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Optimizing Maintenance Activities

Tenth Report

REPAIR OF CONCRETE PAVEMENT JOINTS

Combined State Studies
Of Selected Maintenance Activities
A Cooperative Analysis By Teams From
Iowa, Kansas, Nebraska, South Dakota

February 1980

U.S. DEPARTMENT OF TRANSPORTATION

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VALUE ENGINEERING STUDY OF PAVEMENT JOINT REPAIR

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CONTENTS

LIST OF FIGURES

ACKNOWLEDGEMENT

The opportunity to participate in a cooperative study of mutual benefit to all states involved is greatly appreciated. A special thanks is extended to the Federal Highway Administration personnel who provided the initiation, guidance and support which made the cooperative study possible. Contributions made by the individual participants from the different states have provided valuable assistance toward understanding and improving the various joint repair procedures being followed.

CONVERSIONS

1 inch (in.) = 25.4 millimetres (mm)

1 foot (ft.) = 0.305 metres (m)

1 square yard ($yd.^2$) = 0.8361 square metres (m^2)

1 pound (lb.) = 0.4536 Kilograms (kg)

SUMMARY

This report summarizes methods used and results obtained from a four-state, Iowa, Kansas, Nebraska and South Dakota cooperative value engineering study of portland cement concrete pavement joint repair. The study was initiated under the sponsorship of the Federal Highway Administration to provide an opportunity for the four participating states to work together toward optimizing expenditures being made for pavement joint repair. The study covers repair of non-continuously reinforced concrete pavements only.

Indications from the study show various mechanisms are involved in the transverse joint area failures being experienced. The influx of incompressible materials into the joint, so-called "D" cracking, joint spacing distance, cement-aggregate reactions, effects from load transfer devices and combinations of these factors have been identified as contributing to failure of the concrete at joint locations. This study was strictly limited to repair of concrete pavement joints. A discussion of design consideration, initial construction techniques, maintenance practices and materials deficiencies is not within the scope of this study.

Methods of repair have been designed essentially according to the dimensions of damage at the joint and the condition of the surrounding concrete. Full depth repairs are being utilized where there are relatively large areas of damage at the joint extending well into the slab. Partial depth repairs are being utilized where there is surface damage only at the joint and the surrounding concrete is relatively sound.

Value engineering seeks to identify and reduce or eliminate cost generating elements in any process. Results of team efforts by the different state representatives show that the high cost areas of joint repair center around the sawing operations used to effect removal of the damaged concrete, concrete removal methods and the material costs for the replacement concrete. At present, no innovations have been introduced which will substantially change the sawing and removal practices or the materials of repair. However, the high cost areas have been identified and efforts can be concentrated on reducing these costs in the future.

Mutual benefits were realized from each state's opportunity to analyze repair procedures used by the other states and select for its own use the particular procedures which were found to accomplish the work most effectively and at lowest cost.

There was unanimous agreement that the only way to handle large scale joint repair operations is by contract. Maintenance joint repairs should be restricted to small scale and emergency type situations only.

Although asphaltic concrete is used for varying amounts of joint repair work by all of the states, the main emphasis of the study was on repairs made with portland cement concrete.

Maximizing the use of machinery to accomplish the repair work in place of labor oriented procedures is emphasized.

The joint repair situations of each state are characterized by complex, individualistic requirements, where only varying degrees of adaption between the repair methods of the different states are feasible.

The magnitude of the joint repair problems require efforts toward increasing production in both contract and maintenance joint repair operations. Contract and maintenance joint repairs involve essentially similar operations, but crew size and mobility factors modify what can be adapted from a contract to a maintenance operation and vice versa.

Two states with similar situations found that a savings of approximately $16.00 per square yard (33% reduction in cost) was realized for full depth repairs when the recommended cost savings practices were implemented.

RECOMMENDATIONS

The following recommendations are designed to cover a variety of situations which prevail in the multi-state operations included in this study. Broad terminology, discussion and suggested alternate procedures are required in many cases. The recommendations pertain to the various individual factors and procedural steps which are identified with the repair operations of all the states. These procedural steps, developed by the study groups from the four states, standardize the handling of joint repair into a series of individual functions. Recommendations covering each of these functions only in varying degrees reflect the present repair procedures and policies followed by each of the states.

1. TRAFFIC

Although the handling of traffic is perhaps an indirect activity of the joint repair operations, it is a very real concern, with pronounced sensitivity in the area of safety and public relations. It is recommended that traffic control installations associated with the repair operations be carefully designed, placed and monitored. Warning signs, barricades, continuous delineation and no passing reminders should be placed in a manner which constantly alert and guide the motorist through the repair zone.

The four lane divided highway pavement permits at least two options for the control of traffic. One option consists of maintaining essentially normal traffic flow, closing off one lane at a time to perform the repair work, while shifting all of the traffic flow to the adjoining lane. This procedure offers the advantage of requiring no additional construction to handle the traffic flow, but it requires repair crews to work immediately adjacent to the traffic with associated hazards and restrictions in freedom of operation. If a high early-strength concrete is being used, it is possible for repairs to be completed during daylight hours, with the roadway fully cleared and opened to traffic before nightfall of each working day. Where conventional concrete is being used, continuous day and night maintenance of traffic control is required for the normal curing period.

A second option for four lane divided highways consists of detouring all traffic to the opposite roadway from which work is being performed. This greatly improves the mobility and safety of the repair operations. However, it concentrates two lanes of opposing traffic in the other roadway. It also necessitates the construction of median crossovers to shunt the traffic over and back along with placement of temporary double yellow striping separating the two lanes of opposing traffic, all at considerable cost. Continuous day and night traffic control is required.

Whatever plan for handling traffic is adopted, it should comply with state and federal regulations and be designed with safety as the foremost consideration.

2. LOCATE JOINT AND MARK AREA

A wide variety of circumstances are associated with these activities. These range from preliminary surveys conducted as much as a year ahead of the actual repair work, to locating and marking of the joint area immediately prior to repair. Minimal marking or none at all on initial surveys to determine joint condition is recommended. Reserve extensive use of marking only where required to delineate damaged areas during construction of the joint repairs. Because of the varied circumstances, inidividual procedures will probably need to be developed to obtain effective handling of each situation.

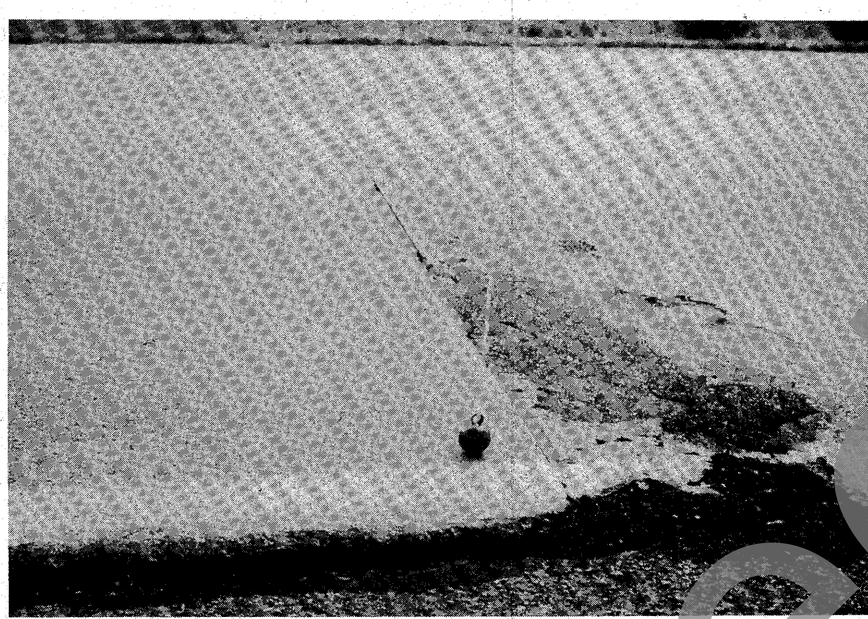

FIGURE 1 – LOCATE JOINT
Combine visual inspection and sounding to check condition of joint area concrete.

FIGURE 2 – MARK AREA
Use minimal marking or none at all on initial surveys to determine joint condition. Reserve extensive use of marking only where required to delineate damaged areas during construction of the joint repairs.

3. SAW AREA

Partial depth diamond-blade sawing, full-depth diamond blade sawing, full-depth cutting with a rock saw (wheel cutter) or a combination of diamond-blade sawing and sawing with a wheel cutter comprise the options used for the joint repair.

Partial-depth diamond blade sawing (2 - 3 inches deep) is recommended around the boundaries of partial-depth repairs where the concrete is to be removed by jackhammering. One state with extremely hard course aggregate and only physical damage at the joints has obtained satisfactory results by diamond blade sawing the perimeter of the partial depth repairs to a minimum depth of one inch. The depth of repair required in these cases is minimal compared to that required for joint distress associated with D-cracking and cement-aggregate reactions. The clean, straight line cuts facilitate removal of the old concrete, aid in edge finishing of the new concrete, minimize the possibility of spalling and provide for a smoother ride.

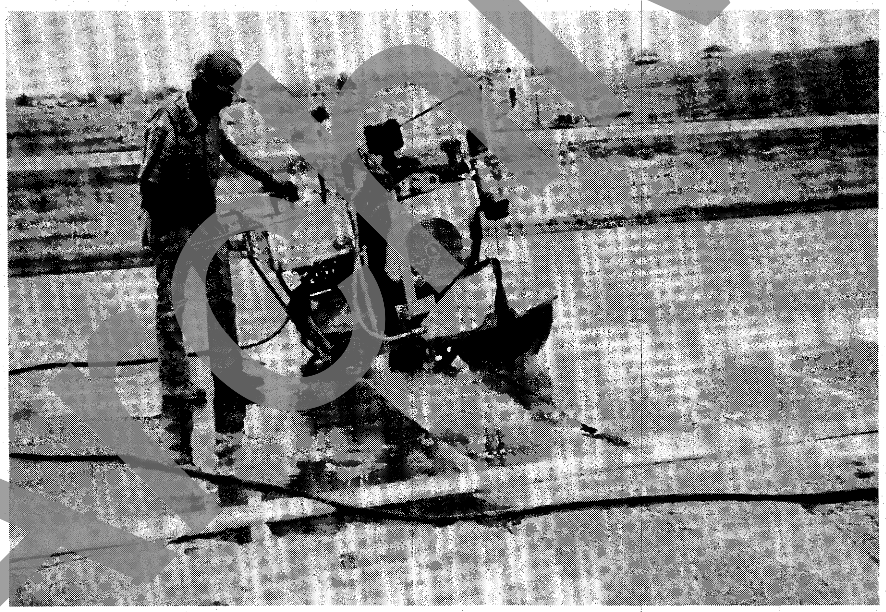

FIGURE 3 – SAW AREA
Diamond-blade saw in operation on partial-depth joint repair.

These same diamond-blade edge sawing procedures may be used when the old concrete of the partial-depth repairs is removed with the aid of scarifying equipment if the irregular edges are not acceptable.

It was the general concensus that full-depth joint repair patches be a four-foot minimum width and no less than full lane width to reduce the chance that the patch concrete would rock under traffic.

Full-depth diamond-blade sawing provides means for removal of concrete pavement sections, with the following consideration.

(a) Among the sawing options available, diamond-blade sawing generally offers the most practical means for cutting full- or partial-depth through concrete constructed with extremely hard aggregate.

(b) Where compressive forces in the pavement may be higher than normal, it is recommended that full-depth sawing be done in the cooler portions of the day to prevent the saw from binding.

(c) The diamond-blade cut leaves a smooth vertical face on the old concrete, with no aggregate interlock produced between the old and new in-place repair concrete. Under some conditions of high traffic volumes, many heavy loads and the condition of the existing concrete, it may be desirable to install load transfer devices. This application would be relegated to small volume repairs.

(d) When diamond-blade sawing full-depth of the slab do not penetrate the subbase or subgrade any more than necessary since this will cause needless and excessive blade wear.

Full-depth cutting with a rock saw (wheel cutter) provides means for removal of concrete pavement sections, with the following considerations.

(a) Cutting concrete constructed with extremely hard aggregate, such as Sioux quartzite, is not feasible with the rock saw. Excessive tooth wear and extremely slow cutting rates make such usage impractical. However, a rock saw can be used to cut concrete constructed with gravels and softer aggregate materials such as limestone. Tooth wear and cutting rates in these cases are within acceptable limits.

(b) The width of cut produced by the rock saw is capable of relieving compressive pressures adjacent to the cut in the pavement slab. Also, the width of cut, approximately four inches, is great enough to permit access to the under side of the slab sections with special lifting devices to remove the deteriorated concrete in one piece.

(c) The rock saw tends to tear and spall the concrete at the top edges of the cut. The degree of tearing and spalling is somewhat dependent upon the quality of concrete and the type of coarse aggregate involved. These irregular edges may not be acceptable as the finished edge around the perimeter of the repair to some agencies. Partial-depth diamond-blade saw cuts in the pavement surface adjacent to the rock saw cuts can be used to provide a sharply defined edge and to produce a joint with less tire slap and a smoother ride. Due to the shelf that is produced by the diamond-blade saw cut it will be necessary to prepare the faces of the old concrete to a near vertical plane using 15 pound chipping hammers or similar equipment.

(d) Using water to cool the rock saw teeth may improve tooth wear somewhat and also reduce dust but at the expense of having to provide water handling equipment.

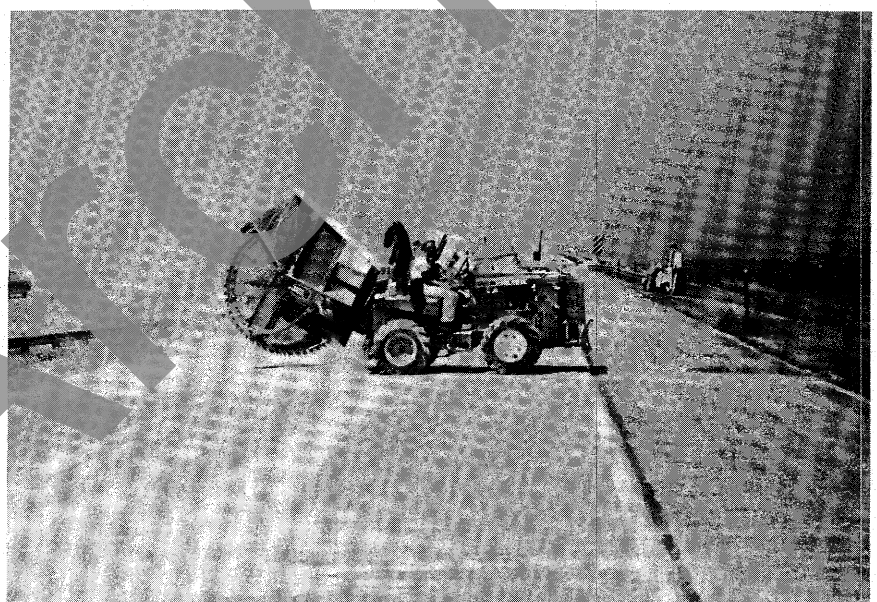

FIGURE 4 — ROCK SAW (WHEEL CUTTER)
Rock saw (wheel cutter) completed full-depth lane width cut.

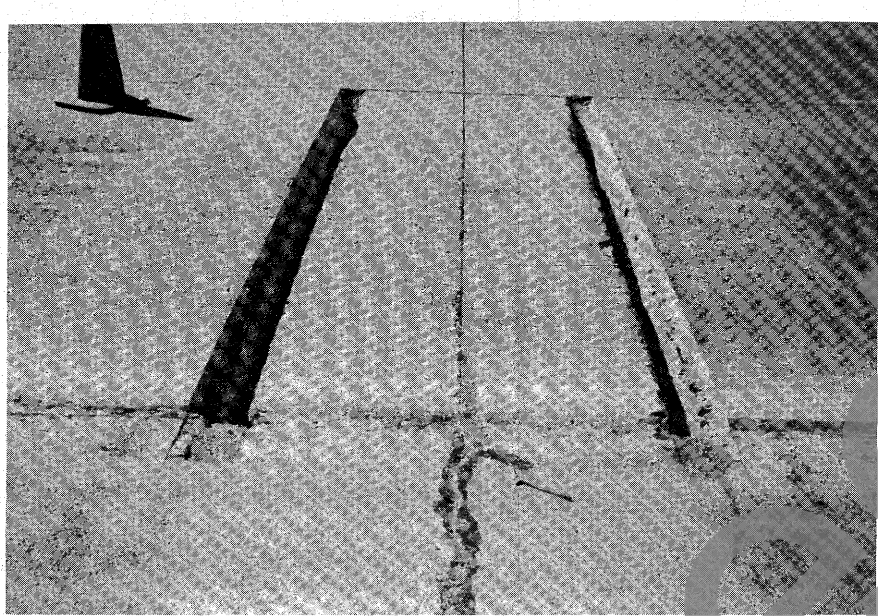

FIGURE 5 — COMBINATION SAW CUT
Full-depth rock saw cut with partial-depth diamond blade saw cut adjacent to it.

4. BREAK CONCRETE

Preparation for partial-depth repairs requires diamond-blade sawing of the perimeter of the repair area and then breaking up of the old damaged surface concrete, usually with jackhammers. It is recommended that maximum emphasis be given to the development and use of power equipment such as scarifiers and roto-mills to accomplish the removal. Jackhammering and manual procedures should be confined to low volume full depth repairs, maintenance partial-depth repairs and clean-up work.

Removal of full-depth repair sections is most efficiently handled by cutting them free of the adjoining pavement through use of sawing and retaining them in one piece for easy removal with special equipment.

FIGURE 6 – BREAK CONCRETE
Breaking concrete with jackhammers.

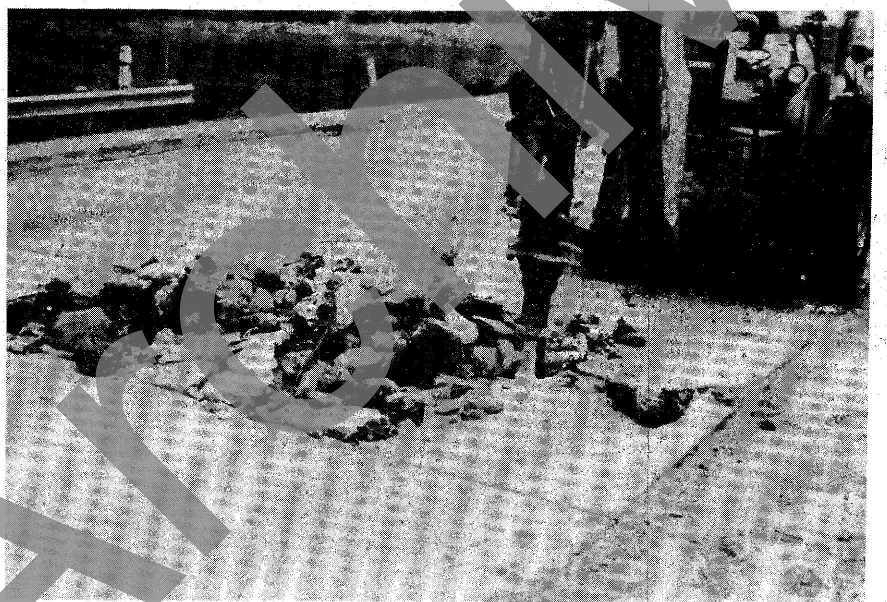

FIGURE 7 – BREAK CONCRETE
Breaking concrete with pavement breaker.

5. REMOVE CONCRETE

Utilizing mechanical means to accomplish any large scale removal of the old concrete is stressed.

A roto-mill type of equipment fitted with a conveyer belt can remove major portions of the old concrete of partial-depth repairs as an adjunct to the cutting action of its rotor. Remove scattered, broken and loose material resulting from use of typical scarifying equipment through use of power brooms, shovels and front end loaders. The use of high powered vacuum equipment for picking up loose concrete pieces of partial-depth repairs prepared with roto-mill type of equipment should be explored.

Manual removal procedures should be confined to small area repairs and for cleanup work around larger repairs.

Concrete from full- depth repair sections prepared by diamond-blade sawing around the perimeter and broken by jackhammers or pavement breakers may be removed by manual methods, but the use of back-hoes, front-end loaders or other mechanical means is preferred.

Removal in one piece is the most efficient way of disposing of full-depth repair sections which have been sawed full-depth with a rock saw or a diamond-blade saw or a combination of both. The removal is accomplished through use of front-end loaders or truck mounted cranes or other specialized equipment. Employ jackhammering to remove marginal portions of the old concrete still remaining around edges of the opening.

FIGURE 8 – REMOVE CONCRETE
The backhoe is favored by some states for the removal of broken concrete.

FIGURE 9 – REMOVE CONCRETE
A front-end loader removes concrete from a full-depth joint repair section.

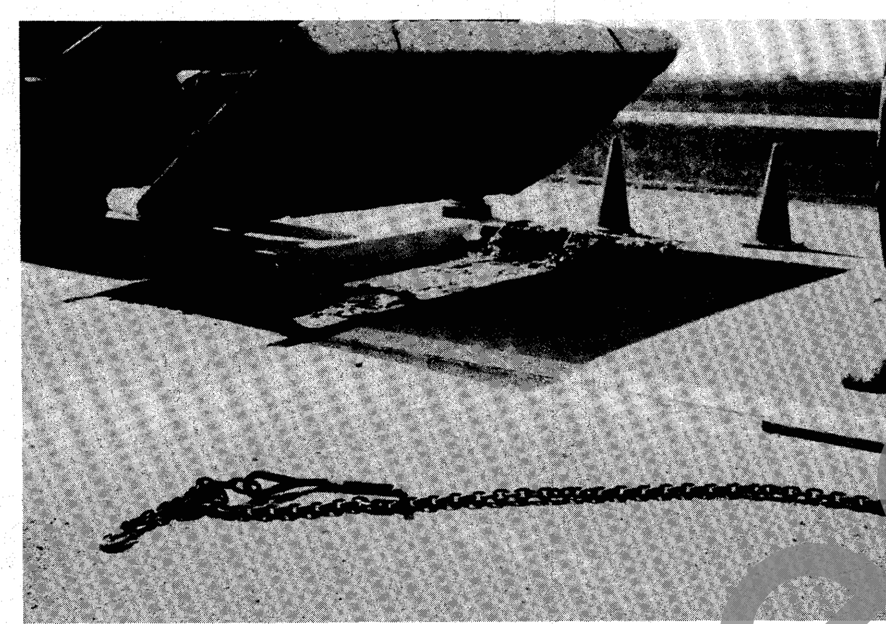

FIGURE 10 – REMOVE CONCRETE
Using a front-end loader with slings to remove full-depth joint repair section disturbs base very little.

FIGURE 11 – REMOVE CONCRETE
Specialized equipment removes full-depth joint repair section with minimum disturbance of base.

6. CLEAN REPAIR OPENING

Final cleanup of partial-depth repair openings is best accomplished by blasting out remaining loose material with compressed air using due caution to protect traffic in the adjacent lane.

Minimum disturbance and cleanup of the full-depth repair opening in the pavement will result when the old concrete section is removed in one piece.

Some states believe that any base material lost or disturbed should be replaced and levelled. Other states believe that it is more simple and expeditious to utilize repair concrete to replace any base material lost or damaged. Using concrete to replace the base material eliminates the possibility of not being able to duplicate or obtain uniform density in the base. An advantage, particularly for contract work, would be the savings in time and labor. In addition, it may reduce careless removal and cleanup.

The cleanup phase includes the cutting off of all projecting mesh and tie bars flush with the joint repair faces. This will free the concrete patch to function independently of the adjacent lane slab and eliminate the transverse joint from forming a crack in the full-depth patch concrete. Under some conditions, it will be necessary to establish the longitudinal joint with some type of bond breaker.

FIGURE 12 – CLEANING REPAIR AREA
Full-depth repair section prepared with a rock saw and a diamond-blade saw. The face of the cut has been prepared to a near vertical face. Projecting wire mesh is being clipped off. A small amount of old broken concrete is being removed with a shovel.

7. PLACE FORM

The use of forms to preserve the edge of the patch (partial or full-depth) adjacent to the shoulders is essential. Failure to do this will result in a rough projecting edge of concrete into the shoulder which may complicate shoulder maintenance or reconstruction.

Some states have used wood forms adjacent to the shoulder to form the edge of the patch. Heavy wood forms are reused while lightweight wood forms are often left in place.

The states in this study were in general agreement that the use of an angle iron (1" by 3" or 2" by 3") of sufficient length would be adequate for forming the patch edge. The angle iron is easily installed and removed to be reused on subsequent patches.

FIGURE 13 – PLACE FORM
A removable wood form is being installed.

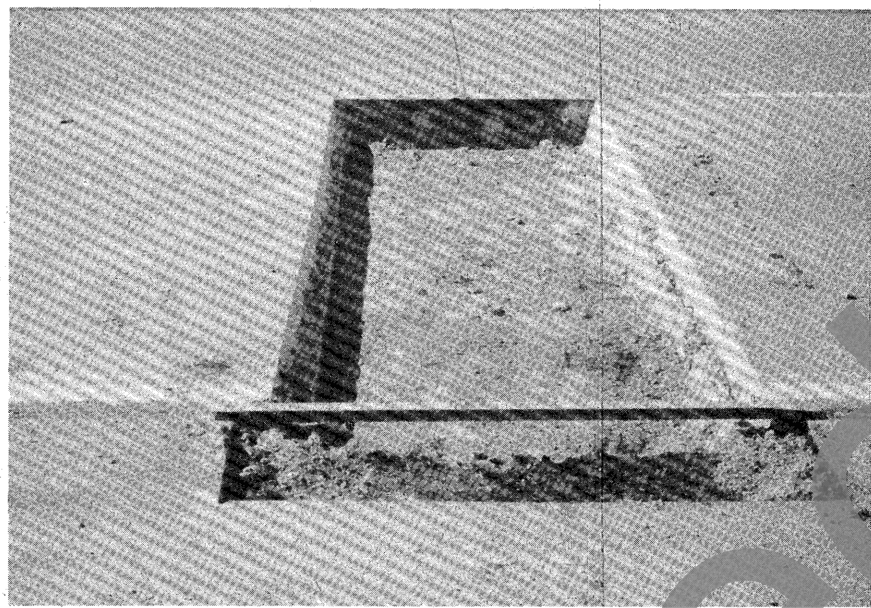

FIGURE 14 – PLACE FORM
An angle iron edge form in place.

8. MIX CONCRETE

The function "mix concrete" appears to be the most appropriate place to deal with the cost of (1) materials, (2) volume of concrete required, and (3) whether the set of the concrete is to be accelerated.

Material costs center around the type of cement used and the location of aggregate sources.

If a section of highway being repaired can be closed to traffic for an individual period of time, then a Type I cement can be used in a conventional pavement mix and the concrete patch can be given a normal curing period.

When the pavement section being repaired cannot be closed to traffic to allow for the normal cure of the patches, a much more expensive mix utilizing a high cement factor (one state uses 799 pounds per cubic yard) Type III cement and calcium chloride can be used and patches can be opened to traffic in four hours, even heavy interstate traffic. One state indicates they have had almost equal success using 823 pounds of either Type I or Type III cement per cubic yard with calcium chloride. If more time is available, a high cement factor mix using Type I or Type III cement with or without calcium chloride may be used.

Some joint repair projects will not be located near acceptable sources of aggregate. Transportation of aggregate from great distances can add as much as 300 percent or more to the cost of the aggregate.

In this instance, it would be well to consider alternate sources of aggregate. It is possible that an aggregate of lesser quality will produce concrete of sufficient durability that will last as long as the existing pavement.

The most economical combination of aggregate and type of cement may not always be consistent with a philosophy of serving the travelling public in the most expeditious manner possible.

On the other hand, safety of the contractor's work force and engineering personnel is also a factor and with the construction of cross-overs on four lane divided highway to divert traffic from the repair area or detouring traffic from two lane roads, it is possible to utilize the less expensive concrete mix designs.

When calcium chloride is to be added to accelerate the set of the concrete, it is recommended that the admixture be premixed with water off of the project prior to beginning repair operations. This eliminates the need to carry scales, bulk bags of material, water and large mixing containers to the field. It also reduces manpower activity in the field at the time of concrete placement. The premixed calcium chloride solution is dispensed by volume into the concrete mix just prior to placement at the repair site. Successful use of such a procedure requires planning for rapid discharge of the concrete into the repair work.

Super plasticizers (super water reducers) offer possibilities and further investigation for use with repair concrete to facilitate handling and provide a lower water cement ratio.

Large quantities of concrete are best furnished from nearby ready-mix plants or from batching plants set up at the repair project. Small quantities of concrete for maintenance type repairs can be prepared as required by bringing needed materials and a small portable mixer to the repair sites. A high daily demand of small volume repairs may justify acquisition of a concrete mobile mixer.

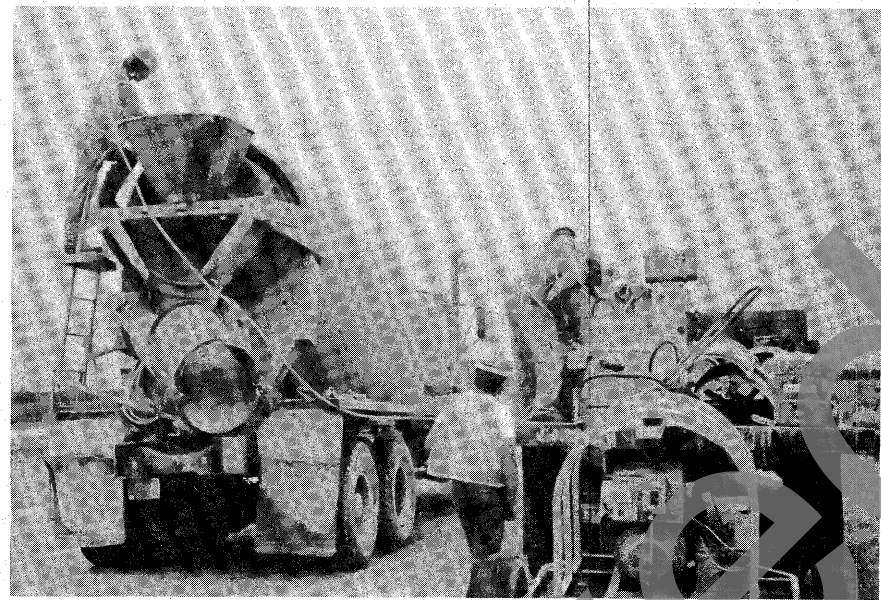

FIGURE 15 – MIX CONCRETE
Adding premixed calcium chloride to ready-mixed concrete prior to concrete placement.

FIGURE 16 – MIX CONCRETE
Truck equipped with materials and small mixer for small volume maintenance work.

9. GROUT AREA

Placing a cement, sand and water grout on the old concrete surfaces of partial-depth repairs wherever there is an interface with the new concrete of the repair is vitally important because any failure of the bond will result in the failure of the patch.

There are diverse thoughts on the necessity for applying grout to the transverse edges of the full-depth repair sections. One view is that grouting the faces of the transverse cuts provides a more uniform contact between the old and new concrete. The grout is not intended to act as a bonding material in full-depth joint repair. The opposite view is that grouting is not necessary. It may be possible to eliminate the grouting operation in full-depth repair sections if proper vibration will consolidate the new concrete thoroughly against the old concrete faces.

The grout should be brushed on the surfaces of the old concrete just prior to placement of the new concrete. Allowing the grout to become dry before the new concrete is placed in a partial-depth patch will almost always assure the failure of the patch. Allowing the grout to dry on the old surfaces of a full-depth patch before the new concrete is added will nullify the reason for grouting in the first place.

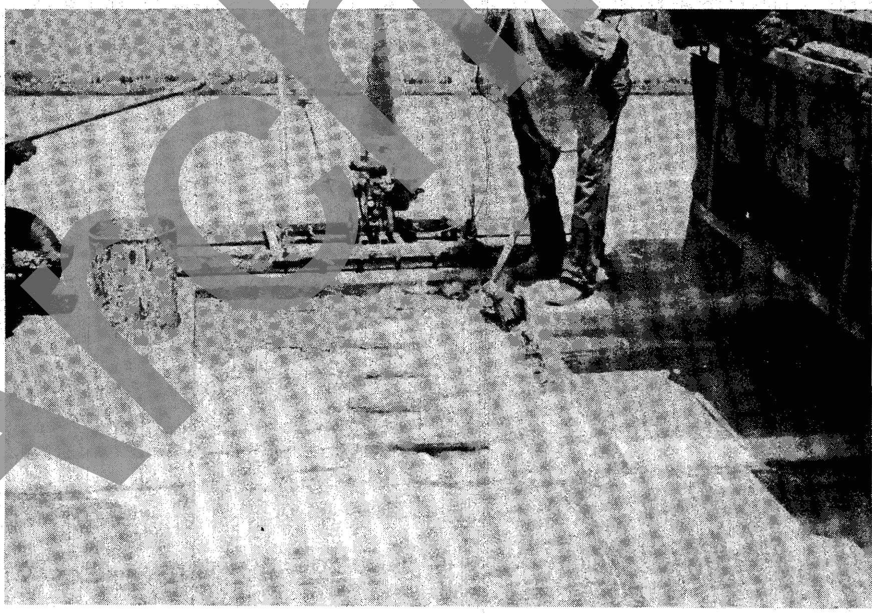

FIGURE 17 – GROUT AREA
Placing grout in partial-depth joint repair.

10. PLACE CONCRETE AND STRIKE OFF

Concrete may be furnished at the various repair sites from such devices as small job-site mixers, ready mix trucks or concrete mobiles. Amounts of concrete to be placed range from cubic feet to cubic yards. Transfer and distribution of the concrete to the repair are accomplished most effectively by means of the delivery chute on the mix truck. When set of the concrete is being accelerated with calcium chloride, it is imperative that internal vibration and strike off begin as soon as enough concrete has been placed to work since the concrete mix sets quickly. Delaying vibration and strike off may result in improperly consolidated concrete and a rough patch. Best results are achieved when the strike off is made with a vibrating screed. This provides additional consolidation.

FIGURE 18 – PLACE CONCRETE AND STRIKE OFF
Internal vibration.

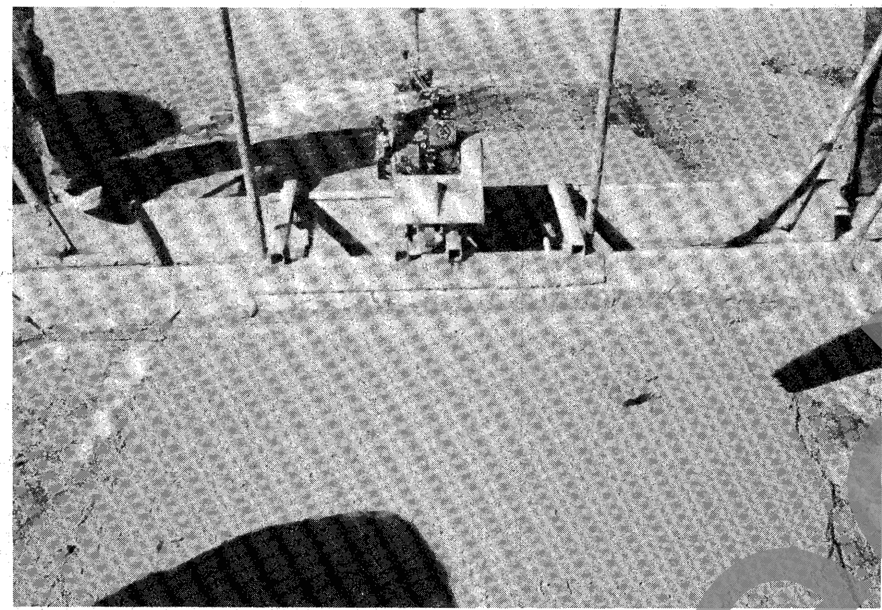

FIGURE 19 – PLACE CONCRETE AND STRIKE OFF
Vibrating screed used to strike off concrete.

11. FINISH CONCRETE

Hand held strike off and small wood hand floats should be limited to repairs of no more than a few square feet. Larger repairs struck off with a vibrating screed generally have an adequate surface finish. Light edge finishing of full-depth patches is recommended to reduce ravelling. Re-establish the transverse joint in partial depth patches.

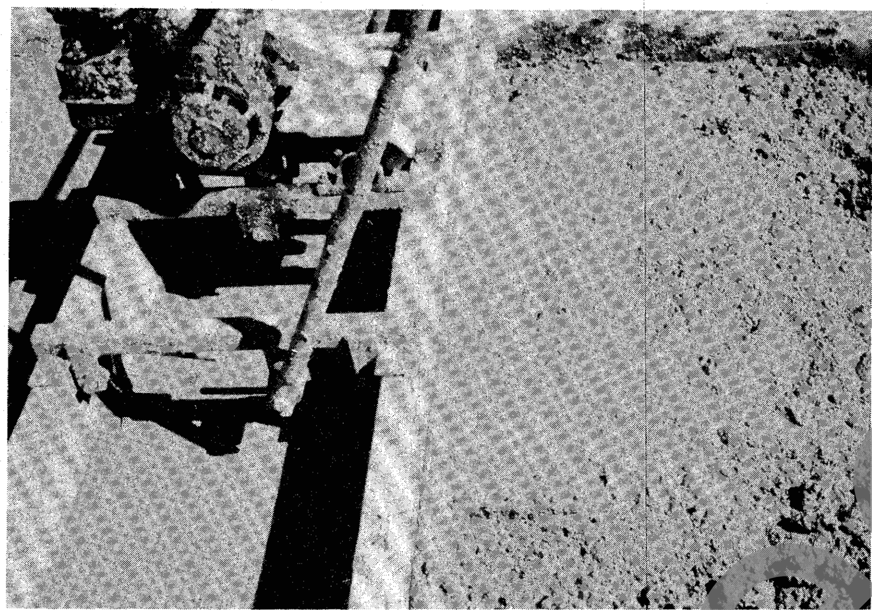

FIGURE 20 — FINISH CONCRETE
The vibrating screed will generally leave an adequate surface finish.

FIGURE 21 — FINISH CONCRETE
Occasionally, additional floating is required to provide a level patch.

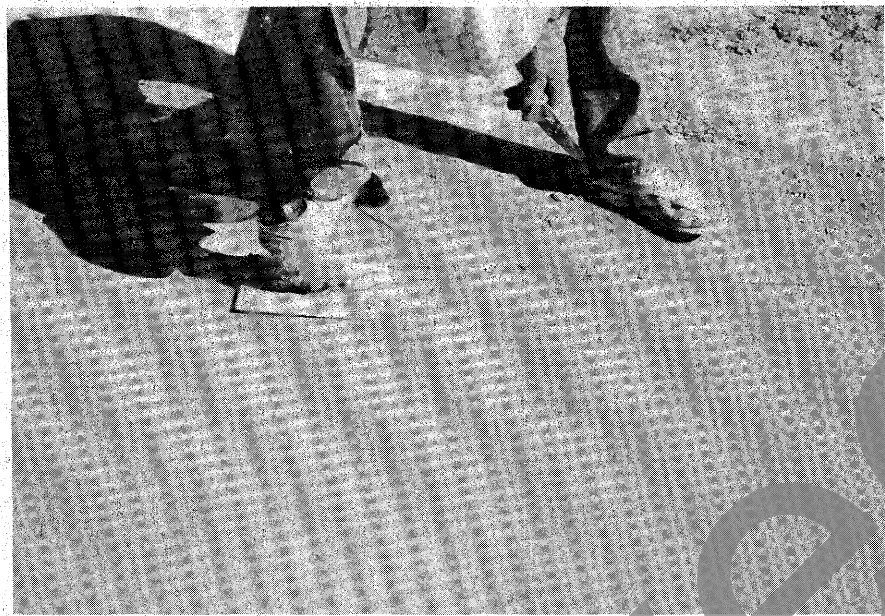

FIGURE 22 – FINISH CONCRETE
Edge finishing a full-depth patch.

12. TEXTURE CONCRETE

Texture imparted to the joint repair concrete surface should match as closely as possible the texture of the adjoining old pavement surfaces. Where the texture left by the vibrating strike off screed is reasonably similar to the texture of the adjoining old pavement, no further adjustments are needed. Where changes in texture are considered necessary, a burlap drag can be used to effect such changes. Tining or brooming textures are not necessary in most cases.

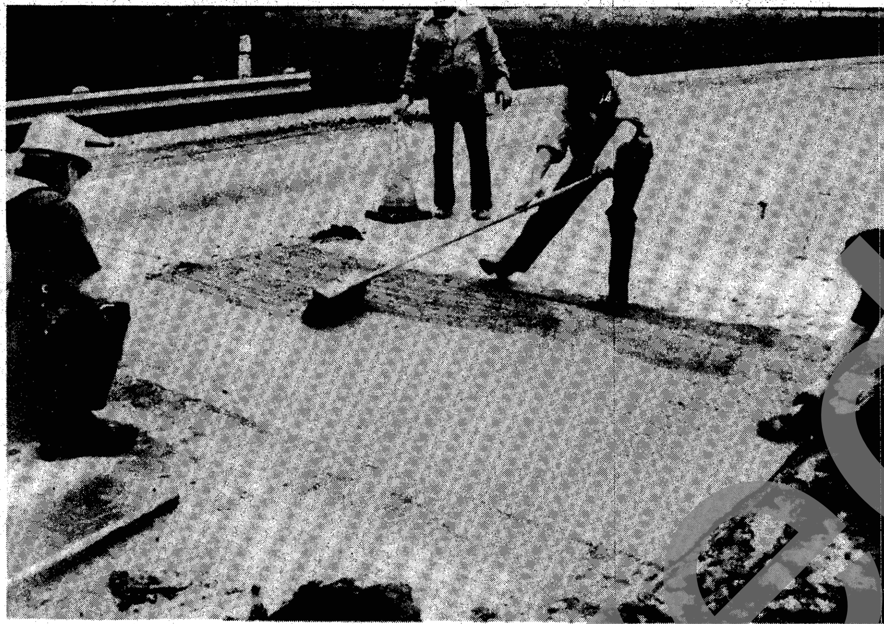

FIGURE 23 – TEXTURE CONCRETE
Broom texturing patch.

13. CURE CONCRETE

Spraying a membrane curing compound on the repair concrete to effect cure is both practical and effective. The simplicity and advantages of this method have made it standard for curing concrete of the repair sections. Several states are considering eliminating the curing operation if studies underway indicate that the concrete does not appear to suffer any noticeable damage. One state, when using an accelerated set concrete, places a polyethylene film over the membrane cure followed by insulation board to retain the heat of hydration and moisture to further accelerate the strength gain of the concrete. It is believed that this procedure is necessary when the repair patch is to be opened to traffic in four hours. However, it was suggested that it is worth further study to determine the real need for curing concrete that gains strength so quickly.

FIGURE 24 – CURE CONCRETE
Curing patch with white pigmented liquid membrane-forming compound.

FIGURE 25 – CURE CONCRETE
An accelerated set concrete patch with curing compound, covered with polyethylene film and insulation board.

14. REFILL JOINTS

It is recommended that all transverse joints in or adjacent to partial-depth joint repairs be re-established and be of sufficient width and depth to permit proper functioning and for sealing.

BACKGROUND

Deteriorated or defective joints in pavement cause unsatisfactory riding quality and performance of rigid pavements. When deterioration reaches the point where temporary surface patching no longer provides a safe, smooth riding surface, removal and replacement of a portion of the pavement becomes necessary. The prospect of having to spend large sums of money for the repair of damage to the joint area concrete over extensive segments of pavement has generated considerable concern.

This study was conducted for the purpose of determining, through actual application, how established Value Engineering techniques lend themselves to the analysis of permanent repair of deteriorated joints in rigid pavements. Value Engineering techniques used in this study consisted of highway engineer team approach in which all basic functions of a process are defined, analyzed and assigned values in respect to their worth in obtaining the end product. The low value/high cost function were then further analyzed to see if they could feasibly be done less expensively by alternate means or in some cases completely eliminated.

The objective of this study is to optimize expenditures of the funds assigned for repair of the joints on portland cement concrete pavement. This includes repairs done by both maintenance and contractor forces using both full- and partial-depth repair procedures.

Joint repair requirements will continue into the future, as additional lengths of pavement attain greater age and are subject to the continuing effects of materials, weather and traffic.

STUDY APPROACH

The cooperative study was conducted by highway agencies from the states of Iowa, Kansas, Nebraska and South Dakota. The Federal Highway Administration sponsored and funded the study, with details and coordination handled out of the Region 7 office in Kansas City, Missouri. Field work was carried out over an eight month period in 1978. This report was prepared upon completion of the field studies and developments from four individual meetings in the different states.

A two-day orientation session held in Lincoln, Nebraska on March 29 and 30, 1978, initiated the study. After an introduction to the principles of value engineering was presented by Mr. E.D. Johnson of the FHWA, each state described and illustrated its current joint repair procedures. The need for thorough study of the procedures and the introduction of innovative cost saving ideas was emphasized.

A second meeting was held in Pierre, South Dakota on June 7 and 8, 1978. Each state presented its current pavement design practices. A second presentation by each of the states was devoted to time and cost studies of the different functions in their joint repair procedures. The use of pressure relief joints to relieve blow-ups in concrete pavement was discussed. The role of dowel bar assemblies in the failure of joint area concrete was discussed. At the conclusion of the meeting, a standard format was established for identifying the successive individual steps in the repair procedures followed by each state. This standard was to be used by each of the states in subsequent analysis and speculation phases of the study.

A third meeting was held in Ames, Iowa, August 9 and 10, 1978. Analysis and speculation phases of the joint repair methods were completed by each of the states. Group discussions were held covering each of the proposed alternate procedures for completing the individual steps of the joint repairs. Selections were made of the procedures which appeared most practical and least costly.

The greatest potential for cost savings was identified as being in the cutting and sawing operations associated with removal of the old concrete and in the material costs for the replacement concrete.

The fourth and final meeting was held in Topeka, Kansas, November 8 and 9, 1978. Each of the state representatives presented their recommendations covering the various elements of the joint repair procedures. The content of the final reports to be prepared by each of the states and the overall report covering the work done by all of the states was discussed.

FINDINGS

Although a standard step-by-step format was used during the study of each state's joint repair procedures, marked differences were indicated in basic characteristics of the joint repair problems of the different states.

Pressure generated from the presence of incompressible materials in the joints was identified as one mechanism responsible for damage. Intrusion of the incompressibles into the joints resulted from unsuccessful performance of a system of patented joint devices. Numerous, relatively small, breakouts at the pavement surface on either side of the transverse joints characterized the damage. Correction consists of placing partial depth repairs in these areas, constructed by diamond sawing, jackhammering and replacing material removed with concrete closely matching the original. The old pavement concrete was generally in excellent condition.

Another reason for joint area concrete failure was attributed to "D" cracking which extends full depth through the joint area. Repair was accomplished by full depth removal and replacement of the concrete extending for two feet or so on either side of the joint. The transverse joint was not reconstructed in the repair concrete, nor were the dowel bar assemblies and reinforcing mesh that were removed with the old concrete replaced in the new concrete. The general condition of the old pavement concrete was only fair.

Too great a spacing between joints was another problem linked to failure of the concrete at the joints. Inability of the joint sealant to accommodate the greater expansion and contraction from the length of pavement allowed incompressibles to enter the joint. Breakouts resulted when expansion pressure buildups developed.

Cement-aggregate reactions also cause general deterioration of the pavement concrete evidenced by failure of the concrete at transverse joint locations. The basic pavement structure is still physically intact, but varying degrees of distress are developing at the joint locations. Delamination, spalling, cracking and breakup require extensive maintenance efforts in many cases. Repairs consisted of full depth removal and replacement of the old concrete, covering the areas of damage on either side of the joints. The transverse joint was not reconstructed in the repair concrete, nor were the dowel bar assemblies and reinforcing mesh that were removed with the old concrete replaced in the new concrete. Partial depth repairs are being made where joints have limited damage and the surrounding concrete is still in fairly sound condition.

General agreement was reached among the four state study groups that the employment of a length of re-usable angle iron to form the repair concrete next to the shoulder is the most rapid and economical procedure. Ease of placement, ease of removal and re-usability of the angle iron form were the qualifying factors. Omitting the form is possible, but a roughened projecting edge of concrete results, which may complicate future shoulder maintenance or reconstruction.

Sawing to remove the damaged concrete has been identified as one of the high cost elements in the joint repair operations. The relative hardness of aggregates in the concrete can very significantly affect the cost of cutting, especially with a rock saw. The quality of concrete can also have a marked influence on sawing with a rock saw. When sawing a good quality concrete, the aggregate constituents are held securely in position and the saw is required to cut through the individual aggregate particles. When cutting a poor quality concrete, the saw will tend to dislodge and shell out the aggregate elements, greatly speeding up the cutting but will leave a spalled edge.

Asphaltic concrete offers at least one significant advantage as a repair material for the portland cement concrete pavement joints, but appearance and cost factors have largely ruled it out for large scale usage. An advantage of the asphaltic concrete is that on portland cement concrete pavements prone to develop expansion from internal reactions, placement of full depth asphaltic concrete repairs across the full width of the pavement will provide built in pressure relief elements. The inherent flexibility of the asphaltic concrete can accommodate changes in length of the portland cement concrete on a long term basis without exhibiting distress. A deterring factor to usage of the asphaltic concrete is the objectionable appearance of asphaltic concrete repairs made on portland cement concrete pavements. Analysis of cost data indicates no clear cut cost advantage for the use of asphaltic concrete as a repair material in place of portland cement concrete.

The replacement portland cement concrete was identified as a high cost element of the joint repair process. Contributing factors are the high cost of portland cement, the use of relatively high cement factors and the cost of obtaining and transporting suitable coarse aggregate to the repair location. Developing use of concrete made with Type I cement as opposed to concrete made with the more expensive Type II and Type III would offer some economies. Where coarse aggregates not prone to reactions with portland cement are specified, such as limestone, the cost can be considerable if there are no locally available sources. One recourse would be to develop concrete designs which utilize locally available coarse aggregate in conjunction with some additive, which has been demonstrated as capable of inhibiting cement-aggregate reactions. A second recourse might be to go ahead and use the locally available coarse aggregate per se, on the assumption that there is no point in placing repairs potentially more durable than the surrounding old concrete. Generally, the savings that can be realized in material costs do not significantly reduce the overall cost per square yard of repair.

The advantages of removing full depth repair sections in one piece from the old pavement have been clearly indicated from the experiences of the different states. Savings in time are generally regarded as the greatest benefit derived from the one piece removal with substantial savings in cost being second. Removal and loading of the old pavement sections in one piece can be accomplished in minutes whereas a much longer time is required to complete the removal with jackhammers and shovels.

A questioning attitude was indicated among some participants of the study concerning the role of dowel bars in the functioning of transverse pavement joints. Where joint problems have developed on pavements undergoing cement aggregate reactions or "D" cracking, the adverse effects from the presence of dowel bars are particularly evident on the old full depth sections of concrete removed during joint repair operations. Delamination of the concrete at the dowel bar level is frequently observed in these sections upon removal. It is speculated in these cases, that differential vertical motion of the concrete on either side of the joint causes the dowel bars to act as levers to pry the structurally weakened concrete apart. The onset of such delaminations is usually the forerunner to breakup of the surface concrete directly over the delamination zones. A delaminated condition is frequently found at pavement joints which appear structurally intact at the surface. Subsequent breakup of the surface area concrete then occurs, as the pavement is subjected to the continued effects of traffic and weather.

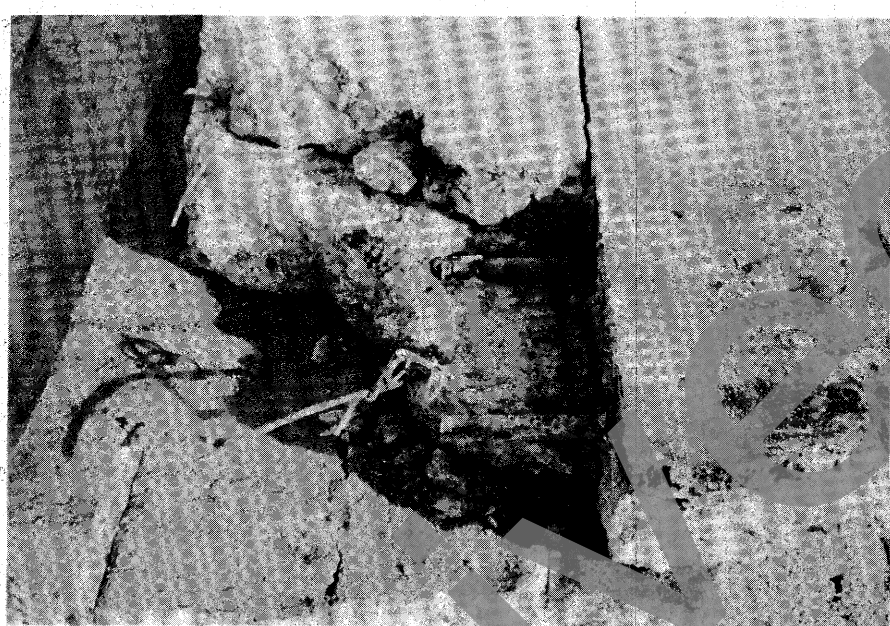

FIGURE 26 – DELAMINATION AT DOWEL BAR LEVEL

Another deteriorating effect can come from rusting of the dowel bars, brought about by the infiltration of de-icing salts into the joint. Corrosion products, with a volume more than two times greater than the original steel, can generate pressures easily capable of forcing the concrete apart. The rusting can also promote "freezing" of the dowel bars, removing the capability of the joint to accommodate changes in length of the pavement associated with moisture and temperature changes. Misalignment of the dowel bars was also noted as a cause for problems developing at joints but not a major cause. The procedure usually followed for correction of the joint problems involving dowel bars is to remove and replace the entire full depth section of joint area concrete containing the dowel bar assembly.

A characteristic of pavements undergoing cement-aggregate reactions and other forms of deterioration is that they tend to "grow" and develop buildups of internal pressures. These internal pressures may contribute to breakup of the concrete at joint locations and most certainly are instrumental in producing "blow-ups" in certain segments of pavement. Another cause for the build-up of internal pressures is the infiltration of incompressibles into the transverse joints. Four inch wide "pressure relief joints" cut across the pavement with a rock saw at regularly spaced intervals are being used to relieve these internal pressures.

Cutting of pressure relief joints should be based on indications that a pressure buildup definitely exists in the pavement even to the extent of the pavement experiencing a few blow-ups. Consideration should be given to the concept that a closely joined pavement system, with some internal pressure variation from temperature and moisture changes is probably desirable. Therefore, proper use of pressure relief joints requires careful assessment to insure that excessive pressures are relieved, but not to the extent that other adverse effects are induced.

Other factors relating to the use of pressure relief joints are the future continued growth of the pavements involved, the effects of construction of full depth joint repairs, the effects of fixed installations such as bridges, spacing of the pressure relief joints in the pavement and timing of the sawing of the joints.

Continuous growth can be expected in a pavement which is undergoing cement-aggregate reactions and other forms of deterioration. Consequently, the cutting of pressure relief joints should logically follow a phased plan, where cuts are made only as pressures build up to critical levels.

It is current thinking that when an initial 4-inch wide pressure relief joint has closed and compressed the filler material to approximately two inches, the joint ceases to be effective. When the opening is reduced to a width of one inch or less, the possibility of a considerable pressure build-up exists and additional sawing to relieve the pressure is warranted.

The spacing of pressure relief joints may have to be established experimentally. A suggestion would be to make initial experimental cuts at relatively wide spaced intervals of 4,000 feet or so, followed by a period of observation. If the cuts close to a width of two inches or less in a relatively short period of time, the introduction of additional cuts midway between the initial cuts may be warranted and so on. The spacing of pressure relief joints at 1,000 and 2,000 foot intervals is not uncommon in some pavement rehabilitation projects. The object is to relieve excessive pressure while still maintaining the pavement as a tightly closed system with some measure of longitudinal pressure. The presence of bridges in the pavement system will of course require some adjustments in placement of the pressure relief joints.

Making a number of full-depth joint repairs across the full width of a roadway will tend to reduce the internal pressures and will have to be taken into account when the location and spacing of pressure relief joints are being considered.

It is desirable to saw pressure relief joints when temperatures are lower and the effects of thermal expansion are minimal. Spring and fall are better times from a seasonal standpoint while early morning and nighttime would be preferred on a daily basis.

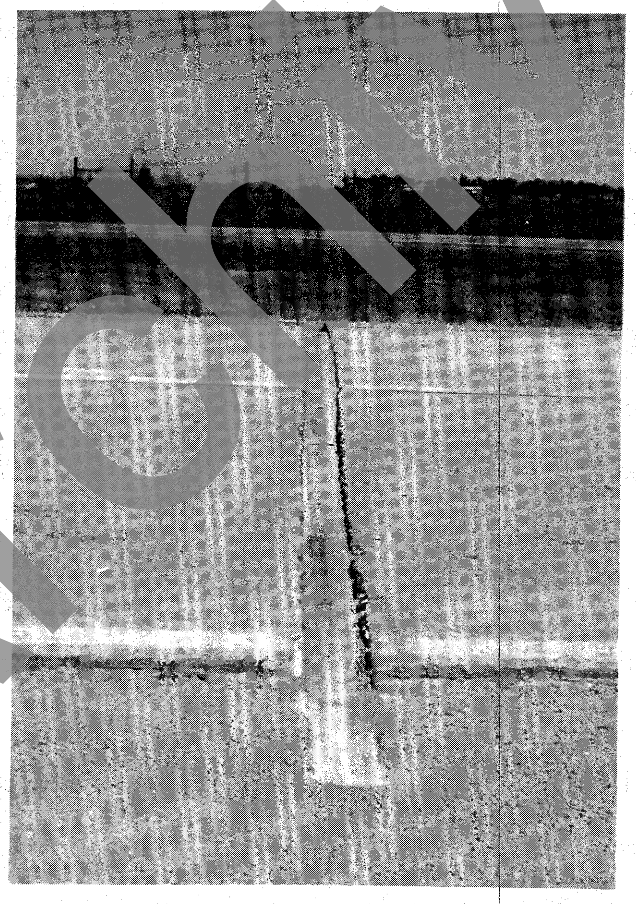

FIGURE 27 — COMPLETED PRESSURE RELIEF JOINT

ECONOMIC CONSIDERATIONS

Data acquired during analysis of typical full depth joint repair being done by contractor's forces in one state indicated that cutting full depth with a rock saw (wheel cutter) and removing the old concrete in essentially one piece required 2.5-5.8 minutes per square yard with associated costs for these two operations ranging around $20 per square yard. In comparison, analysis of full depth joint repair being done by maintenance forces in another state showed diamond blade sawing and jackhammering with piecemeal removal of the old concrete required an average of 12 minutes per square yard with an associated cost for these operations of about $35 per square yard. Accordingly, if the roughened edge left by the wheel cutter is considered satisfactory for the finished edge of the repair, in combination with one piece removal of the old concrete, this procedure can provide a 52-79 percent savings in time and an approximately 43 percent savings in money over the diamond blade sawing and jackhammering method for each square yard of old concrete removed. However, if the addition of diamond blade sawing adjacent to the cut made with the wheel saw is considered necessary to provide a clean cut edge, up to approximately 4 minutes of time and approximately $8.00 in cost will have to be added for each square yard of the old concrete removed. The time and cost are based on one man operating a 2-blade "gang-saw" and two men jackhammering the ledge formed by the diamond-blade saw cut. The resultant savings in this case would be 18-46 percent in time and approximately 20 percent in cost for using the rock saw, diamond-blade saw and one piece removal as compared to diamond blade sawing, jackhammering and piecemeal removal.

Partial depth repairs can offer definite economic advantages over full depth repairs. Although direct comparison cannot be made from the data accumulated during this study, some generalized statements can be made.

A partial depth repair can be constructed in about any size, whereas a full depth repair must, for practical reasons, be constructed with a minimum width of about 4 feet. Partial depth repairs can be used advantageously in situations where the joint damage ranges up to a few square yards in area and where the surrounding concrete is still in good condition. In comparison, the four-foot minimum width full depth repair usually extends across at least one twelve-foot lane width of pavement and requires placement of over five square yards of concrete. Consequently, partial depth repairs used in place of full depth repairs can significantly reduce the number of square yards of repair required with associated reductions in cost to the project.

Removal of the old concrete for partial depth repairs can be accomplished by conventional diamond blade sawing and jackhammering or more rapidly by use of scarifying equipment.

The scarifying equipment has a potential for very rapidly removing the old concrete, but this savings in time may be offset by the fact that the top edges of the cut, due to the spalling of the concrete, may not be acceptable to some agencies. In which case, diamond blade sawing of the perimeter of the partial depth patch and jackhammering of the concrete at the sawed edge can be done to provide a clean cut edge finish.

Experience has shown that the cost per square yard for constructing partial depth repairs may equal or even exceed the cost per square yard for constructing full depth repairs. For this reason, in situations where the damage requires construction of a larger size repair approaching the number of square yards associated with the minimum sized full depth repair, it may be less costly to construct the full depth repair. Another reason for choosing the full depth repair in this case is that the full depth repair is generally preferred over the partial depth repair when extensive replacement of the joint area concrete is required and the surrounding concrete is only in fair condition.

OBSERVATIONS

The rate at which pavements are deteriorating, particularly at the joints is a grave concern to the states participating in this study and to many other states as well.

Progressive deterioration of the concrete is such that maintenance forces cannot keep up with the repairs. The quantity of repairs let to contract is affected by the monies available.

According to one state's findings, a delay of one year in awarding a contract can, in some instances, add 20-25 percent or more to the square yards of repair concrete. Similarly, work that is carried over from one year to the next can expect the same percentage increase.

Consequently, with current repair rates of $55 to $80 per square yard for full depth repair, development of specialized equipment, new procedures and improved techniques capable of significantly speeding up repair of the joints and at a lower unit cost while maintaining suitable quality should be a major concern for the future.

Decreasing the exposure of the motorist to the hazards of detours, barricades, construction under traffic areas and "head to head" traffic on four-lane road work by completing repair work more rapidly is of immeasurable value if lives are saved and associated economic losses are avoided.

Regular inspection and preventive maintenance cannot be overemphasized as means for avoiding joint damage in a number of situations. The primary concern is to keep each joint continuously sealed against the infiltration of deicing chemicals and incompressible materials. Resawing and resealing joints which are no longer functioning properly can forestall costly future repairs.

Judicious sawing of pressure relief joints can drastically reduce the rate of "blow-ups" and provide for additional pavement life.

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A NOTE ON THIS PUBLICATION

This report is the tenth of a special series on highway maintenance that is being developed by cooperating groups of State highway agencies and is being issued under the sponsorship of the Implementation Division, Office of Development, Federal Highway Administration.

Other reports in this series are:

Snow and Ice Control - Materials	FHWA-RD-75-524
Snow and Ice Control - Operations	FHWA-TS-77-208
Shoulder Maintenance	FHWA-TS-77-210
Repair of Continuously Reinforced Concrete Pavements	FHWA-TS-78-215
Bituminous Patching	FHWA-TS-78-220
Sign Maintenance	FHWA-TS-78-223
Bridge Painting	FHWA-TS-79-202
Traffic Striping	FHWA-TS-79-219
Rest Area Maintenance	FHWA-TS-80-210