface was not contaminated by oily deposits, etching was used to clean the surface and give it additional roughness. One common form of etching was done with commercial hydrochloric acid (20 deg Baumé scale). The acid was brushed or sprinkled onto wet concrete at a rate of about ½ to 1 gal per 100 sq ft and allowed to remain until all reaction ceased. The residue was then thoroughly flushed from the concrete to be sure that no acid condition remained.

Mechanical etching with needle guns or sandblasting was another method employed. It was desirable to follow this process with a vacuum cleaner, clean air blast or water jet to remove the fine dust and deposits resulting from the process.

FORMING AND SUPPORT

Generally, deck repair work of anything less than a major nature required relatively little forming. Where partial-depth patches were unsupported on one or more vertical faces, forms were provided to support these faces and permit the placing and compacting of the patching material. Where large-scale areas were being repaired on a deck surface, forms were sometimes used to continue existing structural joints through the repair area. Temporary forms provided guide rails for screeding and finishing equipment where large surface areas were mechanically worked.

No special or noteworthy forming techniques for partial-depth patches were encountered in this study. Generally, forming was accomplished with lumber cut to fit the dimensions of the repair area.

For full-depth repairs to bridge decks, the type of forming used varied widely. Where external sections of deck were replaced, reusable metal forms and form ties used for new construction were frequently employed. For internal full-depth patches, where the repair section was completely surrounded by existing concrete deck section, several efficient methods were used for providing the bottom form.

A number of agencies employed systems of blocks and wedges supporting the bottom forms from the lower flanges of the floor beams. The form work was readily removed after the patch had cured, by driving out the wedges and removing the blocks and forming material. Proper oiling and care of the form panels permitted them to be reused for repeated patching operations.

Another system used to support deck form panels employed a hook and rod arrangement for hanging the form supports from the upper flange of the floor beam (Figs. 9-11). The metal rods were removed after the concrete was cured by backing them out of threaded sockets in the "hook" end.

One project (*13*) employed a system whereby the bottom forms of full-depth internal patches were placed without access to the immediate underside of the bridge deck (Fig. 12). Ropes were lowered through the hole in the deck to the ground where they were fastened to vertical steel bolts extending through the form panels. The panel was then pulled up against the underside of the bridge

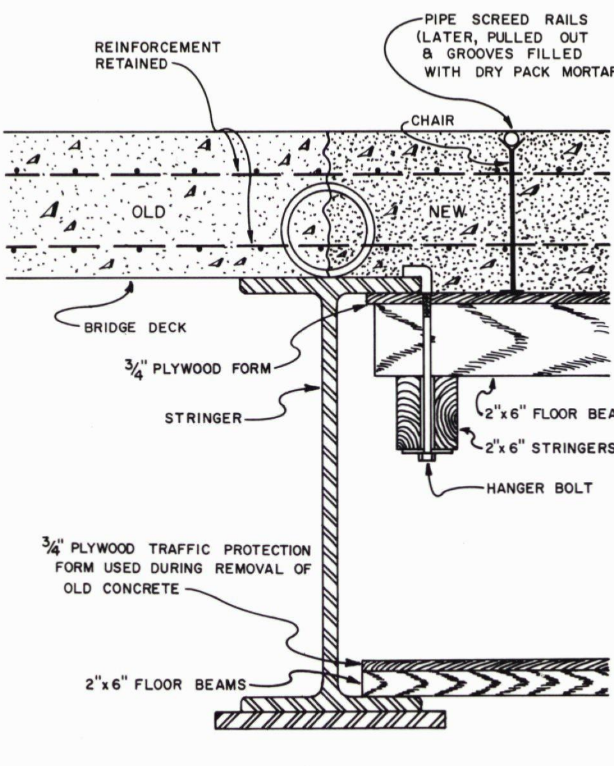


Figure 9. Removable bridge deck forming procedure, New York State Thruway Authority.

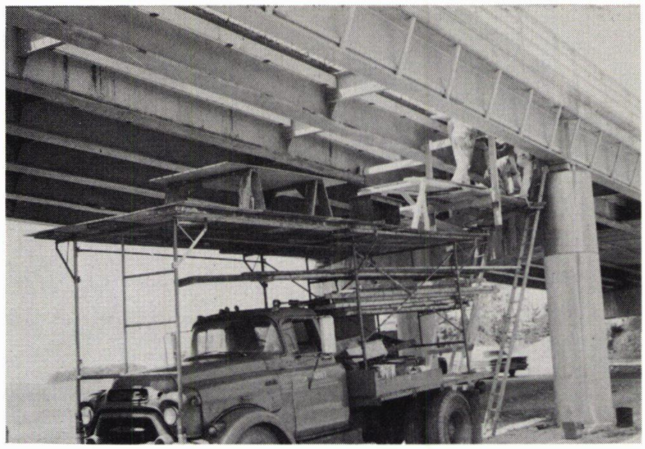


Figure 10. Deck forming for slab replacement, New York Thruway.

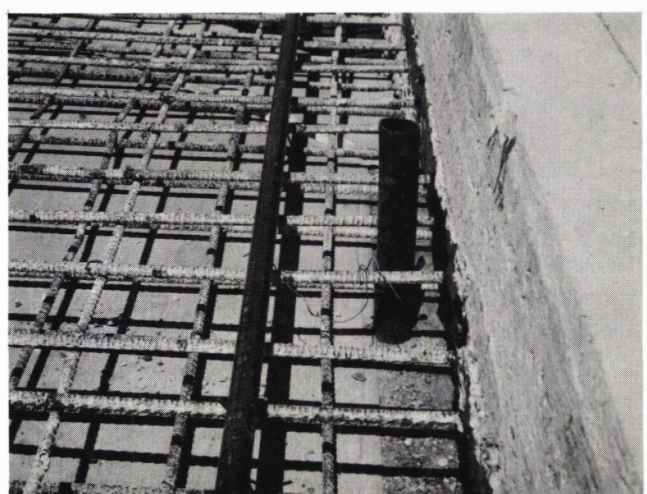


Figure 11. Forming and reinforcing steel in place on structure; vertical pipe provides weep hole in new deck slab, New York Thruway.

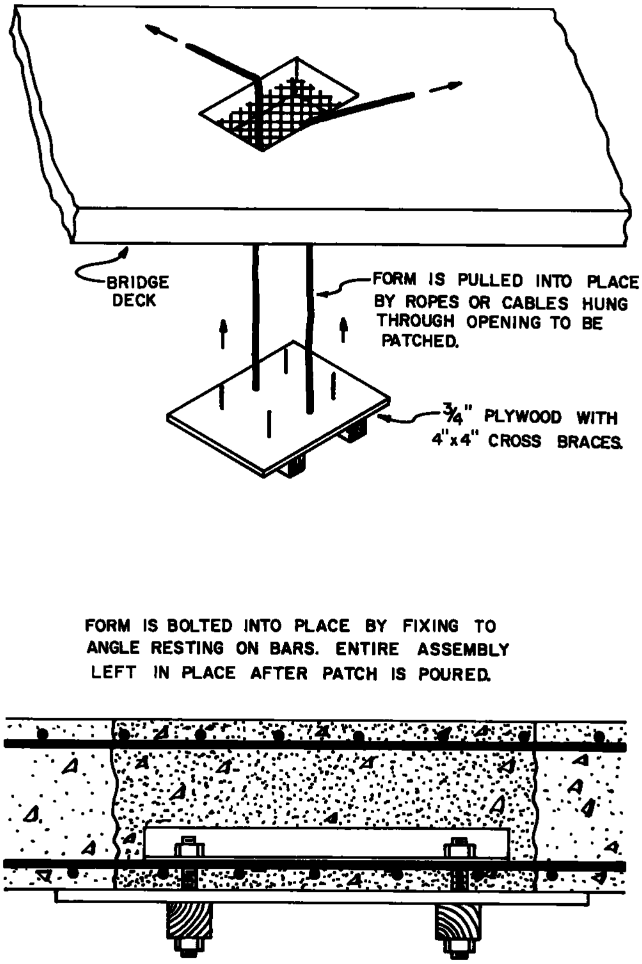


Figure 12. Stay-in-place deck forming procedure used where bridge underface is difficult of access, D.C. Department of Highways and Traffic.

deck from the surface of the deck. When the form panel was in place against the underside of the bridge deck, the bolts were collared with a section of steel angle resting on top of the reinforcing steel and drawn tightly into place by fixing nuts on the threaded bolts. Then the ropes or cables were removed. The angle section and bolts were allowed to remain in place when the new concrete was poured into the repair area. This additional steel was buried in the concrete and became a part of the reinforcing steel network. The form panel was allowed to remain in place on the underside of the bridge deck.

PORTLAND CEMENT CONCRETE PATCHES

Portland cement concrete was the basic patching material used in a majority of the repair programs reviewed in this study. For small, partial-depth deck patches, the so-called "dry-pack" concrete was often used. Conventional construction concrete mixes usually were placed in larger, formed repairs. Portland cement concrete patches were used at least in part by every agency contacted in this study. A number of agencies had no standard repair procedure other than the use of portland cement concrete patching, although, generally, agencies in this category had done and are doing experimental work using other materials and procedures.

Pre-Wetting

There was no consistent practice and no discernible advantage in any one type of pre-wetting of patch areas. Although most agencies provided a damp surface against which to place concrete patches, none permitted standing water in the patch area. The manner of pre-wetting varied from a saturation for several hours in some cases to a moistening immediately before repair in others.

Bonding

A priming or bonding coat was used by most agencies immediately before placing the concrete patching mixture. A common type of bond coat was a grout made of neat cement or sand and cement, usually proportioned 50-50 by volume. The sand and cement used in the grout were of the same gradation and type used in the patching mix and met standard specifications for new construction. The cement or cement and sand was mixed with water to a uniform consistency of thick cream and scrubbed into the existing concrete face with a stiff-bristled brush or broom. The grout coat was applied immediately ahead of the concrete pour so that it did not dry out or set up before the concrete covered it. Most agencies set some nominal time limit, usually 10 min or less, between the placing of the grout coat and the pouring of the concrete.

Synthetic materials have also been employed by a number of agencies as bonding coats. Latex emulsions mixed with portland cement have been used (*14*) as bonding or grout coats. The proportioning of the latex, cement, and water varied according to recommendations of the latex manufacturers. Epoxy resin compounds or polysulfide polymer-epoxy resin blends (*15*) were also used as bond coats, brushed or sprayed onto the cleaned concrete surfaces before placing new concrete patching mixtures. The resins were usually placed immediately before placing the concrete mixtures so that they would not harden before the full patch was completed.

Mix Design

The design of portland cement concrete patching mixtures varied over a wide range. Dry-pack concrete mixes, usually prepared in small batches, consisted of conventional proportioning of cement and aggregate with the addition of the lowest possible amount of water to give proper hydration. A common test for determining the proper water content for dry-pack mixes was made by squeezing a handful of trial mix material in the fist. If the material knitted together into a compact mass while leaving only a light film of moisture on the opened hand, it met the test. Inadequate water resulted in a crumbling condition of the squeezed material; excess water left a noticeable wetness on the hand. Obviously, the dry-pack concrete had to be thoroughly mixed and thoroughly compacted after placement in the patch to achieve proper bond and density.

For conventional concrete, where work was performed by contract and a specification was prepared, the mix design was clearly established and controlled. Where work was performed by force account using maintenance crews, mix design often was done by the crew itself using judg-

TABLE 1
AVERAGE SPECIFIED PORTLAND CEMENT CONTENT IN PATCHING MORTARS

CEMENT (bags/cu yd)	PROJECTS (%)
Less than 6	6
6-7	77
7-9	11
Over 9	6

ment, experience and local materials to determine the final mixture. Both standard and high early strength cements were used in patching mixes. Cement factors were generally in the 6 to 7 bag per cu yd range (Table 1), with slumps of 1 to 3 in. frequently stipulated. Aggregate quality and gradation usually conformed to the agency specifications for new concrete. For very shallow depth patching, maximum aggregate sizes were generally limited to one-half the depth of the patch. In some instances, a standard ½- or ⅜-in. maximum aggregate size was employed for all shallow-depth patching mixtures. There was general agreement on the use of air-entrained concrete in patching mixtures, but the percent of air-entrainment specified varied appreciably (Table 2). Because of the placement and working of the material necessary to make it conform to the patch dimensions, the air content of finished patches was probably somewhat below that specified in the mix design.

TABLE 2
AVERAGE SPECIFIED AIR CONTENT IN PCC PATCHING MORTARS

AIR (%)	PROJECTS (%)
3-6	41
6-9	45
Over 9	14

Admixtures

Admixtures were commonly employed in patching mortars. Calcium chloride or proprietary accelerators (often based on calcium chloride) were used frequently with standard portland cements. Air entrainment was obtained through the employment of air-entraining cements or air-entraining agents. Water reducing and anti-shrinking additives were also employed in many programs. Mix designs were applicable to the full-depth placement of concrete patches except for one recent project where the specification (*16*) called for a 2-in. top course of specially formulated concrete to be placed on the freshly poured lower section of the full-depth repair. The top course included a metallic aggregate to form a dense, non-shrinking topping for the patch.

Placement

Stiff concrete mixtures were placed and consolidated by compaction and/or vibrating equipment. Where mechanized compaction and vibrating equipment were not used, manual tamping and rodding were employed. Patches were usually over-filled so that excess material could be screeded from the top and the patch given a dense uniform surface. The finishing was usually followed by brooming or burlap dragging to provide a skid-resistant finish.

Curing

Curing was frequently accomplished by the application of a membrane curing compound. Pigmented compounds were employed so that the area and completeness of the coverage could be visually controlled.

Vapor barrier covers were also used to provide curing protection for concrete repair projects. Moisture-proof paper and plastic sheets were two common materials. Vapor barriers were placed as promptly as possible without marring the finish of the fresh concrete, and the edges were weighted down.

In a few instances, patches were wet-cured, using wetting blankets such as burlap or quilting. Where wetting blankets were employed, arrangements were made for the patch sites to be checked periodically by workmen to keep the blankets wet. However, a number of sites were inspected where the burlap cover had been permitted to dry. This would appear to be a likely problem unless rigid control is maintained.

Although full-depth slab replacements or repairs were cured at least 3 days, and usually for a full 7-day term, partial-depth patches often were opened to traffic without damage after relatively short curing periods. In 17 percent of the projects for which curing information was available, the patches were opened to traffic after curing periods of only 8 to 24 hours. These short-cured patches were made of high early strength cement or regular cement with accelerators, in very low slump mixes, placed during periods of good curing conditions.

Evaluation and Economics

The acceptance of portland cement concrete patching was based on the relatively low cost of materials, the uncomplicated application procedures, and the general success of this type of patch. Although portland cement concrete repair practices required good standards of workmanship and conscientious adherence to proper preparation and placement, no unusual skill or technique was required to perform highly satisfactory work. Where patches were constructed of sound, air-entrained (5 to 7%) concrete effectively bonded to the original concrete of the deck, the service life expectancy of the repair at least equaled that of the original sound concrete in the structure. Unit costs varied widely depending on the size of the repair project, the complexity and duration of traffic handling, the location in relation to materials and labor crews, the types of equipment employed, the efficiency of the repair crew, and a number of indeterminate factors. Reported costs ranged from $8.90 per sq yd to $54.00 per sq yd, with the weighted average being $23.80 per sq yd of patch.

SYNTHETIC PATCHES

Extensive experimental work with synthetic patching materials was encountered during this study. Almost all agencies had conducted some type of program in which epoxy resin compounds were used. Where the epoxy resin patching materials were adopted for routine repair programs, they were generally used to cope with the problems occasioned by very heavy traffic and limited working time (*17*).

Epoxy Resins

No one standard type of epoxy resin was suitable for all repair programs. Several formulations were available from which to select. The most commonly used materials were either epoxy resin compounds using coal tar pitch and amines, or those with polysulfide polymers and amines. These compounds were formulated to provide resilience and flexible characteristics.

Another important consideration in the formulation of epoxy resin compounds was the coefficient of expansion. In tests made by one agency (*18*), epoxy mortars with aggregate-to-resin ratios varying from 2:1 to 4.6:1 were examined. The coefficients of expansion of the epoxy mortars varied between 3 to 5 times that of portland cement concrete. The larger amounts of aggregate reduced the thermal coefficient of expansion but produced relatively dry mixes which could result in poor adhesion to the underlying concrete surface and in porous, low-density mortars.

In the foregoing tests, one type of formulation, an epoxy-amine-tar compound, demonstrated good plastic flow or stress-relaxation characteristics at low temperatures. This formulation was subsequently specified by the agency for epoxy mortars used in cold climates.

For patching mortars, mixtures of flexibilized epoxy resin and silica sand, usually meeting specifications for concrete sand, were proportioned at a rate of about 4 parts sand to 1 part epoxy resin. The components of the epoxy resin were thoroughly mixed for several minutes before the sand was added, and the entire mixture thoroughly blended for several more minutes. Because of the heat reaction released by the epoxy resins and the thermosetting qualities, relatively small batches of the mortar were usually prepared so that they could be incorporated in the patch quickly without danger of setting before use.

Some epoxy patching mortars were prepared with conventional concrete mixers, but several agencies used the special mixing systems described in Chapter 3. A 5-gal drum was usually adequate for single batches of mortar employed in the patching programs. Mixing equipment had to be cleaned promptly after emptying the batch. Special solvents (*19*) were employed for cleaning mixing drums and finishing tools before the epoxy resin had cured. After curing, it could not be removed and might necessitate abandoning contaminated tools and equipment. Since the materials were toxic, work crews wore protective clothing, rubber gloves and face masks to avoid skin contact.

In applying epoxy resin patching mortars, a bonding coat of the epoxy resin binder was thoroughly brushed into the face of the old concrete before placing the mortar. The bonding coat was applied immediately before the mortar so that it was tacky when the patching material was placed. The use of solvents to reduce the viscosity of the epoxy compound was not permitted in patching operations, because the solvents are volatile and must be allowed to escape before placing the patching mortar. If solvents are trapped below the surface of a repair, they could prevent the proper curing and hardening of the epoxy resin and bonding of the patch.

Epoxy resin mortars were placed and struck off to the elevation of the surrounding material in much the same fashion as portland cement concrete mortars (Fig. 13). Proper gradation of aggregate in the mix design and compaction of the epoxy mortar was desirable to obtain maximum density. Hand tampers, rods or vibrating compactors were used for this purpose. In addition to increasing the durability of the patching mortar, density had an important bearing on the amount of moisture which could penetrate to the old concrete face and cause further disintegration.

One department performed experimental work with epoxy resin patching mortars that indicated a definite relationship between mortar density and service life. Cores were taken of various patches and subjected to freeze-thaw cycles. The cores with 7 to 14 percent voids withstood 75 cycles of freezing-thawing in very good condition, whereas cores with 15 to 19 percent voids were in fair condition, and cores with voids of 20 percent or more were in poor condition on completion of the test (*20*).

Epoxy resin patching mortars required no special protection for curing other than protection against traffic. At 70°F most epoxy resin formulations cured within a period of 4 hours. Where ambient temperatures were somewhat lower than 70°F or other conditions required an accelerated curing rate, heat was applied to the patch. One user (*21*) employed a steel channel section inverted over the patch area with heat applied to the steel by an acetylene torch. Another agency (*20*) used kerosene torches to heat the air above epoxy resin patches. Direct application of flames to the patch could not be made without burning the binder and destroying its effectiveness.

Evaluation and Economics of Resinous Mortars

Determination of the economic feasibility of synthetic patches required special study of each case. When using an epoxy resin patch, the preparation of the area was as exacting as that needed for most other types of repair materials. The warm, dry weather conditions required for epoxy resin patching placed a limitation on its use as did the short pot life and small batch volume. Special care was also necessary in the proportioning and blending of the components of the epoxy resin compound and in thoroughly proportioning and mixing them with the aggregate. The toxicity of the material and cleaning solvents required extra caution.

The cost of the epoxy resin binders is quite high and necessitates their being used with great care and discretion. However, because epoxy resin patches require a short curing time and only a brief interruption of traffic, the overall cost of the patching operation may not exceed, in special cases, that of comparable programs in which conventional materials and extended curing times are used. Dense, well-bonded epoxy resin patches appear to offer good service over a number of years and to meet an important need in critical locations. Unit costs for epoxy mortar partial-depth deck patches as recorded in this

Figure 13. Finishing epoxy mortar deck patch, Goethals Bridge, Port of New York Authority.

study ranged from $4.50 to $8.00 per sq ft with a weighted average of $6.50 per sq ft of patch.

Latex-Modified Cement Concrete Patches

Although no standard program has been adopted for their use, a number of agencies had performed experimental repair projects using latex-modified portland cement concrete mortars. These were used according to the preparation and application procedures stipulated by various latex manufacturers.

Surface preparation of the patch conformed to previously described procedures. All unsound concrete was removed, and in no case was the patch placed to less than ½-in. thickness. Thorough wetting of the old concrete surface was assured by saturating it for 24 hours before application of the patch and keeping it damp but without puddles during the repair operation.

One frequently used mortar mix design included 3½ gal of latex, 282 lb of dry sand, one bag of regular portland cement, and sufficient water to make a firm but workable mortar consistency. An anti-foam additive (*22*) was combined with the latex at the rate of 2 qt per 55 gal drum of latex, and 1 qt of diethylene glycol was added to the mortar during the mixing process. Air-entraining cement was not used and mixing time was a maximum of five minutes.

To provide a bond coat, a portion of the latex mortar was scrubbed onto the wet repair surface with a stiff broom immediately before placing the mortar. The mortar was placed, leveled and struck-off with a screed. A second screed bar was operated 3 to 15 ft behind the first. Because the mortar formed a surface skin or film very quickly after placement, it was necessary to keep finishing to a minimum to avoid tearing the surface.

As soon as the latex mortar had cured sufficiently, a damp burlap cover was placed over the repair area and kept damp for at least 24 hours. At the end of the second day, the burlap cover was removed and the repair area allowed to air cure for an additional three days before opening to traffic. One latex manufacturer reported (*23*) that an initial wet cure followed by an air-dry cure gave maximum strength. The manufacturer also advised that the latex modified portland cement mortar lost some strength on complete wetting but regained it after drying.

Evaluation and Economics of Latex Mortars

When considering the costs and other economic factors involved in the use of latex-modified portland cement mortar, no conclusive data were available because the work was of a recent, experimental nature. For the projects in this inspection, costs ranged between $5.00 and $20.00 per sq yd for shallow depth (½ to ¾ in.) repairs. The special surface preparation and careful workmanship required for placement offer no advantage over more conventional materials. Curing time and traffic protection requirements are no less than those for portland cement mortars.

Expected service life was not fully determined. A majority of the experimental projects inspected in this study showed some evidence of failure or impending failure. It appeared that most of the repairs failed to maintain a sound bond. In one case (*24*), tests revealed air contents in the latex mortars ranging between 25 and 33 percent. On this project, portions of the surface of the latex mortar patch were sealed with a liquid epoxy resin over which an emery and flint abrasive was broadcast for skid resistance. The sealed latex mortar areas were in much better condition than the unsealed surfaces which were failing in bond and spalling badly after two years.

SHOTCRETE DECK PATCHES

A technique, developed and employed in several recent bridge repair programs, used shotcrete rather than conventionally placed concrete to repair the horizontal surfaces of bridge decks. Preparation procedures for repair areas were the same as those required for standard portland cement concrete patches. Shotcrete was applied to a damp concrete surface with or without a bonding coat. One agency (*25*) used a bonding coat of a polyvinyl acetate compound mixed one-to-one with water brushed onto the surface no more than 10 minutes before placing the concrete.

Type I, II or III portland cement was used in pneumatically applied mortar with a washed silica sand, proportioned at one part cement to about three parts sand. Where wet-mix equipment was used, an additive was placed in the mortar to entrain air at specified rates between 5 and 8 percent.

Pneumatically applied mortar was built up to an elevation exceeding that of the surrounding area so that it could be struck off to the level of the adjacent surface and screeded and finished to conform to the plane and texture of the deck.

This technique was employed by another agency (*26*) in the repair of a concrete deck after which the surface was sealed with a tar-modified epoxy resin membrane and covered with a bituminous wearing course.

Evaluation and Economics of Shotcrete Patches

Consideration of the economics of the shotcrete repair method must take into account the need for special equipment and skilled workmen in order to perform the work satisfactorily. Given such equipment and workmen, pneumatically applied mortar can be placed quickly and with a minimum of hand labor. It can result in a dense, sound patch but requires careful screeding and some manual finishing for an acceptable riding surface. No conclusive data on service life were revealed by this study because of the recent nature of the projects observed. Dense patches can be obtained, but air entrainment in any significant degree is not likely using the dry-mix process.

Unit costs for pneumatically applied deck patches varied depending on the preparation of the area, quantity of material, traffic control problems and local influences on material costs, labor costs, equipment rates, etc. Work encountered in this study averaged about $7.00 per sq yd with a reported high of $57.00 per sq yd for pneumatically applied, horizontal, partial-depth patches in place.

BITUMINOUS PATCHES

Both hot-mix and cold-mix bituminous concrete were used as temporary pothole patching materials on bridge decks as well as roadway sections by some of the agencies surveyed. The quality of the materials and workmanship varied over such a wide range that no discernible pattern was established.

Although the initial cost of materials and application of bituminous concrete patches was relatively low, the short service life and potential lack of protection to the adjacent concrete surfaces because of permeability was usually recognized in the selection of this material. This study indicated that most bituminous patching of portland cement concrete bridge decks was confined to temporary patches during periods when permanent patching with other materials appeared to be impractical or unsuccessful.

PROTECTION OF REPAIRED SURFACES

In a significant number of the bridge deck repairs studied, a part of the replacement of the deteriorated concrete was the use of one or more materials for waterproofing and protection of the area. These protective systems included the application of penetrating sealants, such as linseed oil or light bitumens, waterproof wearing surfaces, and more elaborate layered systems of waterproofing membranes with separate wearing surfaces. Where membranes were used, several agencies installed weep holes through the deck or curb to outlet moisture impounded between the membrane and wearing surface.

Coal Tar Pitch Emulsions

Coal tar pitch emulsions were employed by a number of agencies for the purpose of waterproofing repaired concrete deck surfaces. The manufacturers recommended that the surface be thoroughly cleaned by acid etching, sandblasting, or scouring with detergents, to provide an uncontaminated, textured surface to which to bond. Although some agencies followed this practice, others had developed apparently successful programs using a very nominal cleaning procedure by air-blowing when no serious contamination was apparent.

A priming coat, consisting of a volatile oil carrying acidic coal tar in solution, was sprayed at a rate of approximately 0.01 to 0.015 gal per sq yd to produce a light brown fog coat. The primer was used to neutralize the concrete surface and to provide a bond for the membrane film formed by the emulsion.

The coal tar pitch emulsion was applied either alone or as a sand slurry (Fig. 14). Where sand was incorporated in the emulsion, it was thoroughly mixed in a mixing drum and agitated until application so that the sand was retained in suspension. Typical proportioning of the sand slurry was three parts of emulsion mixed with two parts of sand by volume. The fine aggregate specified by one authority (*28*) was a sharp, angular, uncrushed natural silica sand with nothing retained on the No. 6 sieve and 100 percent retained on the No. 20 sieve.

Figure 14. Applying coal tar pitch emulsion membrane to repaired deck, Bayonne Bridge, Port of New York Authority.

The emulsion was usually poured on the surface and distributed with squeegees dragged across the face of the deck in long, transverse overlapping strokes. Application rates usually were not less than 0.5 gal of slurry per square yard. To provide a textured surface for skid resistance or for bonding of additional layers of surfacing material, the wet emulsion or emulsion-sand slurry was covered with fine aggregate broadcast immediately after spreading. Sand application rates averaged about 4 lb per sq yd. Sand was broadcast by hand or by sandblast machines operated without nozzles under low pressure.

Several agencies had developed specifications for waterproofing membranes of coal tar pitch emulsion reinforced with woven glass fabric. The glass fabric meeting one specification (*29*) had a weight of 1.65 oz per sq yd with a 20 by 20 thread count and a uniform coating compatible with coal tar base compounds. Under the same specification, four applications of emulsion were made, each at the rate of 0.13 to 0.15 gal of undiluted emulsion per square yard of surface. Two layers of glass fabric were placed, the first between the second and third applications of emulsion and the second between the third application and the slurry coat which was the fourth emulsion application. Both layers of glass fabric were placed parallel to the length of the bridge. The fabric was laid loosely into the emulsion while the film was still wet and brushed out to eliminate wrinkles but not to stretch the fabric tight. Adjoining widths of fabric were side lapped by 3 in. End laps were at least 12 in. wide. On the top layer of fabric, the side laps were at least 6 in. wide. The emulsion and fiber glass membrane extended up the faces of curbs a minimum of 2 in. Time was permitted between each emulsion coat for proper curing, and the completed membrane was allowed to cure for at least 24 hours before covering with a bituminous concrete wearing course.

A comparable procedure was adopted by a bridge commission (*30*). The final coat of emulsion was covered with an abrasive coating of natural silica sand applied at a rate of approximately 0.7 to 1.0 lb per sq yd, before addition of the wearing course (Fig. 15).

A waterproofing system followed in an extensive deck rehabilitation program on a toll road (*31*) called for the application of a primer and coal tar pitch emulsion-sand slurry to the repaired concrete deck surface, the application of a 1½-in. asphaltic concrete wearing course over the entire deck, and the sealing of the asphaltic concrete wearing course with a coal tar pitch emulsion slurry (applied without a primer) within one year after the asphaltic wearing course was placed. The emulsion-sand slurry was proportioned with two parts of sand to three parts of emulsion. For the seal coat, additional sand was broadcast onto the fresh emulsion, using a low-pressure sandblast application.

Epoxy Resins

Epoxy resin compounds were used extensively on experimental programs and to some degree in standard programs adopted for repaired bridge deck surfaces, both in the

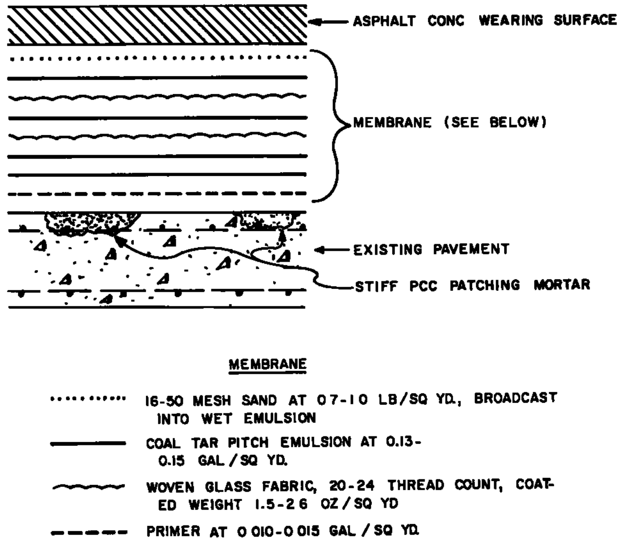


Figure 15. "Exploded" section of membrane waterproofing and separate wearing course installed on repaired deck of Lake Champlain Bridge, Crown Point, N.Y.

form of waterproofing membranes and as waterproofing wearing surfaces. An apparatus used to test the adhesion of epoxy resins is shown in Figure 16. The repaired deck surface was thoroughly cleaned in preparation for the application of epoxy resins. In addition to removal of oils, greases and other foreign material by scouring with detergents and flushing, surfaces were etched with muriatic acid or cleaned by sandblasting to provide a sound textured face for bonding the compound.

For relatively small areas, application of epoxy membranes was often made by hand. After the two components were thoroughly blended, the material was poured on the surface and spread by hand squeegees (Fig. 17). An alternative for small areas was the use of special hand-spray equipment designed to keep the two components in separate tanks and blend them at a mixing nozzle immediately before ejection in the form of a spray. For larger areas of treatment, the specially designed tank distributor discussed in Chapter 3 was employed by a number of agencies.

One state (*32*) developed a technique whereby the repair area was laid out in panels and the epoxy applied to the surface with squeegees and hand brooms, one panel at a time. This provided reasonably good control over the rate of application with clear-cut limits within which to complete the application of the material and the cover aggregate before moving to another location. Another department (*33*) employed long-handled paint rollers to spread an epoxy resin skin coat on a bridge repair surface.

Several formulations of epoxy resin compounds were used in membrane seals, including both polysulfide-epoxy systems and the epoxy-tar-amine systems. The epoxy-tar-amine materials were used predominately. These compounds are described in Chapter 2.

To provide a mechanical bond where the epoxy resin coating was to be covered by a wearing course, and to provide a skid resistant surface where the epoxy resin acted as a surface course, cover aggregate was usually broadcast onto the fresh material immediately after it was spread. Cover aggregates used were silica sand or aluminum oxide grits. The aluminum oxide provided excellent wearing qualities where the epoxy resin served as a surface course. The aggregates also provided a skid-resistant texture. The application of the cover aggregate was made in a sufficient quantity to guarantee an excess of material which would not imbed itself in the epoxy membrane. After the epoxy resin had cured, the excess material was removed by brooming or air blast.

The distribution of the cover aggregate varied widely in procedure. Most agencies, for want of a suitable mechanical device, broadcast the cover aggregate over the wet surface by hand. The aggregate had to be deposited in a nearly vertical path in order not to form waves or ripples that would be retained in the cured surface. Sandblasters were seldom used because the rate of application of material by the sandblaster was inadequate to provide the excess material needed for a large area.

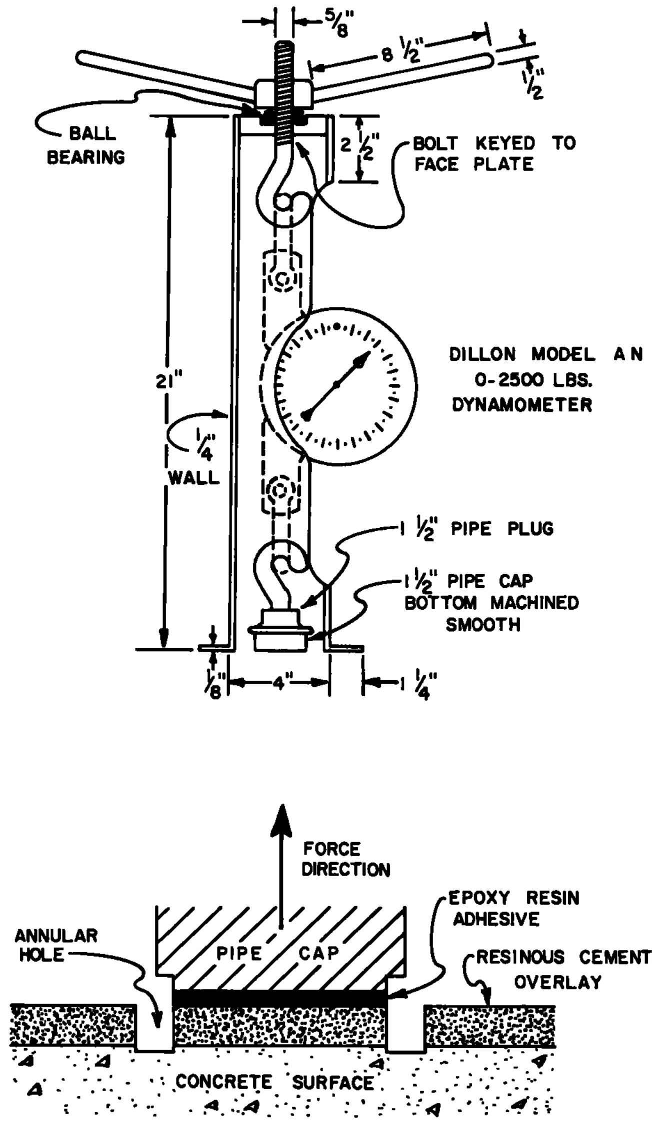


Figure 16. Apparatus for testing adhesion of resinous cement overlay, or cohesion of overlay or portland cement surface.

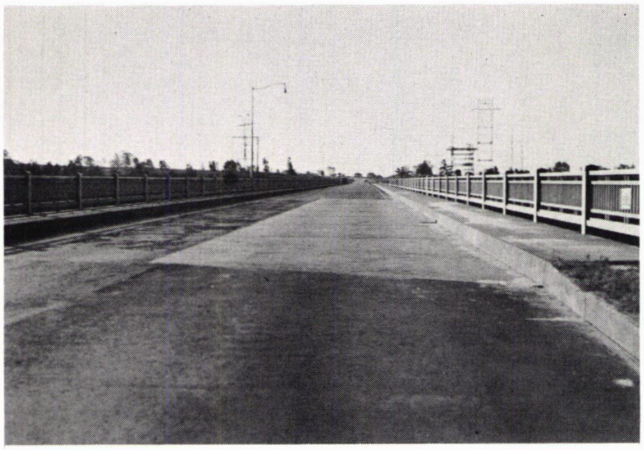


Figure 17. Epoxy resin surface seal over epoxy-mortar patched deck, Rt. 12, Chippewa River Bridge, Wisconsin State Highway Commission.

The size and shape of the aggregate, the rate of application, and the manner in which the cover aggregate was applied to the epoxy resin course, appeared to affect the integrity of the resulting waterproofing membrane. In a report on the surface treatment of a bridge for a county highway department (*35*), the epoxy manufacturer found that pinholing occurred in the surface treatment due to the capillary action of the epoxy resin binder when excess amounts of certain surface aggregates were used. The company suggested six alternate methods of partially or completely eliminating pinholing: (1) Use of finer aggregate, (2) application of a second coat of epoxy resin, (3) application of a carefully predetermined quantity of aggregate which would result in no excess, (4) addition of a siliceous thickener, (5) use of thicker layers of liquid binder, and (6) delayed application of the aggregate so that the curing of the epoxy resin would begin before the aggregate was distributed, but would not progress so far as to prevent proper imbedment of the aggregate. The company recommended an aluminum oxide aggregate with a mesh size of 12 to 30 or 14 to 24 and an epoxy binder rate of 2.5 lb per sq yd for the prevention of pinholes. Rounded, rather than angular, aggregates also appear to assist in preventing pinholes, according to recent investigations by this manufacturer.

Polyester Resins

Polyester resins have also been recently employed for surface treatment of repaired decks in much the same manner as epoxy resins (Fig. 18). One state (*36*) developed a specification for a polyester resin reinforced with 10 percent by weight of chopped glass fibers. The coating was applied by a special spray unit. The equipment was designed so that the glass fiber and polyester resin, premixed and stored in a separate container, were conveyed to a mixing nozzle where the catalyst was added and mixed to form a uniform material. The polyester was placed in two courses, the second course containing a fine aggregate of crystallized silica in the form of quartz in the amount of 60 percent by weight of the total mix. The aggregate was incorporated at the nozzle at the time of spraying with special application equipment. The first course of polyester resin was applied at a minimum thickness of ⅛ in. and the surface rolled with hand rollers immediately after application to smooth out surface irregularities resulting from the application. The first course was allowed to cure for a minimum of 24 hours before application of the second coat. The second course was applied to a thickness of approximately ¼ in.

A turnpike authority (*37*) used a sprayed polyester resin wearing surface over a resinous primer on a concrete bridge deck. The surface was sandblasted and vacuumed clean before application of the primer at a rate of no more than 100 sq ft per gal. The primer was a polyester resin modified with isophthalic acid and a glycol derivative of bisphenol A. The polyester resin was a highly-resilient, low-exotherm resin blended with aggregate at a multihead nozzle under pressure and sprayed on the surface to a thickness of ¼ in. The aggregate, crystallized silica in the form of quartz, was incorporated in the amount of 60 percent by total weight of mix.

Light Surface-Penetrating Sealants

Light surface-penetrating sealants (linseed oil is the most popular) have also been employed as a means of protecting repaired concrete deck surfaces. The typical application called for mixing boiled linseed oil and a petroleum solvent at a 50-50 proportion and applying the mixture to a clean, dry surface in two applications, each at a rate of approximately 0.02 gal per sq yd of concrete surface. Mineral spirits was usually selected as a solvent to provide a low viscosity for penetration and a sufficiently high flash point to be safe to handle. More volatile solvents provide a quicker drying time than mineral spirits but the lower flash point may represent a hazard. The first application was allowed to dry before the second application was made. In times of low humidity and warm temperatures, drying was usually accomplished in less than 4 hours. Immediately after drying, the concrete surface had a mottled appearance. This effect diminished after a few weeks of weathering and was not permanent.

Evaluations and Economics of Protective Coatings

The size of the area to be treated, the use of mechanized application procedures, and the design of the membrane or sealant influenced the cost of protective coatings for concrete deck repairs. Linseed oil penetrating sealants reportedly ranged from $0.08 to $0.12 per sq yd for two

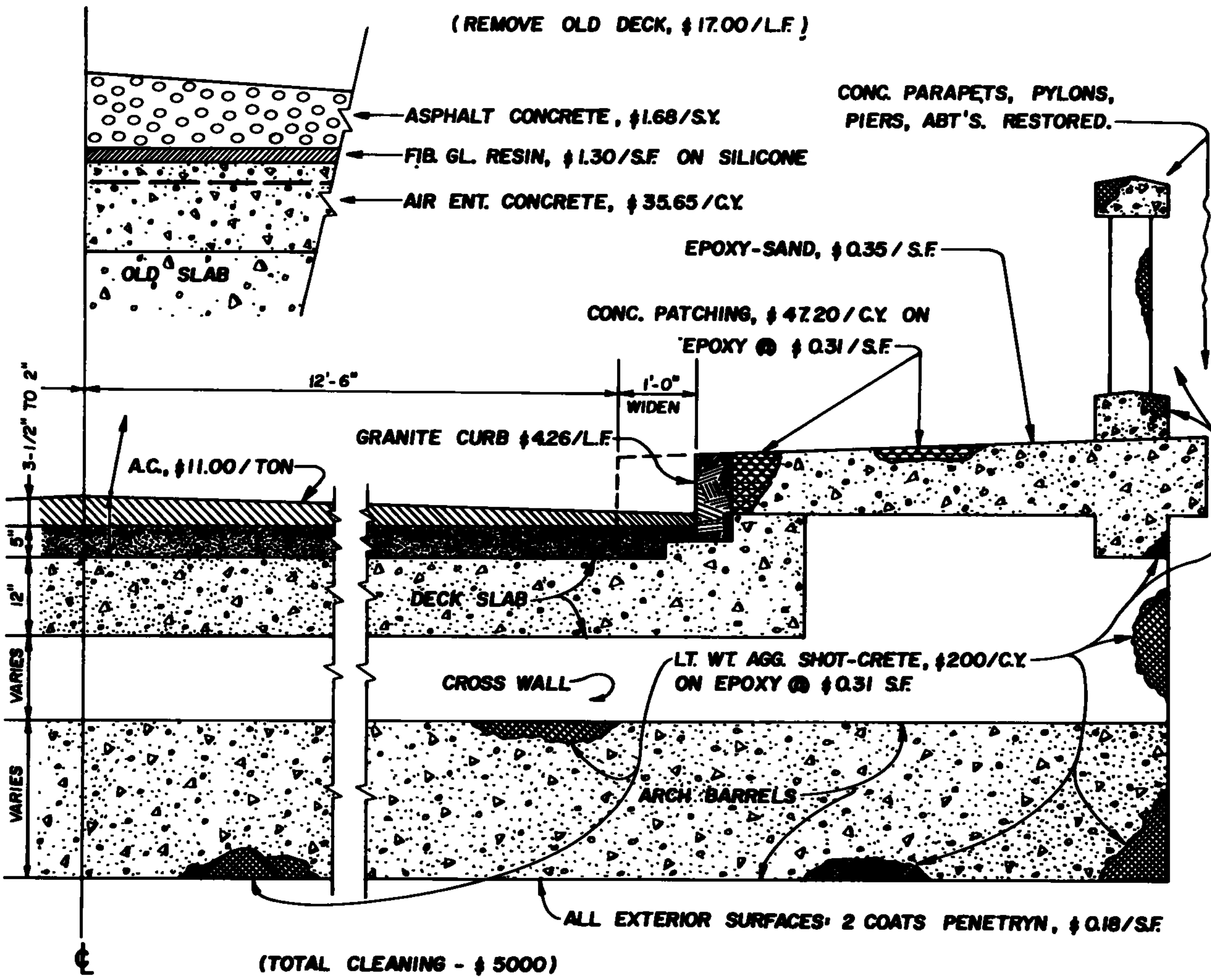


Figure 18. Section of arch structure deck with restoration details and costs, Troy, N.Y.

applications. They were easy to apply, required only a brief interruption of traffic during good drying weather, and were reported to improve the resistance of the concrete surface to the penetration of moisture and freeze-thaw damage.

Coal tar pitch emulsions were reported to cost between \$0.90 and \$1.25 per sq yd depending on the number of applications used in the membrane. The tar emulsions were easy to apply and cured quickly. Although they tended to wear away from the surface under traffic, periodic (annual in most cases) retreatment of the worn areas provided continuing protection at nominal expense.

Where traffic was heavy, the reinforced, layered membrane of coal tar pitch emulsion and fiber glass fabric, placed beneath an asphaltic concrete wearing course, appeared to be an effective means of protecting the concrete slab for an extended period of time.

A two-layer polyester resin reinforced wearing surface was reported to cost \$14.40 per sq yd on one project (*38*) and \$5.20 per sq yd for a single-layer system on another (*37*). The surfaces inspected showed no evidence of wear under traffic during the short periods they had been in service. Some evidence of moisture penetration through pinholes was noted.

Costs of epoxy resin coatings, used either as membranes or surface courses, ranged between \$1.05 per sq yd and \$11.25 per sq yd. An evaluation of these relatively high cost materials in terms of service life was difficult to make as many of the epoxy coatings were of a recent nature. Often preparation or application procedures were of an experimental nature and results varied widely. Some bond failure was apparent in the projects inspected and the problem of pinholing was often noted. Unless the epoxy provides a durable bond of a watertight coating, the investment might not be returned in service rendered. However, effective protection of costly repairs or prevention of further deterioration could represent a savings in concrete repair costs that might offset high protective material costs while permitting uninterruped service to the highway user.

Wearing Courses of Repaired Surfaces

Frequently, repair projects involved removal and restoration of a separate wearing surface of the bridge deck.

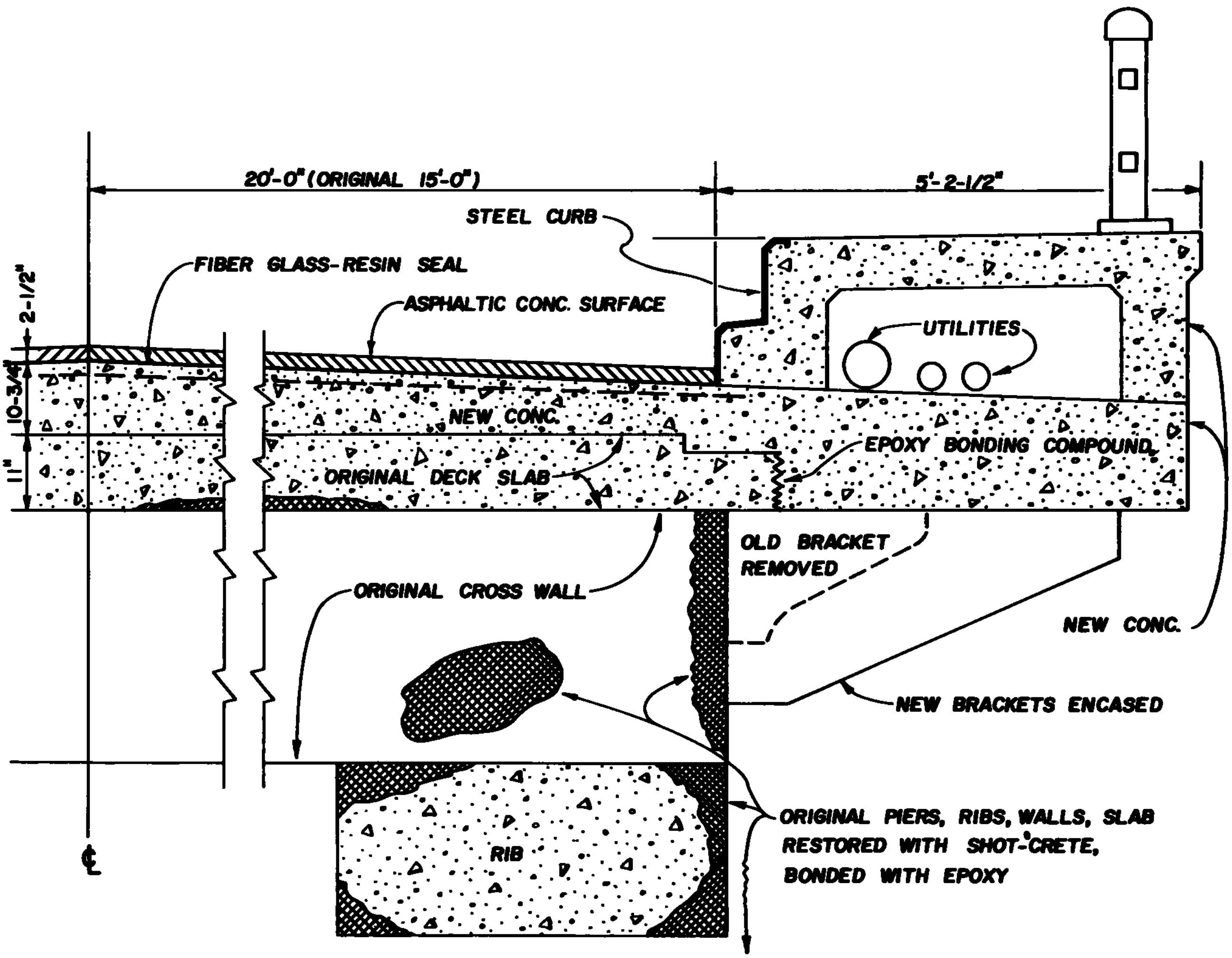


Figure 19. Section of arch structure deck with restoration details, Glens Falls, N.Y.

Bituminous-concrete wearing surfaces were commonly employed for this purpose, usually over a waterproof membrane of the sort previously discussed (Fig. 19). Several agencies developed special bituminous-concrete mix designs utilizing asbestos fibers, neoprene and other synthetic rubber compounds, and other additives to provide low permeability and high stability of the surface course. One toll road (*39*) used a neoprene-modified asphaltic concrete, designed to include Canadian chrysotile asbestos fibers in the amount of 2 percent by weight of the total mix. The binder content (including neoprene) was 8 to 10 percent by weight of the total mix. The Marshall stability value of the mix was set at not less than 1,200 lb and a Marshall flow value between 0.10 and 0.15 in. A major bridge authority (*40*) developed a mix design using 3 percent of asbestos fibers and 9.5 percent of bitumen. Extensive research and testing on such mix designs (*41*), performed by a major producer of asbestos fibers, have indicated that nearly impermeable wearing courses can be obtained without loss of stability or anti-skid properties. An apparatus for measuring the water permeabiltiy of a pavement surface is shown in Figure 20.

An extensive study of the failure of asphaltic concretes made by a research department (*42*) revealed that many such failures were directly attributable to the presence of excessive amounts of water which entered the pavement structure after construction. It was found that the density of the pavement did not necessarily indicate its permeability but rather that permeability was dependent upon the size dimensions of the individual voids and their interconnection. The study indicated that several variables influence the permeability of the pavement during construction and during service life: segregation of the mix during placing, temperature of the mix during rolling, weight of rollers, ambient temperature during placing of the mix, voids content of the compacted mix, and the amount of traffic that passed over the surface prior to the first winter rains. Thin courses of less than 1-in. depth of sand-asphalt mixes were being used by other agencies to provide a dense wearing course with a reduced dead load.

Several agencies made experimental installations of the pigmented polymeric binders in plant-mix surface courses designed and placed in the same manner as asphalt concrete. A heavy prime of the binder was used to provide a tack coat as well as a waterproofing membrane below

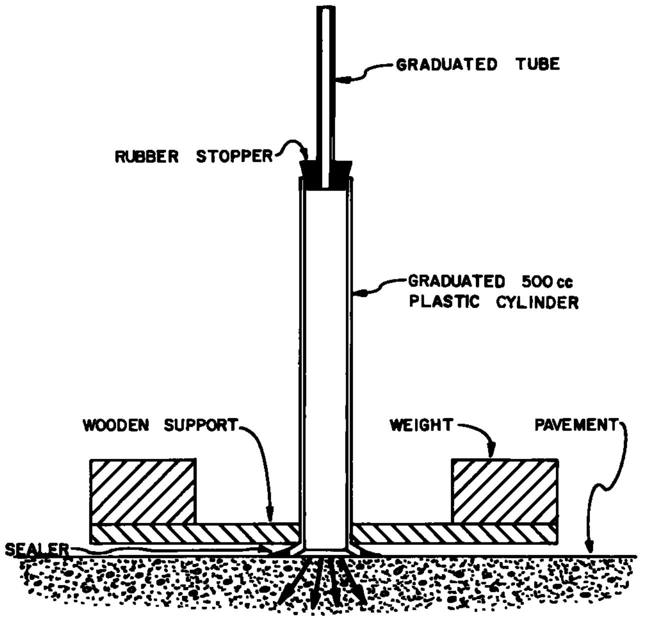


Figure 20. Apparatus developed to measure water permeability of a pavement surface in place (37), based on earlier testing procedures of the California Division of Highways.

the surface of the binder concrete. The tack coat of binder material created a somewhat awkward operation since it was applied in sufficient thickness to "pick-up" on the wheels of the batch trucks. However, this did not appear to handicap the operation. Aggregates were used which substantially matched the color of the pigment used in the binder. If colored aggregate was not employed, the light coating of binder quickly wore off of the surface aggregate and the exposed surface took on the color of the aggregate along with that of the pigmented binder.

Evaluation and Economics of Surface Courses

The costs of asphaltic concrete wearing surfaces and polymeric binder concrete wearing surfaces usually reflected local prices for asphalt paving. Costs for membranes and separate bituminous wearing surfaces ranged from $2.12 to $6.80 per sq yd with a weighted average of the projects studied being $6.36 per sq yd. Where heavy traffic conditions would have caused the rapid wearing of repair work, wearing courses represented an economical alternative to frequent deck repairs. Wearing courses alone did not provide sufficient protection against moisture, however, so waterproofing membranes were an essential part of most successful programs.

CHAPTER FIVE

PIERS, ABUTMENTS AND OTHER COMPONENTS

PREPARATION OF REPAIR AREA

Aside from the problem of accessibility to the repair site of components, the location and removal of deteriorated structural concrete was accomplished in the same manner as that employed on bridge deck surfaces. Pneumatic hammers and chisels were the most common tools used for removal. Some agencies used hand-held power saws with masonry cutting blades to make saw cuts in vertical faces. Generally, however, the perimeter of the patching area was cut with a pneumatic chisel to provide a reasonably clean face against which to bond the new material.

Forming and support of repair material was accomplished using plywood and timber forming members cut to fit the specific job site. On slender columns and piers, some forms were held in place by strapping. Where bracing or straps were not practical, forms were affixed to the sound concrete adjacent to the patch area by fasteners anchored in the concrete. Reusable metal forms were employed for major repairs to special surfaces such as parapets, facias and columns.

Several systems were employed to lift and support deck spans while repairs were being made to bearing pads and pier caps. One method involved lifting and supporting the deck on temporary columns based on the pier foundation (Fig. 21). Another system (Fig. 22) employed a temporary beam positioned across the top of the span, with hanger rods lifting and supporting the deck.

Figure 21. Temporary columns resting on existing footer support deck, New York Thruway.

Where long, shallow repairs were made to vertical faces of abutments or columns, top and intermediate sections of the form were left out to accommodate the placement of the new concrete, after which the forming was completed.

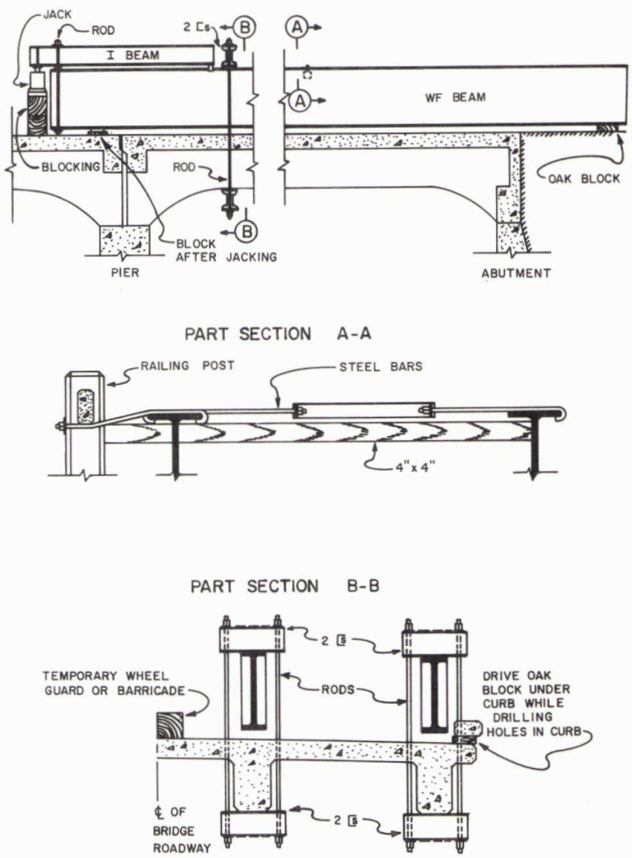


Figure 22. System to lift deck span while making repairs to pier caps or bearing pads, Virginia Department of Highways.

FORMING AND SUPPORT

Bonding coats and concrete mix designs selected for concrete patches on substructure components were the same as those used on bridge deck repairs. Where practical, vertical patches were prepared to such a depth that sections of reinforcing steel were fully exposed to provide a firm anchorage of the new concrete to the old. Where relatively deep patches were made without the advantage of exposed reinforcing steel, light wire mesh was frequently anchored by lag bolts or similar fasteners to the old concrete face to give a mechanical bond for the new concrete. Rodding, where possible, and vibration of the forms were used to consolidate the patching concrete and to prevent honeycombing adjacent to the forms. Forms were left in place during the curing period.

SHOTCRETE REPAIRS

The most widely used method of repair of vertical and overhead faces of structural concrete involved the use of pneumatically placed concrete (Fig. 23). Materials em-

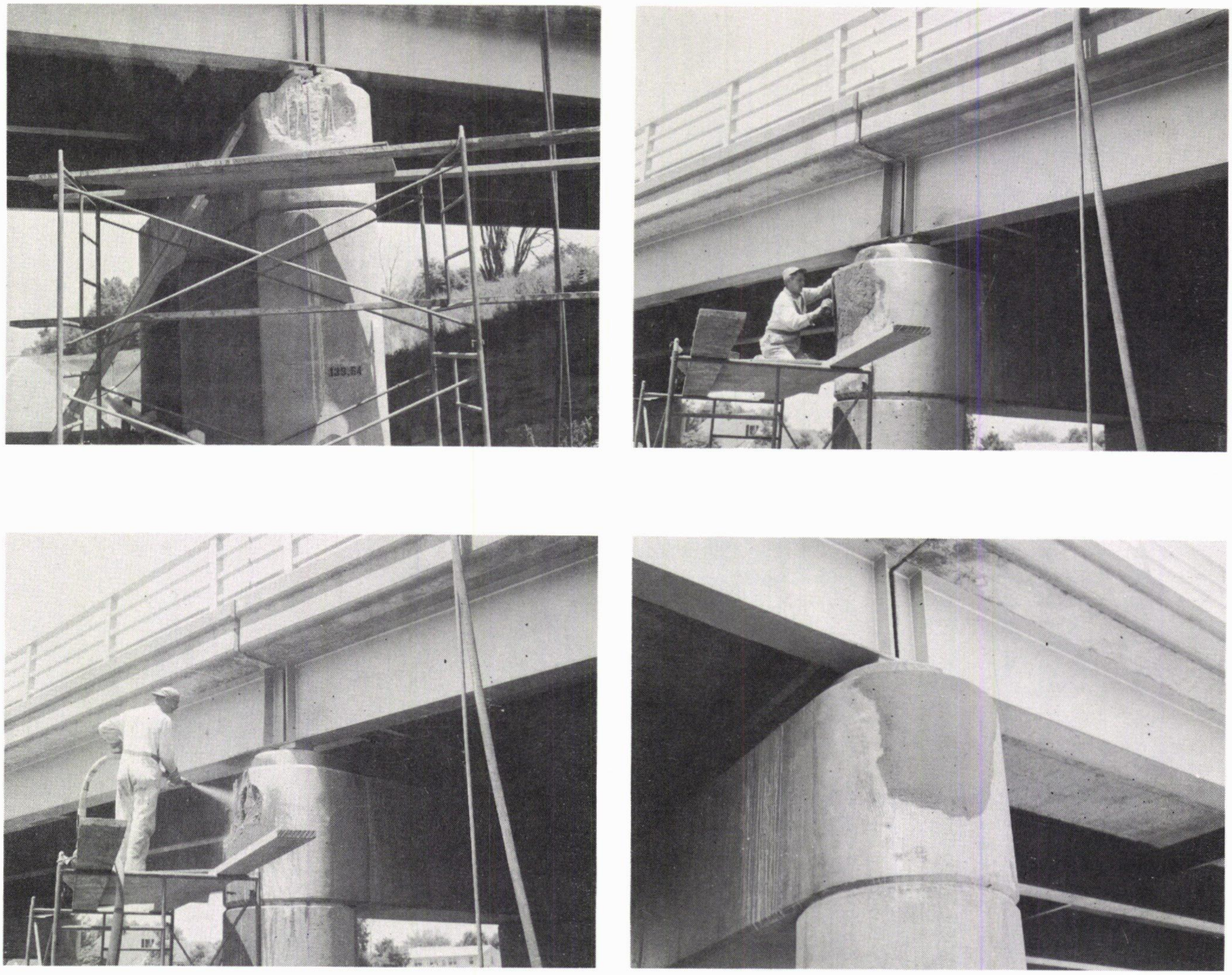


Figure 23. Shotcrete repairs to pier cap, New York Thruway.

ployed in shotcrete mixtures included Types I, II, and III cement and fine aggregate, usually a natural sand with a maximum size of one-quarter to three-eighths inch. Several agencies used additives to improve the workability or hydration of the mix. One authority (*43*) used a wetting agent added to the mixing water at a rate of one part wetting agent to one thousand parts of water. It also used a lightweight aggregate to reduce the dead load of newly placed patches.

Dry Mix

The effectiveness of the dry-mix shotcrete process depended upon close control of the moisture content of the fine aggregate. Most agencies maintained a moisture content between 3 and 5 percent. This range prevented caking of the sand and plugging of the shotcrete equipment while providing sufficient moisture to aid the coating of the aggregate with cement and the rapid hydration of the cement. A completely dry aggregate tended to develop an excessive rebound and poor coating qualities when ejected from the mixing nozzle.

The mixing water in the dry-mix process was added at the nozzle. The sand and cement were premixed and placed in the material bin where they were conveyed to the nozzle and ejected in a pressurized air stream into which was injected a fine spray of water. The sand and cement were wetted as they were carried in the air stream to the repair surface. The equipment operator had to provide adequate water at the nozzle to hydrate the cement and to prevent dusting and blowing of material and, at the same time, to maintain a stiff, dense mortar on the surface of the repair area. In applying the shotcrete, the nozzle was held between 2 and 5 ft from the surface, in such a position that the stream would strike the face at a right angle.

Where the repair face had not been covered with a bonding coat of some sort, the initial shotcrete application caused the sand to rebound while the cement and moisture built up a fine grout coating. As soon as this grout coating developed to a point where the impact of the sand was cushioned, the material began to build up in a uniform mortar layer. The deepest crevices and faces of the repair surface were filled first to prevent rebound material from lodging in them. Where rebound material did rest on the face, it was removed before more shotcrete was applied.

For relatively deep repair sections, the shotcrete was built up in layers and each layer permitted to obtain its initial set before a subsequent layer was placed. One highway department (*44*) specified a maximum layer thickness of ½ to ¾ in., although most agencies permitted thicker layers. Although some equipment manufacturers stated that under well-controlled conditions, with relatively dry shotcrete, layers up to 6 in. thick could be built up on a vertical surface, this study indicated that in general practice layers did not usually exceed 3 in.

Most agencies specified the use of a wire-mesh reinforcement to supplement the bond of the shotcrete to vertical and overhead faces where the patch thickness exceeded 2 in. in depth. In one state (*45*) specifications required the mesh fabric to be securely fastened to the concrete masonry by ¼-in. machine bolts screwed into lead anchors driven into holes drilled in the concrete masonry. The anchor bolts were spaced at 8 in. centers in each direction and set to hold the fabric approximately 2 in. from the surface. Where mesh could be fastened to reinforcing steel, the fastening bolts were not required. Another authority (*31*) stipulated the use of wire-mesh reinforcement for patches with depths exceeding 6 in.

Where the surface was to be finished to an accurate line and elevation, sufficient shotcrete material was applied to permit shaving off the irregular "high" material with a screed or steel trowel to provide a smooth surface. Agencies permitted only a minimum of finishing work in order to avoid possible disturbance of the in-place shotcrete material.

Estimates of the amount of material that rebounded from the surface during the application of the dry-mix shotcrete ranged from 10 to 30 percent. Some agencies caught and reused the rebound sand in later batches of shotcrete but this practice was neither practical nor profitable where the cost of the fine aggregate was nominal. Further, a number of agencies questioned the quality of the shotcrete obtained by this means.

Wet-Mix

In the wet-mix process of pneumatically applied concrete, water was introduced into the material at the mixing chambers. The quantity of water was mechanically controlled by valves or meters. The plastic mixture was then conveyed under air pressure from the mixing chamber to the nozzle and carried in an air stream to the repair face. This process substituted a metered control of the water content for the manual control in the dry-mix process. The wet-mix process eliminated most dusting, blowing and rebound of material. Because the materials were premixed in a mixing drum, additives or air-entraining cement frequently were used to provide air entrainment in the shotcrete. Manufacturers of the shotcrete equipment using the wet-mix process stated that concrete mortars containing up to ¾-in. aggregate size could be used. Application procedures using the wet-mix process were generally the same as those with dry-mix equipment.

One toll road specification (*25*) stated that the wet-mix shotcrete consistency had to be such that it would form a 6-in. cone without slump when blown against a vertical surface. The specification also required an air content of between 5 and 8 percent.

Bonding and Curing

A number of agencies used a bonding coat of synthetic resin to provide bond between the old concrete and the shotcrete repair. One department (*46*) coated the repair faces with an epoxy resin compound immediately before application of the new concrete. Another commission (*25*) used a 1-to-1 solution of latex emulsion and water as a bonding coat brushed onto the surface not more than 10 minutes before applying the shotcrete. A majority of the agencies surveyed, however, applied the shotcrete on a clean, uncoated concrete surface on the assumption that the initial application would deposit a cement grout for bonding purposes. There was no standard condition for the repair surfaces. Some agencies required pre-wetting while others applied the shotcrete to an air-dry surface. Shotcrete surfaces were cured by tying or draping wet burlap on the surface, frequent spraying or wetting of the surface during the curing period, or by the application of curing membranes or other vapor barrier coatings. A number of agencies did not employ any wetting or protection during the curing period.

Evaluation and Economics of Shotcrete Repairs

When compared to other procedures, the economics of shotcrete repairs were directly related to the accessibility of the repair face and the problems that would have been occasioned by forming and pouring concrete instead. Where forming could be done without difficulty, formed concrete repairs appeared to be more economical and were selected by the repair agencies. Where proper preparation of the repair face had been made and where dense, well-bonded shotcrete had been placed and properly cured, the service life of the repair showed promise of equaling that of the adjacent original sound concrete. When applications were made to surfaces which continued to be subjected to excessive moisture or other conditions contributing to the original disintegration the service life of the shotcrete repair was appreciably reduced. Inadequate care in placing and in curing conditions also reduced service life. Numerous shrinkage cracks in repair sections occurred, indicating inadequate curing.

Shotcrete costs, as reported by agencies contacted in this survey, ranged from $200.00 per cu yd to $324.00 per cu yd, depending upon the geographical location, condition, and configuration of the repair area.

PREPACKED AGGREGATE WITH INTRUDED GROUT

A special technique used for massive repairs to retaining walls, abutment faces, columns and other structural concrete, developed and performed by a private company (*47*), found application in some bridge repairs (*48*). The process consisted of the removal of deteriorated concrete and the forming of the sections to be repaired, after which the forms were filled with coarse aggregate and a sand-cement grout was pumped into the voids between the aggregates under pressure.

For thick sections and large masses, the minimum coarse aggregate size was ⅝ in. and for thin sections the minimum coarse aggregate size was ½ in. The coarse aggregate was placed in the form and rodded, vibrated or tamped to provide consolidation. The forms were securely constructed to withstand the pressures of the grout application and to confine it. Special insert fittings were placed in the face of the form at proper levels to permit the intrusion of grout. The coarse aggregate was kept in a moist condition and the face of the old concrete was moistened prior to the intrusion of grout. Grout was pumped into the voids between the coarse aggregate starting at the lowest point so that it could only flow upward and outward. Grouting was continued until the grout appeared in the outlet located at the uppermost point of the cavity. When the cavity was completely filled, as much pressure as the forms would safely hold was then applied to the grout and held for a short time to insure optimum bond between the old concrete and the new.

The intrusion grout consisted of portland cement, a pozzolanic material of low mixing water requirement (*49*), sand (all of which passed the No. 16 sieve and a substantial percentage passed the No. 100 sieve), a patented admixture used to increase the flowability of the mortar (*50*), and sufficient mixing water to produce a fresh grout. The pozzolanic material was reported to replace from 30 to 50 percent of the cement, which otherwise would have been required, and to react with the lime liberated by the cement to form insoluble strength-producing compounds.

The special concrete formed by this process was reported to have a very low shrinkage, about one-sixth of that of pneumatically-applied mortar and one-half of that of conventional concrete. The low shrinkage was assumed to be because the individual pieces of coarse aggregate were in point-to-point contact rather than being separated by a layer of cement grout, as may be the case in conventional concrete. High bond strength between the old concrete and new was reportedly obtained as a result of grout application under pressure. Durability of the material was attributed to the admixture which reacted with the alkalis liberated by the cement in hydration to produce tiny bubbles of hydrogen gas prior to the setting time. This resulted in an "air" entrainment of approximately 4 percent and provided resistance to freeze-thaw cycles in the concrete.

EPOXY RESIN MORTARS

The use of epoxy resins and other synthetic binders in substructure repairs was limited to building up faces, such as pedestals, bearing pads on pier caps and abutments. This limitation arose from the fact that, on vertical faces, epoxy mortars would require the same preparation and forming that would be required for conventional concrete mortars, thus eliminating many of their advantages.

Where such materials were employed, thixotropic agents were often added to improve the stability of the mortar mixture. One state project (*51*) employed epoxy resin mortars for restoration of disintegrated bearing pads under structure beams. Epoxy mortars were also used to spot repair sections of parapets, curbing and sidewalks on structures where their use would eliminate the necessity for forming.

SPECIAL REPAIR USES OF EPOXIES

Epoxy resins were employed for bonding new concrete to old on vertical faces and other substructure components, and for bonding old concrete to old concrete. A technique developed and refined by a western highway department (*52*) involved the use of liquid epoxy resin compounds pumped into cracks or fractures in structural concrete sections to reestablish a bond between the cracked faces. Examples of this procedure involved repair to a concrete bridge parapet, cracked as a result of an accident, and to a traffic divider (Fig. 24). The parapet was straightened and the outside face of the cracks sealed with a polysulfide-epoxy resin compound containing a thixo-

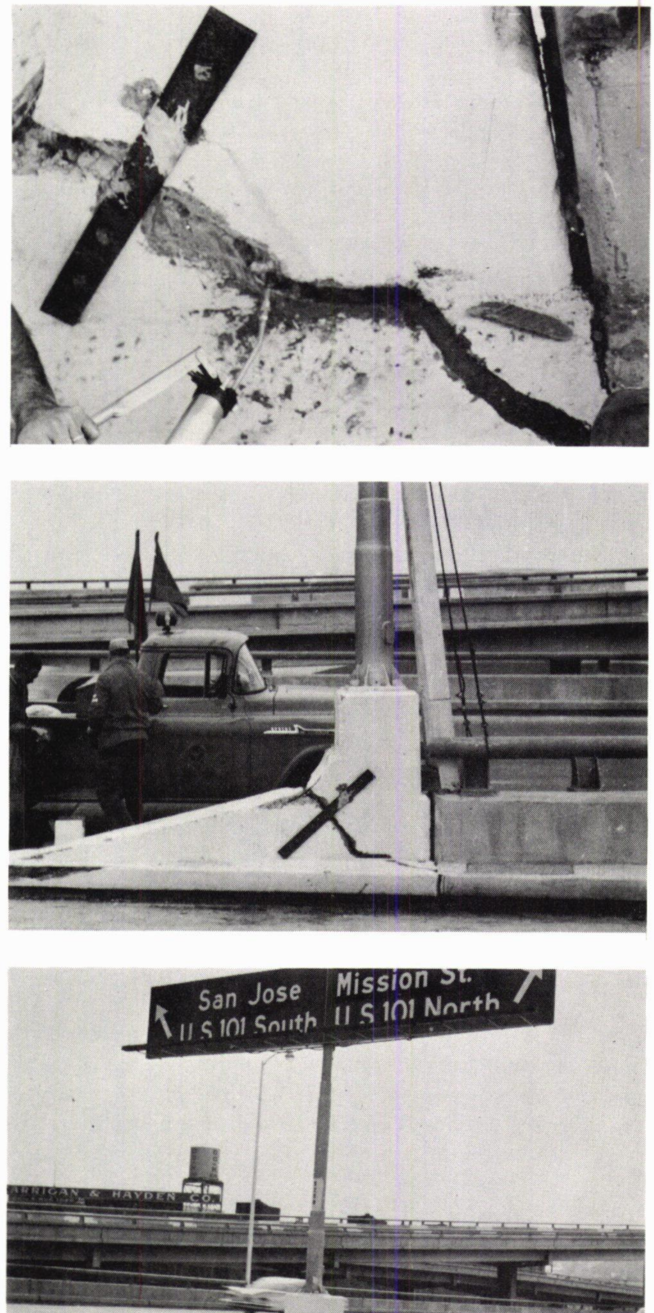


Figure 24. Epoxy grout pumped into crack with grease gun to bond broken faces of median barrier, Bayshore viaduct, San Francisco, Calif.

tropic agent to retain the resin later forced into the crack through special pipe fittings placed at intervals in the crack. Through these fittings epoxy resin was pumped into the crack under pressure, starting at the lowest point, by means of a gun such as is used for applying lubricants to automotive bearings and joints.

SEALING AND PROTECTIVE COATINGS

As a part of the repair program followed in restoring deteriorated concrete on substructures, many agencies employed some type of sealant or protective coating to close hairline cracks and pores and to prevent the penetration of moisture and further disintegration. One department adopted a standard treatment for pier cap surfaces after repairs were made, coating the surface with a heavy black asphalt-based mastic (*53*). The material, which is spread to a thickness of ¼ in. or greater, remains pliable in the normal temperature ranges experienced in that area.

On one turnpike, maintenance crews coated repaired pier caps with a grout of waterproofing cement painted on the surface with a stiff brush (*54*). Another authority developed a special coating for repaired pier caps (*55*). The coating, formulated by maintenance personnel, was applied by paint rollers at a rate of approximately 250 sq ft per gal. The cost per gallon was about $2.00 and one coat was reported to provide protection for about 2 years. Epoxy resins were also used as sealing compounds for pier caps and abutment seats. Where the epoxies were applied to such locations, skid proof aggregates were added to the uncured surface to provide traction in the event that workmen might have to stand on the coated areas at a later date.

CHAPTER SIX

REPAIRING AND SEALING STRUCTURE JOINTS

EXPANSION DAMS

As is the case with many joints in concrete pavement slabs, both fixed and expansion joints in concrete bridge deck sections often create maintenance problems. One common type of repair encountered as a part of this study was that required at open expansion joints where the end dams were loosened and rattled under traffic. The typical design of these dams included some type of T-section or angle section which provided a vertical steel face over the major portion of the end of the slab and a horizontal lip at the surface of the slab, thus encasing the upper corner of the end section. The end dams were usually anchored to the concrete slab with some type of deformed bars welded to the inside face of the dam and extending into the concrete slab for 10 in. or more. Under the pounding of traffic, or as a result of the action of moisture and chemicals, these dams became loosened and eventually caused spalling and disintegration of the adjacent concrete.

A common procedure followed in repairing loosened expansion dams was removal of the end portion of the concrete deck section, repositioning and sometimes supplementing the anchor bars on the expansion dam, and repouring the end section of concrete (Fig. 25). The deck section was removed full depth and reformed along the bottom face before placing new concrete. Where this type of correction was employed, conventional concrete mortar patching procedures were used. Epoxy resin compounds were used frequently as bonding coats between the old concrete and the new, but there were no instances in which an epoxy resin mortar was employed for the patch section itself on these full-depth end-section replacements.

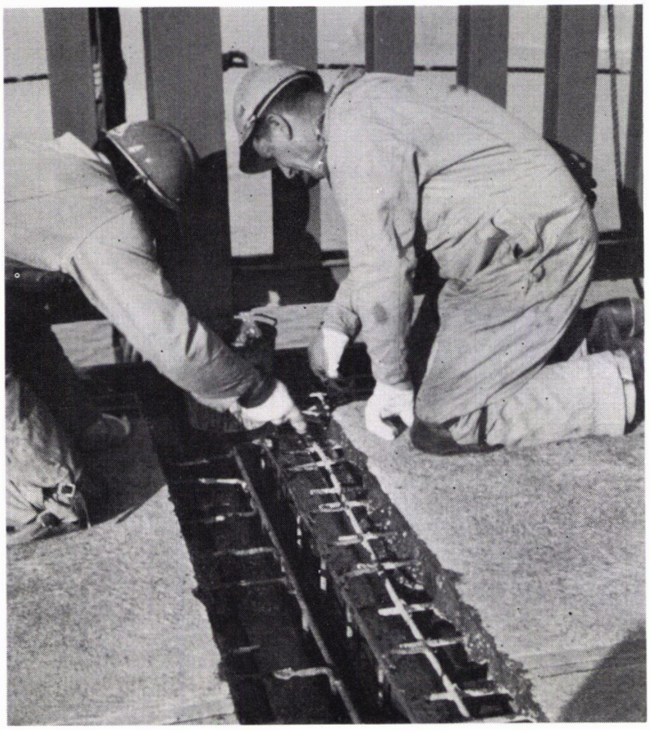


Figure 25. Painting patch area with epoxy bond coat before repouring concrete deck joint, Golden Gate Bridge, San Francisco, Calif.

The expansion dam was usually cut in half at the centerline of the roadway and one lane repaired while the adjacent lane remained open to traffic. After the repaired lane was cured, traffic was diverted to that lane and the alternate lane repaired. This procedure was also followed on multiple-lane structures.

Several techniques permitted the reestablishment of a sound fastening of the expansion dam without removal of the concrete deck section, eliminating the extensive work and traffic handling which such removal required.

One toll road commission (*27*) restored loosened expansion dams by breaking away old concrete down to the upper layer of reinforcing steel in rectangular sections about 8 by 12 in. at 18-in. intervals across the full width of the roadway section or that portion where the dam was loose and rattling (Fig. 26). These rectangular sections, immediately adjacent to the end of the horizontal face of the expansion dam, were first outlined with a 1 in. deep concrete saw cut and then chiseled out with an air hammer. In the top flange of the loose expansion dam, at the end of each rectangular opening, a slot was cut with an acetylene torch to receive the end of a flat steel strap about ¼ in. thick, 1 in. wide and 12 in. long. The steel strap was bent in a Z-shape so that one end could be fitted into the slot in the expansion dam and the other end rest on top of the exposed reinforcing steel. The strap was arc welded to the expansion dam after being fitted into the slot, and welded to the reinforcing steel bars at the other end. The 8- by 12-in. rectangular opening in the concrete deck section was thoroughly cleaned, sandblasted, blown free of all foreign matter, and painted with

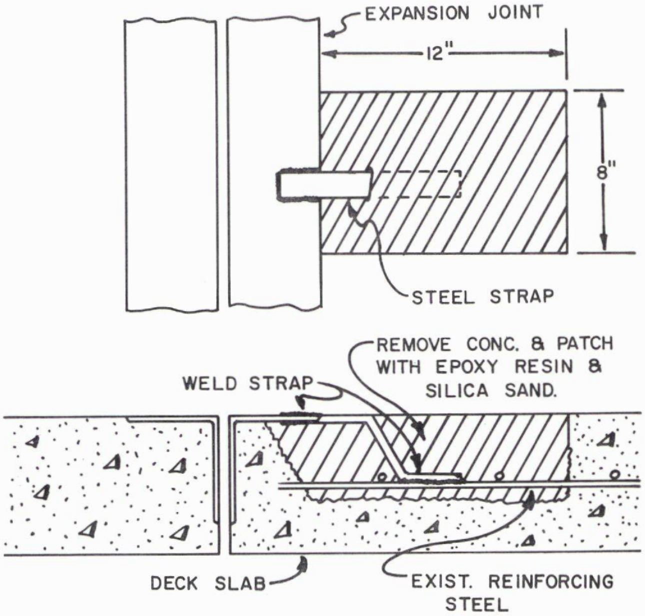


Figure 26. Method of repairing loosened expansion dam, Illinois State Toll Highway Commission.

an epoxy resin bond coat immediately before placing and compacting an epoxy-sand mortar. The mortar was permitted to cure for 4 or 5 hours and then the section was opened to traffic.

Another toll road commission (*56*) developed a system for refastening steel expansion dams by burning a hole through the horizontal flange of the dam and drilling a 1¼-in. hole through the concrete deck slab below the burned hole (Fig. 27). The holes were burned and drilled

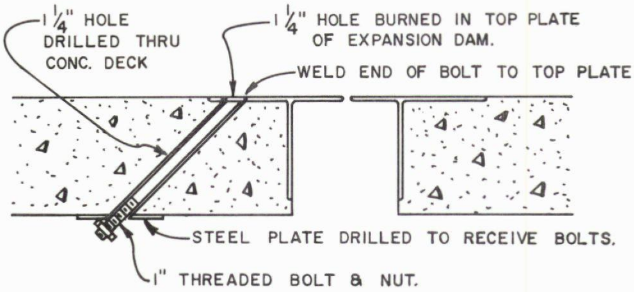


Figure 27. Method of repairing loosened expansion dam, Indiana Toll Road Commission.

at 2-ft intervals across the width of the roadway section on a 45° angle with the horizontal plane of the deck so that they ran parallel to the centerline of the structure and sloped away from the dam. One-inch threaded rods were placed in the holes and welded to the surrounding dam at the surface. The rods were of sufficient length to extend through the bottom side of the concrete deck slab. A steel plate with 1¼-in. holes positioned to receive each bolt was placed against the underface of the deck section, over the steel bolts, and the bolts fitted with nuts which were tightened to draw the bolt and, in turn, the dam, down securely against the concrete deck section. The bolts were trimmed off flush with the deck surface and allowed to remain in place.

A western highway department (*21*) employed an epoxy resin grout to reestablish the bond of loosened expansion dams. The horizontal flange of the expansion dam steel was drilled and tapped at 2-ft intervals across the width of the roadway section. Threaded grease fittings, similar to those used for lubrication points on automotive equipment, were inserted into these holes. Epoxy resin compounds were pumped into the underface of the expansion dam under pressure by lubrication pump guns placed over the grease fittings. The epoxy resin permeated the existing crevices and voids in those areas and rebonded the expansion dams to the concrete. Because the thin film of epoxy adjacent to the relatively cool concrete deck and steel expansion plate would require an extended curing time under normal atmospheric conditions, heat was used to accelerate the cure of the bonding material. A steel box section was inserted over the expansion dam and heat applied from an acetylene torch to the top of the section.

APPROACH SLAB EXPANSION JOINTS

Although not a part of the structure proper, rebuilding or addition of expansion joints at approach slabs was frequently included as a basic part of bridge repair programs. Numerous instances were encountered where the need for bridge repairs resulted in part from compressive stresses exerted on the structure by the adjacent pavement sections (Fig. 28). The phenomenon of pavement movement or

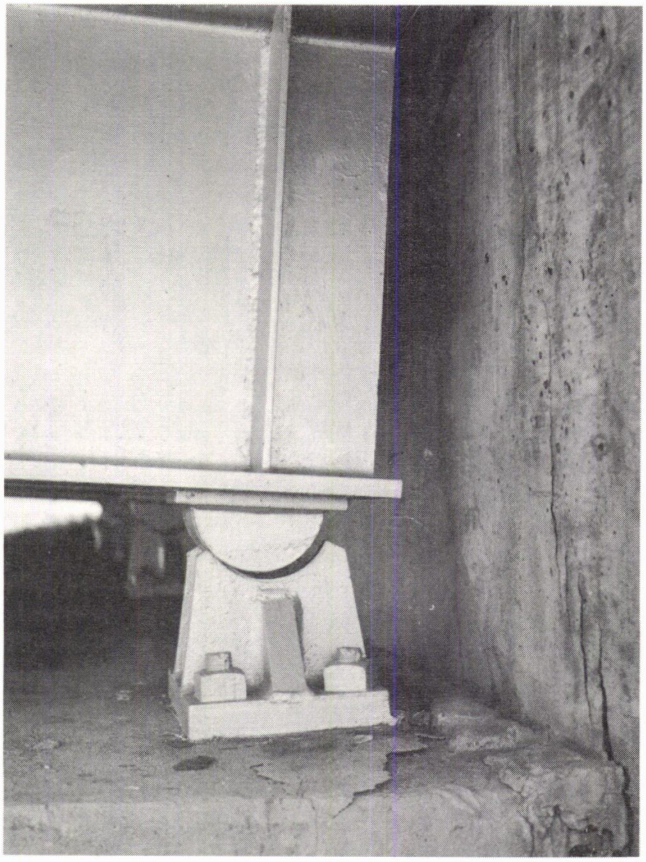


Figure 28. Bearing pad dislodged and rocker displaced by pressure against structure from growth or creep of approach pavements.

"growth" is beyond the scope of this study, but the release of resultant stresses on the structure is important to successful bridge repair programs.

Although most design standards provided for one or more expansion joints adjacent to structures, many agencies found these original expansion joints inadequate to cope with the encroachment of the approach slabs. One state (*57*), which had undertaken a program of installing supplementary expansion joints in adjacent concrete pavements, used joints 5 in. wide. They were formed by saw cutting and removing a full-depth section of concrete pavement at the end of the approach slab away from the structure. These 5-in. expansion joints were then filled with asphalt-impregnated fiber boards. No load transfer arrangement was provided.

Another agency (*56*) developed a system whereby new expansion joints were constructed at the site of the contraction joint nearest to the structure. This system involved the conversion of a contraction joint to an expansion joint by sawing and removing a 1½-in. section of the concrete slab full depth and full width (Fig. 29). The load transfer dowel bars in the existing contraction joint remained

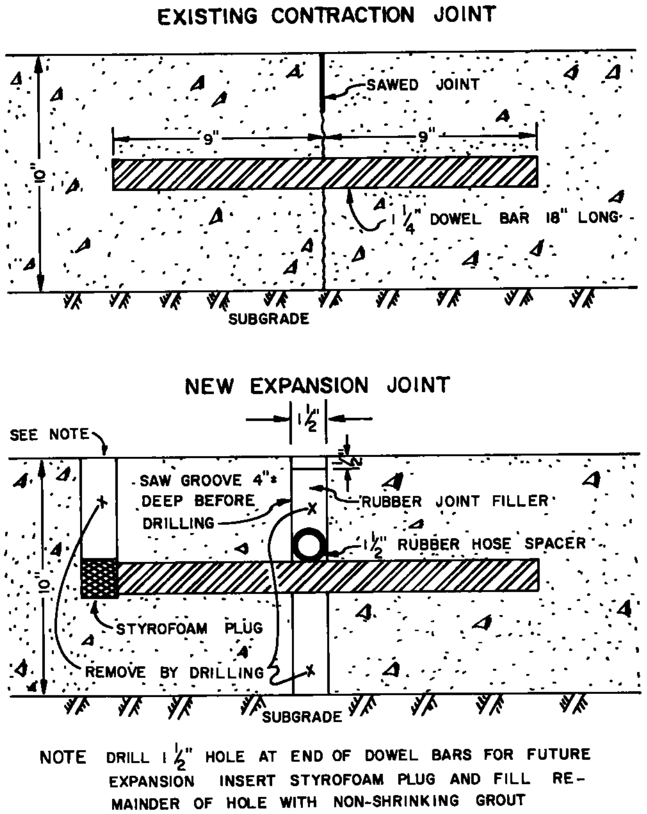


Figure 29. Conversion of contraction joints to expansion joints, Indiana Toll Road.

in place and the concrete was removed around them. To permit movement of the dowel bars in the reconstructed joint, holes were drilled at alternate ends of the dowel bars using a 1½-in. concrete drill. The holes were drilled to the depth of the bottom edge and a compressible plug was placed at the bottom of the hole. The section of the hole above the plug was then refilled using a non-shrinking concrete grout. To seal the 1½-in. expansion joint, a rubber hose section was placed in the newly formed opening to act as a spacer and a stop for the joint filler material. The hose was forced into the joint until it rested on top of the dowel bars and the opening above the hose was filled with a rubberized asphalt joint filler.

A southern highway department (*58*) installed expansion joints in existing concrete roadway pavements by cutting and removing 10-ft sections of the pavement full depth and full width of the roadway (Fig. 30). Below these openings, the subgrade material was excavated to a depth of 8 in. and a reinforced concrete slab poured at this lower elevation. This slab extended under the edges of the existing slab by approximately 3 in. at both ends and was separated from the existing slab by three layers of building paper to prevent bonding. When this subslab had been cured, the top was painted with a coating of asphalt and the existing roadway slab was replaced by 12-in. sections of portland cement concrete bonded to the vertical faces of the old slab and extending over the subslab into the opening for 12-in. full depth and then angled at 30° on a taper from top to bottom. The remaining 8 ft of opening over the subslab and wedge sections were filled with bituminous concrete. The asphalt paint on top of the subslab prevented bonding of the new portland cement concrete slab to the subslab while the 8-ft section of bituminous concrete provided a compressible material to absorb any slab movement resulting from creep or growth of the adjoining roadway pavement.

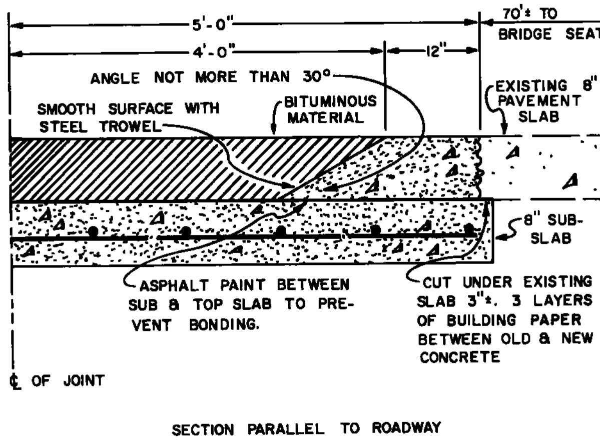


Figure 30. Design of supplemental expansion joints at structure approaches, Virginia Department of Highways.

SEALING JOINTS AND CRACKS

Joints

The effective sealing of structure joints required a material capable of withstanding wide variations in temperature while maintaining elasticity, adhesion and cohesion, and with sufficient body to prevent the admission of dirt, stones and other foreign material. These requirements were not fully satisfied by any of the materials or procedures revealed through this study.

The success of any sealing program was first dependent upon providing a sound, clean surface against which to place the sealing material. Where existing joints were being resealed, routing out old material with plows, wire brushes or cutting tools was necessary. Thorough removal of old sealing material from the face of the joint was considered important if a good bond was to be obtained.

One of the more common types of joint sealants used was a blend of natural rubber and blown asphalt. Typical specifications called for a rubber content of about 15 percent. Both hot- and cold-poured blends were applied, usually with joint sealing machines which extruded the sealant under pressure from a manually controlled sealing nozzle. A number of two-component synthetic sealants also were employed. Polysulfide polymer sealants were used by a number of agencies.

One authority (*59*) coated the concrete faces of cleaned joints with a compatible priming material, and a packing material, such as neoprene foam or polyurethane foam, was installed. The packing material was positioned so that the thickness (depth) of the polysulfide joint sealer which followed would be equal to half the width of the joint but not less than ½ in. A bond breaker, such as polyethylene tape, wax paper, aluminum foil, masking tape or building paper, was used to separate the packing material from the polysulfide joint material.

Another type of joint sealer used on an experimental

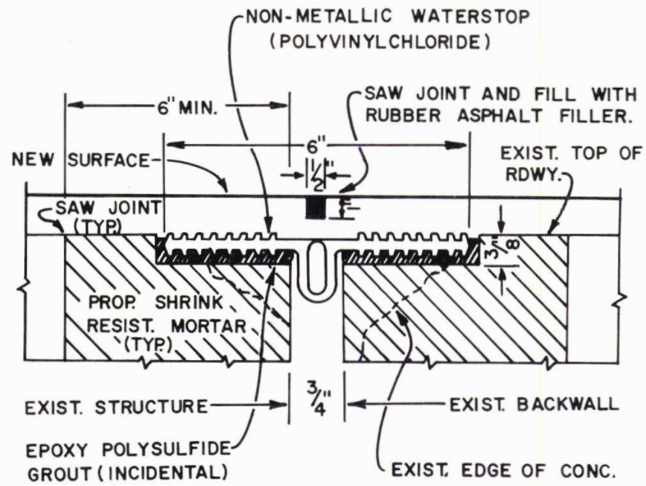


Figure 31. Cross-section of a nonmetallic waterstop installation as a part of a deck resurfacing project, Michigan State Highway Department.

basis by several agencies was a premolded neoprene extrusion. Before installing, the walls of the joint were thoroughly cleaned and primed with a special priming liquid that acted as a lubricant when inserting the neoprene joint sealant. The sealant was forced into the joint under compression and had to remain under compression throughout the expansion and contraction cycle in order to provide proper service. The uniformity of the width of the joint critically affected the serviceability of the sealant. Where the joint faces were irregular and the width of the joints varied, some extruded sections were loosened by the whipping action of traffic and lifted from the joint during periods of minimum compression.

The use of metallic waterstops was encountered infrequently in this study. Where waterstops had been installed as a part of original construction, they were usually replaced as a part of a joint repair project.

A new polyvinylchloride waterstop seated in an epoxy polysulfide grout was installed on one bridge repair project (*60*) to span a joint beneath a bituminous resurfacing (Fig. 31).

To avoid the problem of providing and maintaining an effective joint seal, a number of agencies have converted sealer joints to open joints and have provided for handling the water in gutters and downspouts, drip ledges, or with protective coatings over the exposed surfaces (Figs. 32 and 33) beneath the joint.

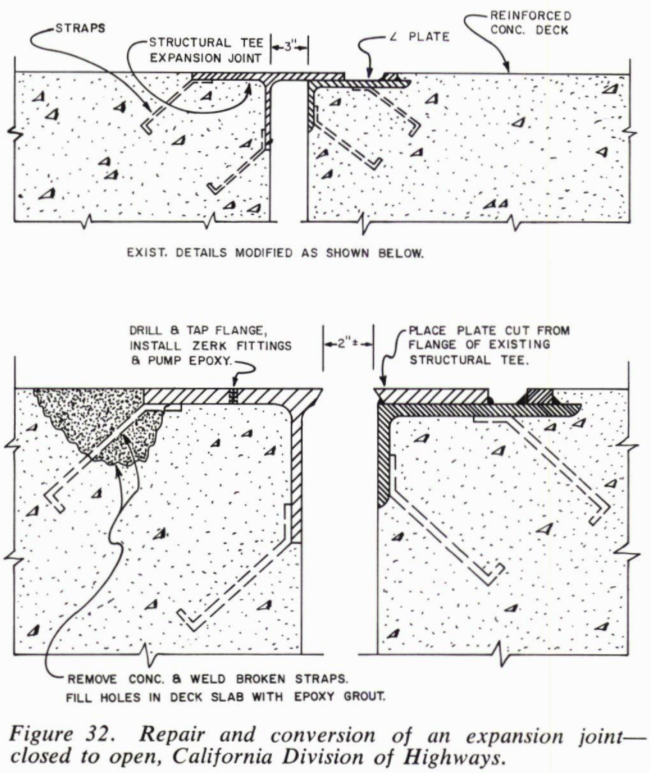


Figure 32. Repair and conversion of an expansion joint—closed to open, California Division of Highways.

Figure 33. Expansion joint repair shown in Figure 32; acetylene torch used to accelerate curing of epoxy materials.

Random Cracks

Another difficult task was that of sealing random cracks appearing in the deck surface. To provide a reservoir of joint sealant, it was usually necessary to cut out a groove or opening in the upper section of the crack in which the sealant could be placed.

The selection of sealants for cracks included those materials used for joints, with the exclusion of the preformed extrusions. Because the crack sealants were subjected to severe wear under traffic and moisture conditions, the two-component polysulfide compounds were selected for a number of installations.

CHAPTER SEVEN

SUMMARY AND CONCLUSIONS

This study involved the field inspection of 238 different concrete repair projects scattered throughout 28 states and the District of Columbia. Concrete repair programs being conducted by state highway departments, by toll facility commissions and by several local government agencies were reviewed.

Many concrete repair programs showed a need for greater use of carefully designed repair plans. Reliance on "foolproof," exotic, and usually quite expensive materials had not proven successful. The successful repair programs were consistently based on quality of suitable materials and careful control of workmanship. Quality-control measures, at least comparable to those followed in good practices for new construction, were employed. This study revealed no special material or shortcut method to substitute for proper construction practices to obtain consisently good results.

Along with control of the quality of materials and workmanship, complete and accurate records of repair work were a basic requisite in those programs which showed consistent progress. Where programs representing considerable dollar investments were performed by force account with incomplete or inadequate records, valuable data needed for evaluation and further refinement of procedures were lost.

SUCCESSFUL PRACTICES AND MATERIALS

Although gaps in the recording of program data were conspicuous, several practices and materials which showed a significant record of success are summarized in the following paragraphs.

Patch Area Preparations

Regardless of the type of patching material to follow, the meticulous preparation of repair areas was essential to the consistent success of the repair program. Saw cutting of the perimeter of the patch area eliminated spalls and feather edges. The tilting of the saw blade (by riding one wheel on a plank) to undecut at a slight angle permitted the patch to be keyed into the sound concrete for additional bond strength.

Complete removal of unsound concrete with proper size chipping tools selected to avoid damage to surrounding areas provided a strong, sound face against which to place the patch.

After removal of unsound concrete, flushing of the area with water pressure or vacuum cleaning removed all loose particles and dust without the possibility of oil contamination from air compressor blowing. Where repair faces were dirty or contaminated, detergent scrubbing removed greasy deposits and acid etching or sand blasting, cleaned and roughened the surface. Mechanical roughening with needle guns was also effective.

For concrete patches, pre-wetting of the repair face (without permitting any free-standing water) prevented the rapid absorption of moisture from the patching mixture. The moisture conditions provided on the repair face for epoxy resin patch mortars varied according to the formulation of the epoxy binder.

Forming and Support

A number of simple and effective systems were developed for forming the bottom of deck repairs. Several removable forms were braced from the lower flange of floor beams. Another removable form assembly was hung from the upper flange of the floor beams. A left-in-place form was pulled into position from the topside of the deck and bolted to the reinforcing steel.

Temporary lifts and supports for deck spans were provided by jacks and steel beam columns based on pier or abutment foundations. Another effective system used a heavy horizontal beam blocked up to span the deck section and to lift and support it while repairs were being made.

Portland Cement Concrete Patches

Perhaps the foremost among the repair techniques being successfully employed was the use of portland cement concrete patches. This type of repair program, which historically preceded most other repair techniques now being considered, showed a high rate of success and service life for a nominal cost where good quality control of materials, workmanship and procedures was maintained.

Dense, well-compacted concrete mortars, with a low water-cement ratio, a cement content of 6 to 7 bags per cu yd, and an air content (in place) of 5 to 7 percent showed the best results. Good bond was obtained using cement grouts and epoxy resin compounds. Proper curing was necessary and was provided most consistently by spray-applied curing membrane coatings.

Epoxy Resin Patching and Bonding Compounds

The term "epoxy resin" is not sufficiently definitive to indicate what characteristics the material might have or whether or not it might be suitable for use in the particular application desired. There are many basic formulations developed to provide epoxy resin compounds with widely varying characteristics. The successful use of an epoxy resin in concrete repair was critically dependent upon the selection of a compound formulated to meet the specific requirements of the application intended. Also, the material components had to be carefully proportioned and blended and applied to thoroughly cleaned repair surfaces. Several epoxy resin compounds demonstrated their ability to provide fast-curing patches under heavy traffic conditions with a good service life. Some epoxy resin compounds were effective as bonding coats where new concrete was joined to old concrete under difficult conditions, or where broken faces of old concrete were rejoined. The latter application was of particular significance since this type of repair was considered unobtainable before the advent of the resinous compounds.

Epoxy formulations and mortar mix designs had to take into account the three to five times greater coefficient of expansion of the epoxy resins compared to that of portland cement concrete. The epoxy resin-tar-amine compounds showed stress-releasing qualities which seemed to best withstand the temperature ranges of the northern states.

Higher aggregate contents reduced the differential in coefficients of expansion of epoxy mortars. Density, obtained through proper proportioning and compaction, improved the resistance to damage by freeze-thaw cycles in the presence of moisture.

Waterproof Membranes

The use of waterproofing membrane courses under a supplemental wearing surface showed promise of extending the service life of repaired decks. The coal tar pitch emulsions used in reinforced, layered, membrane systems appeared to be one of the most effective moisture barriers. The emulsion was applied in four courses with layers of glass fabric laid in the second and third course. After curing, the reinforced membrance was covered with an asphaltic-concrete wearing course.

Epoxy resin compounds were also used as waterproof coatings, either as the wearing surface or as membranes beneath a separate wearing course. The size and shape of the cover aggregates used with the epoxy coatings had a direct influence on the integrity of the resulting membrane. In an effort to minimize pinholes, a fine aggregate of rounded particles passing a No. 30 mesh was recommended by a major epoxy manufacturer. Reinforcing fabrics in layered systems of epoxy coatings did not appear to be necessary in view of the bond and tensile strength of most epoxy formulations.

Recent designs for asphaltic-concrete wearing courses, using neoprene and asbestos fiber additives, improved the density and impermeability of the surfaces without adversely affecting stability. Waterproofing membranes were used beneath the wearing surfaces to protect the concrete deck from moisture.

Shotcrete

Pneumatically-applied mortar was used for many vertical and overhead repairs as well as several deck surface patches. Quality control depended largely on skilled equipment operators. Some mechanical control was available in the wet-mix process which also permitted air entrainment. Epoxy resin bonding agents were used successfully in shotcrete repairs, but many successful programs did not employ a bonding coat. Proper moist curing or membrane curing was necessary for consistently good results.

Joints

A major maintenance problem was the repair of loosened deck expansion dams. Successful repair procedures included: removal and replacing of the end of the deck slab; refastening of the dam by welding straps to the dam and to the adjacent reinforcing steel; pumping epoxy compounds into the voids beneath the dam face to reestablish bond; and partial removal of adjacent broken concrete and replacement with epoxy mortar.

The two-component polysulfide joint sealants and the extruded neoprene joint fillers were used in several special sealing assignments. No fully effective sealant was indicated in this study, however, and a number of projects were noted in which the sealed joints were converted to open joints with gutters, drains or other systems provided to handle the run off.

COSTS

The development of significant specific unit cost data from available records of repair work covered in this study was generally not possible. On many of the projects performed by force account, no cost data were recorded. Where cost records were kept, they usually depended on the judgment, concern and accuracy of the field clerk or foreman. Because bridge repair projects seldom had well-defined units of work as a basis for cost records, costs included different conditions and operations on almost every job. Even on contract work, units varied from state to state and agency to agency.

Traffic control measures, preparatory to the performance of repairs on decks of high-speed, heavily traveled bridges require a large expenditure to place and maintain warning signs, flashing lights, cones and barricades—often over as much as two miles of approach highway. The location of the repair site with respect to the maintenance crew headquarters and with respect to other repair jobs, had an important bearing on the efficiency and travel time of the crew. The degree of disintegration of the old concrete; the difficulty of placing repair material; the need for forming, anchoring and reinforcing; the proximity and size of patches, whether scattered shallow or large full-depth repairs, all had an important influence on the resultant unit cost of the repair.

The data assembled in Table 3 reflect the cost ranges experienced in the performance of the projects included in this study. Where quantitative data were also available, weighted average unit costs were computed. Although costs in Table 3 do not provide specific unit values for estimating other projects, they do provide the broad limits within which typical repair costs fall and on which to judge estimates for specific maintenance jobs.

TABLE 3

RANGE OF UNIT PRICES REPORTED FOR MAJOR BRIDGE REPAIR ITEMS

TYPE OF REPAIR	HIGH	LOW	WEIGHTED AVERAGE
Concrete removal, cu yd	$200.00	$ 40.00	$ —
Bituminous concrete removal, sq yd	—	—	1.50
PCC patches, sq yd	54.00	8.90	23.80
PCC patches, cu yd	330.00	30.00	—
Shotcrete, cu yd	324.00	200.00	257.00
Shotcrete, per bag of cement	80.00	18.00	19.00
Epoxy mortar, cu ft	79.63	64.86	—
Epoxy mortar, sq ft	8.00	4.50	6.50
Epoxy surface treatment, sq yd	11.25	1.05	4.60
Coal tar pitch emulsion surface treatment, sq yd	1.25	0.90	—
Waterproof membrane and bituminous wearing surface, sq yd	6.80	2.12	6.36
Polyester resin surface, sq yd	14.40	5.20	—
Joint sealing, lin ft	1.55	0.45	0.67

AREAS REQUIRING FURTHER STUDY

A number of factors basic to the development of successful concrete structure repair programs appear to merit a comprehensive study beyond the scope of this report. These items include the following:

1. The relationship between concrete bridge deck surface "slope variance" (*61*) and the bridge deck service life. What effect does the smoothness and riding quality of the deck have on its rate of disintegration? Does the vibration and impact loading resulting from a rough surface affect the rate of deterioration of the deck? If the smoothness of the bridge deck does have a significant bearing on its service life, what tolerances should be established? What mechanical means can be used to provide a smooth bridge deck surface? What is the net economic value (or cost) of providing smooth decks?

2. The factors influencing the optimum depth of cover concrete over the top reinforcing steel in a monolithic concrete bridge deck. At what point, or points, does the thickness of the cover concrete resist cracking and admission of moisture to the reinforcing steel under varying factors of design and construction? Are there more economical means of providing protection to the top surface of the deck than the addition of a thicker concrete?

3. Techniques and devices for the measurement of the degree of soundness in concrete structures and for the detection and location of areas of unsound concrete. How can unsound concrete be located? How much should be removed and replaced in a repair program? What is "unsound" concrete? What nondestructive tests or measurements can be made of the soundness of concrete?

4. The predetermination and accommodation of longitudinal movement by concrete pavement slabs adjacent to a structure. What relationship is there between local materials, weather conditions, subgrade, soil conditions, grades, traffic and the like on the movement of approach slabs adjacent to structure abutments? What design can best accommodate the anticipated movement of the approach pavements?

5. The design of epoxy patching mortars. What mix design offers the best density and resistance to freeze-thaw stresses? What mix design offers the best coefficient of expansion for concrete repairs? What are the thermal stresses at or near the bonded faces? What are the temperature and climatic conditions limiting the successful use of various epoxy formulations?

6. The design of joints on bridge decks. What designs best accommodate moisture and movement?

An improved understanding of these problems and promising techniques for their solution would make a valuable contribution to the protection of the major investment in structures on the street and highway systems of the nation.

ACKNOWLEDGMENTS

Deep appreciation is expressed for the valuable assistance and cooperation received from the various state highway departments, turnpike and bridge commissions and other public agencies. Without this aid the study could not have been made.

The willing cooperation received from the universities, individuals, research agencies, associations and manufacturers is also greatly appreciated.

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20. Laboratory tests were made in 1961 by the Connecticut State Highway Department of sample cores taken from the epoxy resin-polysulfide polymer (Thiokol LP_3) patches on the Wilbur Cross Bridge over Connolly Parkway, Hamden, Conn. The samples were subjected to freeze-thaw cycles of 5½ hours' duration; 3½ hours of freezing at 0°F, 1½ hours of thawing and ½ hour of dewatering. Tap water was used to saturate the samples. To prevent thermal shock, the thaw cycle was in water heated to 40°F and kept at that temperature by immersion heaters.
21. Harder, Paul B., "Epoxies Speed Bridge Repairs." *Public Works* (July 1962).
22. "Anti-Foam B", made by Dow Corning Corporation, Midland, Mich.
23. "Dow Latex 560 for Portland Cement Compositions." The Dow Chemical Company, Midland, Mich. (Sept. 1959).
24. Mount Pulaski Overhead, Logan County, Ill. Dow Latex 560 used in this deck repair project by Illinois Division of Highways in 1961.
25. Tri-State Tollway's 71st Street Bridges and 95th Street Bridges, Chicago, Illinois. Albitol bond coats applied before wet-mix shotcrete repairs to decks by Illinois State Toll Highway Commission in 1963.
26. US 22 viaduct, Newark, N.J. Shotcrete repairs covered with Guardkote 140 membrane and asphalt concrete wearing course. Work done in 1963 for New Jersey State Highway Department by contract.
27. Illinois State Toll Highway Commission.
28. New Jersey Turnpike Authority.
29. Michigan State Highway Department.
30. Lake Champlain Bridge Commission.
31. New York State Thruway Authority.
32. Wisconsin State Highway Commission.
33. New Hampshire Department of Public Works.
34. Passaic River Bridge on New Jersey Turnpike. Guardkote 140 and silica-sand membrane placed between repaired deck surface and thin (⅝ in.) asphaltic concrete (containing neoprene and asbestos fibers) wearing course. Work done in 1963 by contract for the New Jersey Turnpike Authority.
35. Ohio Street Bridge, Chicago, Ill. Treated with a Guardkote 140 surface treatment in 1960. Shell Chemical Company reported on means of preventing or correcting pinholing to Cook County Highway Department.
36. New York State Department of Public Works.
37. Bellman's Creek Bridge, MP 115 Southbound, New Jersey Turnpike, done in 1963.
38. I-87 over Central Avenue in Albany, N.Y. New York State Department of Public Works.
39. Passaic River Bridge, New Jersey Turnpike. Work done in 1963 by contract for the New Jersey Turnpike Authority.
40. Triborough Bridge, New York City. Work done in 1963 by contract for the Triborough Bridge and Tunnel Authority.
41. Tamburro, David A., Blekicki, Henry T., Kietzman, John H., "The Effects of Short Chrysotile Asbestos Fibers on the Structural Properties of Asphalt Pavements." Presented at the Meeting of the Association of Asphalt Paving Technologists, 1962.
42. Zube, Ernest, "Permeability Tests." *California Highways and Public Works* (July and Aug. 1963).
43. The New York State Thruway Authority added Multiwet to shotcrete water and employed Norlite lightweight aggregate where vertical or overhead repairs were being made.
44. Ihiihilaukea and Kawaiakaea Bridges, Hawaii. Work done in 1962 by contract for the Hawaii State Highway Division.
45. The Indiana State Highway Commission.
46. Glens Falls and Troy-Cohoes Bridges over the Hudson River. Work done in 1963 by contract for the New York State Department of Public Works.

47. Intrusion-Prepakt, Inc., Cleveland, Ohio.
48. West Sixth Street viaduct, Erie, Pa. Work done in 1954 by Intrusion-Prepakt, Inc. under contract to city of Erie.
49. Alfesil, manufactured by Intrusion-Prepakt, Inc.
50. Intrusion Aid, manufactured by Intrusion-Prepakt, Inc.
51. San Francisco distribution structure. Work done in 1960 for California Division of Highways.
52. California Division of Highways made repairs to the accident-damaged concrete parapet of the Carquinez Bridge on I-80 and to the accident-damaged concrete median barrier on the Bayshore Bridge in San Francisco.
53. The Illinois Division of Highways used Armstrong Uniproof No. 33, made by the Armstrong Paint and Varnish Company, or equal materials for sealing and protecting pier caps.
54. Thoroseal cement grout was used by the Ohio Turnpike Commission maintenance department for pier cap protection.
55. The New York State Thruway Authority formulation for pier cap protection, dubbed "Brindleshine," consisted of 5 gal of Sika Seal; 3½ gal of Penetrol; and 7 lb of 325-mesh flake aluminum paste.
56. Indiana Toll Road Commission.
57. The Illinois Division of Highways.
58. The Virginia Department of Highways.
59. The Port of New York Authority.
60. Wayne Street Bridge, West St. Joseph, Mich. Work done in 1963 by contract for the Michigan State Highway Department.
61. In the AASHO Road Test, the relationship called "slope variance" was defined as the average squared deviation from the mean of the pavement surface slopes taken every 6 in. over a given distance.

APPENDIX A

SPECIFIC BRIDGE REPAIR PROJECTS

LOCATION	TYPE	METHOD	BOND	MORTAR	MEMBRANE	SURFACE
ARKANSAS						
State Highway Dept.						
Main St. viaduct, No. Little Rock	Beam and column restoration	Shotcrete		PC concrete		
Arkansas-Memphis (Tenn.) bridge over Mississippi River	Sidewalk surface treatment	Other				Synthetic
Rt. 70 over St. Francis River	Deck surface treatment	Other				Bituminous, synthetic
Rt. 79 over Arkansas River, Pine Bluff	Deck surface treatment	Other				Bituminous, synthetic
CALIFORNIA						
Dept. of Public Works						
American River bridge on Jibbon Street, Placer County	Expansion dam	Formed		Synthetic		
Bayshore Bridge, San Francisco	Nose section	Formed	Synthetic	Synthetic		
Carquinez Bridge, I-80	Deck and parapet restoration	Formed	Synthetic			
Courtland Avenue, San Francisco	Deck restoration	Formed	Synthetic	PC concrete		
Hinton Rd., I-80	Deck patching	Formed	Synthetic	Synthetic		
Prosser Creek, Rt. 83	Curbing repairs	Formed	Synthetic	PC concrete		
San Francisco distribution structure	Bearing pads rebuilt	Formed	Synthetic	Synthetic		
Sierra Point, San Francisco	Deck patching	Formed	Synthetic	Synthetic		
I-80, Colfax to Magra	Deck patching	Formed	Synthetic	PC concrete		
I-80, Roseville to Newcastle	Joint repairs	Formed	Synthetic	Synthetic		
I-80, Troy	Deck patching	Formed	Synthetic	PC concrete		
Rt. 83 over 38, separation on I-80 near Truckee	Girder restoration	Shotcrete	Synthetic	PC concrete		
Marina viaduct, San Francisco	Pier caps and columns	Formed	Synthetic	Synthetic		
Presidio viaduct, San Francisco	Pier caps and bearing pads	Formed	Synthetic	Synthetic		
California Golden Gate Bridge and Highway Dist.						
Golden Gate Bridge San Francisco	Sidewalk, facia, expansion joints	Formed	Synthetic	PC concrete		
COLORADO						
Dept. of Highways						
Larimer St. viaduct, Denver	Superstructure components	Shotcrete, formed	Synthetic	PC concrete, synthetic		

SPECIFIC BRIDGE REPAIR PROJECTS (continued)

LOCATION	TYPE	METHOD	BOND	MORTAR	MEMBRANE	SURFACE
Connecticut						
State Highway Dept.						
Cedar St. under Conn. Tpk., Branford	Deck crack and surface sealing	Other				Synthetic
Conn. Tpk. bridge over Rt. 1, Guilford	Pier caps	Formed	P cement	PC concrete		
Wilbur Cross Pkwy. over Rt. 15, Hamden	Deck patching	Formed	Synthetic	PC concrete, synthetic		
Rt. 15 bridge ¼ mi west of Rt. 9, Wethersfield	Median curb	Formed	P cement	PC concrete		
Delaware						
Delaware River and Bay Authority						
Delaware Memorial Bridge	Deck patching and sealing	Formed, other	P cement	PC concrete		Synthetic
U.S. Army Engr. Dist., Philadelphia						
St. George's Bridge, Rt. 13	Deck patching and joints	Formed	Synthetic	PC concrete, synthetic		
Florida						
State Road Department						
Pigeon and Knights Key bridges	Under deck and hand rail	Shotcrete		PC concrete		
Hawaii						
Dept. of Transportation						
Ihiihilaukea and Kawaiakaea bridges	Parapets and curbs	Shotcrete		PC concrete		
Paumalu Bridge	Piling restoration	Formed		PC concrete		
Illinois						
Dept. of Public Works						
Clark Br., Rt. 67 over Mississippi R., Alton	Deck patches and seal	Formed, other	P cement	PC concrete		Synthetic
Kings Hwy. over Penna. and B&O RR., St. Clare County	Abutments and deck	Formed		PC concrete		
Rock Br., Rt. 67, Green-Jersey Co. line	Deck patches and seal	Formed	P cement	PC concrete	Bituminous	Bituminous
Rt. 4, Bridges 1 and 2, N of Staunton	Deck surface treatment	Other				Synthetic
Rt. 54 over Rt. 121, Mt. Pulaski overhead	Deck patching	Formed	Synthetic	PC concrete, synthetic		Synthetic
Rt. 66 over Rt. 51, Bloomington	Sidewalk and deck patch and seal	Formed		PC concrete	Bituminous	Bituminous
Rt. 111 over Cahokia Diversion Canal, Madison County	Deck patching and seal	Shotcrete, formed	P cement, synthetic	PC concrete, synthetic		Synthetic

SPECIFIC BRIDGE REPAIR PROJECTS (continued)

LOCATION	TYPE	METHOD	BOND	MORTAR	MEMBRANE	SURFACE
Rt. 150 over Mackinaw River, E of Goudfield	Pier caps and facia	Shotcrete		PC concrete		
Rt. 150 over Sangamon River at Mahomet	Curb, parapet, pier caps, deck	Shotcrete, formed		PC concrete	Bituminous	
Ill. State Toll Hwy. Comm'n. ½ mi. E of plaza 21, E-W tollway	Deck patching and sealing	Formed, other	P cement	PC concrete		Synthetic
Various structures	Expansion dam refastening	Formed	Synthetic	Synthetic		
Mile Long Br. (SBL)	Deck patching	Formed	Synthetic	Synthetic		
RR Br. 0.7 mi. N of Rt. 56	Deck sealing	Other				Synthetic
71st St. bridges	Deck patching	Shotcrete	Synthetic	PC concrete		
95th St. bridge (NB)	Deck patching	Shotcrete	Synthetic	PC concrete		
Cook County Hwy. Dept. Ohio St. Br., Chicago	Deck sealing	Other				Synthetic
INDIANA *State Highway Comm'n.* I-65 over NYC RR, Lebanon	Deck crack and surface seal	Other				Synthetic
I-65 over SB ramp to Lebanon	Deck seal	Other				Synthetic
Rt. 100 over NYC RR, No. of Rt. 67	Joint repair and deck seal	Formed, other	Synthetic	Synthetic	Synthetic	Bituminous
Ind. Toll Road Comm'n. MP 154.6, EB	Abutment repair	Formed	Synthetic	Synthetic		
KANSAS *State Highway Comm.* Exit ramp, Rt. 81 to Rt. 54 WB, Wichita	Deck patching and seal	Other				Bituminous
Rt. 24 over Soldier St., Topeka	Deck seal	Other				Synthetic
Rt. 54 over Arkansas River, Rt. 54-Kellogg St. viaduct, Wichita	Deck patch and seal	Formed	Synthetic	PC concrete		Synthetic
Rt. 54 over canal at Rt. 81 bypass, Wichita	Deck resurfacing	Other				Synthetic
Rt. 54 over Kansas Tpk., Wichita	Deck patching	Formed	P cement	PC concrete		
Kans. Turnpike Authority Bridge 306, NB over Rt. 40, Kansas City	Deck patching	Formed	Synthetic	Synthetic		

SPECIFIC BRIDGE REPAIR PROJECTS (continued)

LOCATION	TYPE	METHOD	BOND	MORTAR	MEMBRANE	SURFACE
KENTUCKY						
Dept. of Highways						
Capitol Ave. over Ky. River, Frankfort, and statewide	Superstructure, substructure and joints	Shotcrete	Synthetic	PC concrete		
MAINE						
State Highway Comm'n.						
Badger Island bridge on Rt. 1 and So. Portland bridge, Rt. 77	Superstructure repairs	Shotcrete		PC concrete		
Badger Island, Rt. 1; Rt. 1 over York River; Rt. 9 over B&M RR; New Co. Rd. over Saco River, Rt. 5	Sidewalk and curb	Formed		PC concrete		
Middle Bridge on Rt. 197, Dresden	Deck resurfacing	Formed	Synthetic			Synthetic
MARYLAND						
State Roads Comm'n.						
RR underpass, Rt. 45, Cockeysville; Rt. 24 over Winters Run, plus various small structures	Superstructure and substructure	Shotcrete		PC concrete		
MASSACHUSETTS						
Turnpike Authority						
MP 17.3, Tpk. over Rt. 20	Deck patching and surfacing	Formed	P cement	PC concrete	Bituminous	Bituminous
MP 90.6 over Southbridge St., Auburn	Deck patching	Formed	P cement, synthetic	PC concrete, synthetic		
MICHIGAN						
State Highway Dept.						
Cheboygen Bridge, Rt. 23	Deck resurfacing	Formed	Synthetic			Synthetic
Millett Rd. over I-96, near Lansing	Deck sealing	Other	Synthetic			Synthetic
Rt. 27 over GTW RR, St. John's	Deck sealing	Other				Synthetic
Rt. 27 overlooking Glass River, S of St. John's	Deck patching	Formed		PC concrete		
Rt. 57 over Flat River, Greenville	Deck patching	Formed		PC concrete	Bituminous	Bituminous
Rt. 66 over Grand River, Ionia	Deck crack and surface seal	Other				Synthetic
I-96 over Grand River S of Portland	Deck sealing	Other				Bituminous, synthetic
I-96 over RR and stream E of Rt. 127, near Lansing	Joint sealing	Other				Synthetic

SPECIFIC BRIDGE REPAIR PROJECTS (continued)

LOCATION	TYPE	METHOD	BOND	MORTAR	MEMBRANE	SURFACE
Rt. 204 over Lake Leelanau Narrows and Benton Harbor bridge	Deck patch and seal	Formed	Synthetic	Synthetic		Synthetic
Wayne County Road Comm'n. Ford-Lodge interchange, Detroit	Deck patching	Formed	Synthetic	Synthetic		
Local road structures crossing Davison Expressway	Facia and sidewalks	Formed	P cement	PC concrete		
Wyoming Ave. over Edsel-Ford Expwy.	Joint sealing	Formed				Bituminous, synthetic
I-94 over Outer Drive	Deck slab replacement	Formed	P cement	PC concrete		Bituminous
MINNESOTA *Dept. of Highways* Washington Ave. between 7th and 8th Aves., N, Minneapolis	Slab resurfacing	Other	Synthetic			Synthetic
2nd Ave., N, between Wash. Ave. and 3rd St., Minneapolis	Slab patching	Formed	P cement	PC concrete		
Rt. 7 over Rt. 100, St. Louis Park	Deck patching	Formed	Synthetic	PC concrete		
Rt. 52 over Mississippi River near Anoka	Deck patching	Formed	P cement	PC concrete		
Rt. 65, bridge #6410, Orchard Gardens	Deck patching	Formed	Synthetic	Synthetic		
Rt. 169, Shakopee	Sidewalk repair	Formed	P cement			
MISSOURI *State Highway Comm'n.* Project I-35(12)1, Jackson County	Deck restoration	Formed	P cement	PC concrete		Bituminous
Rts. 54-83 over Missouri R., Jefferson City	Deck patching and sealing	Formed	Synthetic	Synthetic		Synthetic
I-70 over Big Cedar Crk., Callanan County line	Deck seal	Other				Synthetic
Bridge G-976R, Rt. 63 over MK&T RR, Callaway County	Deck, curbs, piers	Shotcrete		PC concrete		
NEW HAMPSHIRE *Dept. of Public Works and Highways* Rt. 2 at Moore Reservoir, Conn. River	Facia, curbs and deck	Formed	P cement	PC concrete		Bituminous
Rt. 91 over Conn. River, No. Walpole	Sidewalk patch and seal	Formed	Synthetic	Synthetic		Synthetic

SPECIFIC BRIDGE REPAIR PROJECTS (continued)

LOCATION	TYPE	METHOD	BOND	MORTAR	MEMBRANE	SURFACE
NEW JERSEY						
State Highway Dept.						
Rt. 1 over Penna. RR, Middlesex County	Deck and curb patch and seal	Formed	P cement, synthetic	PC concrete		Synthetic
Rt. 22, Newark viaduct, Essex County	Deck patch and resurface	Shotcrete, other		PC concrete	Synthetic	Bituminous
Rt. 46 over Passaic R., Morris County	Deck restoration	Formed	P cement, synthetic	PC concrete		
Rt. 52, Atlantic and Cape May Counties	Deck restoration	Formed	P cement, synthetic	PC concrete		
Rt. 130 over Cranberry Brook	Deck patching	Formed	P cement	PC concrete		
Rt. 130 over Rt. 33 at Hightstown	Deck patching	Formed		PC concrete		
New Jersey Highway Authority						
MP 95.6, NB	Deck surface treatment	Other				Synthetic
MP 95.6, SB	Deck surface treatment	Other				Synthetic
MP 104, NB, Oak Island viaduct	Deck patching and seal	Formed, other	Synthetic	Synthetic	Synthetic	Bituminous
MP 105, NB	Deck seal	Other				Synthetic
MP 116, SB, Telegraph Hill Road	Deck seal	Other				Synthetic
Various, Dist. 4	Deck seal	Other				Synthetic
New Jersey Turnpike Authority						
Lehigh Valley RR overpass	Deck seal	Other			Bituminous	Bituminous
Passaic River bridge, and Oak Island viaduct	Deck patch and seal	Formed, other	P cement	PC concrete	Synthetic	Bituminous
MP 87, NB, over Main St., Edison Township	Deck surfacing	Other				Synthetic
NEW MEXICO						
State Highway Comm'n.						
Br. #1796 on Rt. 85	Superstructure	Shotcrete	Synthetic	PC concrete		
Br. #1820, Rt. 104, Tucumcari	Deck restoration	Shotcrete	Synthetic	PC concrete		
NEW YORK						
Dept. of Public Works						
I-87 over Central Ave., Albany	Deck surfacing	Other	Synthetic			Synthetic
Delmar bypass near Albany	Joint sealing	Other				Bituminous, synthetic
Rt. 9 over Hudson R., Glens Falls, and 112th St. over Hudson River, Troy	Superstructure restoration	Shotcrete, formed	Synthetic	PC concrete		Synthetic

SPECIFIC BRIDGE REPAIR PROJECTS (continued)

LOCATION	TYPE	METHOD	BOND	MORTAR	MEMBRANE	SURFACE
Major Deegan Expwy (Park Ave.-Depot Pl.)	Deck patch and seal	Formed, other	Synthetic	Synthetic	Synthetic	Bituminous
I-81, Syracuse, I-87, Albany	Joint sealants	Other				Bituminous, synthetic
N. Y. State Thruway Authority						
Tappan Zee Bridge	Deck patch and seal	Formed	Synthetic	PC concrete, synthetic	Bituminous	Bituminous
Various locations (48 bridges)	Superstructure and substructure	Shotcrete, formed	P cement	PC concrete		
Numerous locations	Deck restoration	Formed, other		PC concrete	Bituminous	Bituminous
Washington Ave. interchange, Albany	Slab resurfacing	Other	Synthetic			Synthetic
MP 391.76 near Batavia	Deck restoration	Formed		PC concrete		
MP 420.34, Williams-ville 3-level bridge	Pier cap restoration	Shotcrete, formed		PC concrete		
Lake Champlain Bridge Commission						
Crown Point bridge, Lake Champlain	Deck restoration	Formed	P cement	PC concrete	Bituminous	Bituminous
N. Y. State Bridge Auth.						
Mid-Hudson bridge, Poughkeepsie	Deck surface treatment	Other				Synthetic
Port of N. Y. Authority						
Bayonne Bridge	Deck restoration	Formed, other	Synthetic	PC concrete	Bituminous	Bituminous
George Washington Br.	Deck and joint restoration	Formed	P cement	PC concrete		Synthetic
Goethals Bridge	Deck restoration	Formed, other	Synthetic	Synthetic	Bituminous	Bituminous
Outerbridge Crossing	Deck restoration	Formed, other		PC concrete	Bituminous	Bituminous
Triborough Bridge and Tunnel Authority						
Henry Hudson Bridge	Deck patch and seal	Formed, other	P cement	PC concrete		Synthetic
Triborough Bridge	Deck patch and seal	Formed, other	P cement	PC concrete	Synthetic	Bituminous, synthetic
NORTH CAROLINA						
State Highway Comm'n.						
Croaton Sound Br.; Rt. 70 and 25 over Ivy River; Rt. 64 over Broad R.; Old Pee Dee R. Br., Rt. 74, WB	Deck patching	Formed	Synthetic	PC concrete		Bituminous
So. Main St., over WSS Bndry, Lexington	Pier cap restoration	Formed	Synthetic	PC concrete		

SPECIFIC BRIDGE REPAIR PROJECTS (continued)

LOCATION	TYPE	METHOD	BOND	MORTAR	MEMBRANE	SURFACE
Rt. 70 over Haw River, Haw River	Sidewalk, curb, parapet	Formed	Synthetic	PC concrete		
Rt. 150 over Harrison Creek, Salisbury	Deck patching	Formed	Synthetic	PC concrete		
Rt. 64 over Broad R., Hendersonville	Deck patching	Formed	Synthetic	PC concrete		
NORTH DAKOTA						
State Highway Dept.						
Beyond I-94, Valley City	Deck surfacing	Other				Synthetic
OHIO						
Dept. of Highways						
Rt. 22 over Sciota R., W of Circleville	Deck seal					Synthetic
Rt. 23 over Walnut Crk., Pickaway Co.	Deck patch and seal	Formed	Synthetic	PC concrete		Synthetic
Rt. 33 over Walnut Crk., Pickaway Co.	Curb and sidewalk patch, deck seal	Formed		PC concrete		Bituminous
Rt. 40 over Walnut Crk., Whitehall	Concrete girder repair	Shotcrete		PC concrete		
Rt. 316 over Sciota R., Pickaway County	Pier and abutments	Formed		PC concrete		
Rt. 317 over Rocky Fork Crk., Gahanna	Deck patching	Formed	Synthetic	Synthetic		
Rt. 665 over I-71, Franklin County	Deck patching	Formed	P cement	PC concrete		
Ohio Turnpike Comm'n.						
Ohio Tpk., exit 11 over Rt. 21	Deck and pier restoration	Shotcrete, formed, other		PC concrete		Synthetic
Rt. 21 over Tpk., and MP 100.2	Pier and abutment restoration	Shotcrete		PC concrete		
MP 97.8, Racoon Crk. Bridge, EB and WB	Deck repair	Formed	P cement	PC concrete		
MP 99.7, WB	Deck resurfacing	Formed	Synthetic			Synthetic
MP 185.6, Tinkers Crk. EB and WB	Deck patching	Formed	P cement	PC concrete		
OKLAHOMA						
Dept. of Highways						
I-35 over 2nd overflow, N of Cimmaron R.	Deck patch	Formed		Synthetic		
I-35 over 3rd overflow, N. of Cimmaron R. (2 bridges)	Deck resurfacing	Formed, other				Synthetic
Rt. 62 over N. Canadian R., Okla. City; Rt. 33 over Cottonwood Crk.; RR W of Guthrie	Joint repair	Formed		PC concrete		

SPECIFIC BRIDGE REPAIR PROJECTS (continued)

LOCATION	TYPE	METHOD	BOND	MORTAR	MEMBRANE	SURFACE
PENNSYLVANIA *Penna. Turnpike Comm'n.* MP 58.8	Back wall restoration	Formed		PC concrete		
MP 93.3, 100.5, 109.7	Deck crack and seal					Synthetic
MP 212.3, 213.4, 215.2, 218.1, 218.7 (5 bridges)	Deck restoration and seal		Synthetic	PC concrete	Synthetic	Bituminous
SOUTH CAROLINA *State Highway Dept.* Rt. 72 over Rt. 176, Columbia	Deck patching	Formed	P cement, synthetic	PC concrete		
SOUTH DAKOTA *Dept. of Highways* Viaduct over RR, Hot Springs	Deck seal	Formed	Synthetic	Synthetic		
TENNESSEE *Dept. of Highways* Shelby Ave. over Cumberland River, Nashville	Superstructure restoration	Shotcrete		PC concrete		
Tenn. Valley Authority Bridge across Fort Loudoun Dam	Deck surfacing	Other				Synthetic
VIRGINIA *Dept. of Highways* Tidewater Drive over N&W RR; and Rt. 64 over Rt. 17, Norfolk	Deck surfacing	Other				Synthetic
Tripplie int., 13, 460 and 166, S Norfolk	Superstructure and substructure	Shotcrete		PC concrete		
Richmond-Petersburg Turnpike Authority 4 bridges (Appomattox R.; Swift Crk.; Rt. 10) and James River	Deck sealing	Other				Synthetic
16 bridges	Deck sealing	Other			Bituminous	Bituminous
WEST VIRGINIA *State Road Comm'n.* County Rd. over West Fork River, N of Weston	Deck patching	Formed	Synthetic	Synthetic		
WISCONSIN *State Highway Comm'n.* Astico overhead, Rt. 16 near Astico	Pier and girder restoration	Shotcrete		PC concrete		
Chippewa River bridge, Rt. 12, Eau Claire Co.	Deck patching	Formed	Synthetic	Synthetic		Synthetic
Darien overhead, Rt. 15, N of Beloit	Deck patching		P cement	PC concrete		

SPECIFIC BRIDGE REPAIR PROJECTS (continued)

LOCATION	TYPE	METHOD	BOND	MORTAR	MEMBRANE	SURFACE
Jump River bridge, Rt. 8, Price County	Deck patching	Formed	Synthetic	PC concrete		
Lovers Lane over Rt. 100, Milwaukee Co.	Pier restoration	Formed	P cement	PC concrete		
Miss. R. bridge, Rt. 14, LaCrosse Co.	Deck patching	Formed	Synthetic	PC concrete		
Rawson-Howell overhead, Rt. 38, Milwaukee Co.	Deck patching	Formed	P cement	PC concrete		
Ryan overhead, Rt. 100, Milwaukee Co.	Pier restoration	Formed	P cement	PC concrete		
Rt. 12, Lions overhead, Baraboo	Deck seal	Other				Synthetic
Rt. 12, Waken overhead, Madison	Deck surfacing	Formed	Synthetic			Synthetic
DISTRICT OF COLUMBIA						
Dept. of Highways and Traffic						
Chain Br., Potomac R. and Canal	Deck patching		P cement	PC concrete		
Key Bridge	Joint and pier restoration	Shotcrete, formed	Synthetic	PC concrete		
N. Y. Ave. over Wash. Terminal tracks	Deck patching	Formed		PC concrete		
Porter St. over Rock Creek	Deck patching	Formed		PC concrete		
Porter St. over Klinly Road	Sidewalk repairs	Shotcrete		PC concrete		
CANADA						
Niagara Falls Bridge Comm'n.						
Niagara Falls, N. Y. and Ontario	Curb and sidewalk repair	Formed	Synthetic	PC concrete		

APPENDIX B

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APPENDIX C

MATERIALS AND EQUIPMENT

The following list of materials and equipment includes only those commercial materials encountered in this study; others may serve equally as well. The mention of these materials does not constitute an endorsement by the Highway Research Board or the Sponsors.

Materials

ACME JOINT SEAL, *cellular neoprene joint sealant;* Acme Highway Products Co., Buffalo, N. Y.

ALBITOL, *polyvinyl acetate liquid bonding agent used as bond coat or as additive in concrete patching mortars;* American Vamag Co., Inc., 1615 51st Street, North Bergen, N. J.

ALFESIL, *pozzolanic material to reduce cement requirements;* Intrusion-Prepakt, Inc., Union Commerce Building, Cleveland 14, Ohio.

ALLIED JET SEAL, *polysulfide polymer joint sealing compound;* Allied Materials Corporation, Braniff Building, 39th Street Station, Oklahoma City, Okla.

ALLIED JOINT SEALER #9015, *two-component, cold-applied joint sealant;* Allied-Strand Corporation, Braniff Building, Oklahoma City, Okla.

ANTI-FOAM B, *anti-foaming admixture for concrete;* Dow Corning Corporation, Midland, Mich.

ANTI-HYDRO, *calcium chloride based concrete additive;* Anti-Hydro Waterproofing, 265 Badger Avenue, Newark, N. J.

ARALDITE, *epoxy resin;* CIBA Products Corporation, Fairlawn, N. J.

BASLER CONCRETE BOND, *cement powder bonding compound;* Basler, Inc., Omro, Wis.

B & W BONDER, *polyvinyl acetate bonding compound;* Thoro Building Materials, Ltd., 393 Birchmount Road, Toronto, Ont.

CAB-O-SIL, *thixotropic agent;* Godfrey L. Cabot, Inc.

CADOX MDP, *catalyst for polyester resin compounds;* Cadet Chemical Corporation, Burt, N. Y.

CANADIAN CHRYSOTOLE GRADE 7M, *asbestos fibers used in bituminous-concrete mixes;* Johns-Manville Corporation, Manville, N. J.

CEMENT FONDU, *aluminous cement;* Cochrane Dunlop Hardware, Ltd., 1385 Bloor Street, West, Toronto 9, Ont.

COLMA EPOXY BONDING COMPOUND, *polysulfide-epoxy, two-component bonding compound;* Sika Chemical Corporation, Passaic, N. J.

COLMA JOINT SEALER, *joint sealant, two-component;* Sika Chemical Corporation, Passaic, N. J.

COLMA SURFACE-KOTE, CLEAR, *epoxy resin compound;* Sika Chemical Corporation, Passaic, N. J.

CONCRESIVE, *Epon-Thiokol epoxy resin compound with Cab-O-Sil thixotropic agent;* Adhesive Engineering, San Carlos, Calif.

CONCRETE SEALER, *low-viscosity, tar-based, penetrating sealer for concrete surfaces;* Koppers Company, Inc., Tar Products Division, Pittsburgh 19, Pa.

COROCRETE, *liquid latex used in modified portland cement concrete mortars;* Cook Paint and Varnish Co.

DARAWELD, *polyvinyl acetate bonding agent;* Dewey & Almy Chemical Co., 62 Whittemore Ave., Cambridge 40, Mass.

DAREX, *air-entraining additive;* Dewey & Almy Chemical Co., 62 Whittemore Ave., Cambridge 40, Mass.

DC 772 SILICONE, *silicone waterproofing compound;* Dow Corning Corporation, Midland, Mich.

DEL, *synthetic rubber joint sealing compound, cold-applied;* David E. Long Corporation, 220 East 42nd Street, New York 17, N. Y.

DER, *epoxy resin;* Dow Chemical Company, Midland, Mich.

DER 331, *preproportioned epoxy resin aggregate patching compound;* Dow Chemical Company, Midland, Mich.

DMP, *phenolic tertiary amines, flexible curing agents for epoxy resins;* Rohm and Haas Company, Washington Square, Philadelphia, Pa.

DUREZ 22293, *polyester resin;* Durez Plastics Division, Hooker Chemical Corporation, North Tonawanda, N. Y.

EMBECO, *catalyzed metallic aggregate containing a water reducing agent used for shrink-resistant mortars;* Master Builders Company, Cleveland 18, Ohio.

EPIBOND, *epoxy bonding agent;* Furane Plastic, Inc., Los Angeles, Calif.

EPI-REZ, *epoxy resin;* Jones-Dabney Company, Louisville, Ky.

EPOCAST 25A & 530, *epoxy bonding agent;* Furane Plastic, Inc., Los Angeles, Calif.

EPOLAC 301, *clear resin compound;* Lawrence Adhesives and Chemical Company, Lawrence, Mass.

EPOLAC 309, *bituminous resin compound;* Lawrence Adhesives and Chemical Company, Lawrence, Mass.

EPOLITH, *two-component, aggregate reinforced, epoxy resin system;* Sonneborn, Ltd., 133 Laird Drive, Toronto 17, Ont.

EPON, *epoxy resin;* Shell Chemical Company, 1120 Commerce Ave., Union, N. J.

EPOTUF, *epoxy resin;* Reichhold Chemicals, Inc., Elizabeth, N. J.

EPOXEAL PENETRATING SEALER, *surface sealant;* Protective Products Corp., Gulf National Bank Building, Gulfport, Miss.

EPOXY #10, *epoxy binder compound;* Sherwood Chemical Company, Wichita, Kan.

EPOXY PR 940, *epoxy binder compound;* Products Research Corp., Burbank, Calif.

EPOXYN CRETE FC 896 & 897, *epoxy bonding & binder compound;* Co-Polymer Chemicals, Inc.

ERL, *epoxy resin;* Union Carbide Plastics Corp., Bound Brook, N. J.

EXTRUDED NEOPRENE, *joint sealant;* Acme Highway Products Co., Buffalo, N. Y.

FEROBOND, *cast iron particles with oxidizing agent;* G. F. Stern & Sons Ltd., Brantford, Ont.

FLINTAR, *coal tar pitch emulsion;* The Flintkote Company, Whippany, N. J.

FLINTAR PRIMER, *tar-based penetrating primer for concrete surfaces;* The Flintkote Company, Whippany, N. J.

FLINTCRETE, *polysulfide-epoxy bonding compound;* The Flintkote Company, Whippany, N. J.

FLOROKS, *joint sealant,* Charger Products Company.

GENAMID 250, *epoxy resin hardener;* General Mills Company, Chemical Division, 20800 Center Ridge Road, Cleveland, Ohio.

GUARDKÒTE 120, *Epon epoxy resin-amine compound for sealing and bonding;* Shell Chemical Company, 1120 Commerce Ave., Union, N. J.

GUARDKOTE 140, *Epon epoxy resin-tar-amine compound for sealing and bonding;* Shell Chemical Company, 1120 Commerce Ave., Union, N. J.

HARDENBOND, *calcium chloride based set accelerating concrete additive;* G. F. Stern & Sons Ltd., Brantford, Ont.

HEAVY DUTY RESURFACER, *packaged asphalt emulsion slurry;* American Bitumuls & Asphalt Co., 320 Market Street, San Francisco, Calif.

HSI, *glass fiber as used to reinforce polyester resin coatings;* Owen-Corning Fiberglass Corp., Toledo 1, Ohio.

HYDROCRETE, *concrete additive for set acceleration;* Charger Products Corporation.

HYSOL 4210 SPL, *epoxy resin concrete bonding agent;* Hysol (Canada), Ltd., Toronto, Ont.

I-GAS, *plasticized asphalt joint sealer, hot-applied;* Sika Chemical Corporation, 35 Gregory Avenue, Passaic, N. J.

INTRUSION AID, *flowability admixture which produces tiny hydrogen gas bubbles in concrete;* Intrusion-Prepakt, Inc., Union Commerce Building, Cleveland 14, Ohio.

ISOLASTIC, *polyurethane based joint sealant;* H. S. Peterson Company.

JENNITE J-16, *coal tar pitch emulsion;* Maintenance, Inc., Wooster, Ohio.

JENNITE J-16R, *rubberized coal tar pitch emulsion;* Maintenance, Inc., Wooster, Ohio.

JENNITE PRIMER, *penetrating primer for coal tar pitch emulsions;* Maintenance, Inc., Wooster, Ohio.

KOPPERS PAVEMENT SEALER, *coal tar pitch emulsion;* Koppers Company, Inc., Pittsburgh, Pa.

LATEX EMULSION, *latex emulsion;* B. F. Goodrich Company, Akron, Ohio.

LATEX 560, *water dispersion of styrene butadiene copolymer particles;* Dow Chemical Company, Midland, Mich.

LATEX X-2144, *Saran-type latex emulsion used in modified portland cement concrete mortars;* Dow Chemical Company, Midland, Mich.

LATICRETE-L, *synthetic rubber-based copolymer;* Webster & Sons, Ltd., 5521 Dundas Street, West, Toronto, Ont.

LMX 529-5 & 6, *epoxy joint sealing compounds;* Co-Polymer Chemicals, Inc.

MERIDON, *polymeric colorless binder;* Humble Oil & Refining Company, Houston, Texas.

MULTIWET, *liquid wetting agent;* The Deynor Corporation, One Depot Plaza, Mamaroneck, N. Y.

NEOPRENE LATEX TYPE LD-260, *latex additive used in bituminous concrete;* E. I. DuPont de Nemours Co., Wilmington 98, Del.

NEOPRENE LATEX TYPE 950, *cationic water dispersion of neoprene elastomer particles;* E. I. DuPont de Nemours Co., Wilmington 98, Del.

OXIKLEEN, *acid-type concrete cleaner;* Technical Maintenance, Inc., Trenton, N. J.

P-16 PENELASTIC, *coal tar pitch emulsion;* Penetryn System, Inc.

P-220 PRIMER, *tar based penetrating primer for concrete surfaces;* Penetryn System, Inc.

PARACRETE, *latex type bonding compound;* Parex Industries & Products, Ltd., 43 Densley Avenue, Toronto, Ont.

PARAPLASTIC, *joint sealing compound;* Servicised Products Corp., 6051 West 65th Street, Chicago 38, Ill.

PDL 7-894, *polyester resin;* American Cyanamid Company, 48 West 38th Street, New York 18, N. Y.

PENETROL, *an additive used in paints and other coatings to give penetrating quality;* The Flood Company, Hudson, Ohio.

PENETRYN, *waterproof bakelite paint for concrete surfaces;* Union Carbide Plastics Corp., Bound Brook, N. J.

PE SURFACE SEALER, *polysulfide-epoxy resin compound used for concrete;* Thiokol Chemical Corp., 780 North Clinton Ave., Trenton 7, N. J.

PERMA-CEMENT, *quick-setting cement;* Perma Cement Corporation, 2501 N. W. 75th Street, Miami 47, Fla.

PERMALASTIC POLYSULFIDE FLEXIBLE SEALER, *polysulfide joint sealant;* Permalastic Products Company, Detroit, Mich.

PERMATOP, *preproportioned epoxy resin aggregate patching compound;* Permagile Corp. of America, Commercial Street, Plainview, L. I., N. Y.

PLASTICON, *latex compound for concrete patching mortars;* Maintenance, Inc., Wooster, Ohio.

POLYESTER RESIN, *resinous surfacing compounds;* American Cyanamid Company, 48 West 38th Street, New York 18, N. Y.

POLYSULFIDE EPOXY BONDER, *bonding compound;* George W. Whitesides Co., Louisville 12, Ky.

POXYBOND, *epoxy resin concrete bonding agent;* Sonneborn, Ltd., Toronto 17, Ont.

POZZOLAN, *diatomaceous earth used as an additive in concrete mortar to make it more plastic;* Airox Company, Santa Maria, Calif.

POZZOLITH, *concrete additive for water reduction, set retardation, workability;* Master Builders Company, Cleveland 18, Ohio.

POZZOLITH, HIGH EARLY, *concrete additive for early strength;* Master Builders Company, Cleveland 18, Ohio.

PRC RUBBER CALK 120 & 3100, *polyurethane rubber joint sealing compounds;* Products Research Corp., Burbank, Calif.

PRESSTITE No. 55, *two-component cold-applied joint sealant;* Presstite Division, Martin Marietta Corp., 3738 Chonteau Ave., St. Louis 10, Mo.

PRESSTITE 1190 CONCRETE ADHESIVE, *epoxy bonding compound;* Presstite Division, Interchemical Corp., 3738 Chonteau Ave., St. Louis 10, Mo.

PRIMOID, *latex emulsion;* Primoid of New England, Inc., Worcester, Mass.

PROTECT-A-WELD, *bonding agent;* U.S. Protective Coatings, Inc., Baltimore, Md.

RESIWELD, *epoxy resin compounds;* H. B. Fuller Company, 1201 Fuller Road, Linden, N. J.

SELECTRON 5196, *polyester resin;* Pittsburgh Plate Glass Co., One Gateway Center, Pittsburgh 22, Pa.

SIKA AER, *air-entraining admixture;* Sika Chemical Corporation, Passaic, N. J.

SIKA SEAL, *surface sealing liquid used to paint pier caps and other concrete surfaces;* Sika Chemical Corporation, Passaic, N. J.

SIKA SET, *concrete additive for set acceleration;* Sika Chemical Corporation, Passaic, N. J.

SPEED-CRETE, *quick-setting cement and aggregate prepackaged mixture;* Speed-Crete of Louisiana, Inc., 3631 Airline Highway, Metairie, La.

STERNSON BONDING AGENT, St-431, *epoxy resin concrete bonding agent;* G. F. Stern & Sons, Ltd., Brantford, Ont.

SUPERSOL DDM, *catalyst for polyester resin compounds;* Lucidol Division, Wallace & Tiernan Corp., 1740 Military Road, Buffalo 5, N. Y.

SURCO YELLOW LABEL, *latex bonding compound;* Howat Concrete Company.

THIOBOND PE-166-A-144, *epoxy-polysulfide bonding compound;* Steelkote Manufacturing Co., St. Louis, Mo.

THIOCALK, *joint sealant;* Charger Products Company.

THIOKOL EPOXY RESIN MD-143, *bituminous resin compound;* Permalastic Products Company, Detroit, Mich.

THIOKOL LP, *liquid polysulfide polymer;* Thiokol Chemical Corp., 780 North Clinton Ave., Trenton 7, N. J.

THIOKOL PE 101, *polysulfide-epoxy bonding compound;* Thiokol Chemical Corp., 780 North Clinton Ave., Trenton 7, N. J.

UNIPROOF #33, *bituminous mastic compound used for coating and protecting pier caps and other concrete surfaces;* Armstrong Paint & Varnish Co., Chicago, Ill.

UNIWELD, *epoxy resin based bonding compound;* Permagile Corp. of America, Woodside 77, N. Y.

VAPOR BARRIER, *surface sealing liquid used to paint pier caps and other concrete surfaces;* Ziegler Chemical & Mineral Corporation, Great Neck, N. Y.

VERIWET, *cartridge of wetting agent;* The Deynor Corporation, One Depot Plaza, Mamaroneck, N. Y.

VERSAMID 140, *curing agent for epoxy resin;* General Mills Company, Chemical Division, 20800 Center Ridge Road, Cleveland, Ohio.

VIADON, *polymeric colorless binders;* Humble Oil & Refining Co., Houston, Texas.

WELDCRETE, *polyvinyl acetate bonding compounds;* Webster & Sons, Ltd., Brantford, Ont.

WYTON, *polymeric colorless binder;* Velsicol Chemical Company, 330 E. Grand Ave., Chicago, Ill.

ZZL, *hydroxy-aliphatic amines, curing agents for epoxy resins;* Bakelite Corporation.

No. 2191, *polyester resin;* Molder Fiber Glass Company, Ashtabula, Ohio.

Equipment

AIRPLACO BONDACTOR, *dry-mix shotcrete machines;* Air Placement Equipment Co., 1000 West 25th Street, Kansas City, Mo.

AIRPLACO WD GUN, *wet or dry-mix shotcrete machine;* Air Placement Equipment Co., 1000 West 25th Street, Kansas City, Mo.

ALLENTOWN PNEUMATIC GUN, *shotcrete machine;* Allentown Pneumatic Gun Co., 1520 Walnut Street, Allentown, Pa.

BROYHILL RESINOUS PAVING MACHINE, *truck-mounted distributor for applying two-component epoxy resins;* The Broyhill Company, Dakota City, Neb.

JETCRETER, *dry-mix shotcrete applicator;* Engineered Equipment, Inc., 1001 Linden Avenue, Waterloo, Iowa.

JITTERBUG, *small concrete tamping machine;* Goldblatt Tool Company, 1910 Walnut Street, Kansas City 8, Mo.

NEEDLE SCALER, *pneumatically-operated needle gun;* Ingersol-Rand Company, 11 Broadway, New York 4, N. Y.

QUICKSPRAY GUN, *special spray gun for incorporating fine aggregate in sprayed resinous coatings,* Quickspray, Inc., Lorain, Ohio.

RESIN MASTER SPRAY GUN, *hand-held air spray for resinous compounds;* Cathea Concrete Restorations, Ltd., 198 Martin Street, Milton, Ont.

ROUTER, *routing or grooving machine for cleaning pavement cracks and joints;* Windsor Machinery Company, 85 Grassmere Ave., Elmwood 10, Conn.

SPRAY GUN, *two-component, nozzle-mixing spray gun;* Pyle Industries, Inc.

SPRAYTON GUN MODEL 18, *wet-mix shotcrete machine;* Sprayton Equipment Co., 18055 James Couzens Highway, Detroit 35, Mich.

TENNANT, *pavement scarifier and router;* G. H. Tennant Company, 701 No. Lilac Drive, Minneapolis 22, Minn.

TROWELING COMPOUND MIXER, *a continuous type mixer for mixing resins, hardeners and fine aggregates for troweling compounds, using an extrusion screw mixing unit;* G. Diehl Matteer Company, Wayne, Pa.

TRUE GUN-ALL, *wet-mix shotcrete machine;* True Gun-All Division, Detroit Tool Engineering Co., Lebanon, Mo.

VACKER, *large industrial vacuum cleaner for final cleaning of repair surfaces;* Black & Decker Mfg. Co., Towson 4, Md.

VON ARX AIR GUN, *pneumatically-operated needle gun;* C. J. Breitenstein Company, 8805 Sheridan Drive, Buffalo 21, N. Y.

WET WATER MIXER, *attachment for shotcrete to add wetting agent to mixing water;* Deynor Corporation, One Depot Plaza, Mamaroneck, N. Y.

ZIMATICRETER, *cement gunning machine for dry or wet-mix shotcrete;* Zimmerman Manufacturing Co., Ephrata, Pa.

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