Development of Effective Poured-in-Place Systems for Concrete Pavement Joints

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Four years ago Thiokol began to investigate actively the problems involved in sealing transverse highway joints. A series of highway joints were sealed with a number of first-generation highway sealants and periodically investigated for failures. A study of the failures and attempts to duplicate them in the laboratory resulted in new or improved tests of adhesion, cohesion, stress relaxation, and dynamic cycling resistance. Sealant and slab temperature gradients, joint movement, and the relationship of these variables were also investigated, as were nonthermal joint movements in shear and vertical displacement. The results of these studies led to a new testing device and technique that defined and artificially reconstructed an ideal national year in terms of temperature and joint movement.

The study of four second-generation systems in this device resulted in one final sealant system, which was then commercially installed under actual field conditions. After one year of use this sealant's good performance to date reaffirms the validity of the new test method.

•SOME years ago, Thiokol began an active program to determine the physical properties and aging characteristics needed for an effective poured-in-place joint sealant system. Initial investigations were carried out in the field to determine the types of problems that occurred. The ultimate goal was a series of laboratory tests that would screen sealants. Economics dictated this approach, provided laboratory data were a relative measure of field performance. Periodic photographs of both the commercial and laboratory sealants, which were installed in the field, comprised an accurate record of the types of sealant failures that developed. Four major types of sealant failures were identified.

1. The most prevalent and quickest to appear were failures due to lack of sealant adhesion to the sides of the concrete joint. Considering that highway joints are continuously moving, it is important that the sealant adhere to the sides of the joint almost instantaneously, under the following conditions or combinations thereof: high or low temperatures, dry or damp joint surface, expanding or contracting slab, and with or without movement of vehicular traffic.
2. Another prevalent failure was cohesive rupturing of the joint sealant within itself, while subjected to extension and compression after months of exposure to environmental conditions. The majority of these sealant failures were caused by the dynamic stresses imposed by thermal expansion and contraction of the concrete.
3. Failures caused by improper mixing of the two sealant components were identified. Striations of improperly mixed sealant were dispersed throughout the sealant

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within the joint. Eventually they appeared, seemingly as cohesive failures, whereas similar striations at the sealant concrete joint interface appeared as adhesive failures. Obviously, disproportionate mixing of sealant component viscosities and/or volume ratios increased the magnitude of this problem and the frequency of its occurrence, whereas color-coded component differentials decreased them.

4. Sealants that were of sufficient quality to resist adhesive, cohesive, and mixing failures eventually began to crack or tear wherever localized stress concentrations in the sealant occurred, causing points or planes of weaknesses. These would eventually progress, over the years, through the sealant until failure occurred.

As development work progressed, three sets of laboratory tests were developed to simulate the field conditions and screen prospective sealant systems. The adhesion series of laboratory tests consisted of both destructive testing and sealant extension durability testing during artificial aging simulation. In the former case, sealants of a ½- by ½- by 2-in. geometry were extended to failure as a uniform rate on a tensile test under the following conditions: after aging at room temperature and after aging at 158 F and in H_2O (each individually for one week). Lack of any adhesive failure was a prime requisite for selection of a sealant system. In the latter case, sealant test samples were extended 100 percent and then subjected to water, heat, and cold conditions to simulate the adverse environmental conditions in the field.

In addition to adhesion testing of the original laboratory-made sealant specimens, tests on aged sealants were also recognized as important. This resulted in a series of screening tests which measured a sealant's change in hardness and percent weight loss, after aging at elevated temperatures. Such tests tended to eliminate sealant systems containing quantities of volatile plasticizers or solvent components. The loss of volatile materials from the sealant imposes a volume shrinkage that induces internal stresses and makes the sealant susceptible to cohesive failures.

A Bostic cycling machine (Fig. 1) was used to extend and compress repeatedly sealant samples at room temperature, thereby simulating years of dynamic cyclic movement which sealants must withstand—compressing years into days. As dynamic testing of the sealants progressed, it was deemed necessary and desirable to vary the temperature during the cycling test, since the sealant's physical properties will change over a range of temperatures as witnessed by seasonal conditions in the field. The cycling machine was housed in an environmental chamber, and the test cycling fixture compressed the sealant as the temperature rose from 55 to 130 F and extended the sealant while the temperature dropped from 55 to -20 F, thus versus time giving a sinusoidal curve. This expressed sealant movement versus temperature change as shown in Figure 2. A complete cycle was adjusted to a 24-hr period that was postulated to simulate the movement over a year's period.

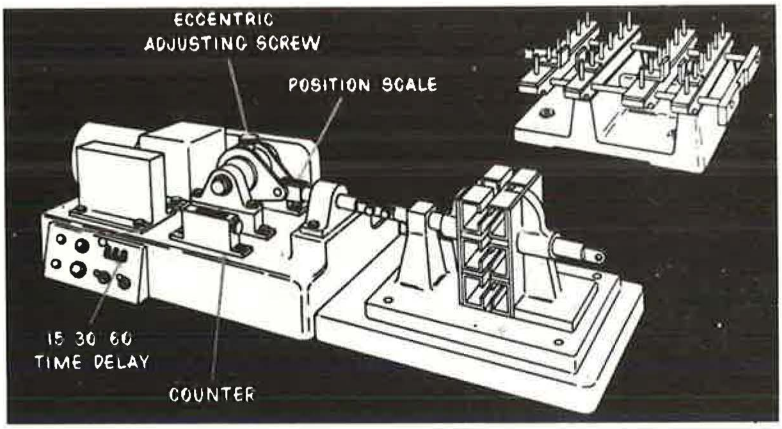

Figure 1. Bostic cycling machine.

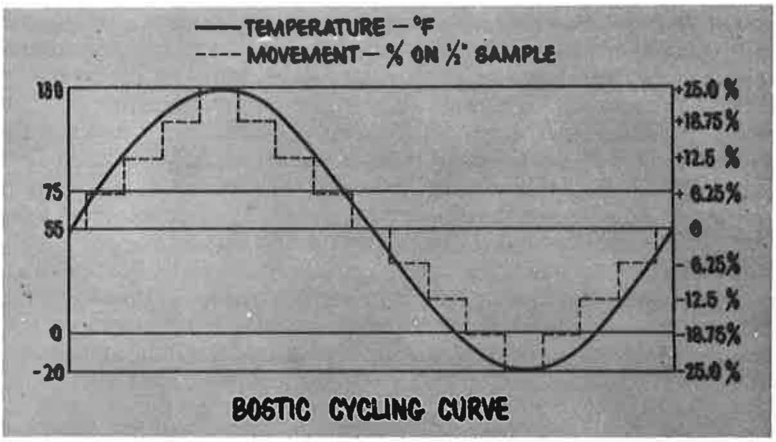

Figure 2. Temperature vs movement.

The development program encompassed three generations of sealants. The sealant extension durability tests provided the ability to overcome adhesive and cohesive failures, whereas heat aging at elevated temperature provided information on how to avoid high weight loss, thereby decreasing the sealant's volume shrinkage on aging. The use of the dynamic cycling tester provided the necessary information to tailor the third generation sealant. It was found that this material could withstand repeated cycles of 25 percent compression and extension over a temperature range of -20 to 130 F. The third generation sealant was chosen for promotion and is now commercially available.

A major contributing factor on the life expectancy of a sealant in the field is the dynamic condition imposed by the movement of the joint due to thermal expansion and contraction of the concrete. Analyzing F. C. Lang's experimental work (1) at Worthington, Minnesota, it can be concluded that the joint movement correlates with the average temperature of the concrete rather than average air temperature. On sunny days, the average concrete temperature is significantly higher than the average air temperature, producing movements greater than would be anticipated from air temperatures. This is due to the absorption of solar heat by the concrete slab.

In Lang's experiment, concrete slabs with lengths ranging from 25 to 60 ft were used. Thermocouples were embedded within the slab 1 in. apart starting ½ in. below the sur-

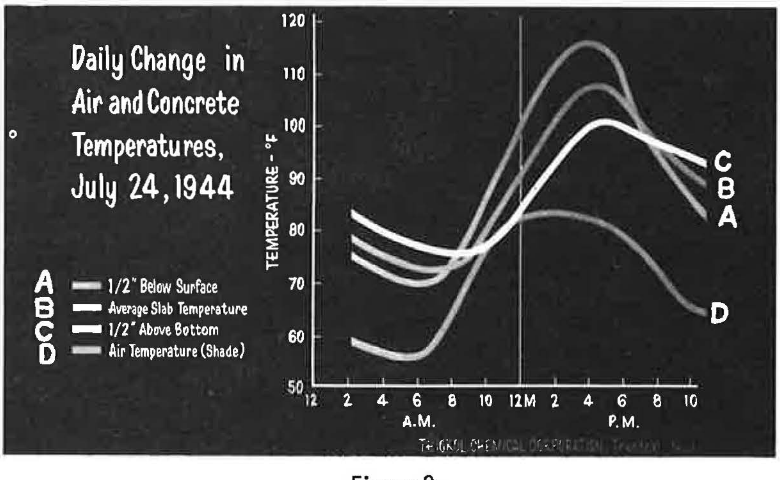

Figure 3.

face and down through the concrete to within ½ in. of the bottom. When hourly temperature and joint movements were made under typical climatic conditions, which included a sunny day, an excellent correlation prevailed between the average slab temperature and joint movement. It is significant to note that the average slab temperature had reached a temperature about 20 F higher than the air temperature (see curves for the air temperature and the average temperature, Fig. 3). However, during cloudy winter days the average slab temperature was essentially the same as the average high temperature. Thus, in utilizing this information with the temperature extremes attained during a typical year, it can be established that the average slab temperature will vary in Minnesota from -20 F in winter, to approximately 130 F during summer, giving a total differential of 150 F. This differential causes joint movements significantly larger than those anticipated only from average air temperature.

To continuously measure joint movement, Thiokol utilized an inexpensive device consisting of a rectilinear potentiometer and a simple, rugged, inexpensive transducer. The mounting of the transducer device across a joint is shown in Figure 4. A concrete highway bridge was instrumented for slab temperature and joint movement. Thermocouples were installed at several points and at varying depths at each of the location points. Figure 5 shows joint movement with changes in temperature at the surface and at the center of the depth of the slab during a 5-day period in the summer. An excellent correlation is shown for the joint movement with the temperature at the center of the slab. As in Lang's work, the peak temperature at the center of the slab was 20 to 25 F above the ambient air temperature.

Based on a paper by Barber (2), we computed the seasonal temperature differential which affected slab movement based on the air temperatures. We then developed a temperature differential map for the continental United States (Fig. 6). In general, the temperature differential areas fall into three groupings: (a) higher differentials in the North and Northwest, (b) middle differentials in the Northeast and Central, and (c) lower differentials in the Southeast. The average differential is 154 F.

Using an average temperature differential of 150 F and the ability of the sealant to withstand continuous cycling of 25 percent compression and extension, the recommended joint widths were then computed for the various slab lengths (Table 1). The depth of the sealant is controlled to give a rectangular profile where the sealant width is twice

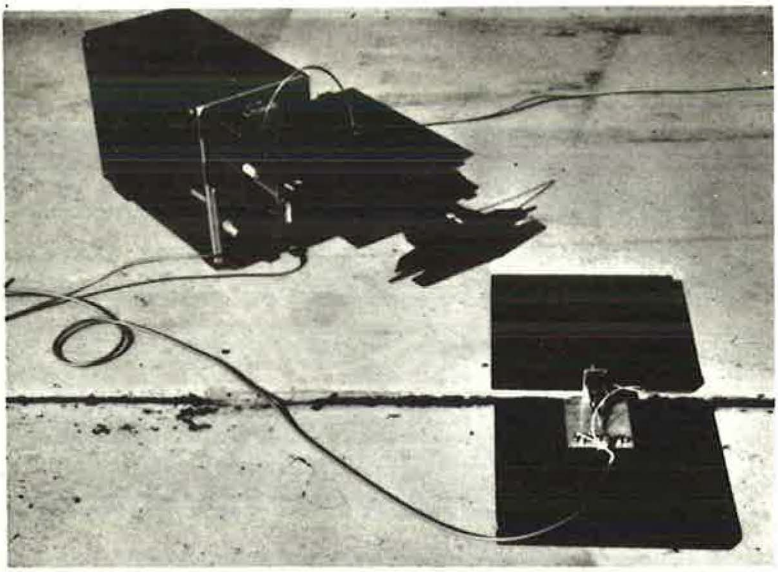

Figure 4. Joint movement measuring device.

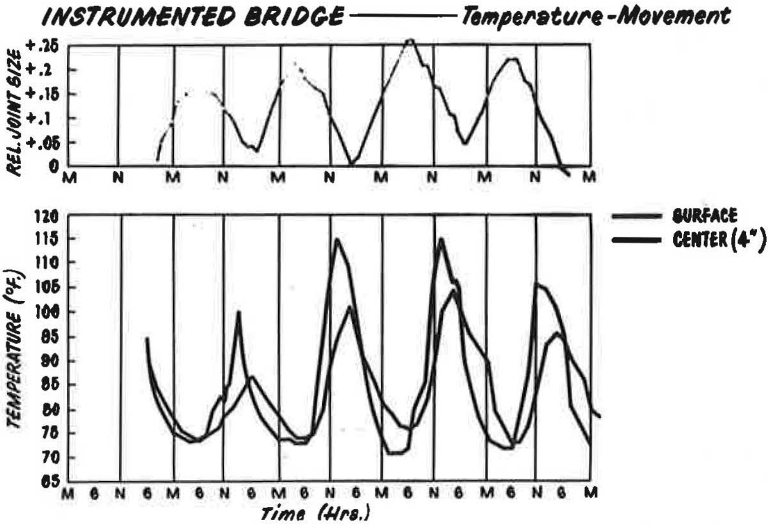

Figure 5. Joint movement and slab temperature.

the height. However, above a 1¼-in. joint width, the sealant depth is retained at ⅝ in. because increase in sealant depth only induces additional strains on the sealant. The optimum condition for cycling would be to have a sealant depth as thin as possible. Any increase in sealant depth imposes higher strains on the sealant. However, a minimum sealant depth must be maintained to prevent intrusion of incompressibles in the sealant.

The use of a poured-in-place sealant must be considered from a systems standpoint. Proper design, material, and application methods are required to make the sealant

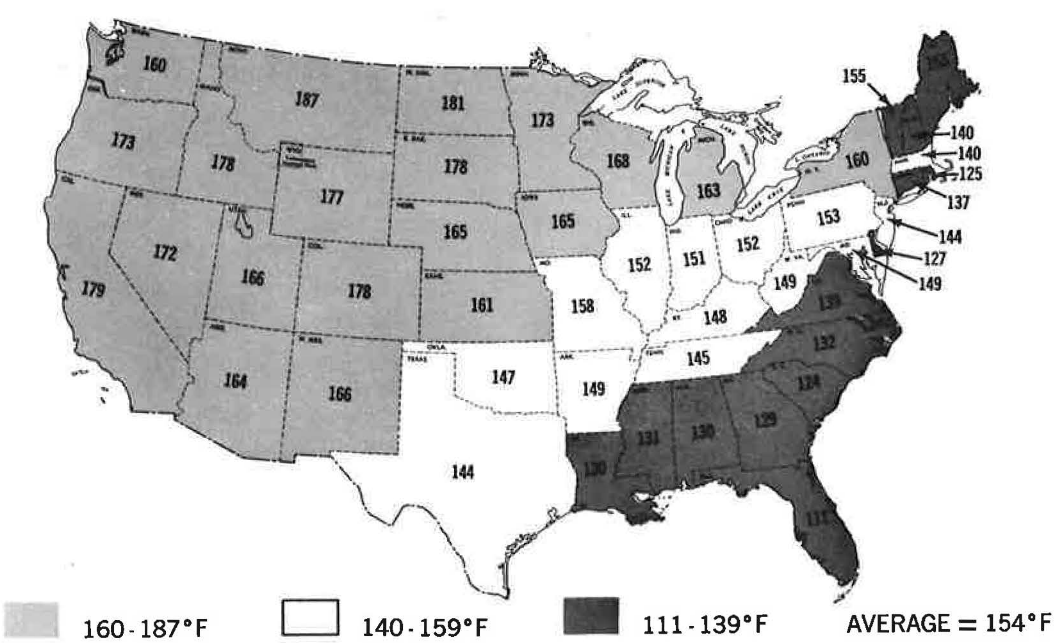

Figure 6. Differential pavement temperatures.

TABLE 1

RECOMMENDED TRANSVERSE CONTRACTION JOINTS

Spacing of Joint (ft)	Joint Width (in.)	Joint Depth (in.)
20	½	⅜
30	½	⅜
40	⅝	⅜
50	1	½
60	1¼	⅝

perform satisfactorily. With our LP® polysulfide base sealant system we recommend:

1. Cleaned joints, preferably by sawing,
2. Use of the proper joint dimensions for slab length,
3. Use of a nonbituminous back-up material to control the sealant depth,
4. Repair of all joint spalls, and
5. Use of a primer and proper mixing and application of sealant.

By utilizing this system's approach, effective sealing of concrete pavement joints can be achieved. By using these criteria it is expected that a life of eight years or more can be obtained in a joint sealed with an LP® polysulfide base sealant.

In conclusion, it is possible to formulate and provide effective, long-lasting, poured-in-place joint sealant systems for highway joints. To date, our experimental program has allowed us to quickly screen and evaluate LP® polysulfide polymer joint sealant systems in the laboratory, with a high level of confidence in regard to their field performance ability. Consequently, better LP® polysulfide base sealants have been developed and better performance will result if the right material is selected, the right joint design is specified and used, and if proper application techniques are followed.

REFERENCES

1. Lang, F. C. Investigational Concrete Pavement in Minnesota. Highway Research Board, Research Report No. 3B, p. 58-72, 1945.
2. Barber, Edward S. Calculation of Maximum Pavement Temperatures from Weather Reports. HRB Bull. 168, p. 1-8, 1957.