NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM
SYNTHESIS OF HIGHWAY PRACTICE

FAILURE AND REPAIR OF CONTINUOUSLY REINFORCED CONCRETE PAVEMENT

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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM
SYNTHESIS OF HIGHWAY PRACTICE 60

FAILURE AND REPAIR OF CONTINUOUSLY REINFORCED CONCRETE PAVEMENT

RESEARCH SPONSORED BY THE AMERICAN ASSOCIATION OF STATE HIGHWAY AND TRANSPORTATION OFFICIALS IN COOPERATION WITH THE FEDERAL HIGHWAY ADMINISTRATION

AREAS OF INTEREST:

PAVEMENT DESIGN AND PERFORMANCE
CONSTRUCTION
MAINTENANCE
(HIGHWAY TRANSPORTATION)

TRANSPORTATION RESEARCH BOARD
NATIONAL RESEARCH COUNCIL
WASHINGTON, D.C. JULY 1979

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 and Transportation Officials initiated in 1962 an objective national highway research program employing modern scientific techniques. This program is supported on a continuing basis by funds from participating member states of the Association and it receives the full cooperation and support of the Federal Highway Administration, United States Department of Transportation.

The Transportation Research Board of the 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, nonprofit 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 and transportation departments and by committees of AASHTO. 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 and Transportation 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 Transportation 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.

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PREFACE

There exists a vast storehouse of information relating to nearly every subject of concern to highway administrators and engineers. Much of it resulted from research and much from successful application of the engineering ideas of men faced with problems in their day-to-day work. Because there has been a lack of systematic means for bringing such useful information together and making it available to the entire highway fraternity, the American Association of State Highway and Transportation Officials has, through the mechanism of the National Cooperative Highway Research Program, authorized the Transportation Research Board to undertake a continuing project to search out and synthesize the useful knowledge from all possible sources and to prepare documented reports on current practices in the subject areas of concern.

This synthesis series attempts to report on the various practices, making specific recommendations where appropriate but without the detailed directions usually found in handbooks or design manuals. Nonetheless, these documents can serve similar purposes, for each is a compendium of the best knowledge available on those measures found to be the most successful in resolving specific problems. The extent to which they are utilized in this fashion will quite logically be tempered by the breadth of the user's knowledge in the particular problem area.

FOREWORD

By Staff
Transportation
Research Board

This synthesis will be of special interest and usefulness to highway design and maintenance engineers and others seeking information on design, construction, maintenance, and repair of continuously reinforced concrete pavement (CRCP). Detailed information is presented on maintenance and repair techniques currently used for CRCP.

Administrators, engineers, and researchers are faced continually with many highway problems on which much information already exists either in documented form or in terms of undocumented experience and practice. Unfortunately, this information often is fragmented, scattered, and unevaluated. As a consequence, full information on what has been learned about a problem frequently is not assembled in seeking a solution. Costly research findings may go unused, valuable experience may be overlooked, and due consideration may not be given to recommended practices for solving or alleviating the problem. In an effort to correct this situation, a continuing NCHRP project, carried out by the Transportation Research Board as the research agency, has the objective of synthesizing and reporting on common highway problems. Syntheses from this endeavor constitute an NCHRP report series that collects and assembles the various forms of information into single concise documents pertaining to specific highway problems or sets of closely related problems.

The performance of CRCP has revealed a number of failure modes that are traceable to design, construction, materials, and maintenance deficiencies and such other factors as environmental conditions and traffic loadings. This report of the Transportation Research Board includes a review of the cumulative experiences of states that have constructed and maintained CRCP. Guidelines for repair techniques are included, and areas of needed research are identified.

To develop this synthesis in a comprehensive manner and to ensure inclusion of significant knowledge, the Board analyzed available information assembled from numerous sources, including a large number of state highway and transportation departments. A topic panel of experts in the subject area was established to guide the researchers in organizing and evaluating the collected data, and to review the final synthesis report.

This synthesis is an immediately useful document that records practices that were acceptable within the limitations of the knowledge available at the time of its preparation. As the processes of advancement continue, new knowledge can be expected to be added to that now at hand.

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Adrian G. Clary, Engineer of Maintenance, Transportation Research Board; Lawrence F. Spaine, Engineer of Design, Transportation Research Board; and Bob H. Welch, Associate Engineer of Materials and Construction, Transportation Research Board, assisted the Special Projects Staff and the Topic Panel.

Information on current practice was provided by many highway and transportation agencies. Their cooperation and assistance was most helpful.

FAILURE AND REPAIR OF CONTINUOUSLY REINFORCED CONCRETE PAVEMENT

SUMMARY

Continuously reinforced concrete pavements, like all pavements, are designed and constructed with the suppositions that: (a) maintenance service will be a necessity if the reduction in serviceability that begins immediately following opening to traffic is to be controlled within limits that will provide adequate service life; and (b) maintenance service requirements will increase with time and pavement use until maintenance no longer offers an economical means for providing acceptable serviceability, at which point some form of rehabilitation will become necessary.

Except for the continuously reinforced concrete pavements that have failed to perform up to expectations because of insufficient thickness, most are giving acceptable performance. Observed structural deficiencies include several kinds of cracking, spalling at cracks, steel rupture, blowups, punchouts, and lug-anchor terminal waves. Generally similar deficiencies also have been observed in jointed pavements, although at different relative frequencies. Underlying causes may at times also be different.

The principal causes of imperfections in CRCP, and of distress and failures that require remedial action, appear to be fairly well known. Where more than one cause is involved, as is very often the case, the mechanisms and interactions that intensify and speed failure are not always thoroughly understood. The initial or primary cause of failure is not always identifiable.

The stress-relieving transverse cracks that develop in all CRCP give generally good service in adequately designed and well-constructed CRCP. These same cracks in underdesigned or poorly constructed pavements have become the focal points of distress, especially where spacings are short.

The most severe type of failure in CRCP is the punchout in which fragments of loosened concrete are punched by traffic into the underlying material. Steel rupture may or may not accompany the formation of a punchout. Corrosion can reduce the shear and tensile strength of the steel. Typically, punchout failures begin between two closely spaced transverse cracks (or a Y-crack) near the edge of the pavement and progress inward to form a longitudinal crack if one is not already present. Thus the cracks complete the perimeter of what will become the punchout.

Preventive maintenance to prolong the life of currently serviceable CRCP is highly desirable, especially in view of the cost and difficulty of repair when failure occurs. Useful preventive maintenance techniques include sealing (or resealing) of the joint between the concrete pavement and the asphaltic concrete paved shoulder, general shoulder upkeep, the addition of underdrains at locations of pumping or visible water entrapment, and asphalt undersealing or cement-grout application to fill voids. Quantitative information on the cost-effectiveness of preventive main-

tenance is lacking, and consequently maintenance often becomes a secondary activity where demands are high simply to keep a pavement passable.

Restorative maintenance, or repair, of CRCP is costly and time-consuming because of the incorporated heavy reinforcement. Patching is the most usual form of repair. Restoration of the failed area to the same condition as the surrounding pavement, or permanent patching, is the usual goal. Temporary patches, however, must sometimes be used, as when a hole demands immediate action. Temporary patching also is used under various circumstances as a holding measure.

Hot-applied or cold-applied asphaltic plant mixtures are satisfactory for temporary patches. Hot-applied mixtures should be given preference if available. Removal of loose material, and in some cases the steel, will extend temporary patch life.

Permanent patching with portland cement concrete is a multistep process that requires careful attention to details for satisfactory results. Some important guidelines for permanent patching of CRCP follow:

- Maintain careful and timely surveillance so that repair needs are identified before damage becomes extensive; try to avoid days of extreme temperature and temperature changes when patching.
- Make sure that all devices for traffic control are on hand, that the maintenance crew knows how to use them, and that closure is in order before repair work is started; repair only one lane at a time.
- Mark patch boundaries clearly, being sure to include all of the damaged area; boundaries should be a minimum of 1.5 ft (0.5 m) away from the nearest sound transverse crack if possible.
- Saw patch edges deep enough to avoid spall at break-out, being careful not to cut the reinforcement.
- Select and use tools to match patch size—jackhammers alone to break-out for small patches, heavier mechanized break-out and loading equipment for large patches.
- Use care to provide a vertical face in sound concrete at the patch edges.
- With a saw or torch, cut steel that is to remain for splicing.
- Use heavy mechanized equipment only where steel is to be removed; do not subject remaining steel to bending.
- Remove all concrete; then inspect and restore base at least to original condition, preferably with new concrete when practicable, and provide proper drainage if needed.
- Replace removed steel with Grade 60 bars in same amount, and tie or weld as desired.
- Place a side form if needed.
- Perform final cleanup and wet base, patch faces, and steel immediately before concrete placement.
- Use a concrete mixture containing Type I cement, enriched with added cement if early opening is desired.
- Consolidate the concrete by internal vibration, using special care around the steel and at the patch faces.
- Final-finish the surface to match the smoothness and texture of the surrounding pavement.
- Apply curing compound immediately after patching has been completed.
- Do not open to traffic until concrete has achieved adequate strength; 3- and 4-hour curing periods are not sufficient for long-term service.

Slabjacking can be used to correct CRCP distortion in areas of expansive soils and foundation settlement if knowledgeable and experienced crews are available to avoid further damage.

Transversely cut openings are sometimes needed and useful to relieve expansion pressure that may force a pavement blowup or lug-anchor terminal waves.

A considerable amount of research effort has been expended on CRCP, but accumulating performance history and maintenance experience provide a strong incentive for further research. Areas where additional information is needed include:

- A thickness design method that provides for better consideration of the principal variables of influence.
- A reinforcement design method that can optimize selection of steel content for climate, crack spacing, and crack width.
- Variable crack spacing including cluster cracking and means for reduction.
- Mechanisms of failure and interactions between causes.
- Value, frequency of application, interrelationships, and cost effectiveness of the various available preventive and restorative maintenance procedures.
- Improved cost-effective procedures for preventive and restorative maintenance.
- Design methods for CRCP overlays and for overlays of CRCP.

CHAPTER ONE

INTRODUCTION

The principle of continuous reinforcement in concrete pavements was introduced many years ago to avoid the need for transverse joints. Although these joints had proved preferable to the uncontrolled cracks of uncertain size and location that were sure to develop otherwise, they often became focal points of distress in otherwise serviceable pavements and frequent sources of travel discomfort. Continuous reinforcement offered the alternative of omitting the joints and permitting cracks to form, but held tightly closed, thereby providing load transfer and freedom from sealing.

Cracks in continuously reinforced concrete pavement (CRCP) form at close intervals (Fig. 1). Such conditions as the type and amount of longitudinal steel, air temperature at concrete placement, air temperature range at an early age, the composition and uniformity of the concrete, base friction, traffic loadings, and air temperature drops from the placing temperature all affect crack spacing (*1, 2*). Cracking begins during the first few days following construction and continues for the life of the pavement, although typically most cracks form within the first three or four years. Pavements that perform well usually have average crack spacings of about 3 to 10 ft (1 to 3 m) (*3*). If cracks are too widely spaced, there is a danger of wide openings with a consequent loss of aggregate interlock and rupture of the steel, which would destroy continuity. Fortunately, the steel content of the pavement can be selected to avoid this condition. Crack intervals that are too short can add an undesirable flexibility to the pavement that also is to be avoided. The cracks in well-designed and constructed CRCP have not experienced excessive spalling or widening (Fig. 2).

Continuously reinforced concrete pavements, like all pavements, today are designed and constructed with the suppositions that: (a) maintenance service will be economically necessary to provide adequate pavement life; and (b) maintenance service requirements will increase with time and pavement use until maintenance no longer offers an economical means for providing acceptable serviceability, at which time some form of rehabilitation must be applied.

During the design process, careful attention in the selection of pavement and base type and in relating the design to the forces of deterioration that are to be combatted is of

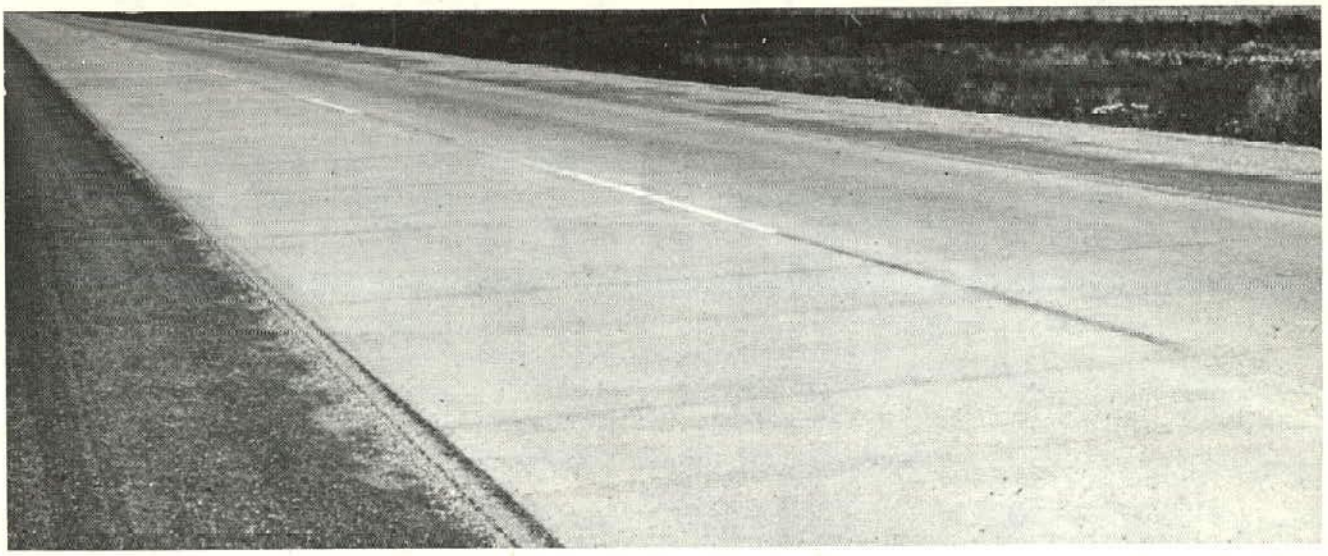

Figure 1. Normal transverse crack pattern.

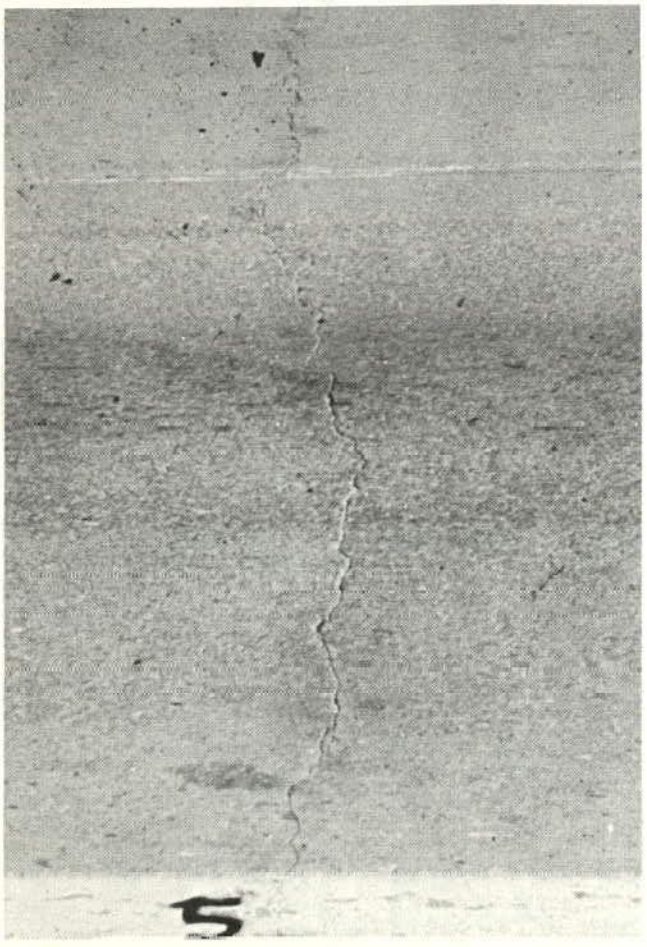

Figure 2. Typical tight transverse crack.

aid in reducing maintenance requirements and in prolonging useful pavement life. So also are the judicious application of construction processes and selection of materials.

More than 13,000 equivalent two-lane miles (21 000 km) of CRCP have been constructed, all but 80 miles (130 km) since 1958. The equivalent of 350 two-lane miles (563 km) of CRC overlay also have been constructed since 1959. Less than 200 equivalent two-lane miles of CRCP have been resurfaced to date, all with bituminous concrete.

Most users of CRCP are reasonably well satisfied with the service they are receiving. Over-all, the amount and severity of the distress that has occurred usually have been within normal bounds for pavements serving high volumes of heavy traffic, as do most continuously reinforced pavements. Nevertheless, disappointing service is not unknown in CRCP. Fortunately, the reasons for poor performance appear to be generally avoidable through judicious application of current information at the design and construction stages. The essentials of CRCP design and construction practice considered to be the best currently available are outlined in Appendix A. The reader's attention also is directed to reference (*3*) for additional summarization of the subject.

Advantages that have been attributed to CRCP include improved riding quality, safety, relatively long life, and limited need for maintenance. Easy, low-cost repair when restoration becomes necessary has never been cited as an attribute. CRCP is indeed more difficult and expensive to repair than other pavements because of the large quantity of heavy steel reinforcement. As a consequence, application of the best available knowledge regarding not only the design and construction but also the maintenance of CRCP offers the opportunity for substantial savings in both maintenance expenditures and replacement costs. Early users with extensive mileages of CRCP are now finding the expenditure of money and time for CRCP maintenance to be significant. With the greater portion of the mileage of this relatively new kind of pavement still at a comparatively youthful age, substantial increases in maintenance requirements can be expected in the years ahead.

CHAPTER TWO

MODES OF FAILURE AND UNDERLYING FACTORS

For the prevention of abnormal early failures and for satisfactory control of the normal wear and tear that can be expected to occur in the life of a pavement, it is important to know the failures that may take place, the manner in which they occur, and the underlying causes. Because of the relative newness of CRCP, reliable information on these subjects is only now becoming generally available.

"Deficiency" is but one of many terms used in discussions of pavement condition that require definition and description for full communication. A proposed standardized nomenclature with definitions applying to both pavement components and deficiencies is available for conventional pavements (*5*). No similar standardized nomenclature is currently available for conditions unique to CRCP. The Associated Reinforcing Bar Producers and others are developing this nomenclature.

For the purposes of this synthesis, the nomenclature and definitions for pavement condition offered by the Highway Research Board (now Transportation Research Board) Committee on Pavement Condition Evaluation (*5*) are used. Where necessary, they are supplemented by nomenclature and definitions used primarily by authors of reports pertaining to CRCP condition.

The term "deficiency" as applied herein to CRCP condition covers all imperfections ranging from the very minor to the total "failure" that requires immediate correction for continuation of satisfactory traffic service. The term "defect" is used to describe an imperfection that experience has shown is sometimes a forerunner of "failure." The term "distress" is used to describe a condition that almost certainly will become a "failure" if unattended.

Failures that occur in CRCP are rarely catastrophic in the sense that they occur suddenly and without warning. Evidence that failure may take place almost always becomes visible first as a defect, then as distress, before failure occurs. The progression from defect through distress to failure may be very slow or may not take place at all during the life of a pavement, or on occasion it may be very rapid.

Deficiencies known to occur in CRCP are named and defined in the sections immediately following. Early signs of potential weakness are described, and the mechanisms through which deficiencies develop and the underlying causes are discussed. A thorough understanding of these factors should aid in selecting maintenance procedures for avoiding or postponing problems and for providing reliable corrections when problems do develop.

The pavement deficiencies that are discussed are related primarily to the structural character of CRCP. Such deficienices as surface scale, crazing, and loss of skid resistance that usually do not affect the structural capacity of concrete pavements are not discussed.

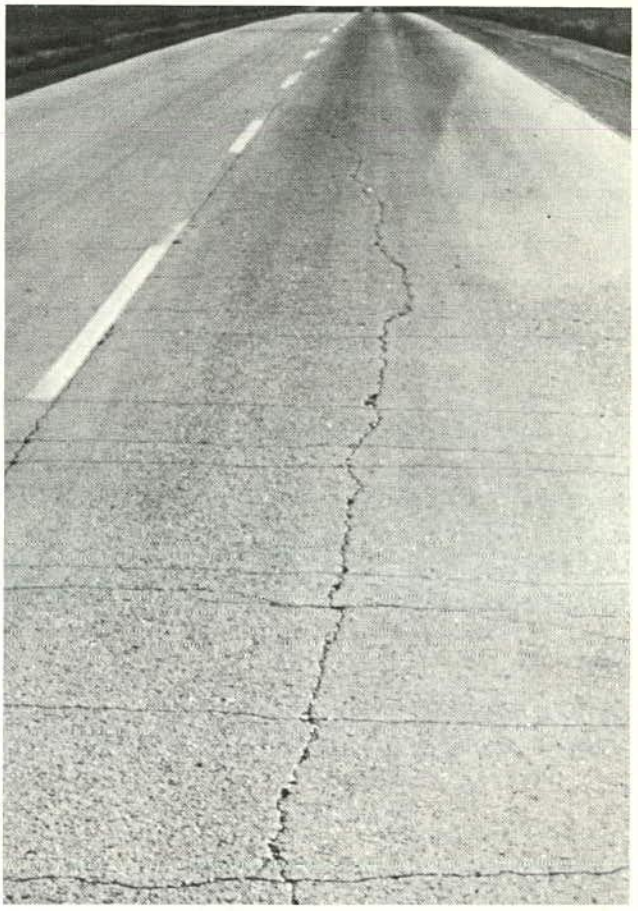

Figure 3. Longitudinal cracking.

Figure 4. Diagonal cracking.

CRACKING

Uncontrolled cracking occurs in all kinds of pavement and takes many forms and patterns. Causes of the various forms of cracking can be very different. CRCP is unique in that the occurrence of random transverse cracks at frequent intervals is expected based on the design.

Definition

Terms and definitions that were developed primarily to describe and distinguish the different kinds of cracking that occur in jointed concrete pavement (*5*) are generally appropriate for the same kinds of cracking in CRCP. These are used herein where applicable, sometimes with minor modifications. Only two additional terms, "Y-crack" and "cluster cracking," have been introduced.

A *transverse crack* is any crack or break essentially at right angles to the pavement centerline (Fig. 2). A *longitudinal crack* is any crack or break approximately parallel to the pavement centerline (Fig. 3). A *diagonal crack* extends in a direction oblique to the pavement centerline (Fig. 4). A *Y-crack* is a crack or break with a Y or forked appearance (Fig. 5). *Cluster cracking* is a grouping of three or more closely spaced transverse cracks or Y-cracks where the spacings may be on the order of 6 to 24 in. (150 to 600 mm); clusters can extend to 10 ft (3.0 m) longitudinally (Fig. 6). *D-cracking* consists of a series of fine, discolored, and darkened, hairline, crescent-shaped cracks in the concrete surface usually paralleling a joint or crack and generally curving across slab corners (Fig. 7).

The foregoing terms and definitions cover all of the principal types of cracking that have been observed in CRCP. A few types only rarely seen in CRCP or without structural importance are not included.

Early Signs

Transverse cracks are allowed and expected to develop randomly in CRCP. Tight transverse cracks showing little spall in CRCP are, like transverse joints in a well-designed and well-constructed jointed concrete pavement, deficiencies only to the extent that they are interruptions in what might be considered the ideal but so far unattainable concrete pavement—a single, unbroken ribbon of concrete. Transverse cracks in groups at close intervals, i.e., cluster cracking, can be the sign of a potential problem area (see later section on punchouts). Any abnormal increase in the amount of transverse cracking, especially when accompanied by an increase in spalling, also can be a sign of problem development.

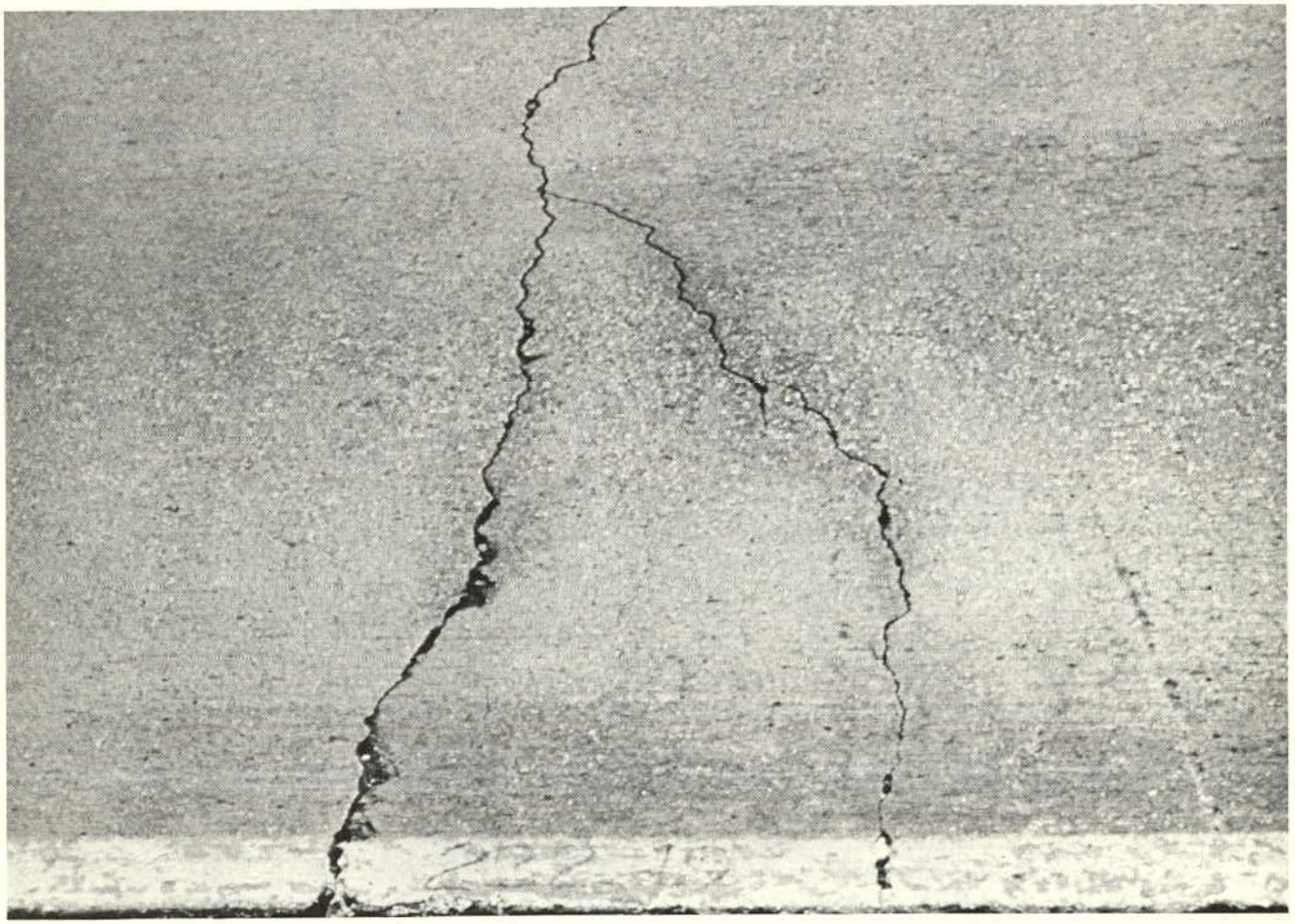

Figure 5. Y-cracking.

Figure 6. Cluster cracking.

Figure 7. D-cracking.

Longitudinal cracking in CRCP, unlike transverse cracking, is not a planned or expected happening. In this respect it can be considered to be a deficiency even at its slightest stage. Most longitudinal cracking, and especially that which results when fracture does not take place at weakened-plane longitudinal joints as planned, does not become a performance problem nor is it usually a precursor of problem development elsewhere. Occasionally, however, and especially where progressive widening or spalling of the crack becomes evident, a longitudinal crack can signify the beginning of foundation settlement that prompt treatment may control. If unattended, the open crack can provide easy entry for surface water to aggravate an already damaging condition. Longitudinal cracking, if not already present, may take place during the development of punchouts.

Diagonal cracking is infrequent in CRCP, but whenever present can be viewed with suspicion as an indicator of the existence of a foundation problem (settlement or expansion) that may be controllable through early treatment.

Y-cracking appears to develop mostly when nominally transverse cracks meander sufficiently to either branch or join. Like closely spaced transverse cracking, it can be a problem location if the underlying support weakens.

D-cracking is a progressive condition in that the first cracks that appear at junctions of joints and cracks with other joints and cracks and with the pavement edges progress outward to involve greater slab areas. Cores have shown that the entire thickness of the pavement has become affected by the time the condition becomes visible on the surface. The development of D-cracking is strongly dependent on the physical and chemical character of the ingredients of the concrete mixture, especially the coarse aggregate. No maintenance procedures are known that will slow or stop the progression of deterioration in susceptible concrete. Early recognition of D-cracking can assist in avoiding the use of unsatisfactory materials or combinations of materials elsewhere but is not of consequence in prolonging the life of an affected pavement.

TABLE 1

FACTORS THAT INFLUENCE CRACK SPACING (*3*)

I. *System Stiffness*
   - A. Thickness of concrete
   - B. Concrete modulus of elasticity
   - C. Underlying support
   - D. Bond
   - E. Steel amount and depth

II. *Restraint to Length Changes*
   - A. Internal restraints
     1. Steel: amount, surface area, deformations, connection to transverse steel, strength, coefficient of expansion, creep characteristics.
     2. Concrete: thickness, strength, modulus of elasticity, shrinkage, creep.
   - B. External restraints
     1. Friction on base
     2. Bond to adjacent lane
     3. Distance from end
     4. Encroachment of adjacent pavement

III. *Construction*
   - A. Laps
   - B. Consolidation
   - C. Construction joints
   - D. Environmental conditions
     1. Temperature
     2. Precipitation

IV. *Time*
   - A. Changing concrete properties
   - B. Environmental conditions
     1. Temperature variations
     2. Precipitation
   - C. Changing bond conditions
   - D. Corrosion
     1. Deicing chemicals
   - E. Traffic
   - F. Base erosion

Mechanisms of Distress and Underlying Factors

The vast majority of cracks that occur in CRCP, especially the stress-relieving transverse cracks that are an essential and planned characteristic of CRCP, do not become focal points of distress and failure. However, when distress or failure does occur, cracking is invariably present. Most cracking results from one or more of the following actions to which concrete can be subjected (*2*):

1. Volumetric changes, which may be due to (a) drying shrinkage, (b) creep under sustained load, (c) thermal stresses including elevated temperature, (d) chemical incompatibility of concrete components.
2. Direct stress due to applied loads or reactions, internal stress due to long-term deflection, and environmental effects including differential movement in structures.
3. Flexural stress due to bending.

In CRCP, the stresses that induce cracking through loss of foundation support appear to have a particularly adverse effect on performance.

Transverse cracking in CRCP is viewed by McCullough et al. (*2*) as the result of the frictional restraint of the pavement slab to dimensional changes induced by both internal and external forces. The internal forces are associated with shrinkage and temperature; the externally induced stresses result from wheel loads and the frictional resistance between the concrete pavement and the supporting material. Shrinkage and temperature may be considered to act together at all times.

The satisfactory performance of CRCP requires that cracks be held tightly closed. Open cracks are sure signs of substandard performance and a need for corrective action. Open transverse cracks have often been traceable to improper lapping of the longitudinal reinforcement. Overstressing of the reinforcement also has been associated with open cracks, as will be discussed in a following section on steel rupture.

The spacing of transverse cracks, along with the associated crack openings, profoundly affects the performance of CRCP. Table 1 includes a wide range of factors that

influence crack spacing in concrete. Steel percentage has a definite influence on crack spacing in CRCP—the more steel, the closer the spacing for a given slab thickness. Although not enough quantitative information is available, what is available indicates that such factors as bond area of steel, depth of reinforcement, friction between concrete and base, concrete strength, time of year and even time of day when constructed, and temperature while curing all definitely influence crack spacing in CRCP (*3*).

Cluster cracking is believed to be associated with such factors as localized areas of change in subgrade support, lack of concrete consolidation, inadequate pavement thickness, high base friction, poor drainage, and high temperatures at the time of construction (*3*). Concrete mixture variability might be added to the foregoing list. Because cluster cracking is so often seen early in the life of a pavement, traffic loads probably are not a basic cause. Knowledge of the relative impacts of the causes of cluster cracking is incomplete.

Cluster cracking is sometimes observed near transverse construction joints, especially on the "morning" construction side and especially when the adjoining concrete has been in place for some time. High stress from temperature change before the concrete has achieved adequate strength is a likely major cause of the cracking. Substandard concrete, commonly found in the final batches of the day and also in the start-up batches, is often thought to be a contributing factor. Poor concrete consolidation has also been identified at these locations.

Longitudinal cracking was found in early CRCP experimentation to almost certainly occur where longitudinal stress-relief joints were not used to divide the pavement slab into widths about equivalent to a normal traffic lane. The use of sawing or insertion of a plastic strip to cause a separation to occur at the resultant weakened section (usually a lane line) has proven to be a reasonably effective means for avoiding most longitudinal cracking. Where longitudinal cracking has continued to occur, it usually can be attributed to late sawing, shallow saw-cut depth, improper placement or omission of the plastic separator strip, or the use of a strip too narrow in relation to pavement thickness to produce the desired effect. Longitudinal cracking resulting from these causes at times may be unsightly but rarely advances to a problem stage unless more deep-seated problems are present.

Longitudinal cracking, and sometimes diagonal cracking, may be seen in localized areas where traffic load stresses have become concentrated through loss of pavement support due to such factors as foundation settlement and base erosion. The formation of cracks under these conditions often presages ultimate total failure. Open cracks provide water access to the underlying materials, which become active agents in the failure process.

D-cracking, although still under study, is generally considered to be a concrete material problem attributable to freeze-thaw cycles and a peculiar aggregate pore structure (*5*).

SPALLING

Spalling in CRCP usually occurs at cracks. It is seen more rarely at construction joints and in the concrete surface at reinforcement locations.

Definition

Spalling is defined as the breakdown or disintegration of slab edges at joints or cracks or directly over reinforcing steel, usually resulting in the removal of sound concrete (*5*). Typical spalling at cracks in CRCP is shown in Fig. 8.

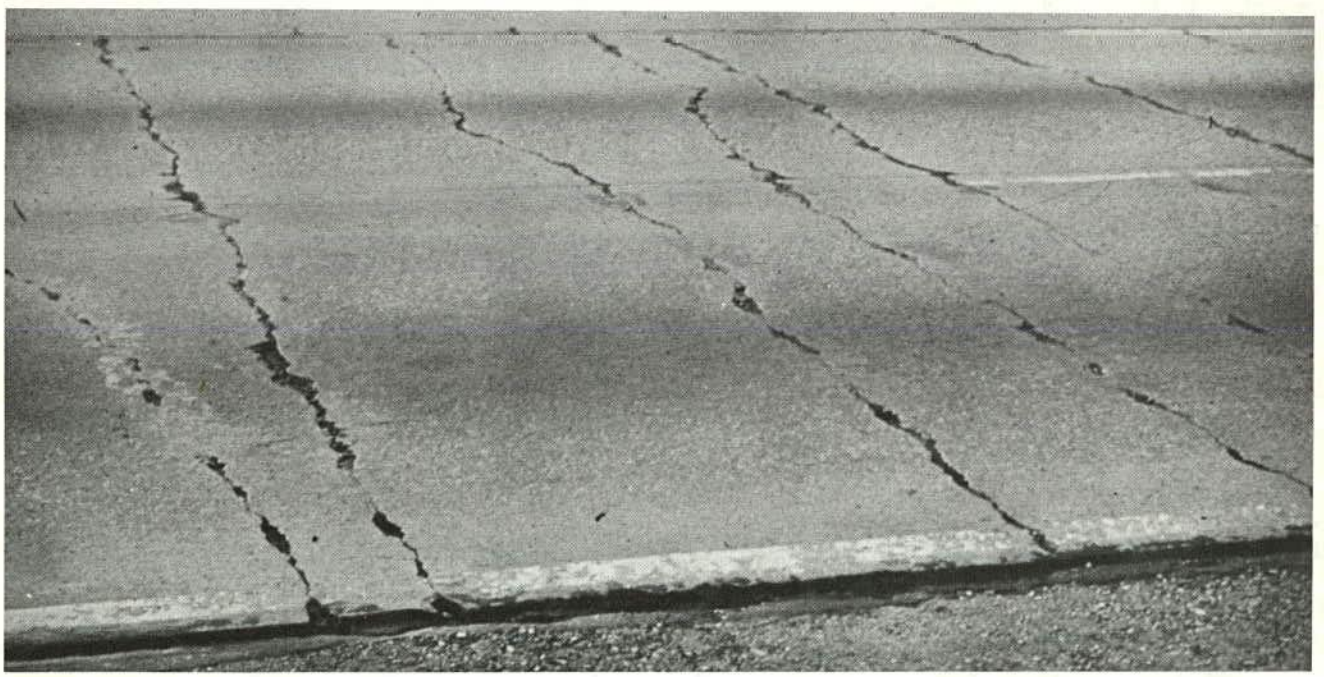

Figure 8. Spalling at cracks (4).

Slight spalling, in which the flaking is confined mostly to the mortar in the concrete matrix, is sometimes referred to as raveling. Although slight spalling is often seen at cracks in CRCP, it usually is not a progressive form of deterioration nor is it of structural consequence. Spalling alone, without accompanying deterioration, rarely becomes so severe that some form of maintenance is required. However, progressive spalling often is a good indicator of future distress.

Early Signs

Experience has shown that slight spalling or attrition of the slab faces at cracks and sometimes at joints in CRCP is to be expected, that it is not of structural consequence, and that ordinarily it is not a progressive condition. Because slight spalling at cracks and joints usually remains stable, its appearance cannot be considered a reliable early sign of weakness. However, any rapid increase in crack and joint spalling, especially where pieces of coarse aggregate become involved in addition to the mortar in the concrete matrix, is among the best available signs that problems of a more deep-seated nature exist. If not already obvious, the nature of the problems needs to be determined expeditiously and corrective measures applied. Slight spalling needs no maintenance; more severe spalling may produce holes that require filling for riding comfort.

Spalling over steel reinforcement in CRCP, similar to that in bridge decks, is not widespread. However, its presence has been identified in northern areas where considerable quantities of deicing salts are used, and it is considered to be a major problem in Minnesota (*30*). When spalling becomes evident, little can be done to check its progression. Hole-filling may be necessary to preserve riding quality, and partial or full-depth permanent patching may be required eventually to preserve structural integrity.

Mechanisms of Distress and Underlying Factors

The first spalling to occur at cracks probably results from discontinuities that develop during the crack propagation process as the forming crack probes for the path of least resistance (*2*). Later spalling at both cracks and construction joints results from stress concentrations induced mechanically by wear and deflection of the pavement under traffic. To some extent spalling also results from the entry of incompressibles during periods of pavement contraction followed by attendant concentrations of stress during expansion. Progressive spalling that deepens more rapidly than it expands outward is primarily related to structural weakness. Spalling that widens more quickly than it deepens [often widening to over 2 in. (50 mm) while deepening less than ½ in. (13 mm)] usually is related more to weakness of the surface concrete.

Surface spalling associated with steel reinforcement results from the pressure exerted by corrosion products when the steel rusts. Rusting is caused by moisture, oxygen, and chloride that have been able to penetrate the concrete. Inadequate concrete cover or porous concrete can allow the damaging chloride penetration.

Weak or improperly consolidated concrete can aggravate spalling.

STEEL RUPTURE

Ruptured steel in CRCP is almost invariably associated with open cracks or open construction joints [⅛ in. (3 mm) or more]. Open joints and cracks also sometimes indicate improper splicing and, more rarely, an absence of steel.

Definition

Steel rupture in CRCP is breakage and full loss of continuity in the steel reinforcement (Fig. 9).

Early Signs

Loss of tightness at any crack or joint in CRCP is evidence that the steel reinforcement is not functioning properly and is either in a weakened condition or has already ruptured. Excessive spalling is likely to be present. Rust stains on the pavement surface suggest loss of cross-sectional area and the possibility of rupture. Faulting or slab settlement often indicate that rupture has taken place. Although the actual fracture that takes place may be a rather sudden occurrence, the weakening process may be gradual, taking place over a period of time. Asphalt undersealing or application of cement grout at an early stage can postpone or avert failure. Failure usually requires repair by removing the damaged material and patching the area.

Mechanisms of Distress and Underlying Factors

At cracks in CRCP, stresses in the longitudinal steel induced only by temperature and drying shrinkage theoretically can reach very high levels (*2*). As far as is known, however, stresses from these two sources alone have never caused ruptures. One group of investigators concluded that steel ruptures initiate in much the same way as do edge punchouts described in the following section (*4*). The causes and mechanisms of failure probably are the same, the only difference being that steel rupture may take place at a transverse crack not in close proximity to another transverse crack, whereas punchouts, which may or may not include steel rupture, take place between two closely spaced cracks.

The primary cause of steel rupture probably is a localized loss of support that results in relatively high slab deflections under traffic. The high deflections increase the stress in the reinforcement and the shear that must be carried across the affected crack. Aggregate interlock becomes broken, and bond is lost between concrete and steel as deflections continue. Temperature drop and drying shrinkage add to the stress in the steel, and corrosion, if present, can have a particularly debilitating effect. Fracture of the steel members usually begins at the pavement edge where load stresses are highest and works inward as more stress is placed on the inner members. Pumping and faulting under traffic in the absence of load transfer between slabs can lead to further cracking and ultimately to failure unless remedial action is taken.

PUNCHOUTS

Although not exclusive to CRCP, punchouts seem to occur much more frequently in CRCP than in jointed pavement. Most states with extensive CRCP have experienced

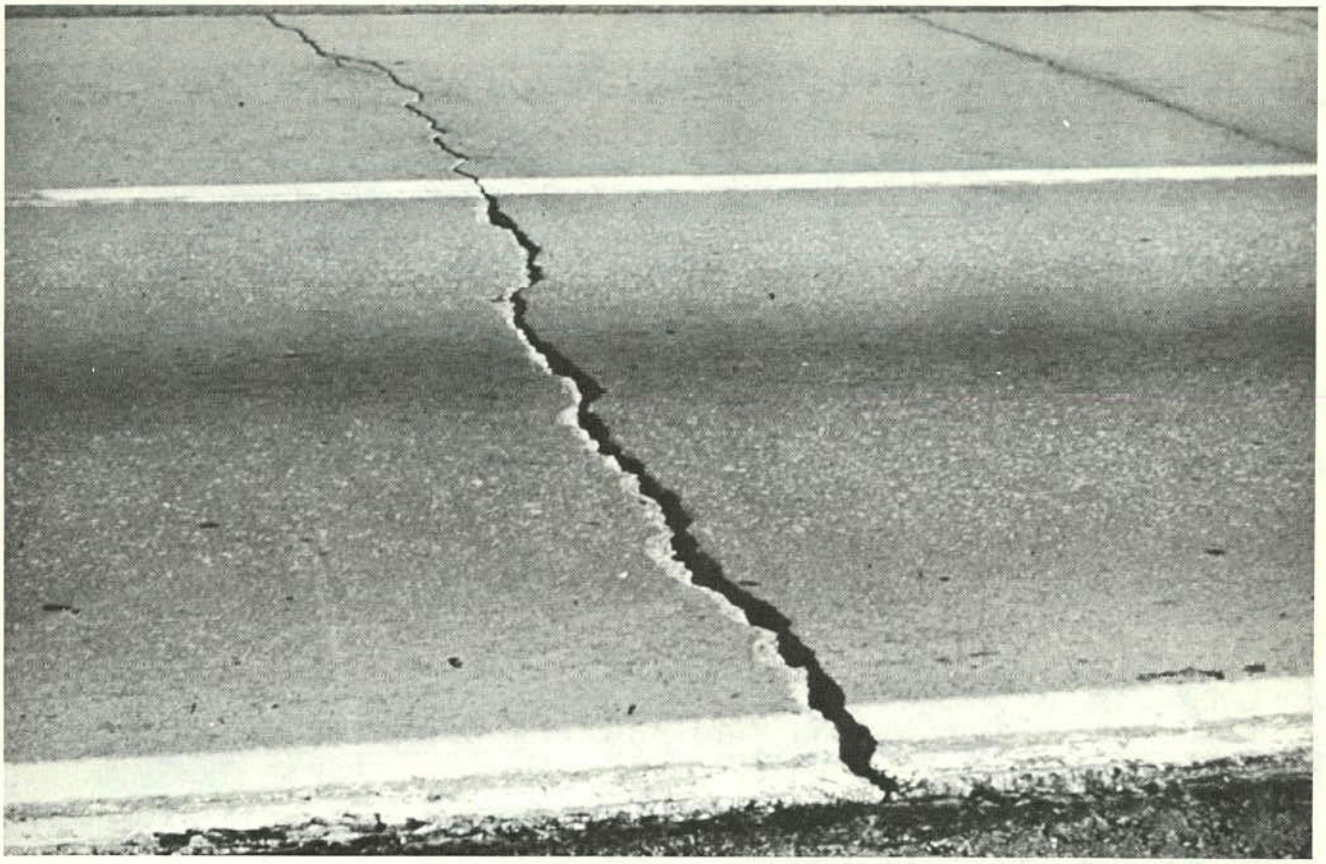

Figure 9. Open cracking indicating steel rupture (4).

punchouts, and many consider punchouts the most severe problem associated with CRCP.

Definition

A *punchout* is a structural failure in which a small segment of pavement is loosened from the main body and displaced downward under traffic. The punchout usually is bounded by two closely spaced transverse cracks, a longitudinal crack, and the pavement edge (Fig. 10) and sometimes by the branches of a Y-crack and the pavement edge. More rarely, a punchout may occur in the interior of a pavement away from the edge (Fig. 11), but these differ from edge punchouts in both severity and cause (*4*).

Early Signs

Punchouts are invariably associated either with short transverse crack spacings [1 to 2 ft (0.3 to 0.6 m)] or with Y-cracks. Short crack spacings and Y-cracks, however, are not always forerunners of punchouts and in most instances never become associated with punchout failures. Although they can be viewed with a degree of suspicion, further evidence is needed for early pinpointing of a potential punchout location. The advance of spalling at closely spaced cracks or at Y-cracks beyond the amount taking place at other cracks in the area is a more certain sign that a punchout is likely to develop; this is often accompanied by signs of pumping activity or excess trapped water. At this stage of distress, improvement of drainage, slab reseating by asphalt underseal or cement grout, and sealing of open cracks may postpone or eliminate further development of conditions leading to a punchout. Full failure requires removal of the damaged area, restoration of the base, possibly the addition of drainage, and a permanent patch.

Mechanisms of Distress and Underlying Factors

A comprehensive field study of the condition of CRCP in Illinois in 1977 found the edge punchout the major structural distress being experienced (*4*). The study covered most of the mileage of Interstate CRCP in Illinois 5 years old and older [1,230 equivalent two-lane miles (1980 km) surveyed].

The results of the Illinois field survey were combined with the results of a stress analysis and a deflection study to provide a description of the probable development mechanism of edge punchouts. A localized loss of support that results in relatively high slab deflections under heavy traffic is the prime initiating factor. The loss of support occurs in several ways, including softening of the base or underlying material by moisture accumulation, and ejection of base material by pumping action. The presence of moisture was noted in all weakening processes. The resulting high deflections under traffic increase the stress in the reinforcement and also the shear that must be transmitted across cracks. The wider the crack, the sooner the aggregate interlock will break down under repeated loadings.

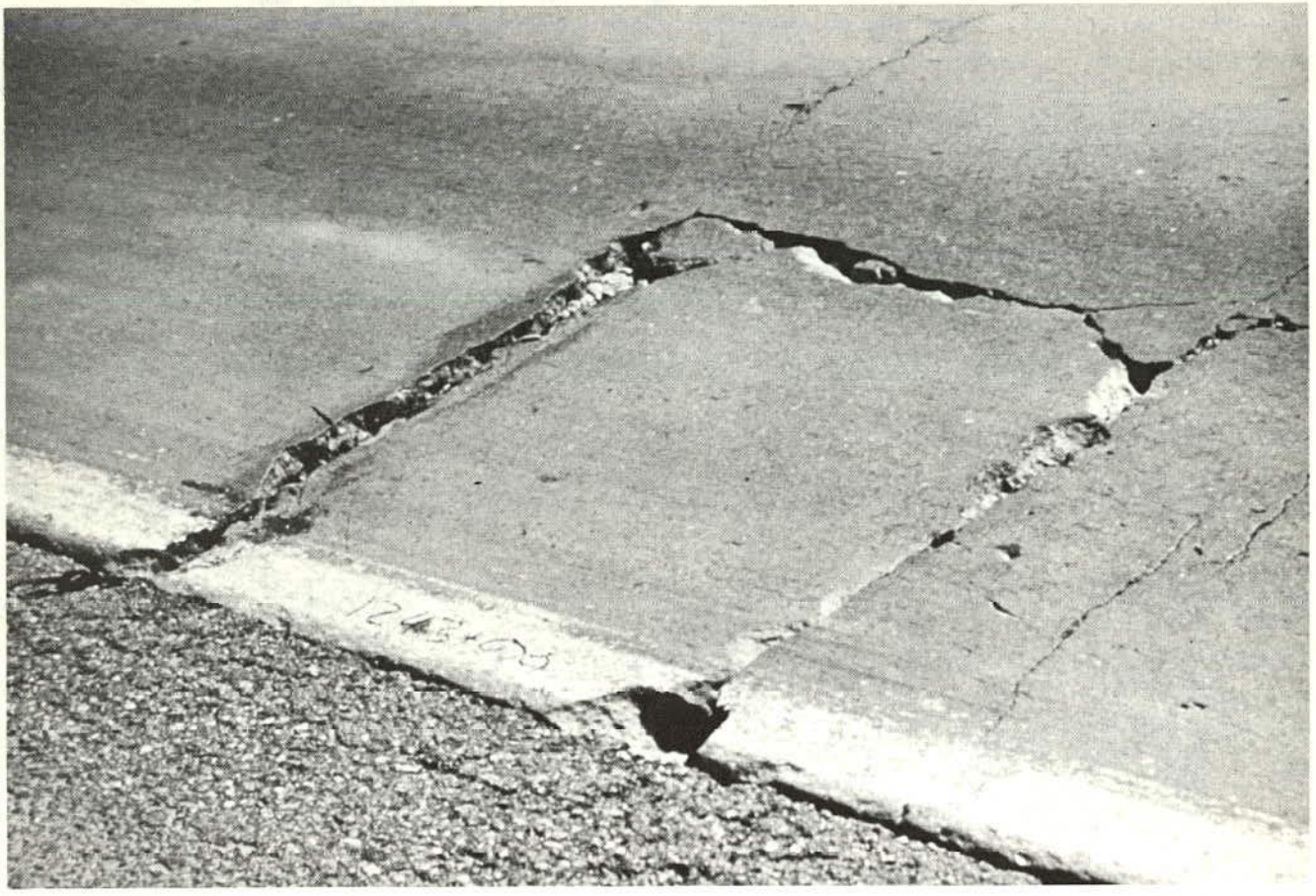

Figure 10. Edge punchout (4).

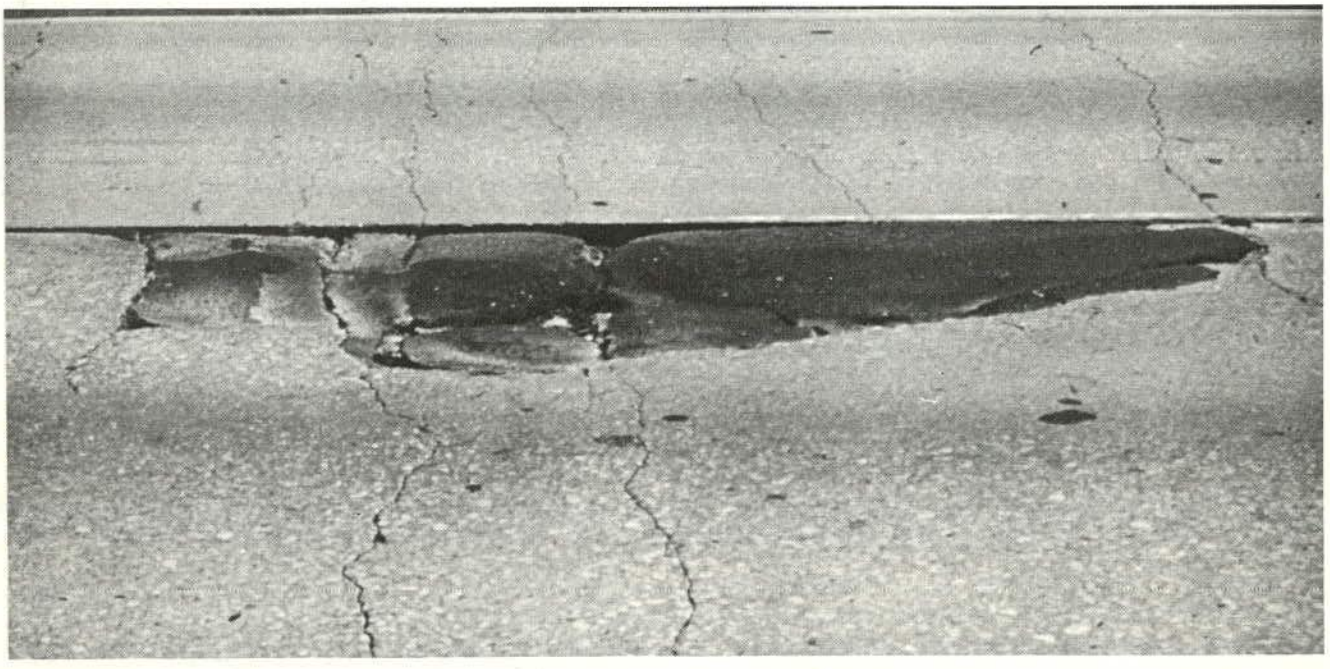

Figure 11. Interior punchout.

The Illinois researchers note that, once a transverse crack has begun to open, repeated heavy loads continue the breakdown of aggregate interlock. As this takes place, a slight faulting and spalling will appear first near the slab edge and progress inward. An accompanying increase in deflection aggravates the condition. As the aggregate interlock is lost, more of the vertical shear from traffic loadings is transferred to the steel, which eventually will rupture. The process may be aided by corrosion of the steel, which begins when the crack width becomes large enough to admit water and deicing salts. This will hasten the failure. If a longitudinal crack was not initially present, increasing transverse tensile stress and accumulating load fatigue damage eventually cause one to form between the two transverse cracks that, along with the pavement edge, have become the initial boundaries of the potential punchout. Aggregate interlock wears away completely and the outside portion of the slab begins to depress into the base.

The Illinois researchers noted that the occurrence of punchouts accelerates with pavement age and traffic applications because fatigue, corrosion, loss of aggregate interlock, and pumping all increase with time and traffic.

BLOWUPS

Blowups in CRCP are not viewed generally as a major problem. However, they have taken place with sufficient frequency to justify discussion.

Definition

A blowup is a localized upward buckling or shattering of a pavement slab usually occurring at a transverse joint or crack. Blowups are not unique to CRCP. A buckling blowup is easily identified by the substantial rise that takes place at the affected joint or crack (Fig. 12). The rise can be of sufficient magnitude to endanger the safe passage of traffic. The dominant feature of a shattering blowup is an accumulation of debris from the shattering process (Fig. 13).

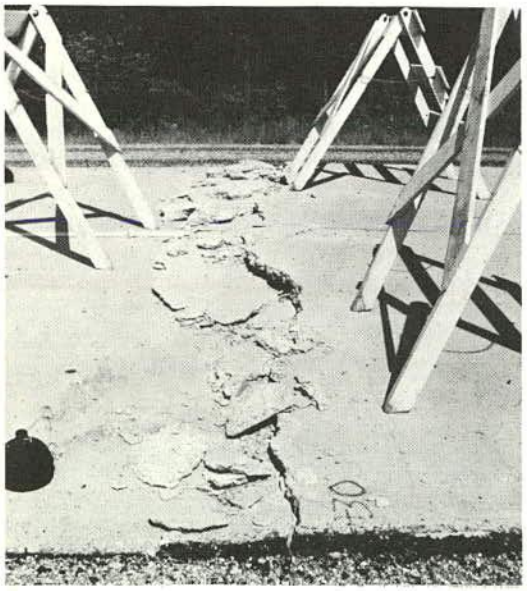

Figure 12. Buckling blowup.

Early Signs

Blowups usually occur during periods of high temperature and precipitation. The late spring and early summer, when temperatures are on the rise following rainy periods, provide optimum conditions for blowups.

Although blowups are often thought of as taking place suddenly without warning, they are the culmination of an activity that has been in progress for some time. A marked increase in spalling at a single joint or crack that appears unrelated to high deflection under traffic very often identifies a potential blowup location. An initial slight rise in the pavement may also be observable. Spalling fragments may accumulate on the pavement faster than they can be removed by traffic, especially when a shattering blowup is taking place. The affected joint or crack will generally appear tight from the applied pressure.

Relief joints cut early in the blowup process may avoid later major repair or at least allow some latitude in selecting the time for repair (see Chapter Three). Avoidance of hot-weather patching will help prevent blowups in adjacent lanes due to transfer of all restraint to the reduced cross-sectional area.

Mechanisms of Distress and Underlying Factors

Blowups occur in concrete pavements when available expansion space is not sufficient to accommodate expansion. They almost never ocur in new pavements. The longitudinal pressure build-up that produces them is initiated by the entry of incompressibles into previously available expansion space in cracks and joints during periods of pavement contraction. When rising temperatures and moisture contents produce later expansion, pressures become excessive and blowups occur. The affected crack or joint will be the weakest in a series insofar as the axial transfer of expansion stress is concerned. Some inadequacy in the joint or crack face, or an inadequacy of the adjacent concrete, will control the location of the blowup.

Blowups can occur in concrete experiencing growth from chemical reaction, but this type of blowup is not very common.

LUG-ANCHOR TERMINAL WAVES

Lug-anchor terminal systems (see Appendix A) have given generally satisfactory service in CRCP construction. However, a type of failure unique to these structures has occurred with enough frequency to warrant discussion.

Definition

Lug-anchor terminal waves are transverse undulations in the pavement surface in lug-anchor terminal systems. The undulations are related to lug movement, and in severe cases may reduce riding quality to the extent that maintenance restoration of surface smoothness is required.

Figure 13. Shattering blowup.

Early Signs

The development of pavement waves at lug anchors is a progressive process first identifiable by a slight increase in surface roughness at the affected location. Transverse waves that can be traced to lug locations will appear. Treatment before pronounced roughness develops can reduce appreciably the amount of maintenance work needed to restore satisfactory riding quality after severe roughness occurs.

Mechanisms of Distress and Underlying Factors

Illinois (*6*) and Iowa both have noted surface waves in lug-anchor terminal areas. The waves appear to be associated primarily with a rotational movement of the lug anchors caused by an outward thrust of the CRCP. Illinois believes that nonuniform foundation settlement may sometimes be involved and could at times be the sole cause. Most problems in Illinois have occurred about five years after construction at locations with four lugs spaced at 40-ft (12-m) intervals. Few problems have developed at locations with three lugs spaced at 20 ft (6 m), but these are somewhat newer installations. The Iowa system includes five lugs spaced at 20-ft intervals. The riding quality has been affected in these two states to the extent that correctional treatment has been necessary. This treatment has included the introduction of relief joints as described in Chapter Four, and for extreme cases in Illinois, slabjacking (Chapter Four) and the use of asphaltic leveling courses. Based on its experience, Iowa has discontinued the use of anchor lugs. Illinois also has turned away from anchor-lug terminals toward the use of wide-flange beam terminal joints, but on the basis of a somewhat lower initial cost.

CHAPTER THREE

CURRENT CRCP MAINTENANCE AND REPAIR TECHNIQUES

Two terms that require definition are used in this chapter. The term "preventive maintenance" is applied to those items of upkeep that are performed mainly to prevent or postpone the need for the more difficult and expensive task of restoring lost continuity and riding quality. Preventive maintenance includes such items as application of sealant to the joint between pavement and shoulder, addition of underdrains at wet or pumping locations, leveling spalling areas, and spot asphalt undersealing and cement-grout application to fill voids. The term "restorative maintenance" is applied to repair work undertaken after damage that usually affects riding quality has occurred. The principal repair applied to CRCP is removal and replacement of failed areas by patching. Other repair techniques include slabjacking and intermittent asphaltic concrete resurfacing to improve riding quality, and to a lesser extent, cutting of transverse joints to relieve undesirable pressure buildup.

DETERMINATION OF NEED

Highway maintenance organizations place top priority on maintaining pavement surfaces in a passable and safe condition. When maintenance funds and manpower are limited, as is very often the case, the routine application of preventive maintenance measures aimed primarily at prolonging the life of a currently serviceable pavement assumes secondary importance. Unfortunately, hard figures on the economic value of preventive maintenance are not available. Nevertheless, engineering judgment suggests that preventive maintenance procedures can be economical, and most highway agencies apply them in varying degrees to continuously reinforced concrete pavements.

No organization is known presently to have established a formal system for the selection and scheduling of preventive maintenance procedures for CRCP. Such a system would need to include some kind of analysis of the economic desirability of undertaking the procedures. Information on which such an analysis could be based is not now available. In current practice, the area field maintenance engineer or supervisor makes frequent checks for signs of potential need, sometimes weekly and sometimes even more frequently, and schedules preventive maintenance procedures as time and resources permit.

Determination of repair needs, and the scheduling of repairs, likewise have not been formalized. Repair work is generally a case-by-case response to keep a highway serviceable. The need for and scheduling of repairs also are usually determined by area maintenance engineers and supervisors. Good communication between office and field and careful training of maintenance personnel can aid both this effort and the scheduling and conduct of preventive maintenance.

When repair work is found to be required, the decision as to whether the repair should be permanent or temporary is guided largely by expediency. The term "permanent" is usually used in the sense that the repair should last as long as the pavement. The term "temporary" is used to suggest an expected life of relatively short duration, perhaps a season or two or even less. Permanent repairs are the usual goal. However, for a variety of reasons, the application of temporary repairs is often necessary. Sometimes this is required simply to keep a pavement passable until forces can be marshaled for more comprehensive permanent repair. Temporary repairs may also be used when weather conditions are unfavorable for permanent repairs. Occasionally, where failures are isolated but of continuing occurrence, permanent repairs may be postponed in favor of temporary repairs until the job becomes large enough for the utilization of more efficient, volume production methods. In this connection, the intensity of traffic may influence the decision; isolated repairs may be more practicable from a traffic control viewpoint under low-volume conditions than where the volume is high. Temporary repairs may also be applied where a pavement is fast becoming a candidate for rehabilitation but must be held together until a full-scale rehabilitation project can be planned, programmed, funded, and placed under contract. No formal economic analysis is available to select between temporary and permanent repair.

PREVENTIVE MAINTENANCE

The "stitch-in-time" philosophy of preventive maintenance is especially important for continuously reinforced concrete pavement because of the high cost of restoring original riding quality and continuity after failures occur. However, the direct cost of repair may be small in comparison to user loss from delay due to lane closure, especially in the typical urban setting. Preventive maintenance procedures for CRCP and jointed concrete pavement are not appreciably different.

Both general observations and study have shown that surface water can infiltrate through pavement surfaces and adjacent areas in damaging quantities. One study showed that a typical open crack or joint with an unfilled cavity beneath can remove 70 to 97 percent of the rainfall flow (*7*). Another study that included a variety of pavement types provided documentation that, in a majority of instances, pavement distress is associated with poor subsurface drainage (*8*). In recognition of the first-order im-

portance of excess water as a causal factor in highway damage, most preventive maintenance that is performed in relation to CRCP is directed at preventing water from entering or accumulating below the pavement surface. Some agencies attempt to use preventive maintenance on a routine basis; others await evidence that damage-causing agents, mostly trapped water or pumping activity, are present before applying preventive procedures.

Sealing (or resealing) of the joint between the concrete pavement and an asphalt paved shoulder, a combination common to most CRCP projects, is probably the most widely used preventive maintenance procedure at the present time. Sealing of transverse cracks and joints showing satisfactory performance is not required and not practiced. Open cracks and joints showing substandard performance are sometimes sealed to slow the advance of distress. Recessed longitudinal joints are also sealed. Among agencies that seal the pavement-shoulder joint as a preventive maintenance measure, some try to apply sealant every year or two; others base sealing frequency on observed need. One agency begins maintenance sealing when the joint opening exceeds ¼ in. (6 mm). Asphalt, rubber-asphalt, and silicone sealants are used. The value of sealing has never been quantified, and its effectiveness is generally considered to be temporary. Sealing alone should never be considered a cure-all.

The addition of pipe or French underdrains extending from the pavement edge to the side slope is a preventive measure that some agencies use at locations where trapped water or pumping are observed. Occasionally, and especially where a considerable length of pavement is involved, a longitudinal pipe underdrain may be placed at the pavement edge with an outlet at the side slope. Some states now use underdrains at the pavement edge on all new construction, and one state is installing longitudinal underdrains on all CRCP projects where they were not included in the original contract. Filter fabric also has shown promise.

Asphalt undersealing and the application of cement grout are receiving limited use where there is reason to expect potentially damaging voids under CRCP. They may be used in combination with other preventive maintenance procedures including the addition of underdrains.

General shoulder maintenance, although aimed primarily at preservation of shoulder condition, may also have a beneficial effect on pavement performance. Paved shoulder maintenance, as currently performed, includes such operations as surface sealing, addition of asphaltic material at the pavement edge where settlement has occurred, patching of failed areas, and full rehabilitation. Some of these treatments are obviously beyond the usual connotation of preventive shoulder maintenance, as, for example, the addition of portland cement concrete shoulders in Indiana. All, however, can be expected to have a favorable effect on pavement performance.

RESTORATIVE MAINTENANCE

Because of the relative youth of most CRCP installations, repair of distressed or failed areas has been concentrated primarily on the few pavements that have shown premature failure. As all the pavements now in place become older, normal wear and tear can be expected to increase the need for repair.

TEMPORARY PATCHING

Temporary patching of CRCP is generally looked upon as a stop-gap technique to keep the pavement in service until permanent patching or other rehabilitation can be undertaken. Temporary patches have at times given good service in CRCP; however, because of early removal by wheel action, their short life span is often inconsistent with their cost and inconvenience to traffic. Their use should be viewed with caution especially in areas of severe winter weather. Nevertheless, when a hole appears in the pavement and the weather or the available resources do not permit immediate placement of a permanent patch, quick repair by temporary patching is the only feasible alternative.

Most agencies that have had to resort to temporary patching of CRCP have used either hot-applied or cold-applied bituminous plant mixtures as the patch material. An effort is made to remove loose pieces of concrete before placing the asphalt mixture. A wrecking bar can sometimes be useful for this purpose. At least one agency has found temporary patches placed full depth to have a better chance of remaining in place if the steel reinforcement is cut or completely removed. Hand or mechanical tamping is used to consolidate the asphaltic mixtures.

Traffic control practices follow agency policies and FHWA's Manual on Uniform Traffic Control Devices (MUTCD) (*9*). Traffic control is discussed further in the next section.

PERMANENT PATCHING

The restoration of distressed or failed areas in CRCP to full service by permanent patching is time-consuming and expensive. The patching process consists of many steps, and carelessness or nonobservance of techniques known to produce acceptable results during any step will greatly reduce the chance of success. The need to observe currently acceptable techniques does not mean, however, that present practice can not be improved upon, and the desirability for further experimentation is generally recognized.

Similarities and differences exist in current CRCP permanent patching practices, both among states and within states. Some of the differences are due to local conditions; others have come about because of the developing nature of the activity and the resultant general absence of standardization. Standardization, in fact, has been avoided by some states' central maintenance organizations to encourage field forces to adapt treatments to the needs of individual locations.

Permanent patching is intended generally to restore damaged areas to at least the condition of the surrounding pavement. Most agencies consider this to include the use of portland cement concrete as the patching material and reestablishment of the continuity afforded by the steel reinforcement. Minnesota, however, has found that reestablishment of the steel continuity at patch locations has caused the longitudinal reinforcement to rupture in weak-

ened sections as much as 200 to 300 ft (60 to 90 m) distant. To overcome this difficulty, Minnesota has made some use of asphaltic concrete as the patching material without restoration of reinforcement. These patches have had relatively short service lives. A better alternative has been found in a portland cement concrete patch that includes a double-acting wide-flange beam expansion-contraction device. This installation removes the continuity causing the steel-rupture problem and is reported to be giving excellent service. Details of the installation are shown in Appendix B.

Details of the permanent patching processes now being applied by agencies having most of the mileage of CRCP in the United States follow. This information has come primarily from: (a) responses to a questionnaire sent the 20 highest mileage states among the group of 33 states reported to have awarded CRCP contracts prior to April 1, 1972; (b) individual reports prepared by the highway and transportation organizations of Arkansas, Louisiana, Mississippi, and Texas, following participation with the FHWA in a value engineering study of CRCP repair (*10-13*); and (c) the final report of the foregoing value engineering study (referred to as the "Four-State Report") prepared jointly by the four participating states in cooperation with the FHWA (*14*). Although the value engineering study was centered in southern states, the findings should prove useful elsewhere because of the general similarity of the problems being faced by all CRCP users.

Recognition of Need

The need for repair by permanent patching usually is not difficult to recognize. Punchouts, settling pavement, excessive movement between cracks of individual slabs under traffic, and severe spalling at cracks or construction joints all signify failure or incipient failure. Good surveillance will reduce the number of surprises and aid in the identification of potential repair sites before damage becomes extensive. Temporary patching should be considered if permanent patching can not be done within a reasonable length of time.

Safety and Traffic Control

Traffic control for patching is critical to the safety of both highway crews and highway users, and seriously affects both the efficiency of maintenance operation and the flow of traffic. Traffic control during maintenance is currently receiving much attention (*29*), and readers should keep abreast of new developments. Some states follow the recommendations in the Manual on Uniform Traffic Control Devices (MUTCD) (*9*) with a minimum of change. Many states have prepared their own work site layouts. These layouts include placement and removal instructions that provide an additional margin of safety beyond the basic requirements of the MUTCD. It is important that, whatever an agency's practice may be, it is carefully followed.

All of the devices that are needed for pavement closure should be on hand at the start of the work, and crew members should know what is expected of them in setting up a closure. It is common practice to confine closure to a single lane of traffic, both for safety and to avoid the excessive longitudinal movement of the pavement into the breakout area that can take place when all resistance to expansion is removed by full-width breakout.

The Four-State Report (*14*) contains the following statement regarding traffic detouring:

> Many suggestions for improving traffic control were investigated but any procedure used will have to comply with State and Federal standards for controlling and handling traffic through construction and maintenance zones. Much additional consideration must be given to detouring procedures on projects where patching is an almost continuous or recurring operation.

Patch Delineation

Patch boundaries usually are selected and delineated by an engineer or other person knowledgeable of CRCP performance. Care must be exercised in seeing that all failed areas are included within the patch boundaries. An Illinois study (see later section on performance) showed failed areas adjoining patches or patch extensions at 21 percent of the patches surveyed. Recent experimentation in Indiana has indicated that relative deflection measurements with a Dynaflect instrument can be effective in patch delineation, especially where loss of support is the underlying failure mechanism.

A fresh face usually is established in the existing concrete against which the patch will abut. This is expected to provide a face that is cleaner and more even than that at an existing crack and removes the new opening from a location where rusting of the steel may have started. Some states require that the new face be established if possible no closer than 1½ or 2 ft (0.5 or 0.6 m) from a crack that is to remain. Locations where the new face would cross a diagonal crack are avoided.

Some agencies have placed lane-width patches on a skew (usually 1:4) to avoid simultaneous crossing of the patch-pavement interface by both wheels of axles. Fewer agencies are using this procedure than formerly. One agency reports that the skew cuts tended to form unstable blocks as cracks became more numerous.

Most patches are placed full-depth and full-lane width, with only sparing use being made of partial-depth and partial-width patches. As indicated previously, patching is usually confined to a single lane.

Some states have established a minimum length for patches, usually either 6 or 10 ft (1.8 or 3.0 m). This has been done in the belief that at least these amounts are needed for work space and for reestablishing continuity when longitudinal steel is removed. Other agencies allow removal and replacement to be confined to the distressed area if steel condition permits and have noted no adverse effects. Good service from small patches where all unsound concrete has been removed has been reported.

The Four-State Report (*14*) contains the following statement on patch delineation:

> Delineate the area to be patched, making sure that all fractured or deteriorated concrete to be removed is included in the area delineated. There was not complete agreement on how to delineate the area to be patched.

The merit of having an experienced person mark off the area in some manner was acknowledged; however, an experienced breakout crew would be able to determine the extent of the area to be removed without being constrained by previously set markings.

The minimum size of the area to be patched should depend on the extent of the deteriorated concrete although some of the states recommend that the width should not be less than full-lane width. Other states have reported that small patches have proven to be as durable as large patches if all adjacent unsound concrete is removed and if the cause of the original failure is eliminated. It was the consensus of all states that the patch area should be rectangular and not on a skew.

Breakout and Removal

It is important that faces of the remaining concrete against which the patch will abut be as near vertical as possible and of solid concrete throughout their depth. Faces that deviate substantially from vertical, or loose pieces of concrete left in place below the reinforcing steel, produce damaging stress concentrations.

Patch edges are commonly established with a saw cut 1 to 2 in. (25 to 50 mm) deep (Fig. 14). Care is exercised not to cut into the longitudinal steel. This cut is intended to aid in the establishment of a vertical face and to provide an unspalled edge at the pavement surface where the patch will abut. Sawing is time-consuming and expensive but judged to be worth the effort by most agencies. However, agreement is not unanimous, and some crews omit the sawing operation, beginning instead by scoring the concrete with a hand-held jackhammer. No actual performance comparisons are known to have been reported.

The number of patches that need to be installed and the sizes of the patches influence the selection of breakout and removal equipment. It is common to employ only a jackhammer and other hand tools for small patches. On larger jobs, heavier mechanized breakout equipment, such as a drophammer or hydra-hammer, may be used to break up interior concrete, and mechanized lifting equipment, including a back-hoe or front-end loader, may be used for removal and loading (Figs. 15-18). Because heavy breakout equipment can damage concrete and steel beyond the immediate point of operation, it is common practice to restrict its use to areas where the steel will not remain in place and away from patch face locations (Fig. 19).

The existing steel reinforcement is usually left in place where patch areas are small. It is customary to cut the longitudinal steel before breakout in larger areas to facilitate concrete removal. The cuts are made parallel to where the patch faces are to be located and a sufficient distance in from the face locations to allow splicing or welding replacement steel to the existing steel (see later section on treatment of reinforcement). Heavy equipment is allowed to operate only in the interior space and only after the steel has been cut. Care must be exercised at all times during the operation of heavy equipment to avoid subbase damage.

Breakout of the concrete from the interior area with jackhammers alone can consume the greatest time of any

Figure 14. Sawing patch edges (14).

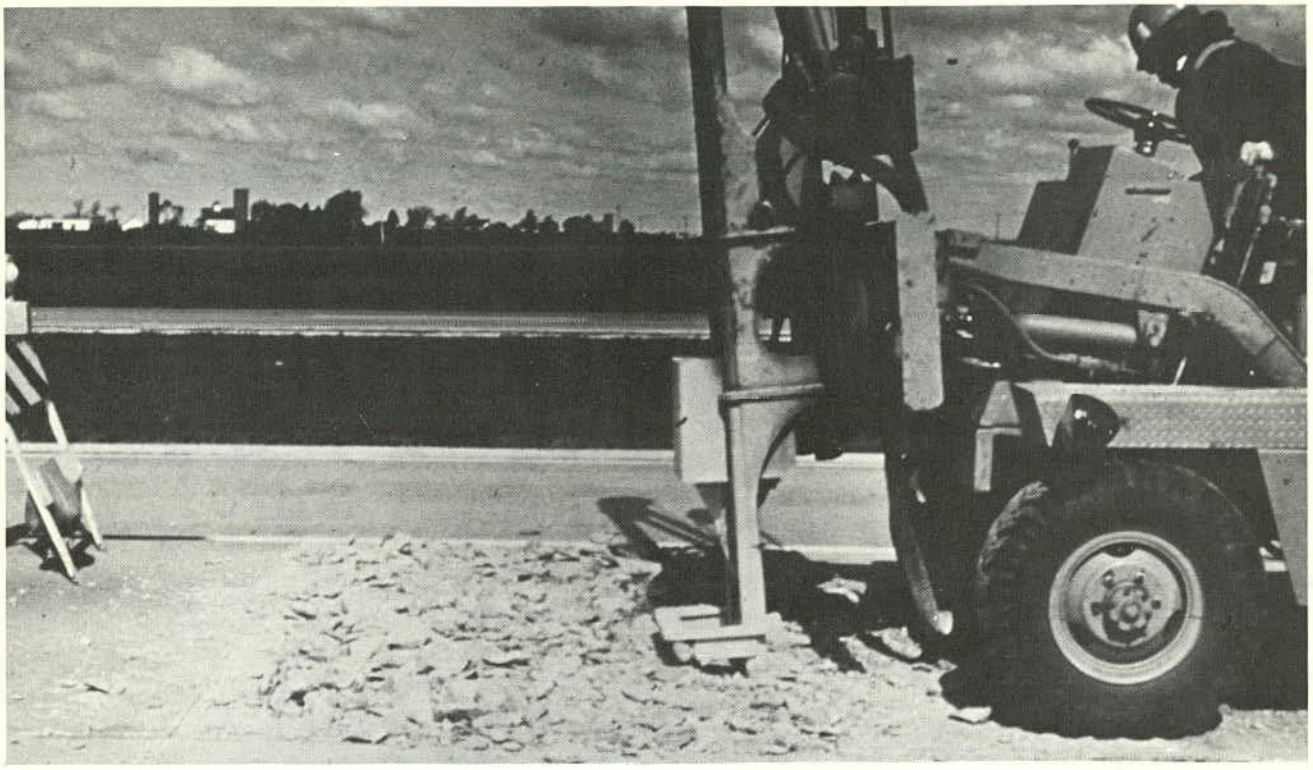

Figure 15. Heavy-equipment breakout (15).

Figure 16. Jackhammer breakout (15).

Figure 17. Backhoe loading (15).

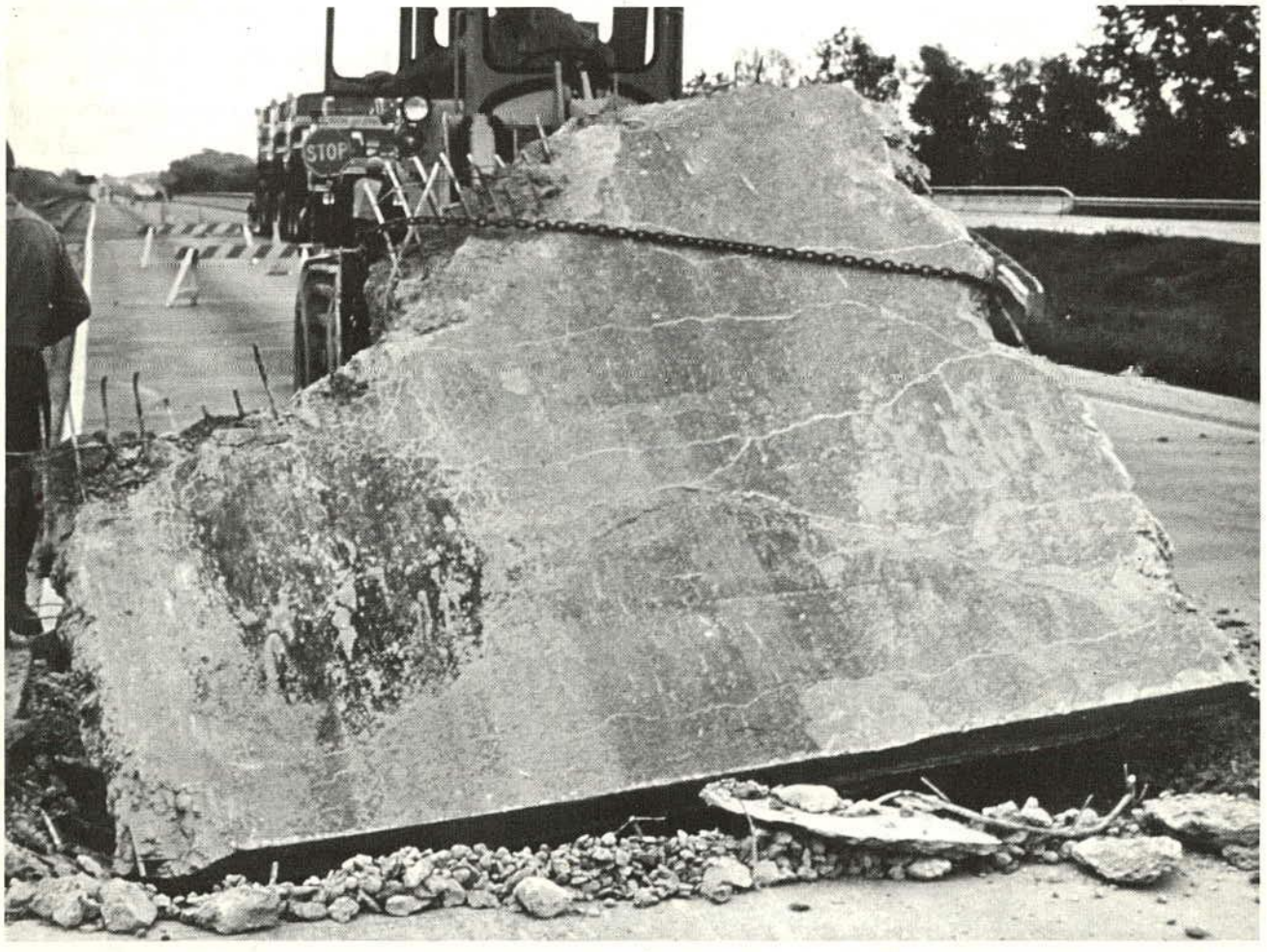

Figure 18. Lifting slab for loading (15).

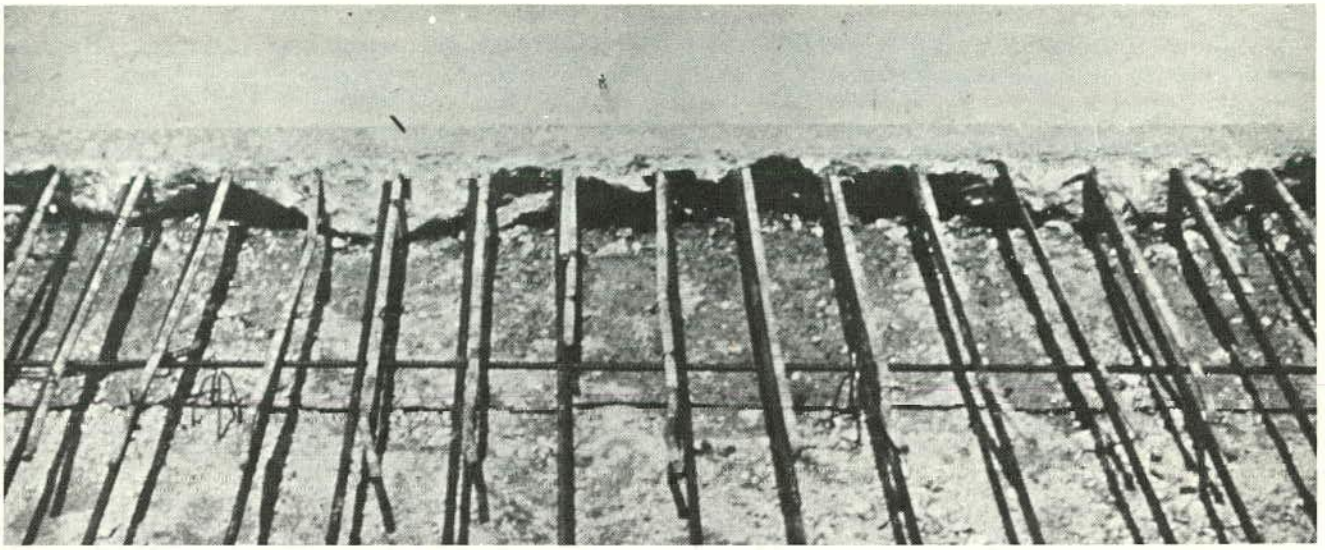

Figure 19. Damage by drop hammer used too close to patch face (15).

individual patching operation. Lift-out of the full section, or of the section cut into a few large pieces, is the fastest means of removal.

Jackhammers are the usual means for breaking the concrete where the longitudinal steel is to remain in place. Removal of the fractured concrete is essentially a hand operation.

The Four-State Report (*14*) contains this statement regarding breakout and removal:

> Break out and remove the failed area to sound concrete providing for a vertical face on the existing concrete. There was no agreement on whether a saw cut should be made. It was acknowledged that sawing hard aggregate is difficult and does not always provide a clean, unspalled face as intended. The advantages of eliminating the saw cut as practiced by some repair crews were not sufficient to change the minds of those who preferred the saw cut. Some of the economic analyses indicated that the sawing operation amounts to approximately 4 percent up to 10 percent or more of the total cost of a patch. On a typical 10-ft (3.0 m) long, lane-width patch, the sawing operation could cost from $100 to $200.
>
> There are several acceptable methods of breaking out and removing the concrete. The size and number of patches will have a bearing on the equipment and techniques to be used. For small patches, a jackhammer may be all that is needed. For numerous, larger patches, heavier mechanized pavement-breaking machines are desirable. In using heavier equipment, more care is needed to avoid damaging the adjacent concrete. For some situations it is more expedient to break the concrete into small pieces for removal by shovels or small loading equipment. In other cases, it is preferable to break out around the edges of the failed concrete, cut the steel, and remove most of the damaged area in one or more pieces with heavy lifting equipment.

Base Restoration

Following removal of the broken concrete from the patch area, attempts are usually made to restore the base to a stable condition. Material that is unstable should be removed and replaced with better material. Additional concrete is often used where replacement needs are not great. The use of concrete is an important consideration because the confined area of a patch reduces the probability of adequate compaction of new base material. Underdrains are used occasionally to drain entrapped water. Base preparation has an important influence on future patch performance and should never be neglected or done in a haphazard manner.

The Four-State Report contains this statement regarding base restoration:

> Remove any unsound subbase (base). In most cases it was determined that it was better to replace the removed subbase (if any) with additional concrete rather than refinish the subbase with new subbase material. Where the amount of subbase to be removed is excessive, it may be more economical to replace it with new subbase rather than with additional concrete.

Treatment of Reinforcement

All agencies recognize the need for protecting reinforcement that is to remain in place from damage during the concrete removal process. Bending of the bars makes concrete removal easier, but breakage and S-curves that result when the bars are bent back into place can disturb continuity and cause early patch failure. Early failures attributed to bending of the steel are reported (*16*). It is common practice to require that bar bending be held to a minimum, but enforcement can be improved.

When the longitudinal steel is cut to facilitate concrete removal, the cut is made a sufficient distance from the patch face location to allow continuity by tying or welding new steel to that which is retained. Lap lengths for tying equal to or greater than the original lap lengths are commonly specified. Specified lap lengths for tying range from 1 to 3 ft (0.3 to 0.9 m), with a concentration between 2½ and 3 ft (0.8 to 0.9 m). A minimum of 25 bar diameters and preferably 30 diameters is recommended for tying.

Texas and Mississippi are the only agencies now using welded splices regularly in CRCP patching, but others have begun to use them experimentally. Recent tests conducted at the University of Texas at Austin on several field-welded, billet-steel bars removed from a portion of CRCP showed all welds to have developed the yield strength of the steel and most to have approached the ultimate strength. The welded splices were 7 in. (175 mm) long. Texas has used welded splices as little as 6 in. (150 mm) long; Mississippi uses a 20-in. (500-mm) length. Only billet-steel reinforcement can be welded; rail-steel bars are not weldable. One agency that does not replace cut-away steel (Iowa) specifies cutting the steel 9 in. (230 mm) from where the patch face is to be and coating the remaining bars with a generous amount of grease or capping them before concrete placement.

The longitudinal steel is cut either with a concrete saw (Fig. 20) operated parallel to the patch-face locations or by torch. When a torch is used, the concrete is first chipped away from the cut locations by jackhammer. Saw cuts parallel to the steel about 6 in. (150 mm) apart are sometimes made before jackhammering.

Ordinarily, bars of the same size and grade (usually Grade 60) as those in place should be used for replacement steel, and the amount of steel added is the same as that removed. One agency, however, is known to require supplementary reinforcement to increase the amount of longitudinal steel by 50 percent. Where the original reinforcement was welded-wire fabric, duplication of wire size is difficult, and Grade 60 deformed bars totaling about the same cross-sectional area are used.

The new steel is secured to the old by wire ties or clips and occasionally by welding (Figs. 21, 22). Chairs are used to hold the reinforcement in position during the concrete placement process. Instances of a need to loosen and retie the reinforcement to accommodate pavement movement resulting from temperature change between time of

Figure 21. Tied reinforcement splice (15).

Figure 20. Cutting reinforcement (15).

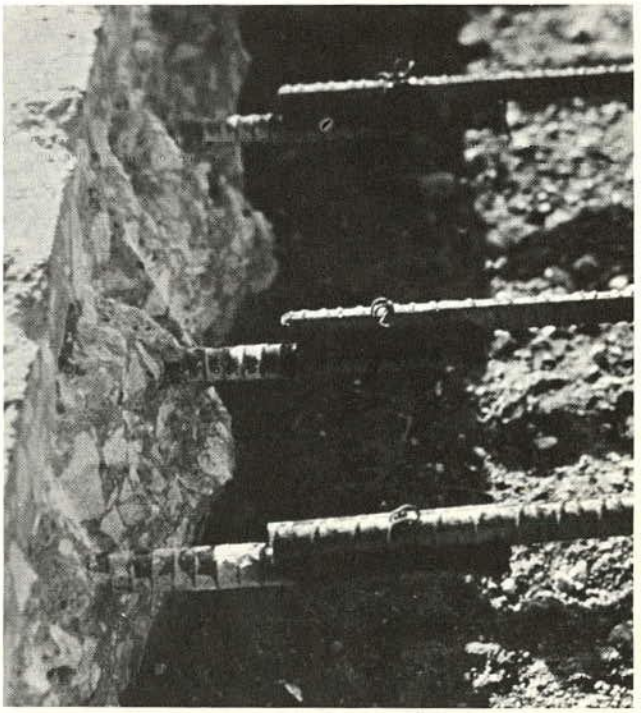

Figure 22. Welded reinforcement splice (15).

tying and time of concrete placing have been observed. This movement is even more critical where welded splices are used, and at least one agency withholds welding at the second face until maximum expansion has been reached (usually 3 to 4 pm).

One agency requires that a patch be lengthened if more than 10 percent of the steel is damaged in the lap area. If the damage is 10 percent or less, full lap distance is achieved by welding an additional length of bar to any damaged bar.

An effort usually is made to retain tie bars or transverse bars crossing the longitudinal joint, especially in long patches. One agency is known to require the addition of transverse reinforcement at 50-in. (1300-mm) spacings.

With regard to reinforcement treatment, the Four-State Report (*14*) states:

> Cut steel to provide sufficient length for lap splicing or welding. Some of the states preferred welding while others preferred tying. The advantages of welding to maintain positive continuity of the steel were acknowledged. Tying of the steel eliminates the need for a welder on the job and in most cases has been satisfactory. The existing steel could be left in place if the unsound concrete can be removed without breaking the steel. The practice of cutting the steel in the middle, bending it up to remove the concrete, then bending it back down for reuse is considered unsatisfactory.
>
> Replace the steel to match the existing bars and either splice in accordance with usual specifications or weld at least six inches. The need for placing any additional steel in the patch has not been demonstrated.

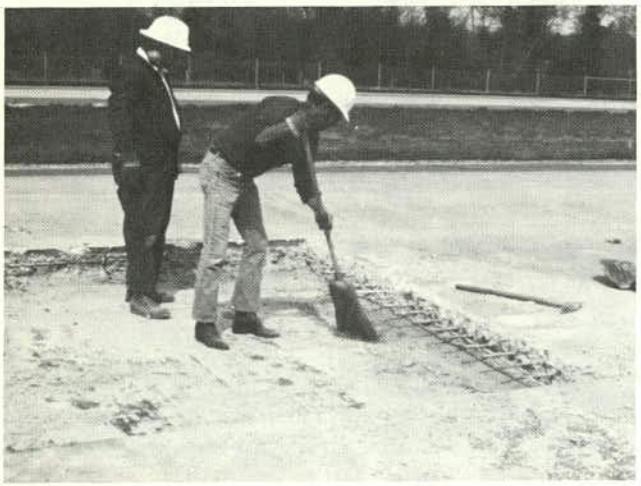

Figure 23. Preparation of excavated area (14).

Side Forms

Some agencies make use of side forms in patching; others use only the paved shoulder. The use of a paved shoulder as a guide in surface finishing has produced poor riding quality in patches. The Four-State Report considers use of a side form next to the shoulder optional for patching.

Preparation of Excavated Area

In final preparation for concrete placement, loose material is removed from the excavated area (Fig. 23). Some agencies prefer to use an air nozzle connected to a compressor for cleanup, and good results have been reported (Fig. 24).

Figure 24. Compressed-air cleanout (15).

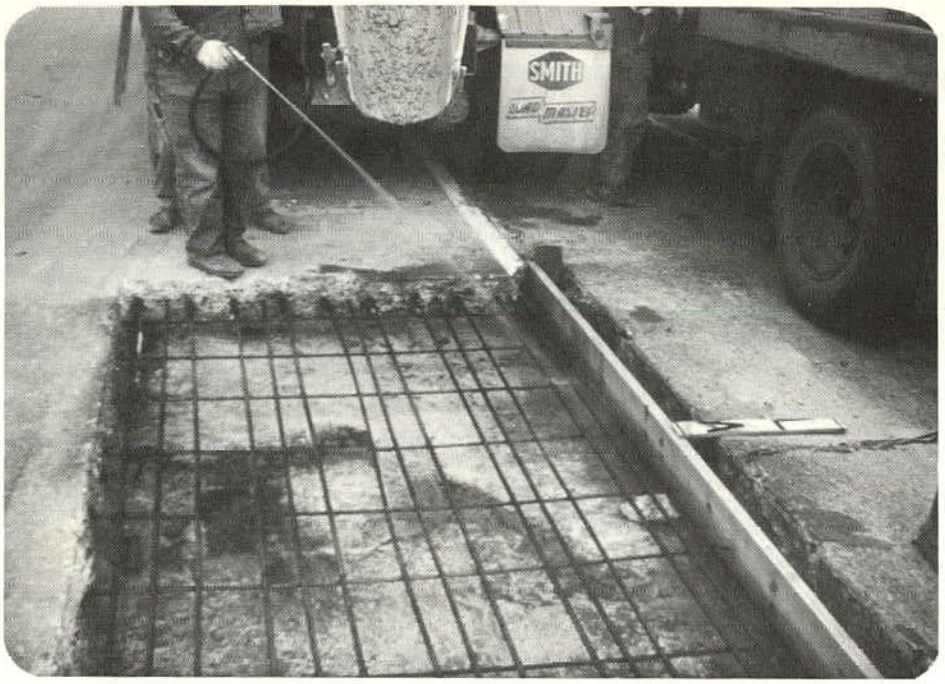

Figure 25. Wetting patch area before placing concrete (14).

The base, patch faces, and reinforcement are often wetted just before concrete placement (Fig. 25). Occasionally cement grout or epoxy resin are also used to aid in establishing bond between the old and new concrete at the patch faces.

With regard to preparation of the excavated area, the Four-State Report (*14*) states:

> The subbase (base), existing concrete faces and steel should be sprayed with water before the concrete is replaced. The use of grout, or epoxies, on the concrete faces was not considered to be cost effective by a majority of states.

Concrete Placement and Curing

Because it usually is desirable to return the pavement to traffic as soon as possible after patching, most agencies use high-early-strength concrete as the replacement mixture. Rich mixes ranging from 7 to as high as 9 bags of cement per cubic yard of concrete (390 to 500 kg/m^3), high-early-strength cement, accelerators, water reducers, and water reducer-retarders have all been used, sometimes alone and sometimes in combination, to achieve early pavement opening. Calcium chloride also has been used as an accelerator, but at least one agency specifically prohibits its use because of the possibility that it may cause steel corrosion. Patches that have included high-early-strength cements have not always performed well, and the use of such cements in patches is not encouraged.

After placement and strike-off, the concrete is consolidated by vibration (Figs. 26-28). The need for careful consolidation of the concrete in CRCP patches is generally recognized. Internal vibration is most often used; less used is surface vibration. Finishing to grade and texturing follow consolidation.

White-pigmented membrane is the principal agent used in curing. It offers the advantage of providing some protection after new patches are opened to traffic. Limited use also is made of plastic sheeting, wet burlap, wet sand, and water spray. A well-constructed patch is shown in Figure 29.

Traffic-closure periods in general range from as little as three hours to three days. Very short periods are not recommended. Some of the agencies specifying longer closure periods permit earlier openings based on strength testing of cast specimens. Minimum modulus of rupture values of 500 psi or 600 psi (3.45 or 4.14 MPa) are sometimes used as the basis for opening to traffic. Very limited use has been made of special materials, such as polymer concrete, to permit early opening. The cost and effort involved in maintaining the longer curing periods, combined with pressure to return pavements to the user, make closure for the full period needed for adequate curing often difficult to achieve. Nevertheless, premature failure of a patch caused by early opening is not a good economic trade-off.

The Four-State Report (*14*) contains this statement regarding concrete placement and curing:

> Fill the excavated area with concrete using a design to provide for quick setting where needed. In most cases, it is desirable to return the road to traffic service as soon as possible for the convenience and safety of the public and maintenance personnel. Experience is needed to provide the proper additives or batch design which will develop early strength and still provide for a satisfactory patch life. A material is needed which can be placed and returned to traffic in the same day. Several maintenance crews have developed special designs and accomplish this to their satisfaction. Other crews reported a lack of success with anything but a regular concrete mix with some minimum curing time before opening to traffic. The question of providing materials and mixing equipment or using

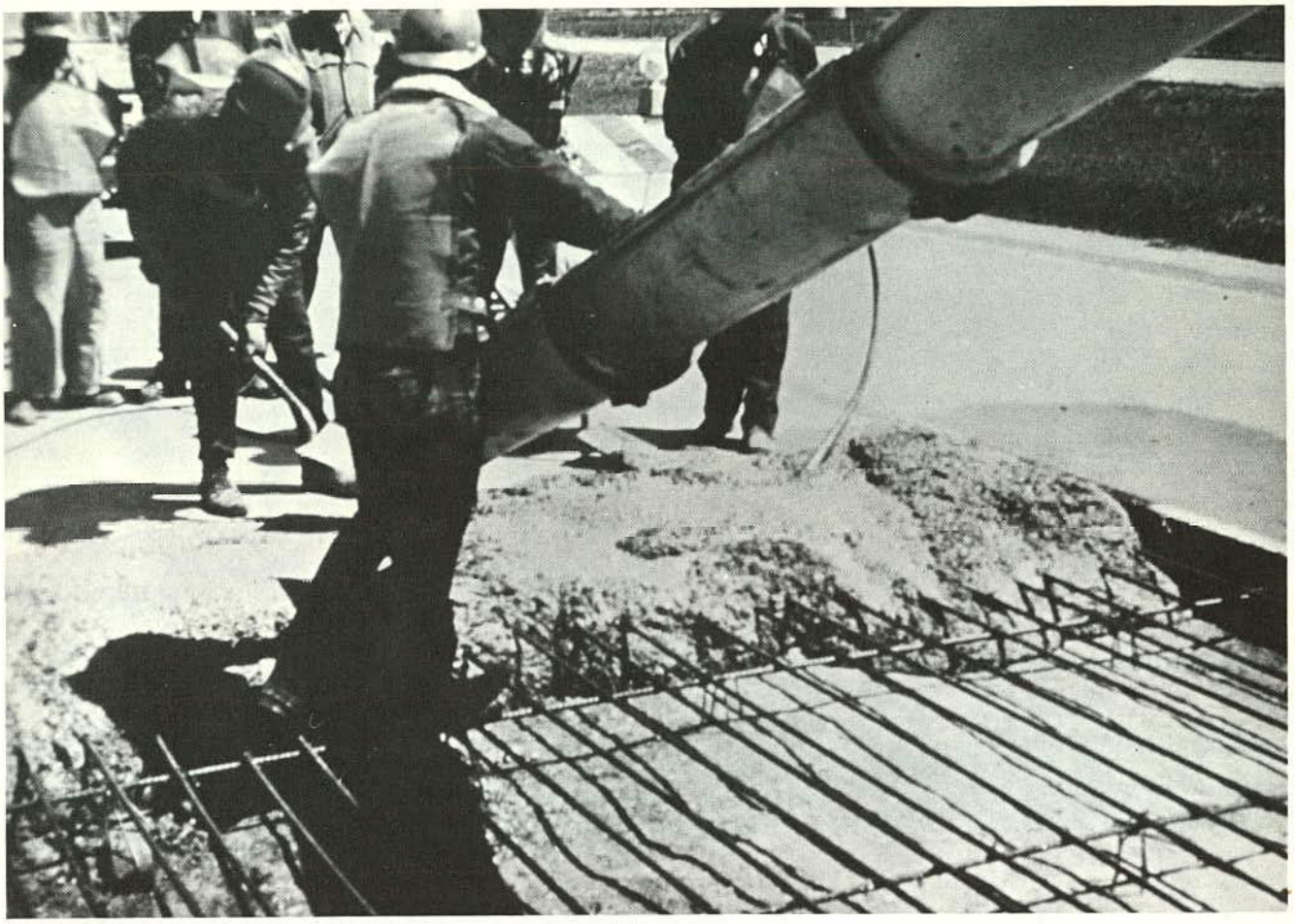

Figure 26. Spreading concrete (15).

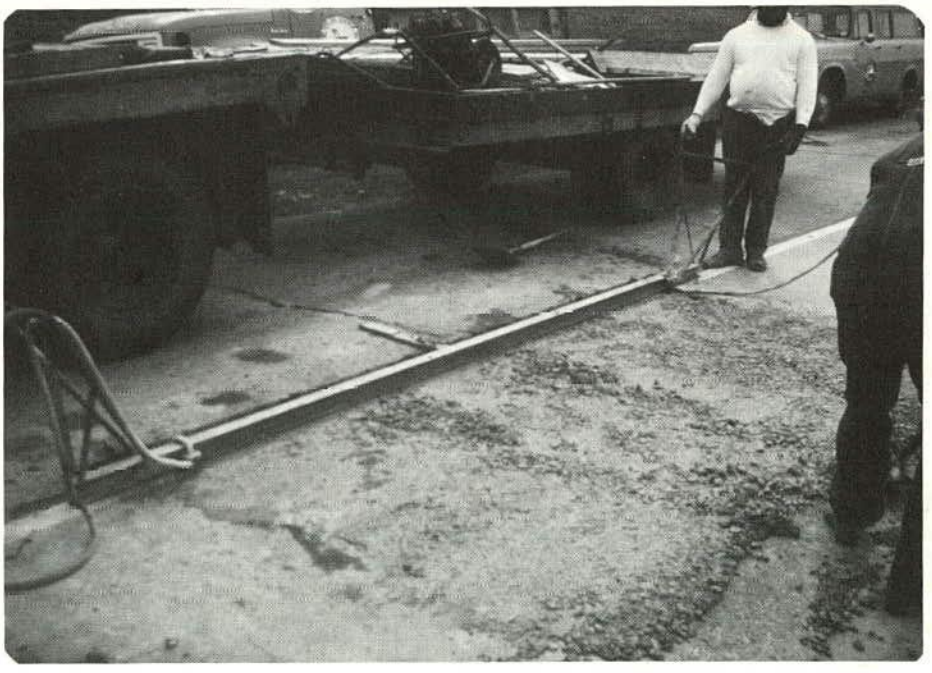

Figure 27. Striking off concrete (14).

Figure 28. Vibrating concrete (15).

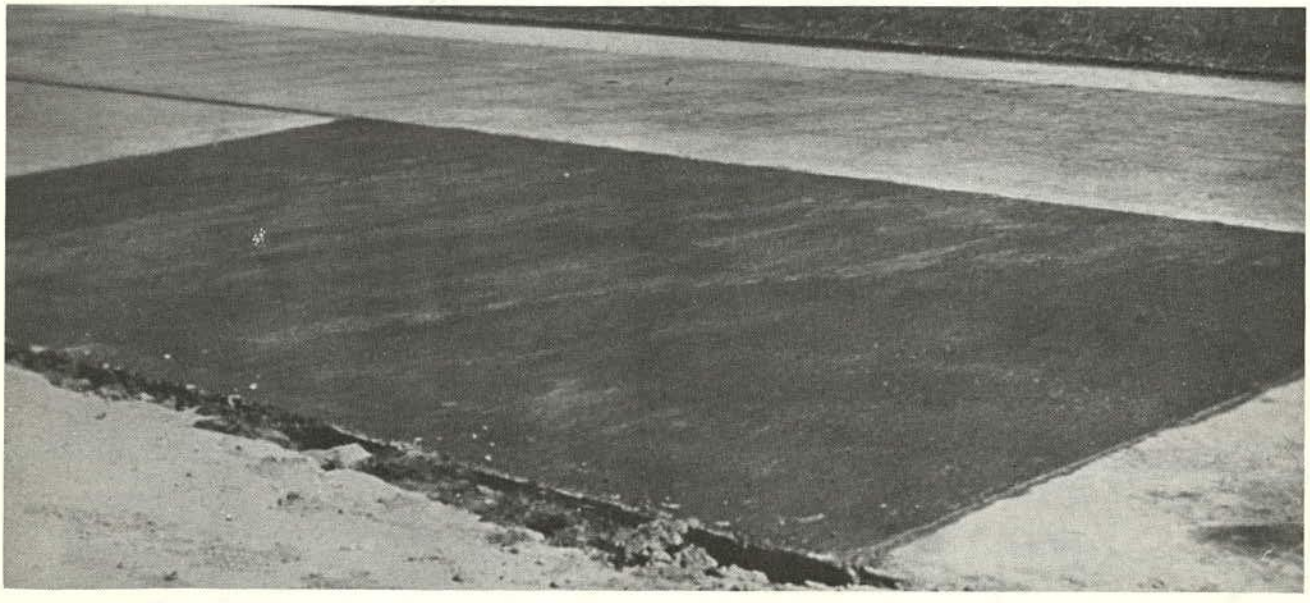

Figure 29. Completed patch (15).

commercially furnished concrete must be determined by the conditions. One state, using a mobile concrete mixer, reported that their costs were from 66 percent to 75 percent lower than the cost of using a commercial supplier, so long as the total yardage needed in one day was less than approximately 18 cubic yards (14 m^3).

Consolidate the concrete by mechanical vibration and screed the surface for riding quality. Adequate consolidation of the concrete is imperative and this can best be assured by mechanical vibration. Also, it is unnecessary to provide for a surface finish in excess of the condition of the existing concrete.

Use a sprayed membrane curing compound to cure the concrete patch. Other curing methods provide for a satisfactory patch but the use of a curing compound is the most practical.

Patch Performance

Permanent CRCP patches are generally considered by the users to be giving reasonably satisfactory service. Failures usually seem attributable to improper procedures (Fig. 30). Quantitative information relating patch performance to patching techniques is generally lacking. Evidence shows that gross neglect of accepted procedures, such as excessive bending of the longitudinal steel and premature opening to traffic, can result in early failure.

A recently completed survey (*15*) of 831 patches averaging about 3 years in age and including some that had been in place over 10 years showed 60 percent "excellent," 16 percent "good," 18 percent "fair," and 6 percent "poor" on the following basis:

Excellent—no defects, except that very slight spalling can be present at interfaces of patch and existing pavement.

Good—same condition as "excellent," but cracked.

Fair—no longer smooth and undetectable, and showing significant spalling and perhaps the beginning of a punchout.

Poor—failed; replacement due and temporary patch needed for acceptable riding quality.

A fifth category was established to cover failed areas in the pavement immediately adjacent to patches and patches of such areas adjoining older patches. Twenty-one percent of the 831 patches surveyed were in this category (Fig. 31).

Not all of the factors contributing to the failures observed in the study were determinable. Workmanship, structural condition of base and foundation soil, degree of drainage, slab thickness, curing time, concrete mix, steel fastening, and traffic were cited as probable factors influencing patch performance. Excessive stress in the unhardened patch concrete by movement of the adjacent concrete might be cited as an additional factor. Size of patch in relation to failed and pumping areas at time of placement, degree of load transfer to patch (bonding and steel contact), and structural condition of the existing pavement were cited among factors that influence the performance of adjacent pavements.

Several trial installations for CRCP repair and preservation are currently being investigated in Indiana under the Joint Highway Research Project of Purdue University and the Indiana State Highway Commission (*17, 18*). A pavement that had already experienced a considerable number of failures was selected for the study. Maintenance methods included concrete patching, a small amount of full-depth bituminous concrete patching, asphalt undersealing, addition of pipe underdrains, asphaltic concrete overlay, asphaltic concrete overlay in combination with asphalt

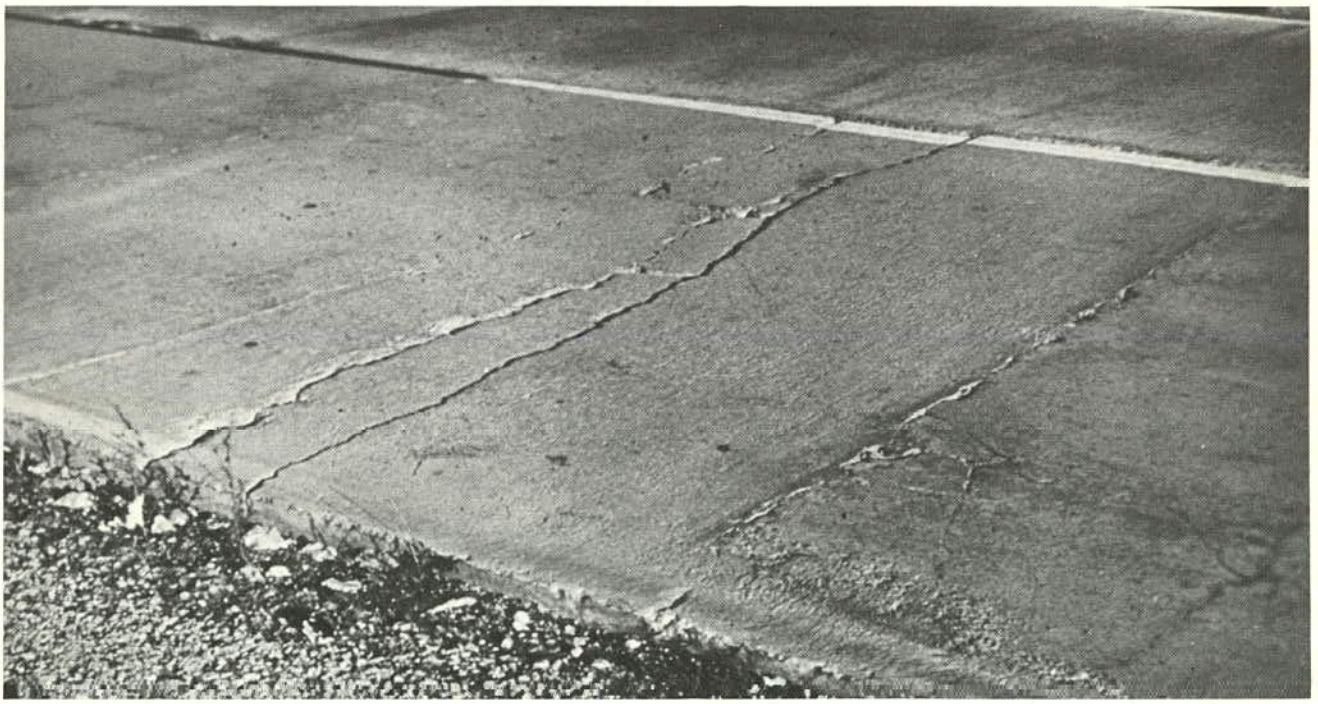

Figure 30. Failed patch (15).

Figure 31. Failed pavement adjacent to patch (15).

undersealing, asphaltic concrete overlay in combination with pipe underdrains, and the addition of concrete shoulders (tied to the pavement) alone and in combination with pipe underdrains. Existing breakups in *all* test sections were repaired with concrete patching (except in the section of bituminous concrete patching). Dynaflect deflections [with a deflection of 0.9 mils (0.23 mm) or more considered to indicate possible poor performance], crack width, and number of breakups were used as criteria in selecting test sections. Deflection measurements are also being used as part of the performance assessment.

After two years of service, too short a time for final conclusions, all asphaltic concrete overlay sections [2, 3, and 5 in. (50, 75, 125 mm) thick and surfaced with a thin asphalt-emulsion antiskid mixture] showed no further failure, although some reflection cracking was noted. The asphalt-underseal section showed very few failures. Greater numbers of failures have occurred in the concrete-patching, underdrain, concrete-shoulder, and concrete-shoulder-with-underdrain sections. One of five bituminous concrete patches had failed. Failure of the underdrains and concrete shoulders to improve performance at this early stage of the experiment was not readily explainable. Evaluation of all test sections is continuing.

SLABJACKING

Portland cement has been used as an ingredient in the slabjacking of CRCP primarily where the pavement has become distorted on highly expansive soils. The operation is generally similar to that which has been used for many years to fill voids under concrete pavements and adjust pavement elevation for better riding quality—see "Slabjacking Concrete Pavement," Portland Cement Association (*19*). Mississippi (*12*) suggests a slabjacking mixture containing Type III high-early-strength cement (20 percent by volume, minimum), calcium chloride (5 percent by weight of cement, maximum), natural silt or fine sand (75 percent by volume, maximum), and sufficient water to produce a pumping consistency (time of efflux 20 sec. by Corps of Engineers Method CRD-C79-58). Type I cement may be substituted if Type III is not available (28 percent by volume, maximum). The calcium chloride is premixed with the water. Holes are drilled using 1.5-in. (38-mm) bits. For CRCP, it is considered very important to drill through the total pavement structure (slab, base, and treated subgrade if present) for jacking below all layers. Holes are spaced no less than 5 ft (1.5 m) apart and not located in a straight line. Care must be exercised to

prevent additional cracking in the pumping operation, especially from irregular or excessive jacking. A stringline is used when jacking a long section of pavement to grade. Jacking is from an area of greater lift to an area of lower lift by rotation. Low areas are jacked a greater amount each time. Wetting the pavement before jacking facilitates removal of the slurry from the pavement surface. The best time for slabjacking is in cool weather (spring and fall) while the pavement slabs are not at maximum expansion. The number of holes drilled during a day is limited to the number that can be filled that day.

RELIEF JOINTS

Few agencies have found a necessity for cutting joints in CRCP to relieve expansion pressure for blowup control. Illinois and Iowa have cut transverse openings of about 4-in. (100-mm) width on the CRCP side adjacent to anchor lug areas to relieve pressure that was causing lug rotation to distort the pavement surface. Satisfactory results are reported for the short period that the cut joints have been in service (not more than two years). Polyethylene foam filler 5 in. (130 mm) wide for a 4-in. (100-mm) opening has been recommended for installation in the joint openings. Similar methods can be used for blowup control.

Minnesota's practice of installing expansion joints in conjunction with patching has been described previously. Illinois and Michigan also have added doweled expansion joints in patching CRCP. These have been used in patching older pavements containing the now-abandoned smooth-wire fabric. The joints in Michigan are serving satisfactorily after 16 to 20 years.

OVERLAY FOR CRCP

The attritional influence of weather and traffic eventually brings every pavement to a state where repair by intermittent patching is no longer cost-effective. Thus, an overlay for renewed or added structural strength or to improve serviceability for a substantial time period must be considered.

Any of the overlays that have been used successfully on jointed concrete pavement, including asphaltic concrete, jointed concrete, and continuously reinforced concrete, seem likely candidates for use on CRCP. However, only asphaltic concrete overlays have been used to date, and not many more than 200 equivalent two-lane miles (320 km) of these have been placed. Furthermore, most of these have not been in place long enough for reliable estimates of ultimate performance.

Texas, with asphaltic concrete overlays varying from 2 to 10 in. (50 to 250 mm) in thickness, reports excellent and fair service from the overlays. Overlays in the "fair" category show some spalling at cracks, and one project has required patching. Texas suggests that a thickness of at least 6 in. (150 mm) be used when structural support is needed. Minnesota reports asphaltic concrete overlays of less than 3-in. (75-mm) and mostly 1-in. (25-mm) thickness separating from the original pavement surface after only a year of service and recommends that thicknesses of at least 3 in. (75 mm) be used. Ohio reports 3-in. (75-mm) asphaltic concrete overlays adding to service life, the only deficiency being reflected longitudinal cracks in the wheelpaths. Arkansas typically has used a 7-in. (175-mm) thick asphaltic concrete overlay with undersealing of the base, but the construction is too recent to judge performance. Illinois, which previously had made some use of a 3-in. (75-mm) asphaltic concrete overlay of CRCP, has placed under contract an asphaltic concrete overlay of CRCP that will have thicknesses in the range of 4 to 4.5 in. (100 to 110 mm) as a first-stage construction. The second stage will include a 2.5- to 3-in. (65- to 75-mm) overlay to be placed as needed at a later date. Because of severe D-cracking that has developed in the existing pavements, a considerable amount of restoration and rehabilitation work is needed to prepare the existing pavement for support of the overlay. The overlay thickness is the same as the Illinois overlay design procedure and would provide for the overlay of a jointed concrete pavement under the same conditions.

Additional information on overlay design is included in Appendix A.

CHAPTER FOUR

GUIDELINES FOR MAINTENANCE AND REPAIR OF CRCP

Present knowledge of CRCP behavior suggests that the following guidelines for the maintenance and repair of CRCP will in most instances provide satisfactory and economical service for this type of pavement.

DESIGN AND CONSTRUCTION

Many of CRCP's problems requiring maintenance are traceable to design and construction deficiencies. Elimination of as many of these deficiencies as possible can be expected to significantly reduce maintenance needs. Appendix A summarizes current design and construction practices that have evolved largely from long-term experimentation and experience and have been proven reasonably successful. Careful application of the suggested procedures will provide a high degree of assurance that future maintenance requirements will be within acceptable limits.

MODES AND CAUSES OF FAILURE

Constant feedback of information by maintenance engineers to design, materials, and construction engineers regarding failures in pavements, the manner in which they occur, and the believed causes of their occurrence is a key factor in improving pavement service and reducing future maintenance needs. The same information is of direct importance to maintenance engineers themselves (a) in recognizing potential failure early enough to perform preventive maintenance or repair work before extensive damage occurs and (b) in selecting remedial measures that provide not only temporary relief but also remove or neutralize the causes of future deterioration. Detailed information on the modes of failure that have been observed in CRCP and on the underlying factors believed to be responsible was presented in Chapter Two.

MAINTENANCE OF CRCP

The following major guidelines are offered for CRCP maintenance. Added details are provided in Chapter Three.

Determination of Need

Engineering judgment suggests that preventive maintenance to prolong the lives of currently serviceable CRCPs is highly desirable, especially in view of the cost and difficulty of repair when failure occurs. Unfortunately, existing quantitative information on the value and cost-effectiveness of preventive maintenance is not sufficient to assure adequate use of preventive procedures, particularly when funds and manpower are in short supply. Nevertheless, the money- and time-saving potential of preventive maintenance always should be given careful recognition during budget preparation, and area field maintenance engineers and foremen should remain continually aware of its potential.

Restorative maintenance or repair is now generally a case-by-case response to keep a highway passable. When repair work is required, a decision as to whether the immediate repair should be temporary or permanent is guided largely by expediency. A permanent repair, in the sense that restoration will be to the same condition as that of the surrounding pavement, ordinarily should be the goal. However, time required to muster manpower and material for permanent repair, the economic desirability of grouping isolated repairs into a single project, and occasionally the need for a holding action where major rehabilitation must be scheduled, may call for temporary repairs.

Educational activities that upgrade the quality of CRCP maintenance, and a specific effort to preserve good communication between office and field, should be a part of all maintenance programs.

Preventive Maintenance

There is little room for doubt that excess water contributes more to all kinds of pavement distress than any other controllable cause. The importance of concentrating preventive maintenance efforts on procedures that reduce the entry or accumulation of water below the pavement surface is widely recognized.

Ideally, preventive maintenance procedures probably should be applied on a routine basis before signs of imminent distress develop. Certainly, they should be applied when such indications of potential distress as water flow, pumping activity, and excessive spalling are first observed.

Sealing (or resealing) of the edge joint between concrete pavement and the adjoining paved shoulder blocks the entry of large quantities of potentially troublesome water. Measured edge-joint movements suggest that a fairly wide joint sealant recess and a relatively high-type sealant will be needed for lasting service (*7*). Open cracks and joints in CRCP showing substandard performance also should be sealed.

The addition of pipe or French underdrains can be effective where accumulated water or pumping is noted.

Asphalt undersealing and application of cement grout are means for filling voids under pavements to reduce harmful accumulations of water and improve support.

Paved shoulder maintenance, including such items as surface sealing, buildup of settled areas at the pavement edge, patching, and of course major rehabilitation, also can be expected to favorably affect pavement performance. The addition of portland cement concrete shoulders, tied to the existing pavement to increase its load-carrying capacity, is considered by some engineers to have economic potential. Obviously, some of these shoulder treatments are more than preventive maintenance.

Restorative Maintenance

The single most important, expensive, and time-consuming restorative maintenance procedure applied to CRCP is permanent patching. Quick repair by temporary patching may sometimes be necessary if a hole appears in the pavement and immediate action is demanded. The relatively short life of temporary patches is usually inconsistent with cost and inconvenience to traffic.

Temporary Patching

Hot-applied and cold-applied bituminous plant mixtures are the best materials for temporary patching. Hot-applied mixtures, although not always readily available, should be given preference when available. Removal of as many loose pieces of concrete as possible from the failed area before placement of the asphaltic mixture will prolong the service life of a patch. Cutting or complete removal of the steel when the patch extends to full depth will also help to extend patch life. The patching mixture should be properly compacted by mechanical tamping or other means before opening to traffic.

Permanent Patching

Permanent patching with portland cement concrete requires careful attention to details during every step for satisfactory results. Experience has shown that patches constructed in strict accordance with known principles of good practice have a reasonable chance of serving satisfactorily over long periods of time. Ample evidence also shows that nonobservance of these principles can result in very early disappointment. An analysis of CRCP permanent patching experience in a wide cross-section of states suggests that the following procedure will afford reasonable success in most situations. Local conditions may sometimes require variations, and further experience will provide needed improvements.

1. Careful and timely surveillance of pavement condition should be exercised to identify the need for repair before damage becomes extensive. Patching should be scheduled for periods when extreme temperatures and temperature changes are not expected.

2. Adequate traffic control is critical to the safety of both highway crews occupying a pavement area and highway users, and impacts strongly on both the efficiency of the maintenance operation and the flow of traffic. The agency's practice should be carefully followed. All of the devices needed for pavement closure should be on hand at the start of the work, and crew members should know what is expected of them in setting up a closure. Patching normally should be confined to a single lane of traffic for safety and to avoid excessive longitudinal movement of the pavement into the patch area that can take place when restraint is lost by removing the full width of pavement.

3. Patch boundaries should be delineated by a person knowledgeable of CRCP performance. It is important that the patch encompass the entire area of failure to prevent further failure. A fresh vertical face should be established in the existing concrete for the patch to abut against. This face should be cut transversely to the direction of travel and, if possible, no closer than 2 ft (0.6 m) to a crack that is to remain. It should not cross a diagonal crack. Patches generally should be placed full-depth and full-lane width. The minimum length of a patch should be whatever is necessary to remove the failed concrete and allow reestablishment of continuity of cut longitudinal steel.

4. Patch edges may be established either with a saw cut deep enough to prevent spall at break-out, but not into the longitudinal steel, or with a jackhammer. Agreement does not exist on this point. Sawing costs more and takes more time but produces a smoother edge. The number and size of the patches to be installed influence the selection of breakout and removal equipment. A jackhammer and other hand tools serve adequately for small jobs. Heavier mechanized breakout and lifting equipment is desirable for larger jobs. It is important that the heavier pieces of equipment not operate in areas where the longitudinal reinforcement is to remain in place. The existing reinforcement can be left in place in small patch areas. In larger areas, it is usually more convenient to cut the steel for easier concrete removal. Cutting the steel is a necessity where heavy mechanized equipment is to be used. Sufficient lengths of longitudinal reinforcement should be left in place for tying or welding added reinforcement. It is also important to future performance that the faces against which the new concrete will abut be cut in sound concrete as close to vertical as possible.

5. Following removal of the broken concrete from the patch area, the base (and underlying material if necessary) should be examined for evidence of inadequate support. Unstable material that may have contributed to failure should be removed and replaced with better material. Added concrete can be the most convenient and satisfactory replacement material. Underdrains should be added where entrapped water is a problem.

6. When the longitudinal steel is cut to aid concrete removal, the cut should be made a sufficient distance from the patch face to permit adequate tying or welding of new steel to that which is retained. Lap lengths for tying probably should be no less than the original lap length, but as short as possible consistent with good performance because of the difficulty of removing concrete from under the steel without bending it. A bar lap of 25 diameters should be considered a minimum and a lap of 30 diameters is recommended for tying. Welding appears to offer a promising alternative to long lap lengths. Only billet steel reinforcement is weldable; rail steel bars can not be welded. Bending longitudinal steel to facilitate concrete removal produces unsatisfactory results. The longitudinal steel can be cut either with a concrete saw or by torch following jackhammering. Bars of the same grade, size, and amount as in the original pavement should be used for replacement when possible. Chairs should be used to hold the steel when concrete is being placed. Ties should be loosened and retied at concrete placement if pavement expansion is bending the bars; the completion of welding should sometimes be withheld until just before concrete placement for the same reason. Some effort to retain tie bars and transverse steel may be worthwhile, especially in long patches.

7. The use of side forms can be considered optional, except when needed for producing a surface of acceptable riding quality in long patches.

8. In final preparation for concrete placement, all loose material should be removed from the excavated area. Compressed air will produce good results in the cleanup operation. The base, patch faces, and steel should be wetted immediately before concrete placement. The efficacy of grout or epoxies applied to the concrete faces has not been proven. When the air temperature is high, water-cooling the surrounding pavement may aid patch performance.

9. High-early-strength, air-entrained concrete should be used as the patching material when early use by traffic is desired, as is almost always the case. The use of rich mixes for attaining high early strength is preferable. After placement and strike-off, the concrete should be carefully consolidated around the steel and at the patch faces by internal vibration. Final finishing and texturing should be consistent with the condition of the surrounding pavement surface. White-pigmented membrane provides satisfactory curing. Curing periods of three days or longer before opening of a patch to traffic are desirable for achieving long-term performance. Curing periods of as little as three or four hours are not recommended where patch permanency is a major goal.

Slabjacking

Slabjacking of CRCP is sometimes needed to remove pavement distortion over highly expansive soils or to bring settled areas up to grade. The equipment, procedures, and portland cement mixtures developed over the years for leveling jointed pavements are equally applicable to CRCP. The best time for slabjacking is in cool weather while the pavement slabs are not at maximum expansion.

Relief Joints

Cut openings may be needed infrequently to relieve expansion pressure causing blowups or lug-anchor rotation. An opening of about 4 in. (100 mm) usually produces acceptable results. Saw cutting can produce better edges and faces than jackhammering. The use of an elastic filler in the cut joint is recommended.

CHAPTER FIVE

RESEARCH

CURRENT RESEARCH

Several agencies currently are known to be conducting research and evaluation studies into continuously reinforced concrete pavements and overlays. Other unreported work very likely is in progress.

Both the Illinois DOT and the Texas Department of Highways and Public Transportation have been engaged for many years in long-term, broad-based studies of the performance of CRCP. The University of Texas at Austin has been cooperating in some of the Texas work, as has the University of Illinois in some of the Illinois work. A major study being conducted by the University of Illinois in cooperation with the Illinois DOT is entitled "Determination of Optimum Maintenance Procedures and Materials for Continuously Reinforced Concrete Pavement." Illinois also has scheduled experimentation with patching, slabjacking, and undersealing in connection with a construction project that involves resurfacing of CRCP with asphaltic concrete.

The Minnesota DOT is investigating solutions to the problem of CRCP spalling caused by steel corrosion. One aspect of this research entails scarifying the surface and placing a low-slump overlay. Several variations are being tested including different depths of scarifying, sawing of joints in the overlay and existing pavement, and placement of wide-flange joints at tension failures. Another aspect of the research involves installation of cathodic protection in an attempt to control corrosion of the reinforcing steel.

Purdue University, in cooperation with the Indiana State Highway Commission, is conducting a comprehensive study that includes field experimentation with several CRCP maintenance techniques.

Research entitled "Field Study of Performance of Continuously Reinforced Concrete Pavements" by the Ohio DOT is nearly complete.

The Wisconsin DOT has underway a statewide CRCP crack and distress survey and is evaluating curing procedures, steel corrosion, and ride and friction values for CRCP. The Kentucky DOT is monitoring CRCP placement and evaluating performance, with special emphasis on time of cracking and crack interval.

The Virginia Department of Highways and Transportation currently is studying CRCP end movements as a function of end-anchor type (including no end anchor); the North Carolina DOT and others are investigating the feasibility of welded bar laps in patches; and the Maryland DOT is also investigating CRCP performance.

The Connecticut, Georgia, Maryland, and Pennsylvania DOTs are evaluating the performance of CRC overlays.

Additional research into CRCP evidently also is underway in several countries, notably Belgium, where wide use is being made of CRCP.

FUTURE RESEARCH

Much is now known about CRCPs, but performance histories that have been accumulating as these pavements age suggest that much is still to be learned. Further improvements in design, construction, and maintenance are highly desirable. Following are several areas where research and experimentation can be particularly helpful.

Design and Construction

Field evaluation studies have shown clearly that failures in CRCP are, in most instances, related to design and construction deficiencies. Although substantial improvements have been made in both design and construction techniques since the early days of CRCP construction, performance of pavements designed and constructed by the best of currently used procedures is not as uniformly dependable as desired.

CRCP design has evolved on an ad hoc basis primarily from statistical correlations derived from short-term studies relating CRCP performance to long-established performance trends for jointed concrete pavements. Given the sometimes uncertain performance of CRCP in the past, it is imperative that CRCP design address more directly the variables that influence performance.

Excessive deflections under heavy loads appear to be the prime cause of failures in CRCP. In current thickness design, neither stresses nor deflections under load are taken directly into account. To encourage a rational CRCP design procedure, future research should concentrate on developing a mathematical model of CRCP behavior based on principles of structural mechanics. Such an analytical approach, similar in scope to the pioneering work of H. M. Westergaard, would integrate the structural characteristics of CRCP (e.g., the continuity requirements, support conditions, and the externally induced load and environmental stresses). The analytical model so developed could be calibrated by laboratory experimentation and field studies of full-scale pavements. This approach would be somewhat different from that used in the NCHRP 1-15 study (*2*).

Most CRCPs in service contain longitudinal steel amounts within the range of 0.5 to 0.7 percent based on the gross cross-sectional area of the pavement. The primary function of this steel is maintenance of crack closure sufficient to provide 100 percent load transfer and to prevent entry of harmful amounts of water and corrosion-causing agents. The percentages of steel in use are based largely on experience, although theoretical analyses that relate temperature-induced stresses to a few variables such as steel and concrete strengths and base friction produce results in the same range. These steel percentages are generally producing satisfactory results where base support is adequate and load deflections stay within acceptable limits. However, further research could provide an optimizing design procedure that would consider a larger number of variables, important among which would be crack width and crack spacing, bar size, steel location, moisture and temperature regimes, and sliding friction between the base and pavement. The possibility of using two layers of steel instead of one, which becomes more practical with the thicker pavements that are sure to be used, is of interest.

Performance surveys have shown that crack spacings on individual projects often vary over wider ranges than appropriate for uniformly good performance. A high frequency of crack spacings in the range of 2 ft (0.6 m) and less has been correlated with a greater expectation of failure in CRCP resulting from excessive deflection under load when support is reduced. Variations in subgrade support and base friction, temperature during concrete placement and curing, and concrete mixture variability are prominent among the factors believed to be associated with crack spacing irregularities, but little is known about their specific influence on CRCP performance. Research that would lead to better control over crack spacing would be extremely valuable. The potentials of higher strength concrete and increased bar size for increasing crack spacing may also be worthy of investigation. Research might also include additional investigation of the use of elastic joints in conjunction with continuous reinforcement for more positive crack spacing control.

Research of the kind needed for establishing an analytical procedure for CRCP design also is needed for CRC overlay design. Experimental studies regarding the use of bond breakers and leveling courses between CRC overlays and existing pavements, and concerning CRC overlay terminal treatments, are needed.

Finally, an urgent need exists for a wide range of research studies concerning the requirements for preparation of worn CRCP to receive resurfacings and the structural requirements and efficacy of various kinds of resurfacings for application to CRCP. Rehabilitation strategies including optimum timing should be developed and made ready for application before the extensive mileage of CRCP now giving good service begins to wear out.

Maintenance

A critical need exists for information on the value, frequency of need, interrelationships, and cost-effectiveness of the various preventive maintenance activities available for prolonging the lives of continuously reinforced concrete pavements. The best methods for performing the activities need to be identified. The consequences of not performing the activities, or changing the frequency of performance, need to be established. The needed studies would cover such preventive maintenance activities as sealing the shoulder-pavement edge joint, undersealing, installation of underdrains, sealing spalled cracks, and shoulder improvements. The full potential of preventive maintenance can never be realized without this information.

The same kind of information needed for the effective use of preventive maintenance is needed with the same degree of urgency for the effective application of restorative maintenance procedures as exemplified by permanent patching. Improved techniques are needed to give better assurance of long-term service both within and adjacent to repair areas.

Greater mechanization of repair operations is needed to reduce existing high time and labor requirements. Further investigation of preformed patches is desirable in this connection. The substantial and immediate reward in terms of improved service, lowered cost, and reduced time of construction obtainable from improved permanent patching procedures makes research into this area particularly attractive. More specific information is needed on lapping requirements for replacement steel. Information is also needed on the effects of interrupting steel continuity in patches, as is being done in Minnesota, where expansion joints are being added, and in Iowa, where short sections of existing reinforcement are being converted to dowels. The relationship between the particulars of patch design and general pavement condition needs to be investigated. This investigation may well show patching design requirements to be dependent on over-all pavement condition. Fast-setting patching materials, too, are in need of further study. Some experimental work already is being done with these materials in Illinois, Mississippi, and Texas. The advantage of fast-setting materials that would provide early opening to traffic without shortening patch life is attractive.

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APPENDIX A

CURRENT CRCP DESIGN AND CONSTRUCTION PRACTICES

CURRENT DESIGN PRACTICE

Current procedures for designing CRCP have evolved mostly from observations made on early experimental and normal construction projects and to a lesser extent from theoretical and laboratory studies. Empirical methods have been derived from experience in several states. Rational design methods also are available, the best known and most often used being the "AASHO Interim Guide" procedure (*20*). This procedure considers fatigue and the need for continuity in determining pavement thickness; concrete strength, steel strength, and subgrade friction are used to determine the amount of steel reinforcement.

Design procedures now in use for CRCP thickness relate CRCP design to the design of jointed pavements in the absence of better information relating specifically to CRCP (*3*). This tie-in assumes that the influence of distress mechanisms for CRCP can be considered the same as for jointed pavement. Performance observations of the two pavement types suggest that this may not be realistic.

Regardless of the approach to design, the results often are routinely reduced to "standard designs" by the states using CRCP.

Structural components that must be considered in the design of CRCP include base, concrete, steel reinforcement, construction joints, and terminals.

Base *

The very early continuously reinforced concrete pavements were placed directly on the available natural earth roadbed material and gave satisfactory service. However, as pumping failures became more prevalent in the more commonly used jointed pavements placed on fine-grained soils without granular bases, prudence suggested that granular bases be made a part of CRCP systems design. The use under CRCP of unstabilized granular bases 3 to 6 in. (75 to 150 mm) in thickness, and thicker when frost problems could be expected, the same as for jointed pavement, became common. Further experience with unstabilized granular bases under both CRCP and jointed pavement showed that, as the volume and weight of heavy vehicles continued their historic increase, even these often were not immune to the problems of degradation, water retention, consolidation, and erosion by pumping. Most agencies are now using bases in which granular material is stabilized with cement, asphalt, and to a lesser extent lime-pozzolans to overcome these problems. Lime stabilization of the roadbed material immediately below the base is also sometimes practiced.

* This layer of material supporting the concrete pavement is often referred to in highway standards, specifications, and other writings as "subbase." The term "base" is used herein to conform with current published definitions (*5, 21*).

A few agencies are continuing to use unstabilized granular bases under CRCP with apparent success. Positive and fast drainage and good compaction of the base material appear to be key factors. A study of the performance of unstabilized granular bases in Indiana showed base-related distress in CRCP to be more generally associated with gravel bases than with crushed stone and slag bases (*22*). Poor performance was attributed to inadequate compaction, poor stability (as evaluated by penetrometer CBR), and low permeability. Based on the results of the study, the following were recommended for adequate base performance under CRCP: an effective minimum density of 100 percent of AASHTO T 99 and preferably AASHTO T 180 [in both cases corrected for material retained on the ¾-in. (19.0-mm) sieve], a minimum stability of 100 percent CBR, and a minimum coefficient of permeability of 1000 ft (300 m) per day. Crushed stone bases were reported in some instances to be giving better performance than comparable bases stabilized with mixtures using bituminous emulsions, but additional study was considered desirable.

Base design and type are influenced by local climatic conditions, including precipitation and frost penetration, and by the nature of the base materials locally available.

Further experience and observations of damage caused by retained water under both CRCP and jointed concrete pavement have led several agencies, including Georgia, Illinois, Maryland, and Pennsylvania, to add longitudinal underdrains at the pavement edges as standard practice. "Daylighted" sections in which porous granular layers are carried through the shoulder areas to the side ditches are also being used by some agencies for the removal of potentially damaging water. Reference *8* offers specific guidelines for the design of subsurface drainage systems for highway pavement structural sections.

Pavement Thickness

No single method for selecting the thickness of CRCP has received general acceptance. Commonly, a thickness less than that for jointed concrete pavement is selected by applying a predetermined ratio or subtracting a specified amount. The 1972 "AASHO Interim Guide" simply states that the thickness of CRCP "may be" less than that obtained from the charts for jointed pavement, with the amount of reduction in thickness being based on local experience or other studies (*20*). The interim guide also contains an alternate design procedure for concrete pavement that includes a nomograph for pavement thickness considering traffic, concrete strength and modulus of elasticity, modulus of support (subgrade reaction), terminal serviceability index, and load transfer. The use of this procedure produces CRCP design thicknesses that are about 80 percent of those for jointed concrete pavements.

Many agencies translate their design thickness results into "standards." Currently, the most commonly used standard thickness is 8 in. (200 mm) (*23*). A thickness of 9 in. (230 mm) also is frequently used. One state that has tested both 7- and 8-in. (180- and 200-mm) thicknesses extensively recommends 8 in. (200 mm) as a minimum (*24*). A 10-in. (250-mm) thickness appears in some state standards, but not much use has been made of it. However, based on the results of a recent Illinois CRCP performance study that found 10-in. pavements 11 to 13 years old serving very heavy traffic with no signs of distress and outperforming 7-, 8-, and 9-in. (180-, 200-, and 230-mm) pavements by a very substantial margin, greater use of this thickness may be warranted (*4*).

The thickness designs used for CRCP are currently suspected of providing pavements that are sometimes too thin for the conditions under which they are serving. Several early failures that appear attributable to excessive deflections under heavy loads suggest that increased thickness will improve pavement performance. A number of agencies, including the Federal Highway Administration, believe that CRCP thicknesses greater than those resulting from current design procedures are warranted in some instances. A new FHWA position permitting greater thicknesses when the need is documented was issued on April 4, 1978. The AASHTO Task Force on Pavement Design is currently considering a proposal that the Interim Guide (*20*) be revised to call for thicker CRCP designs.

Immediate development of a CRCP design procedure that addresses the variables experience has shown must be considered appears to be highly desirable. Until a new and more reliable procedure is developed, the present design procedure included in the AASHO Interim Guide (*20*) for jointed pavement, without a downward adjustment of thickness, probably will cover most situations adequately. Other design procedures that have produced adequately performing CRCP thicknesses in the past also will be acceptable.

Longitudinal Reinforcement

The main function of the longitudinal reinforcing steel in CRCP is to maintain and protect structural continuity by holding the transverse cracks that form at close intervals tightly closed. Several methods are available for determining the longitudinal reinforcement percentage. One such method is presented in the 1972 AASHO Interim Guide (*20*). Use of any of the methods will result in steel contents in the range of 0.5 to 0.7 percent.

As in the case of pavement thickness, states have standardized the amount of longitudinal steel used in CRCP. Most states currently use 0.6 percent steel (*23*). A few northern states use 0.7 percent steel, and other, mostly small variations exist. One state uses 0.5 percent steel in some of its pavements where temperature variations are not large.

At the present time there is no strong movement toward the use of larger percentages of longitudinal steel in CRCP as a means for improving performance. This could change as more becomes known about the influence of crack width on performance. Also, the trend toward greater thicknesses of CRCP may encourage experimentation with the use of two layers of steel instead of the one layer now commonly used.

Deformed steel bars and deformed welded wire fabric are used as reinforcement (*23*). Smooth welded wire fabric is no longer used because of unsatisfactory performance. Bars are always of 60,000 psi (414 MPa) yield strength (Grade 60) steel. Deformed wire fabric is of

70,000 psi (483 MPa) yield, which is the only strength available. Most states require the steel to be placed slightly above mid-depth, and a few specify mid-depth. Typically, No. 5 or No. 6 bars are used at spacings to produce a 0.6 percent steel content.

Experience has shown that adequate lapping of either bars or fabric is essential to satisfactory performance of CRCP. Currently specified minimum laps are most often in the range of 16 to 20 in. (410 to 510 mm) for bars and 16 to 28 in. (410 to 710 mm) for deformed wire fabric (*23*). Laps are staggered or skewed in a variety of patterns, all aimed at avoiding the location of too many splices in the same transverse plane, which experience has shown to have an adverse effect on performance. One recommendation is that not more than one-third of bar laps fall in any one transverse plane.

Transverse Reinforcement

Transverse reinforcement has been used to aid steel placement, to hold chance longitudinal cracks closed, and to serve as tie bars across longitudinal joints. The chance occurrence of longitudinal cracks in a properly designed and constructed pavement with longitudinal joints is remote enough to make transverse reinforcement unnecessary, at least for two-lane pavements and if not needed otherwise (*3*). With the development and improvement of mechanical methods for placing longitudinal reinforcement, the use of transverse reinforcement has been made optional by many agencies. Tie bars are used conventionally at longitudinal joints in the absence of transverse reinforcement. Some agencies consider transverse bars necessary for pavements having more than two lanes. Texas reduces the bar spacing for pavements over 40 ft (12.2 m) wide. Texas also uses a free joint or dowels instead of tie bars for widths over 90 ft (27.4 m).

The size and spacing of transverse reinforcement, when used, are related more to fabrication and construction needs than to any other factor (*1*). A typical size and spacing layout for deformed bar reinforcement is No. 4 at 30 in. (760 mm) (*23*).

Longitudinal Joints

Where concrete placement is two or more lanes in width, as is usually the case, a weakened-plane longitudinal joint is provided to prevent longitudinal cracking. Either tie bars or transverse reinforcing bars are used to keep the joint from opening. Current practice in the provision of longitudinal joints seems to be reasonably effective. In the few instances where longitudinal cracking has occurred, it usually has been traceable to construction deficiencies rather than longitudinal joint design.

Construction Joints

Early users of CRCP found that special design features and careful construction procedures were necessities for transverse construction joints to provide dependable service in this type of pavement. Numerous changes in design details for the immediate area of the construction joint in the first years of CRCP use resulted in a progressive strengthening of this area. Design practice appears to have stabilized in the past several years, indicating perhaps that the acuteness of the problem has lessened from a design viewpoint. However, the construction joint area continues to remain critical with regard to proper application of construction techniques.

Deformed bars are added across the construction joint to increase the steel content by at least one-third and often to double the amount of regular reinforcement. Bar lengths usually range between 3 and 6 ft (0.9 and 1.8 m) (*23*). The relative performance of different designs in current use has not been reported.

Occasionally, splices within the construction joint area also have been the location of troublesome cracking and premature failure. Several different designs are being used to combat the problem. These designs either limit the use of construction joints to areas free of splices, increase lap distances at splices in the construction joint area, or are combinations of the two measures. Plan details often require that lap lengths be doubled or that deformed bars of the same size as the longitudinal steel and 6 ft (1.8 m) long be added at laps within 3 or 4 ft (0.9 or 1.2 m) of the construction header on the back side (with respect to the direction of paving operations) and within 8 ft (2.4 m) on the forward side.

Leave-outs (gaps in the pavement to allow temporary movement of cross traffic) induce damaging stresses in the green concrete because of movement of the adjacent pavement ends and are to be avoided (*1*). Most states do not permit them (*3*).

Terminals

The free ends of CRCP, if not restrained, can be expected to experience outward movements of up to and exceeding 2 in. (50 mm) and annual movements of 1 to 2 in. (25 to 50 mm). A variety of treatments is in use either to restrain or accommodate the movements (*23*).

If restraint is planned, a series of 2 to 6 reinforced concrete lugs set transversely in the foundation material and rigidly connected to the CRCP slab is usually installed. The lugs are spaced at 15- to 40-ft (5- to 12-m) intervals. Because experience has shown that lugs may be only partially effective in restraining movement, a few, short, reinforced concrete slabs separated by dowelled expansion joints are usually used in conjunction with the anchor lugs. Lugs are dependent on the resistance to movement of the soil material in which they are installed and should not be used in cohesionless soils (*3*).

Although some agencies have used lug anchors successfully, others prefer to accommodate rather than to restrain end movements. This is done by using a wide-flange steel-beam terminal joint (Burdell type). The wide-flange beam is set in a sleeper slab, and expansion space is provided.

A recently published survey of state practice in the design of terminals for rigid pavements showed perhaps a slight preference among CRCP users for anchor lugs over wide-flange beam joints and no superior method in terms of performance and total cost (*25*). However, at least one state (Illinois) has recently discontinued the use of the lug-anchor system in favor of the wide-flange beam system because of lower cost.

Occasional surface waves in lug-anchor areas in Illinois and Iowa have required leveling procedures to maintain acceptable riding quality (see Chapter Three).

Ramp Junctions

Where the mainline CRCP adjoins concrete ramp pavements, most states use free joints to allow rather large differential sliding movements to take place freely. Those that tie ramps to the mainline pavement commonly use tie bars in only the middle third of each ramp panel as a means of avoiding overstress in the CRCP adjacent to ramp joints where appreciable movement takes place (*3*).

Shoulders

Because the use of CRCP has been reserved primarily for major highways, paved shoulders are routinely a part of the over-all design. The trend in shoulder design has been continually in the direction of upgrading. Experience has shown that the use of shoulder sections substantially lower in load-carrying capability and resistance to the climatic environment than required for the adjoining pavement almost invariably results in disappointing performance. A detailed survey of CRCP conditions in several North Central states, which included incidental observations of shoulder conditions, showed more than 40 percent of the surveyed pavements having some type of shoulder problem (*26*).

Besides contributing to highway safety, well-designed and structurally sound shoulders aid adjoining pavements in maintaining their structural capabilities by containing underlying layers and assisting in the quick removal of potentially damaging surface water.

Paved shoulder designs now often include an asphaltic concrete surfacing placed on a variety of stabilized and unstabilized granular bases. Limited use also has been made of portland cement concrete shoulders, usually jointed and tied to the mainline pavement.

Because of a tendency toward differential vertical movements of asphaltic shoulders and adjoining portland cement concrete pavements, and also a tendency toward opening of the pavement-shoulder joint, sawing and sealing have been recommended to help control infiltration of surface water (*7*). Tying portland cement concrete shoulders to mainline pavements seems to offer an advantage over asphaltic shoulders in this respect while providing added structural strength to both slabs.

CRC Overlay

The ability of continuously reinforced concrete to tolerate cracking and to hold the cracks tightly closed has encouraged the use of CRC overlays to reduce the undesirable reflective cracking that often occurs in other overlay systems. The need for matching joints in the concrete below is eliminated. Like other thick overlay systems, CRC overlays also can be expected to upgrade structural capacity where needed.

The first CRC highway overlay was placed in 1959, and now more than 350 equivalent two-lane highway miles (563 km) are in service. The majority of this mileage has been in use for less than 10 years.

Most of the CRC overlays built to date have been 6 or 7 in. (150 or 180 mm) thick (*31*). Reinforcing steel contents and arrangements and construction joint treatments are about the same as in regular CRCP. All have been built either to be free of bond to the old surface or to be partially bonded. Most have been built to be bond-free.

Unbonded overlays are used where it appears desirable to reduce reflective cracking or where obstructions to normal temperature movement of the overlay, such as distorted or faulted slabs, are present. Asphaltic mixtures placed as leveling courses, wax-base curing compounds, and polyethylene sheeting are among the materials that have been used with the intent of eliminating bond. Several advantages have been cited for the use of a leveling-course bond breaker, among which are improved thickness control, establishment of a more constant friction factor to better control crack distribution, and minimization of reflective cracking (*27*).

Partial bonding consists of placing the overlay directly on the old surface following removal of loose debris and excess joint sealant. It should be used only on a relatively level surface where the individual slabs are firmly seated and not visibly rocking under traffic loading.

Designs for existing CRC overlays have been selected on the basis of the performance of existing CRCP. Several formalized design procedures have been proposed, the most recent of which applies thickness reduction factors to regular portland cement concrete pavement designs based on the structural condition of the supporting pavement, drainage quality, and the inclusion of steel continuity (*27*).

Most of the CRC overlays that have been constructed are giving satisfactory service. In the few instances where deficiencies have developed, the manifestations are similar to those observed in regular CRCP. These have included punchouts and excessive spalling at cracks. Nonuniform thickness of overlay, poor consolidation of concrete, inadequate subgrade drainage, and nonuniform base pavement support are probable causes of poor performance.

Failures in some relatively new (constructed 1975-77) CRC overlays in Pennsylvania are currently under investigation. The distress has begun as abnormal cluster cracking in the CRC overlay, most often over the transverse joints in the old pavement, and has progressed in several instances to breakage and punchouts that require patching. Wide open cracks also have been observed.

The old pavement was conventionally reinforced concrete 10 in. (250 mm) thick, with contraction joints at 61.5-ft (18.7-m) intervals. It was in very poor condition at the time of resurfacing. Heavy rollers were used to locate rocking slabs, and these were replaced. A 1-in. (25-mm) minimum thickness sand-asphalt leveling course was applied for CRC overlay thickness control and to serve as a bond breaker. The overlay concrete was specified to have a minimum thickness of 7 in. (180 mm). Longitudinal reinforcement consisted of No. 5 bars at 6-in. (150-mm) centers, producing 0.7 percent steel content. Chairs and transverse reinforcement were used and the longitudinal steel placed at about mid-depth. Concrete was placed by the slipform process.

The exact cause of the failures taking place has not been established, and the problem is still under investigation. High deflections noted at failed areas indicate poor foundation support as a possible factor; evidence of a lack of separation between the overlay and the bond breaker suggests this to be another factor. Seriously damaged areas are being removed and patched by the techniques ordinarily applied to regular CRCP. Also, epoxy has been poured in punchouts in an effort to improve stability in areas of lesser damage. Results of the maintenance techniques are not yet known.

Overlay of CRCP

With some of the earliest CRCPs now reaching the end of their expected service lives, and the certainty of more to follow, overlay systems to prolong the usefulness of these pavements are needed. Any of the types of overlays that have served successfully on jointed concrete pavement can be considered candidates for overlaying CRCP. This would include jointed concrete and CRC overlays and asphaltic concrete overlays. Only asphaltic concrete overlays have been used on CRCP to date, and these in limited amount. There are perhaps less than 200 equivalent two-lane miles in service at this time, and much of this mileage has been in use only a short time. Asphaltic concrete overlays of less than 3-in. (75-mm) thickness have not performed well on either CRCP or jointed concrete pavement in Minnesota (*28*). The performance of asphaltic concrete overlays is discussed in more detail in Chapter Three.

In the absence of better information on overlays of CRCP, it seems prudent to apply the same design and construction procedures as would be used on overlays of jointed pavement. The use of a 3-in. (75-mm) minimum thickness for asphaltic concrete overlays probably should be observed until more becomes known.

CURRENT CONSTRUCTION PRACTICE

Procedures that are being used for constructing CRCP are much the same as those being used for jointed concrete pavement. This is reflected in the standard specifications of states using CRCP, which usually make only a few additions to accommodate the newer type of pavement. However, there appears to be general agreement that CRCP is more sensitive to construction aberrations and considerably less forgiving when construction errors take place. Evidently, the continuity that is responsible for the good service to be expected from a well-designed and well-constructed CRCP can also channel disadvantageous stress concentrations into areas that do not measure up to the norm, resulting in early failures.

Base

Base construction for CRCP is accomplished by conventional means. All of the work must be done carefully and in absolute accord with specifications to achieve satisfactory results. Segregation of the base material and unsatisfactory compaction, insufficient compaction of asphaltic mixtures, and inadequate mixing and late compaction and working of mixtures containing portland cement are representative of base construction deficiencies that contribute eventually to poor pavement performance. Also, base construction should never be attempted on a weak and yielding subbase or subgrade material.

Reinforcement

The placing of reinforcing steel for continuously reinforced pavement within the specified location tolerances and in full observance of lap splice specifications is essential to ensure satisfactory pavement performance. Deviations from specifications, especially those concerned with construction joint details and with splicing, are known to have been responsible for subsequent poor performance in numerous instances.

In early CRCP construction, the reinforcement usually was placed on chairs and tied in advance of paving. Less use was made of two-lift construction in which the steel was sandwiched between two separately placed layers of concrete. The two-lift method is no longer permitted by a number of agencies because of the danger of lift separation and is not recommended. The chair system is acceptable provided the chairs offer adequate support, do not sink into the base, and maintain the steel at the proper location. Mechanical methods for placing the steel reinforcement have proven to be both workable and economical. Usually, the longitudinal reinforcement bars are passed through metal tubes into the plastic concrete. Heavier bars (No. 6 as compared with No. 5) handle better than lighter bars. The bars are spread out on the base, then lapped and double-tied before pickup and passage through the approaching tubes. The bars are supported on rollers before passing through the tubes within the spreader. The tubes hold the bars at the proper elevation and spacing until the concrete is placed and consolidated. The omission of transverse bars adds to the efficiency of this method, and experience indicates this can be done without loss of performance. The use of tie bars along the longitudinal joint is retained.

Another mechanical placement method involves the use of a depressor to apply vibration and pressure to embed the reinforcement in the plastic concrete. This method has been applied to the three kinds of reinforcement in use: deformed wire fabric, bar mats, and loose bars. Experience has shown that special care must be taken when using this method to make certain design splice lap distances are maintained. Double-tying of all laps is required.

Concrete

The methods of handling and placing concrete materials and mixtures in CRCPs do not differ from those used for jointed pavement. The slipform paving process has become the accepted method of concrete placement.

Adequate vibration and consolidation of the concrete around the reinforcement is essential for good CRCP performance. Problems following construction are most often traced to voids in the concrete resulting from poor consolidation around the steel. Surface and internal vibration, sometimes in combination, have been used effectively in achieving proper consolidation. Hand-held vibrators must

be used around the closely spaced reinforcement at construction joints to assure good consolidation.

Some states believe that the type of cement used for CRCP has an influence that should be considered with regard to ultimate performance. Type II cement is sometimes favored on the basis that its slower rate of strength gain provides more uniform crack spacing in better accord with design assumptions.

Finally, vigilance in batch-to-batch concrete mixture quality control is vital for achieving the over-all uniformity needed for satisfactory crack control in CRCP.

Construction Joints

All concrete paving requires establishment of joints where temporary work interruptions occur as at the end of a day's construction operations. These joints are known locations of higher stress concentrations in CRCP, and extra longitudinal reinforcement is provided for stress control. The high stresses result from temperature changes in the concrete and steel, sometimes occurring before full working strength is achieved by the concrete. They also result from weakness of load transfer caused by lack of aggregate interlock at the smooth vertical joint faces.

Construction joints are formed by placing headerboards transversely at the location where operations are to be temporarily terminated. Split headers that allow the steel to pass through are preferred for easier removal. The steel beyond the headerboard is supported on chairs and must be protected carefully from movement in the fresh concrete.

CRCP performance problems that result from faulty construction practice are more prevalent at construction joints. Experience has shown the construction joint area to be more sensitive to construction deficiencies and that careful construction know-how is required to assure problem-free pavement at these locations. Improper consolidation of the concrete is a frequent cause of distress at construction joints. Thorough hand vibration is needed because the closely spaced steel at these joints compounds the difficulty of obtaining satisfactory consolidation.

The foam and froth and otherwise segregated material that often accumulates in front of the screed should be wasted and not retained in the concrete placed at the end of a day's work. At least one state (Oregon) regularly uses concrete with a lower water-cement ratio at construction stops for added strength in this area. Several states (including Oregon) use added cement in the first few start-up batches to compensate for the loss of cement and other deviations that seem normally to occur following a shutdown of operations.

Delays in construction of more than a few days or extreme temperature variations at continuation produce undesirable cracking in the concrete just forward of the joint. Procedures such as early-morning starts when air temperatures are lower; addition of cement for more rapid strength gain; stabilization of the temperature-change movement of the last 100 to 300 ft (30 to 90 m) of the hardened concrete with water, wet straw, etc.; and adding more steel beyond the construction joint have been used to combat this problem. The inclusion of a few elastic joints at about 15-ft (4.6-m) intervals to cause cracking at predetermined locations has also been suggested.

Terminals

Anchor lugs can be placed either in advance of pavement construction or monolithically during the paving operation. The concrete is placed directly against the sides of the excavation without forming. Sleeper slabs for expansion devices must be cast ahead of pavement construction.

APPENDIX B

MINNESOTA DOUBLE-ACTING WIDE-FLANGE JOINT DETAILS

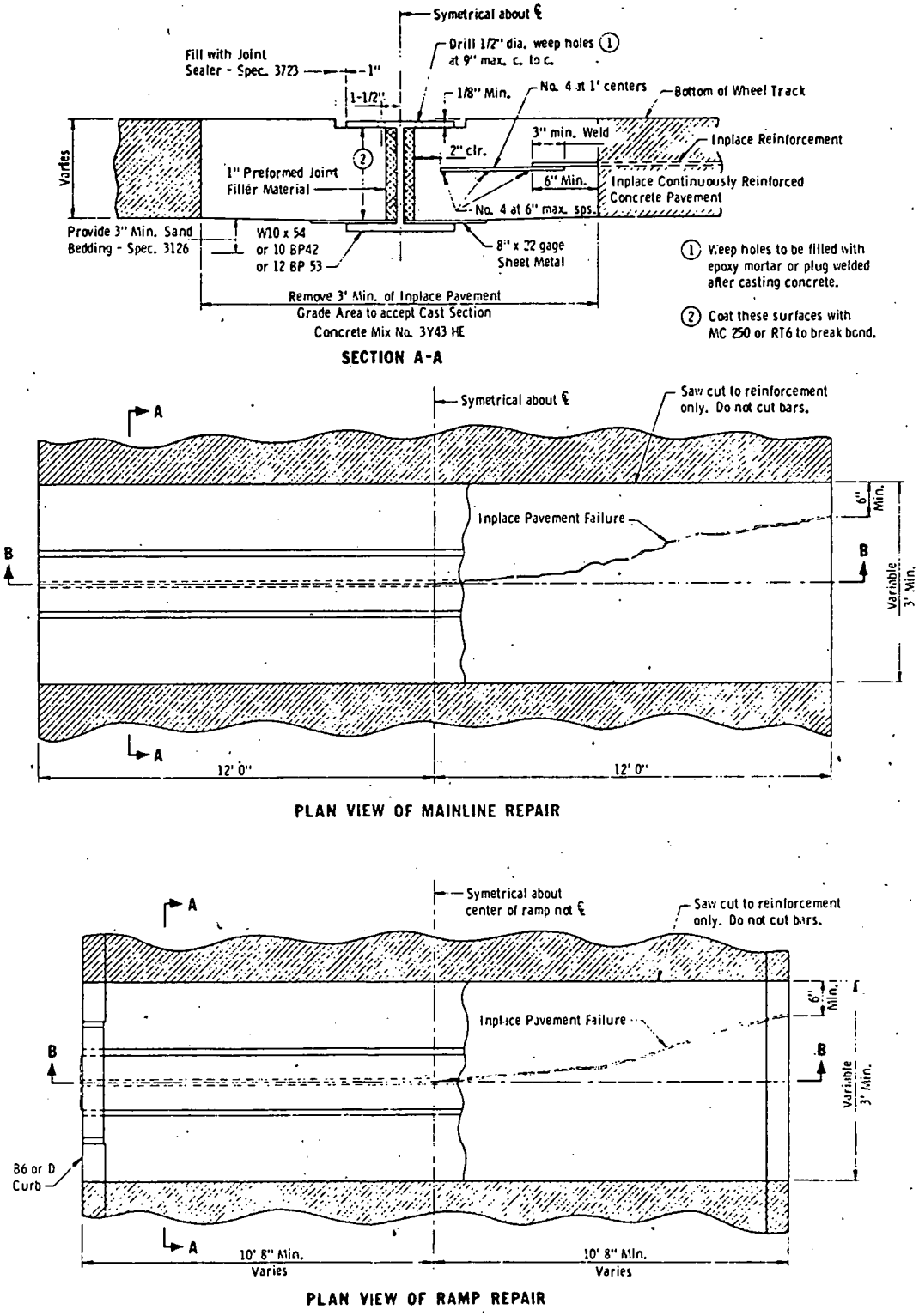
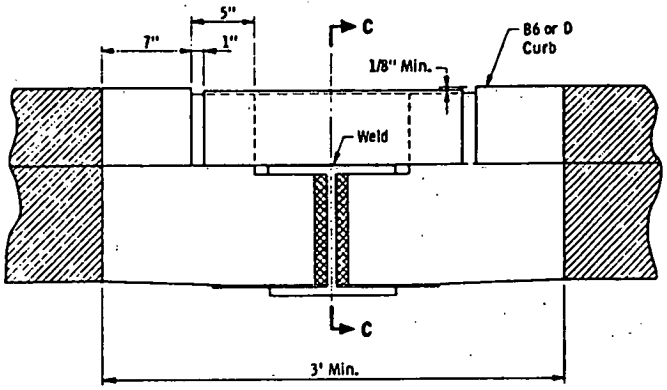
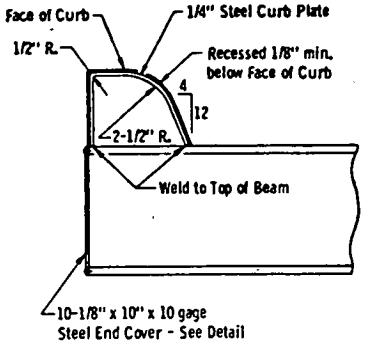


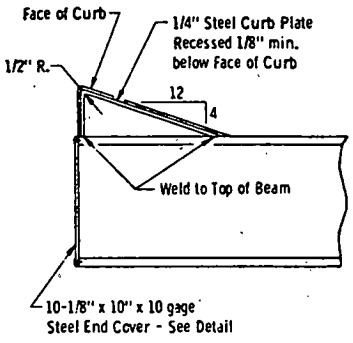
Figure B-1. Minnesota double-acting wide-flange joint details.



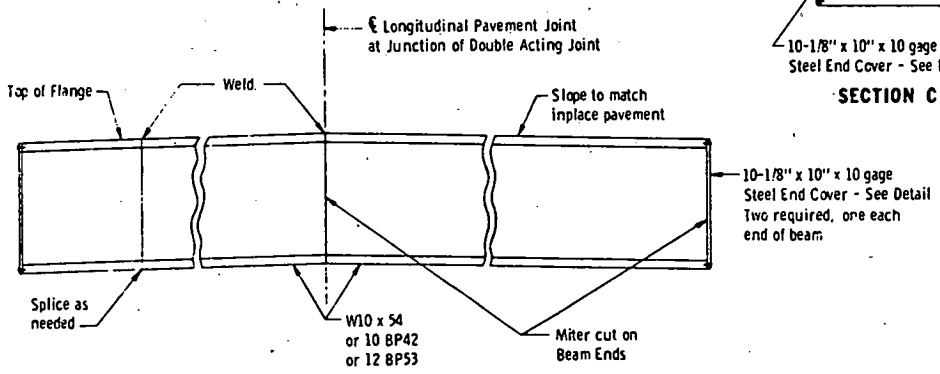
CURB EXPANSION ASSEMBLY



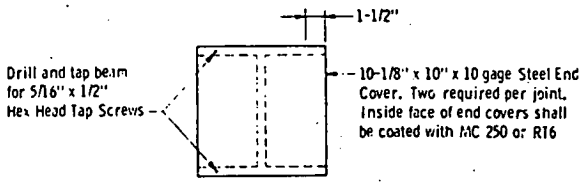
SECTION C-C – B CURB



SECTION C-C – D CURB



SECTION B-B BEAM ONLY



END COVER DETAIL

GENERAL NOTES

For mainline repair, sections shall be cast in 12 ft. lengths to facilitate installation of each lane separately.

For ramp repair, cast each half of ramp separately up to a maximum of 12 ft. sections.

Final position of curb expansion assembly shall be 1/8" min. below top surface of curb.

All steel shall comply with Spec. 3306.

Figure B-1. Continued.

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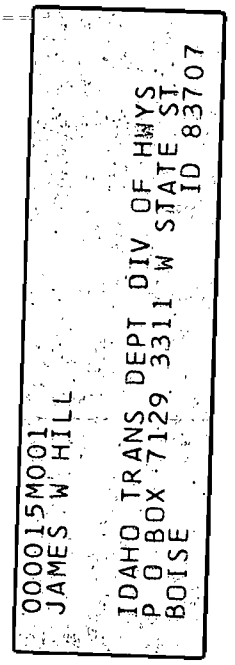
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