PERFORMANCE EVALUATION OF UTAH'S CONCRETE PAVEMENT JOINT SEALS

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During the summer of 1972, Utah experienced the first major pavement distress in its concrete pavement Interstate highways in the form of pavement blowups. Subsequent investigation indicated that these resulted from poor construction and repair, which allowed contraction joints to be filled with incompressibles. Growing concern about more widespread pavement distress led to additional visual inspection and joint corings. Six sections were chosen, ranging in age from 6 months to 10 years, from which cores were taken, and it was found that all but the most recently sealed joints had seal failures, even in those that were only $1\frac{1}{2}$ years old. When it was determined that seal failure was so common, the designs were reviewed, and it was found that the present seals are overstressed. It was recommended that either a $\frac{7}{16}$-in. preformed seal be installed in a $\frac{1}{4}$-in.-seal reservoir or a PVC hot-pour seal in a $\frac{3}{8}$-in.-wide joint be used instead of the present design. Other observations showed that the longitudinal joint at the pavement edge was in poor condition and needed resealing but that the longitudinal centerline joint was in good condition.

•DURING the summer of 1972 on I-15, between the 31st Street Exit in Ogden and the Layton Exit, 2 blowups occurred in the concrete pavement. These major pavement distress problems were the first such problems to occur on the state's Interstate highways since the concrete-paved sections were opened to traffic approximately 10 years ago. At the time of construction the contractor had failed to remove the wooden bulkheads laid at the end of each day's paving when he started to place concrete the next morning. When the pavement was nearly completed, the wooden bulks, which had been left in the pavement, were noticed. In removing the bulkheads the pavement was only partially cut and the remaining depth of pavement was broken with a jackhammer. Instead of having a vertical break, the remaining slab was undercut as in Figure 1a. The gap was then filled with expansive concrete containing iron filings. Several years later the expansive concrete had started to deteriorate rapidly due to rusting of the metal filings, leaving a depression in the pavement (Figure 1b).

Plans were made to remove the deteriorated concrete, but before this could be done the pavement blew up at the construction joints (Figure 1c). During the investigation of these blowups it was observed that the joint seals in this area had failed and the joints were being infiltrated by incompressibles. With the joints infiltrated the horizontal stresses resulting from thermal changes could not be relieved. When the forces became large the pavement was pushed up the ready-made ramps at the construction joints.

After these blowups were examined and their cause was determined, additional investigation to evaluate the condition of the concrete pavement in other areas was proposed. The proposed study objectives were to

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Figure 1. Repair, deterioration, and blowup sequence.

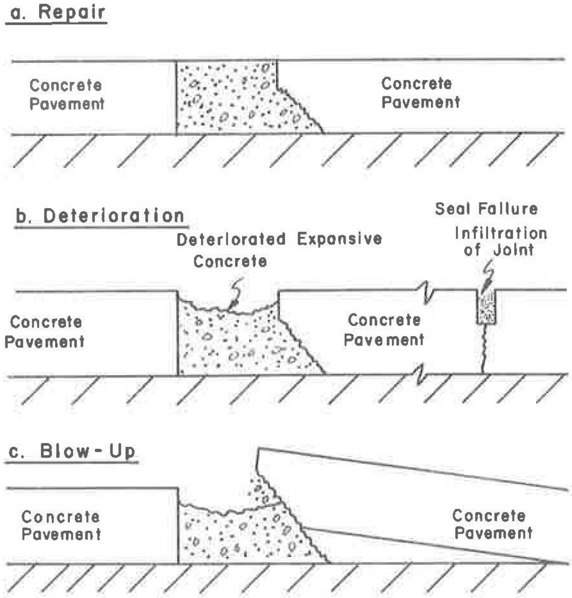


Figure 2. Aggregate interlock.

Figure 3. Joint location for 48-ft roadway.

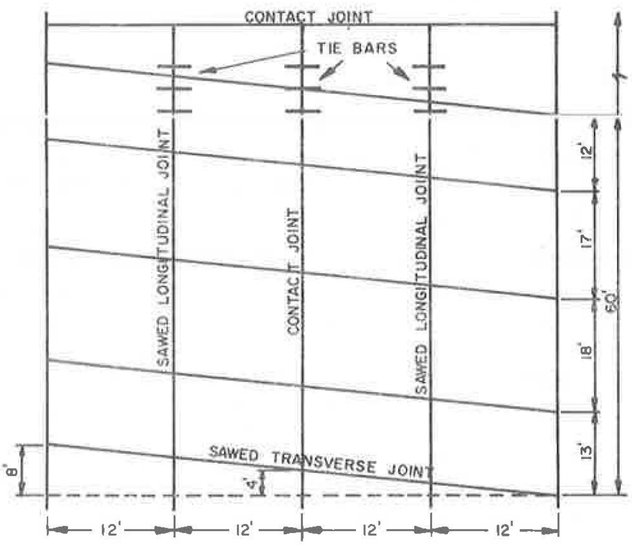
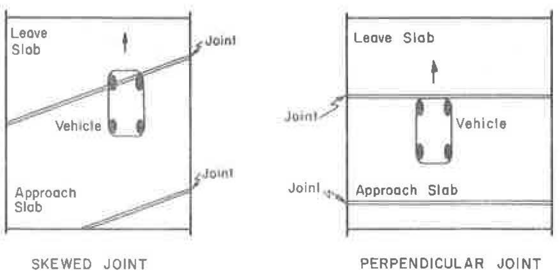


Figure 4. Vehicle crossing skewed joint versus perpendicular joint.



1. Evaluate existing pavement joints and determine if seals are still effective and if the joints are being filled with incompressibles,
2. Determine if there is pavement growth,
3. Determine if bridges are being pushed by the pavement, and
4. Formulate recommendations for action.

This report covers the results of the study.

PROJECT DESCRIPTION AND FINDINGS

The purpose of concrete pavement joints is to control cracking, to accommodate movements caused by changes in temperature and moisture, and to facilitate construction. After the joint is designed and built, its preservation as a working component of the pavement is important. Sealing is the means by which preservation is attempted. If for some reason the seal fails, either through poor design or construction, the joint will begin to be infiltrated with incompressibles and water. Continued infiltration will result in pavement distress in the form of raveling, spalling, faulting, pumping, and blowups.

To evaluate potential future pavement distress through joint seal failure, a literature review, visual inspection, and joint coring program were conducted.

Present Paving Practice

Plain concrete pavements are used in Utah, with tie bars used only along the longitudinal joint.

Aggregate interlock, which is the simplest means of load transfer, is used in transverse joints (Figure 2). The effectiveness of aggregate interlock varies inversely with the joint openings, so the shortest practical slab length is therefore desirable. To keep the slabs at the shortest practical length, random joint spacings of 12, 17, 18, and 13 ft (3.6, 5.2, 5.5, and 4.0 m) are used (Figure 3). This random spacing breaks up the resonance that can be created by vehicles when a uniform 15-ft (4.5-m) joint spacing is used. The randomly spaced joints are cut on a 1:6 skew (Figure 3). Skewed joints have the advantage of reducing stresses in the impacted corner and help reduce the corner cracking that used to be prevalent with older narrow pavements. The impact on the leave slab is reduced by causing the wheel axles to be more gradually applied to the leave slab and one at a time rather than to have the entire axle load "fall" onto the leave slab, as is the case with perpendicular joints (Figure 4). Overall, the skewed joints provide a smoother ride to the traveling public.

The concrete slabs are supported on a cement-treated base material. Figure 5 shows a typical section. It seems significant that western states (1) have been employing cement-treated bases and aggregate interlock joints with success, whereas such joints have not proved durable in other areas where untreated bases were used.

Once the transverse saw cuts of $\frac{1}{8} \times 2\frac{1}{2}$ in. (0.31×6.3 cm) are made, the joint is sealed. The joint is first cleaned with compressed air and then filled with a hot-poured seal meeting Federal Specification FSS-SS-S-164.

Joint and Seal Evaluation

Concerning pavement distress in the form of pavement blowup (one of the most spectacular forms), Stott and Brook (2) describe the mechanism by which the blowups may occur: "This theory may be developed in detail. It supposes that material infiltrates into open joints during the winter months either from the upper surface of the road, from material in the base, or from dislodged material in the joint itself. This material settles at the bottoms of the joints due to gravity. The material creates local points of contact between the opposite faces of the joints when the joints close in sum-

Figure 5. Typical cross section of roadway with treated base.

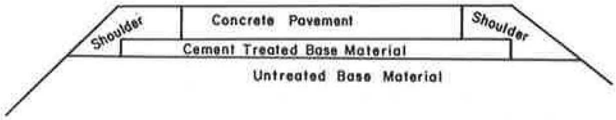


Figure 6. Mechanism for pavement blowup.

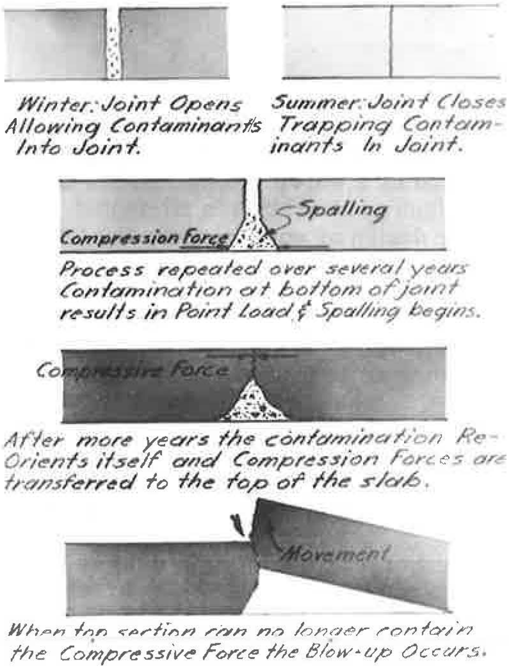


Figure 7. Locations of test sections.

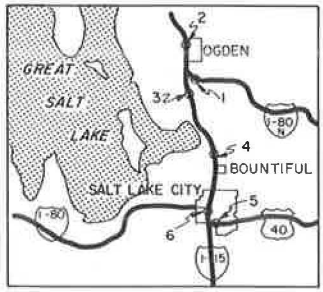
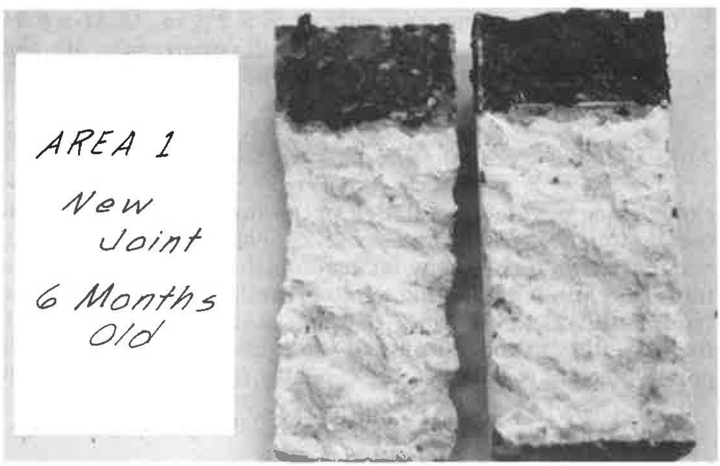


Table 1. Test sections.

Section	Location	Age	Joint Formed by	Comment
1	I-80N, Uinta Jct. and Riverdale	6 months	Sawed	
2	I-15, Sladerville Exit	5 years	Plastic strip	
3	I-15, Roy Exit	9 years	Sawed	Blowups in area
4	I-15, near Centerville Exit	1½ years	Sawed	
5	I-80, 20th East St., Salt Lake City	8 years	Sawed	
6	I-15, 2nd South St., Salt Lake City	10 years	Sawed	

Figure 8. Core from section 1.



mer and therefore local concentrations of compression arise which spall the joints. The spalled material is added to that already at the bottom of the joint and the process is repeated over several years with progressive spalling. After some years, the situation changes and the compression is transmitted through the relatively sound tops of slabs. This may happen because the infiltrated material reorients itself in the joints so that it will no longer transmit compression between the bottoms of slabs. The relatively sound tops of the slabs present a reduced area to the compression force and an upwards eccentricity so there is a much greater liability to blow-up than in the original sound slab." This phenomenon is shown in Figure 6. The deterioration of the pavement at the bottom of the joint is also a contributing factor in the faulting, cracking, and pumping of pavement slabs (4).

One major problem with deterioration on the underside of the pavement is that it is very difficult to detect before the pavement failure occurs. In many cases a visual inspection of the top of a joint does not disclose potential problems at the bottom. To evaluate deterioration at the bottom of the joints, cores were taken. Six areas (Figure 7) were chosen for sampling that would represent pavements of different ages and conditions, as listed in Table 1.

A total of 45 cores were taken in these test sections. Before coring, an epoxy was poured into the joint to set the contaminants so they would not be removed while coring.

The pavement in section 1 was 6 months old at the time of coring. No pavement deterioration was evident from the top of the slab. During the coring process the water used in coring ran along the top of the joint, indicating that it was watertight. Of the 3 joints sampled, only 1 had cracked. The core from the joint that had cracked is shown in Figure 8. The seal in this core was in excellent condition as evidenced by the amount of cohesion. There was no deterioration of the joint walls or bottom. Only a slight discoloration was apparent on the joint walls.

The joints in section 2 were formed by use of a plastic strip and were 5 years old. A visual inspection of the joint surface indicated that the joint was open and being infiltrated with contaminants. The longitudinal joints, which were also formed with plastic strips, were displaced at each transverse joint intersection (Figure 9). This displacement has been noted in another report (3) and is a construction problem with plastic strips. The cores revealed that a dense layer of granular material 2 in. (5 cm) deep lay at the bottom (Figure 10). All of the joints sampled had cracked, affirming that the plastic strips do indeed produce an effective weakened plane in the pavement, giving a controlled crack location.

Section 3 had the most deteriorated joints of any test section. This section was also the section in which the pavement blowups had occurred. In the wider joint openings large aggregate was noted at the surface. Some grain dropped by passing trucks was also observed in the joints (Figure 11).

A temporary bituminous filler had been used to repair the blown-up section and a small amount of slab migration was evident in the joint widths approaching the patched sections. The bituminous mix filler acted as a pressure relief joint, permitting the slabs to migrate. To maintain the load transfer between slabs the aggregate interlock must be maintained. Therefore, because of slab migration a bituminous slab filler must only be used as a temporary repair measure.

The cores taken in this area (Figure 12) revealed 3 layers of contamination. These layers indicated that a crushing action was taking place. The layer at the top of the joint was mainly large aggregate whose size depended solely on the opening of the joint. The middle layer contained a fine-grained material, and coarser material was at the bottom. In several cores the coarse-grained material was $\frac{1}{4}$ in. (0.63 cm) thick and 5 in. (12.7 cm) deep. One of the cores had a sprouted seed midway down the core (Figure 12). The joints close to the blowup showed little evidence of contamination layering. While the cores were being taken it was noticed that little water was coming to the surface. It was felt that there was a void under the joint. If this was true, then the coarse aggregate would have dropped into the void, forming no aggregate layer in the joint.

Section 4 was $1\frac{1}{2}$ years old and the surface of the joint showed some deterioration (Figure 13). Adhesion between the seal and the top of the joint walls had started to

Figure 9. Longitudinal joint displacement in section 2.

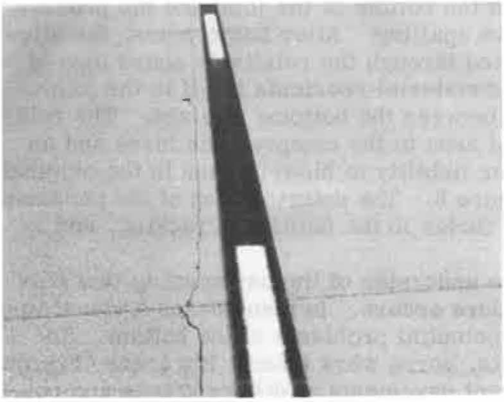


Figure 10. Core from section 2.

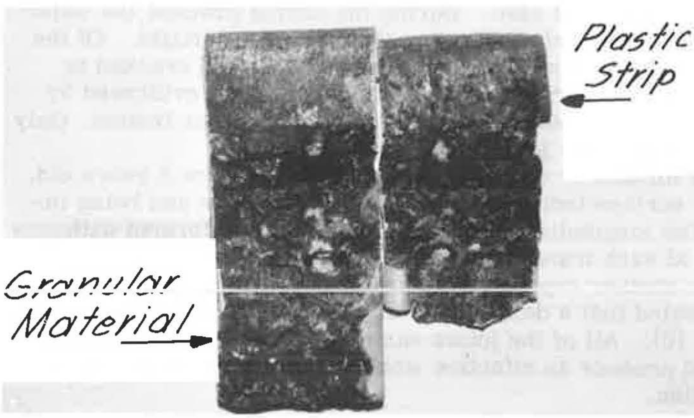


Figure 11. Joint containing grain seeds.

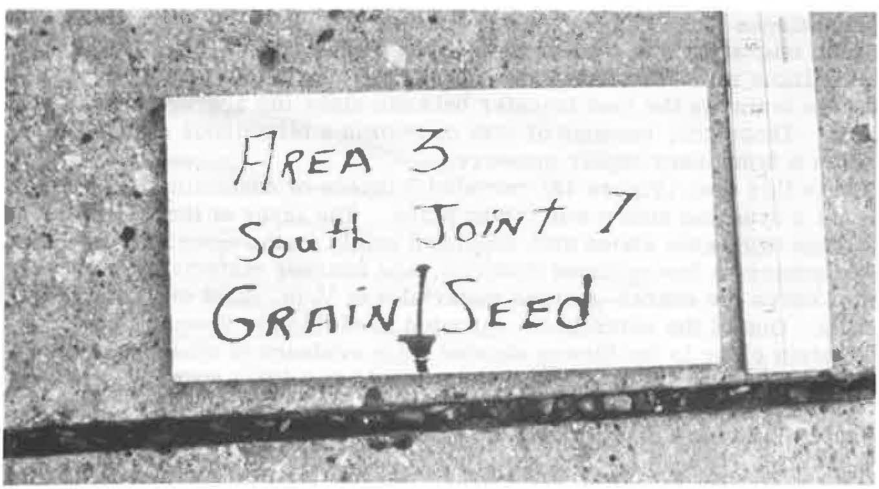


Figure 12. Cores from section 3.

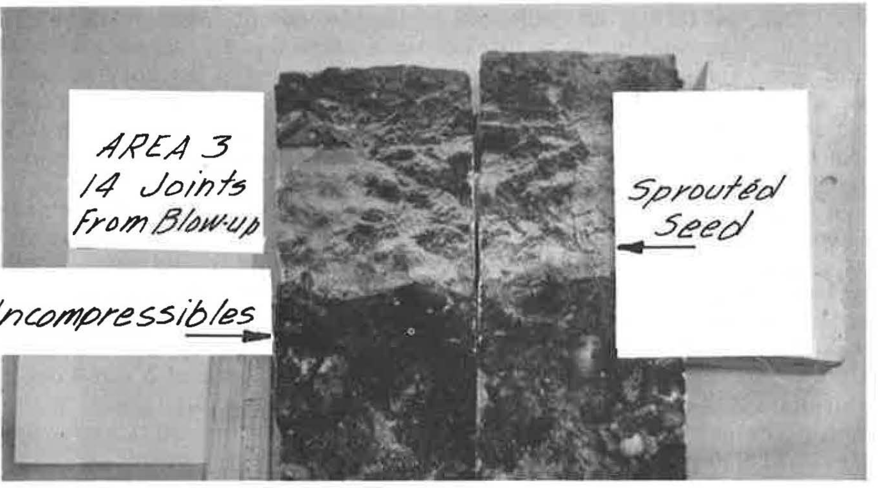
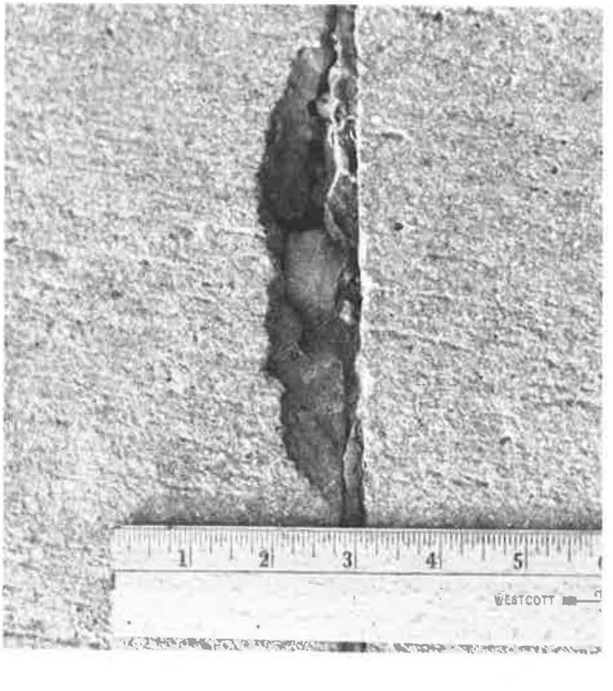


Figure 13. Spall at joint in section 4.



fail (Figure 14). The cores revealed that some seals had failed where others had not. The 3 cores shown in Figure 15 are at different stages of failure. The core at the left contains a seal that has not failed, as evidenced by the absence of epoxy or other contaminants in the joint. The seal of the center core has started to fail as shown by the limited amount of epoxy that was able to pass the seal. The seal of the core at the right has failed, as shown by the epoxy and incompressibles found at the base of the core. In Figure 16 the problem of adhesion is apparent. The seal was adhering to the aggregate but not to the cement mortar. Cleaner joint walls may solve this type of adhesion problem.

Sections 5 and 6 are respectively 8 and 10 years old. The surface conditions of the joints in these areas were about the same, with no apparent excessive deterioration. The lack of epoxy on the walls of the cores indicates that the joints were closed when the epoxy was poured (Figure 17). In the laboratory all of the cores separated easily, indicating there was no adhesion of the seal. The contamination in the joint was different from those joints sampled in sections 2 and 3 (Figure 18). In sections 2 and 3 the contamination formed layers, whereas the contaminants in sections 5 and 6 displayed a fairly even coating of very fine, clay-like material on the joint walls, with no apparent layering. The presence of contamination indicates that the joints are subject to infiltration, even though at the time of coring no infiltration was evident.

One possible reason for the difference in the type of incompressible in sections 2 and 3 and 5 and 6 is the winter maintenance procedures in these areas. In the Ogden area, where sections 2 and 3 are located, sand and salt are used. In the Salt Lake City area, where sections 5 and 6 are located, only salt is used.

The possibility that the contamination in the joint is material from the base was considered, but because of the treated base it was felt that any migration of this material would be minimal.

Deterioration at the joint slab bottom was detected in all but the newest pavement. The bottoms of the joints in section 1 were square, with no spalling (Figure 19). Cores from the oldest sections (3 and 6) had spalling that was around 2 in. (5 cm) in height (Figure 20). The rate at which this spalling occurred was not investigated.

During inspection of the transverse joints it was observed that the longitudinal joint between the pavement and asphalt shoulder was in a bad condition. In many cases a ½-in. (1.3-cm) horizontal gap existed between the 2 surfaces. Also, there was a depression forming a trough at the concrete pavement edge (Figure 21). Any water falling on the roadway would run off the pavement and into the longitudinal edge joint (Figure 22) instead of running off the pavement and over the shoulder. With the longitudinal edge joint badly in need of repair, the quantity of water entering the base material via the transverse joints is insignificant compared to the amount entering via the pavement edge joint. If watertightness was a serious problem, the longitudinal edge joint should be repaired before attending to the water-tightness of the transverse joint. To alleviate the pavement edge joint problem in the future, the concrete pavement will be widened so that the shoulders will be of concrete instead of asphalt.

A limited investigation was conducted to determine if any bridge pushing from pavement growth had occurred. The only evidence of possible pushing was found on the Bluffdale overpass on I-15. The abutment joint on the bridge had been closed and spalling on the abutment had occurred (Figure 23).

The longitudinal joints in the pavement were found to be in good condition in all test sections. Movement experienced by the longitudinal joint is restricted due to the tie bars.

ANALYSIS OF FINDINGS

After finding that all but the most recently sealed joints had failed, a further literature review was conducted to determine if there were problems with the type of seal used or possibly the joint design.

The expected movement for an 18-ft (5.5-m) slab over a 130 F (54.4 C) temperature range is 0.112 in. (0.28 cm):

$\Delta L = \Delta T \alpha L = 0.112$ in. (0.28 cm)

where

$\Delta T = 130$ F (54.4 C),
$\alpha = 4 \times 10^{-6}$ in./in./deg F (7.2×10^{-6} cm/cm/deg C), and
L = 18 ft (5.5 m).

The coefficient of thermal expansion for ordinary concrete has commonly been assumed to be about 5 to 6×10^{-6} in./in./deg F. Because of subgrade restraint a practical calculation for anticipated joint movement for either plain or reinforced slabs can be made by modifying the expansion coefficient to 4×10^{-6} in./in./deg F (7.2 cm/cm/deg C) to compensate for restraint (1). A slab length of 18 ft was used to determine the expected movement instead of the average joint spacing of 15 ft so that the proposed seal design would perform in the worst condition. Thus, for a seal to be effective it must be able to extend a minimum of 0.112 in. (0.28 cm) or W + Δ L (Figure 24).

Tons (5) investigated the effect of the width-to-depth ratio on the sealant. If a straight-line extrapolation of Tons' Figure 14 is used, Utah's present joint design would result in strains along the parabolic curve of 1,780 percent when extended to the calculated maximum width. Strains of this magnitude far exceed the strain limits of any seal in use, and this gives reason for the universal seal failure that was found. Therefore, a new joint design will be needed to ensure that the joints will be properly sealed.

NCHRP Synthesis 19 (1), in discussing durability and working range of joint seals, states that hot-poured seals have had a service life of about 2 years and preformed materials between 5 and 10 years. Part of this limited life is due to faulty installation, improper design, or excessive spacing.

When these hot-pour materials are used in transverse contraction joints, the reservoir must be wide enough to keep extension of the sealant within its capabilities (usually less than 20 percent).

The recommended working range of the preformed seal was suggested to be 30 percent of the seal width (7, 8).

A polyvinyl chloride (PVC) hot-poured elastomeric sealant is now on the market with a 10-year service life warranty (6). A minimum joint size of ⅜ in. (0.95 cm) by 1¼ in. (3.7 cm) is recommended for an average joint spacing of 25 lineal feet.

If the 20 percent capability limit for a hot-pour seal is used, the required reservoir width (R.W.) would be 0.56 in. (1.4 cm):

$$\text{R.W.} = \frac{\Delta L}{C_H} = \frac{0.112 \text{ in. } (0.28 \text{ cm})}{0.2} = 0.56 \text{ in. } (1.4 \text{ cm})$$

where C_H = 20 percent extension limit.

If the 30 percent capability limit for a preformed seal is used, the required working range (W.R.) would be

$$\text{W.R.} = \frac{\Delta L}{C_p} = \frac{0.112 \text{ in. } (0.28 \text{ cm})}{0.3} = 0.37 \text{ in. } (0.94 \text{ cm})$$

where C_p = 30 percent extension limit.

The size of preformed seal that would be compatible with the expected movement would be one 7/16 in. (1.1 cm) wide. The seal would be installed in a joint ¼ in. (0.64 cm) wide. The working range of the preformed seal is shown in Figure 25, a force-deflection curve for a typical 7/16-in. (1.1-cm) seal. For a preformed seal the working

Figure 14. Sealing material in section 4.

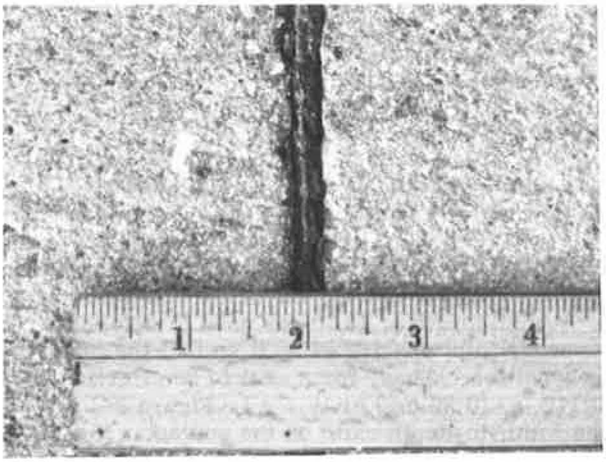


Figure 15. Cores from section 4.

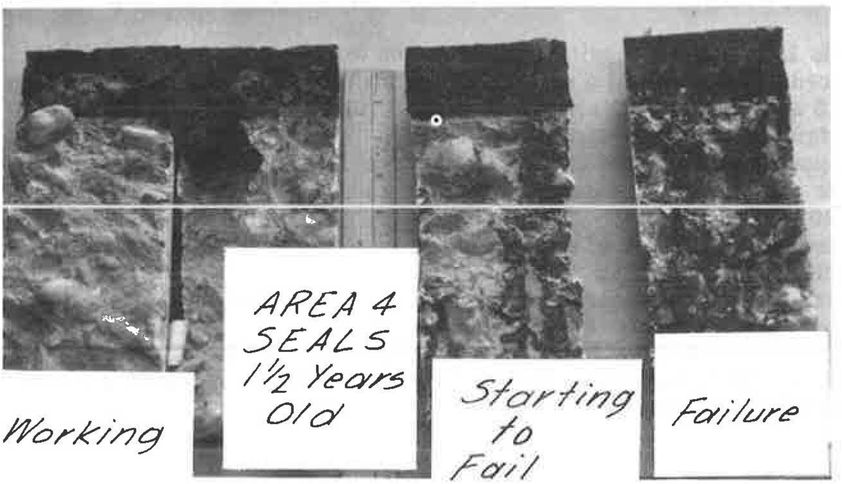


Figure 16. Seal failing in adhesion in section 4.

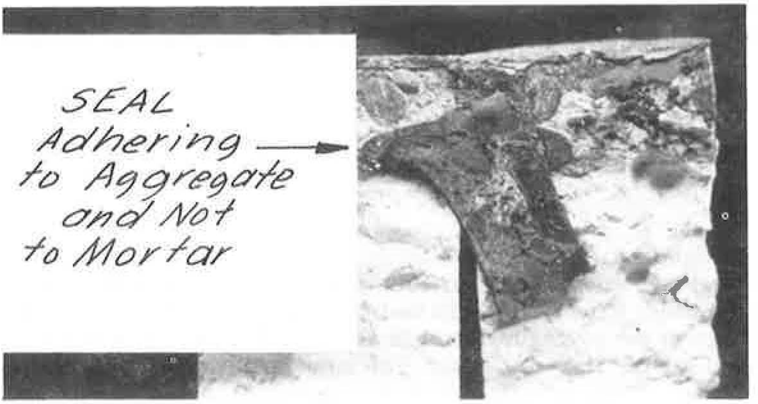


Figure 17. Core from section 6.

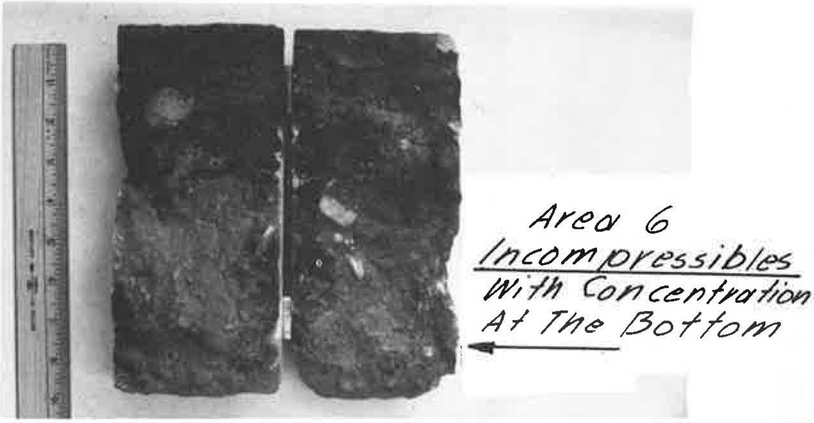


Figure 18. Cores from sections 3 and 6 showing different types of contamination.

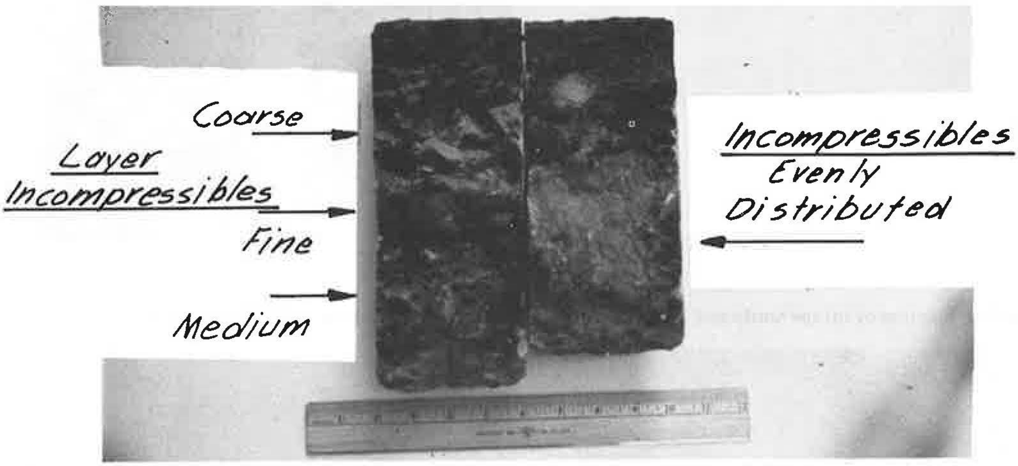


Figure 19. New pavement core with no spalling at the bottom.

Figure 20. Cores from 9- and 10-year-old pavements with spalling at bottom of joint.

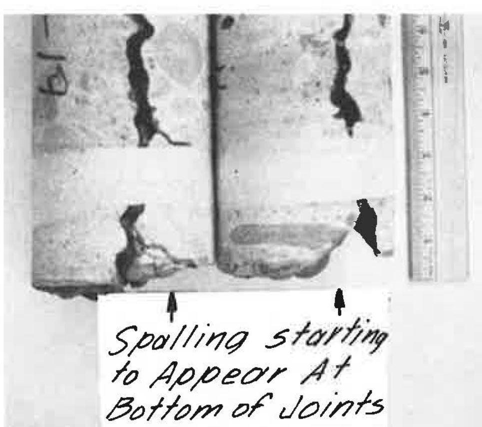


Figure 21. Trough formed between concrete pavement and asphalt shoulder.

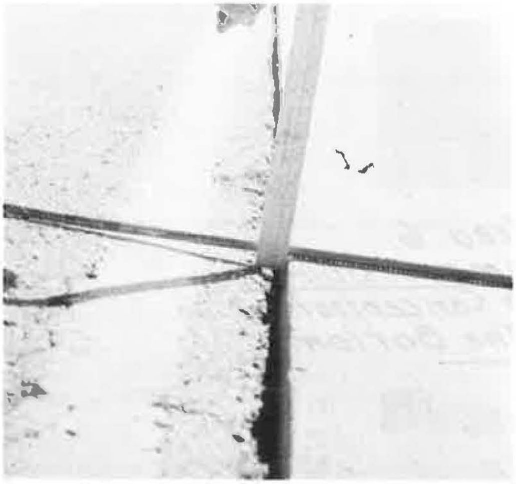


Figure 22. Water in depression between pavement and shoulder.

Figure 23. Spalling of bridge abutment joint.

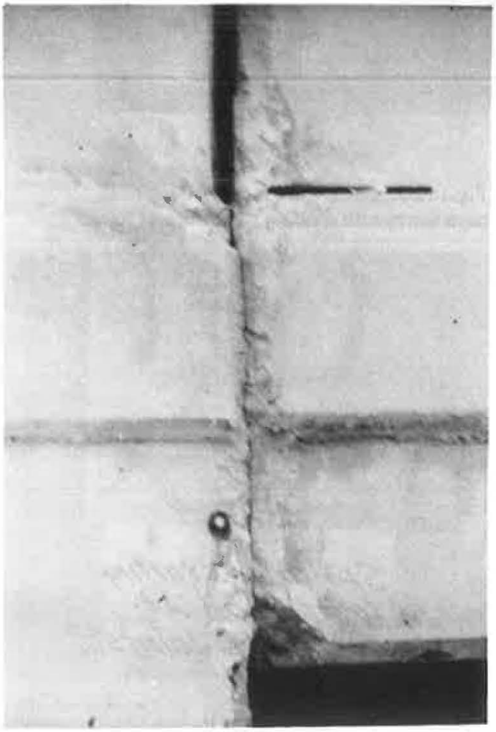


Figure 24. Estimated joint movement.

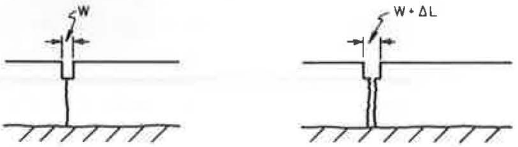
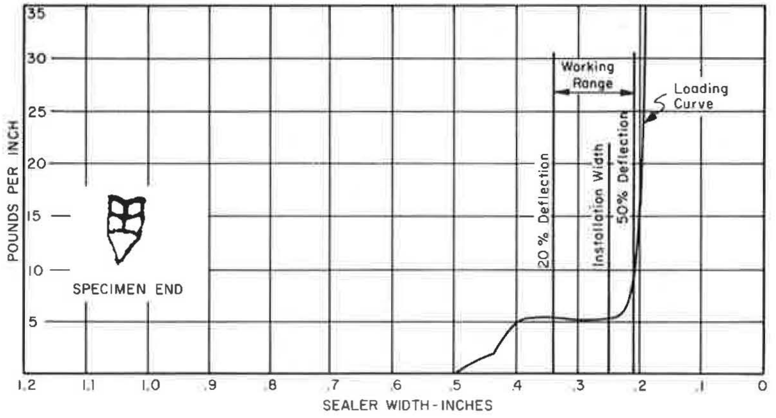


Figure 25. Force-deflection curve for typical $^7/_{16}$-in. seal.



range is considered to be between 20 percent and 50 percent of the deflection of the seal; 20 percent deflection is used so that enough sidewall pressure is exerted by the seal to keep it in the joint if failure of the lubricant adhesive occurs. At 50 percent deflection the seal has not reached a rubber-on-rubber condition, which would eventually lead to web adhesion and failure of the seal. A sawed reservoir of $^1/_4 \pm ^1/_{32}$ in. (0.63 ± 0.07 cm) was chosen because the seal is to be installed during the summer months when in the future the joint would be closed, thus ensuring that the seal would not be overly compressed. Also, the $^1/_4$-in. (0.63-cm) saw cut allows the contractor to use two $^1/_8$-in. (0.31-cm) blades, which would save on sawing costs.

It was determined from the study results that during the colder months of the year the pavement joints were open and being infiltrated with incompressibles. However, the overall past performance of the pavements has been excellent. At the present time, joint infiltration has not adversely affected the overall pavement performance. This may not be the case in the future, because there was spalling at the bottom of the joints. Spalling in the joints is one of the steps in the mechanism for blowups. To correct the problem, the presently sealed joints should be cleaned and resealed and the present sealing practice should be changed to ensure a more durable sealing system.

Regarding the possible cause for the blowups in Utah, Patrick R. Nolan of Portland Cement Association stated the following concerning the importance of the narrow joint width used in Utah: "If joint seals are effective so that sand and other incompressible materials do not infiltrate the joints, the contraction joints will easily provide for temperature expansions. Blow-up problems have been nearly nonexistent in pavements with short joint spacing (20 ft or less). First, joint sealants perform better at joints with less total movement. Secondly, infiltration of unwanted material is minimized with smaller openings. Blowups are much more common in pavements utilizing mesh dowel design with joint spacing of 40 ft or more. In older pavements, blowups were common at expansion joints where sealants failed, allowing large rocks to enter the joints." To maintain the present pavement design, the smallest possible joint opening that is compatible with the expected joint movement and seal capabilities is desirable. The hot-pour seal, with 20 percent extension capabilities, would be undesirable because of the large joint opening required.

The estimated additional costs for installing the $^7/_{16}$-in. (1.1-cm) preformed seal and PVC sealant would be as follows:

Preformed seal

Second saw cut, $\frac{1}{4} \times 1\frac{1}{8}$ in. (0.63 × 3.2 cm)	14 cents
Materials (28 cents) and installation (15 cents)	43 cents
	57 cents
Less cost of present sealing	07 cents
Additional total cost per foot	50 cents

PVC hot-pour

Second saw cut, $\frac{3}{8} \times 1\frac{1}{4}$ in. (0.95 × 3.7 cm)	16 cents
Material (7.6 cents) and installation (7 cents)	14.6 cents
	30.6 cents
Less cost of present sealing	07 cents
Additional total cost per foot	23.6 cents

The additional cost based on square yards of surface concrete (using an average slab length of 15 feet) would be 30 cents for preformed seals and 14 cents for PVC hot-pour per square yard.

If a figure of $7.00 per square yard of concrete is used, the percentage increase in construction cost would be 4.2 percent for preformed seals and 2.0 percent for PVC hot-pour.

The cost per service year over the entire life of the pavement (20 years) would include removal of the old seal and resealing at the end of 10 years for each type of seal. Resealing with a preformed seal would require the seal to be pulled out, the joint cleaned by a wire brush or sandblasting, spalled areas repaired, and seal replaced, at a cost of 48 cents per foot. Replacement of PVC hot-pour sealing requires that the old sealant be plowed out, the joint widened to $\frac{1}{2} \times 1$ in. (1.27 × 2.54 cm), joints cleaned by sandblasting, and seal replaced, at a cost of 28 cents per foot.

Over the 20-year design life of the pavement the cost per year would be 2.9 cents per square yard per service year for preformed seal and 1.5 cents per square yard per service year for PVC hot-pour seal.

CONCLUSIONS

Prior to the pavement blowups that occurred during the summer of 1972, little thought was given to the concrete pavement because the overall performance had been excellent. Following the blowups an investigation of the potential for future blowups in the existing pavements was conducted. The study evaluated the existing pavement joint sealing systems, determined if there was any pavement growth resulting in bridge pushing, and formulated recommendations for actions.

In the evaluation of the existing pavement joint sealing system, 6 pavement sections were inspected and cored. The ages of the pavements ranged from 6 months to 10 years. Even though the general performance of the pavement has been excellent, the joint cores revealed that the seals in all but the most recently sealed contraction joints had failed. Seal failure was noted in joints that were only $1\frac{1}{2}$ years old. In the longitudinal pavement lane joints that were sealed at the same time as the contraction joints, no failures were found. After measuring the widths of the joints and evaluating the extension limits of the seals, it was found that the seals were being overextended. To correct the seal failure problem, wider joints would be required so as to keep the movements within the capability of the sealing material.

The narrowest possible joint width that is compatible with the expected movement and seal capability is desirable when using Utah's pavement design system. Hot-pour materials presently being used would require a joint width increase to 0.56 in. (1.4 cm). This width of joint is undesirable. A $\frac{7}{16}$-in. (1.1-cm) preformed seal installed in a joint $\frac{1}{4}$ in. (0.63 cm) wide or a PVC hot-pour seal in a $\frac{3}{8} \times 1\frac{1}{4}$-in. (0.95 × 3.17-cm) joint was recommended.

The cost per service year over the life of the pavement to change to either a preformed seal or a PVC hot-pour would be comparable.

During the coring of the joints it was noted that the pavement edge joint between the concrete and the asphalt shoulder was in very poor condition. Any runoff water would be funneled into the longitudinal edge joint instead of over the shoulder. This water entering the base and subbase could cause damage to the roadway foundation, eventually resulting in pavement distress problems. Resealing of the joint is important to retaining the integrity of the pavement.

The visual inspection for pavement growth and bridge pushing found that no serious problem of this type existed. Only one possible example was found but this case was not serious.

In conclusion, this study found that even though pavement distress problems have been minor, the existing sealing system has failed. With joints being freely infiltrated, there is good reason to believe the pavement distress problems will become common if action to correct the problem is not taken.

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DISCUSSION

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I agree with the authors that proper and positive sealing of pavement joints is necessary to reduce pavement distress. They have shown that premium sealant materials are available to perform that function.

The paper compares costs per square yard per service year. I would like to suggest that the final figures may be further refined. Consider the following:

1. A longer service life than 10 years is being reported for the PVC hot-poured

sealant. Annual field surveys confirm continued excellent performance in sizable installations since 1963, which totals 12 years without failures. No loss of their rubber-like properties is apparent after 12 years in the field subject to exposure from -40 F to 125 F ambient temperatures. It seems certain they will go 15 years, possibly 20 years. In reference to neoprene compression seals, there are published highway department data to substantiate that compressive force decreases up to 70 percent of the initial force after 2 years of service. It is now established that neoprene compression seals after a relatively short time in service (several years) take a "set" and do not maintain their original compression recovery force and, more important, do not maintain initial dimension widths.

2. The resealing of joints with preformed neoprene compression seals may be more costly than estimated because the seals will have to be individually sized for each joint and generally larger than the original width seal used in the joint.

I am suggesting these items be considered for revision because PVC hot-poured sealant is warranted for a 10-year period as a minimum life rather than a maximum. A 15-year life would reduce the cost per year for the PVC sealant. In reseal work, nonuniform slab movements, infiltration of fines, and loss of concrete on joint faces from cleaning, shrinkage, and other factors make the joint widths vary. It is also established that preformed seal extrusions vary considerably in width, as there is a variability of $\pm\frac{1}{16}$ in. in the extrusion process that must be considered. These factors require the individual sizing of preformed seals for each joint when being considered for resealing.

We have recently surveyed a number of state and provincial highway departments by written questionnaire on this subject. Several have done some resealing of joints originally sealed with preformed seal and have found that individual sizing of preformed seals for each joint is required. This would add to the cost per year for preformed seals.

Incorporating these items in the original paper would show an even greater cost advantage accruing from the use of the PVC hot-pour than that shown originally.

AUTHORS' CLOSURE

The purpose of the study was to evaluate the performance of the existing sealing design used in Utah. After finding that the present design was inadequate, a change to a preformed neoprene compression seal or PVC hot-pour sealant was recommended. The recommendation was based on the expected joint movement and the reported service life of each material. Since completion of the report a longer service life of the PVC material is reported by Knoblock. This longer life would indeed reduce the cost of the material over the life of the pavement. How this cost reduction would affect the cost comparison between PVC hot-pour material and neoprene compression seals is unclear because during the same time since completion of the report the service life of the neoprene seal has also been extended.

It is well established that neoprene compression seals do take a permanent set with age. During early design work with compression seals this set was not taken into account and the seal was underdesigned. As stated in the report, a 30 percent working range is now recommended by several states. This working range allows for permanent set, thus guarding against early seal failure through permanent set.

In reference to resealing with preformed neoprene seals, results reported in "Thermal Expansion and Contraction of Concrete Pavements in Utah" indicate that there is not enough variation in joint widths to require individual sizing of each joint resealed or to require a larger seal.