Testing of Bridge Expansion Joints by Large-Scale Testing Apparatus

S. S. Kuo, Kirk Eastman, and D. Michael Waddell

A full-scale accelerated testing facility designed and constructed by the University of Central Florida was used to simultaneously test five separate bridge rehabilitation joint systems under the effects of wear, abrasion, and impact loading. During a 5-week test period, the program established a simulated life expectancy for each joint system as a result of its performance under full-scale live loading. This method of testing proved to be a timely, feasible alternative to live bridge applications and monitoring procedures. Test results indicated several areas of deficiency common to many of the joint components and systems. The results also promoted further development of some of these products to enhance their performance.

During the past several years engineers have become increasingly aware of the importance of bridge joints and joint materials in the design and maintenance of bridge structures. A bridge joint must provide to the various superstructure elements the same level of protection from exposure that would otherwise be provided by the deck, in addition to accommodating all movement transmitted by the superstructure to the joint. The joint materials must be durable enough to withstand the wear and impact of heavy traffic loads and must be resistant to roadway oils and chemicals, debris, ultraviolet rays, and other harmful influences. Yet the joint also must remain flexible and resilient throughout its life to accommodate numerous cycles of temperature extremes.

Histories and documentation indicate that most bridges have a life expectancy in excess of 50 years. However, most bridge joints experience problems within the first 5 to 10 years of life, and many joints experience some failure within the first 6 months to 1 year after installation. Failure of a joint system or individual component can occur in many ways and in varying degrees. For joint nosing materials and headers, failure can occur from a debonding of the nosing and substrate, a delamination of separate material layers, severe wearing or grooving of the material, cracking or spalling of the nosing, or a collapse of the material resulting from improper mixing and placement. Steel armor retainers can experience failure resulting from fatiguing of their anchorage systems under impact loading. Bridge joint seals can become debonded, ripped or torn, disfigured from excessive wear or deformation, or damaged by environmental influences.

Engineers and manufacturers continue to develop new joint configurations and materials in an attempt to improve upon this poor record of serviceability. However, testing methods are limited and most promising new joint products must be placed in live bridge installations to be tested. Although this method of testing is the most reliable and realistic, several years of monitoring may be required to prove a joint product acceptable. A literature search has not revealed any previous methods of full-scale testing or modeling to predict the life expectancy of expansion joints, yet full-scale accelerated testing can prove a timely and economical method of continuously monitoring the performance of bridge joints.

The Department of Civil and Environmental Engineering at the University of Central Florida (UCF) recently developed and constructed a facility for full-scale accelerated testing. The facility comprises a test track 15.2 m in diameter, a variable weight-loading apparatus, and a power source. The circular test track is a reinforced concrete slab 1.2 m wide by 38.1 cm thick supported on an earth embankment. Within the track are two 2-span bridge decks 3.7 m long by 1.8 m wide with a 20.8-cm reinforced concrete slab and transverse center joint. The loading system consists of three support beams 7.6 m long, W36 × 150 spoked from a center pivot at 120-degree intervals. Each support beam is attached to a hydraulically driven dual-wheel truck-axle assembly. A water tank 3.7 m in diameter by 2.4 m high is centrally mounted on top of the support beams and is used to generate additional weight to the loading system. The total weight of the loading apparatus and water can vary between 133 kN (30,000 lb) and 333.6 kN (75,000 lb), and is evenly distributed to the three dual-wheel assemblies. The entire loading device is powered by a 220-hp diesel engine with a hydraulic transmission and is capable of speeds up to 48 km/hr. A center support assembly, used to hold the entire system in place, is designed to restrain the testing apparatus from horizontal movement while allowing free rotation and vertical movement and a small amount of tilt. The support allows for a total load transfer to the dual-wheel assemblies and is hollow to accommodate the hydraulic transmission lines. Figure 1 shows the complete testing facility. The facility can accelerate the testing of bridge joint products under heavy wear and impact.

It should be noted that there are limitations to this method of testing. The test-track facility is not configured to examine the effects of ultraviolet radiation. Hence this form of testing cannot be included in test programs. Also, because of the scale of the test bridges and relatively short duration of testing for this program, the effects from thermal movement cannot be accurately measured. The 48-km/hr top speed of the loading apparatus is also considerably lower than the speed of actual traffic. To partially compensate for this fact, a heavier-than-normal wheel load is used.

In spring 1992, engineers from the Florida Department of Transportation (FDOT) District 5 and Howard Needles Tam-

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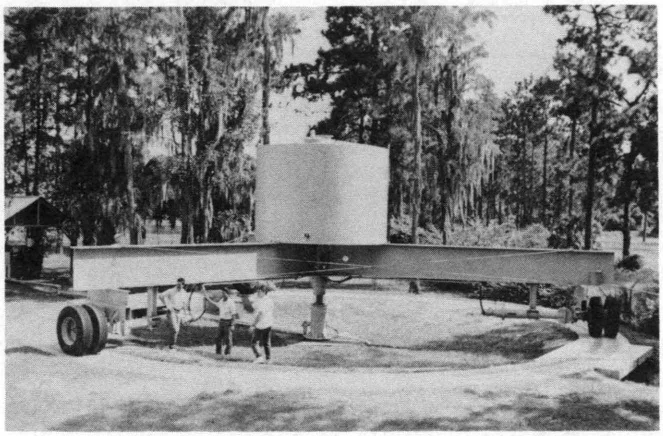

FIGURE 1 University of Central Florida test track.

men & Berdendoff (HNTB) needed to select replacement joints for several bridge joint locations along the heavily traveled corridor of Interstate 4 through Orlando, Florida. A product investigation revealed several new bridge joint products using current technology, but little in-place performance history to aid in selection. It was decided to set up a testing program at the UCF test track to establish a minimum 5-year simulated life expectancy of wear capabilities for various expansion joint types through accelerated testing procedures. Five separate manufacturers of bridge joints agreed to install one of their bridge joint products for testing. Each was asked to install a nominal 6.4-cm joint. Those bridge joint products will be identified here as bridge joints A through E.

LIFE EXPECTANCY SIMULATION ANALYSIS

The test program was developed to monitor continuously the performance of each expansion joint system placed on the large-scale test track under the application of repetitive dual-wheel loading. The sum of the repetitions successfully completed was used to equate the tested joint materials to a simulated life expectancy (SLE) of normal highway use. The SLE has been tailored to site-specific applications through the use of actual traffic volumes and joint opening requirements from the Interstate 4 project mentioned.

The first step of the simulation analysis was to determine the actual volume of yearly heavy truck traffic to equate to the tests. The I-4 joint rehabilitation project is to be constructed in 1993 with a joint life of 5 years determined as a minimum requirement. Therefore, a median year (1995) volume of average daily traffic (ADT) of 75,000 vehicles for three lanes of westbound travel was obtained from the 1989 I-4 Corridor Study for use in this project. The average proportion of trucks through this corridor was determined to be 6 percent, with a conservative assumption that half of these, or 3 percent, would be heavy trucks concentrated mainly in the center lane. Thus the annual volume of heavy truck traffic was determined using the following equation:

$$\text{AHT} = \text{ADT} \times \%\text{HT} \times \text{MLF} \times \text{days/year}$$

where

AHT = annual heavy truck traffic,
ADT = average daily traffic,
%HT = percent heavy trucks, and
MLF = multilane factor.

Hence, for this test program, the annual volume of heavy trucks was calculated as

$$75{,}000 \times 0.03 \times 0.9 \times 365 = 739{,}125$$

where 0.9 is the multilane loading reduction factor as set forth by AASHTO for three travel lanes in one direction.

For this project, a 66.7-kN wheel load was used for the accelerated testing. This wheel loading is considered to be much heavier than normal applied wheel loads. Therefore, it is necessary to convert this heavier wheel load to an equivalent standard wheel load. For the seven Florida legal load trucks used by FDOT, the maximum single-axle load present on a majority of the trucks is 98 kN. An equivalent wheel-load factor generally defines the damage per pass caused to a specific pavement system by the vehicle in question relative to the damage per pass of an arbitrarily selected standard vehicle moving on the same pavement system. One of the most widely used forms of load equivalency factors is that presented in the *AASHTO Guide for Design of Pavement Structures*. On the basis of AASHTO conversion tables from the 1986 manual, the differential equivalency factor between the 133.4-kN single-axle load used for testing and a standard 98-kN single-axle load is 5.51 for the concrete slabs 20.3 cm thick. The test track, unlike actual field conditions, applies the wheel loading over the same path for every repetition. An assumed probability-of-occurrence factor of 3 has been used for analysis purposes. In other words, every third wheel load is assumed to cover the same path along the bridge joint. The following equation was used to equate the test track results to a simulated life expectancy of one year:

$$N \times \text{DEF} \times \text{POF} = \text{AHT}$$

where

N = number of test track load repetitions per year,
DEF = differential equivalency factor,
POF = probability of occurrence factor, and
AHT = annual volume of heavy truck traffic.

Given DEF, POF, and AHT, solving for N provides a total of 44,715 repetitions required annually. A simulated life expectancy of 5 years thus would require a minimum of 223,600 repetitions of test-track loading for this project. In an effort to allow conservatively for any margin of error in the analysis procedures, a minimum of 250,000 repetitions was used for this testing program.

Although the simulated life expectancy can be equated to site-specific conditions for traffic volumes and joint opening requirements, it is restrictive because as a result of the scale of the testing apparatus and the short duration of the tests, it does not take into account aging or weathering considerations. These factors are not considered as important in the life of a bridge joint as the wear, impacts, and abrasion included in this test program, but they can have a significant effect in certain climates. This test was performed in central Florida temperatures of +27°C, which, coupled with high temperatures generated from the testing apparatus, showed significant effects on certain products. Other factors, such as freeze-thaw and road salts, can have equally significant effects on some bridge joint materials in northern climates. This testing program could not feasibly test for all external factors affecting the life expectancy of a bridge joint; therefore it targeted the factors considered most important.

TESTING PROCEDURES

The entire program for testing expansion joints was carried out in 5 weeks, including down time for joint and tire repair, with the testing apparatus in operation 8 to 10 hr per day. Approximately 260,450 load repetitions with 66.7 kN of dual wheel load were applied. The program included testing for normal wear, abrasion, and impact. A constant operating speed of 24 km/hr was maintained throughout the testing program. The tire pressure on the radial 12R22.5 tubeless truck tires was maintained at 758 kPa. With this tire pressure, the footprint of the tire was measured at approximately 21.6 by 27.9 cm.

The normal wear test was conducted during the first week. The loading apparatus was run for approximately 25 hr clockwise and another 25 hr counterclockwise. A total of 73,124 repetitions was achieved during this phase of the test.

The second week included the abrasion test. Each joint was covered lightly with a mix of coarse sand, small aggregates, fragments of broken glass, and miscellaneous metal parts (small bolts, screws, etc). As in the previous test, this phase was divided into 25 hr of clockwise rotation followed by 25 hr of counterclockwise rotation. During the clockwise rotation phase, a small bolt punctured one of the tires on the apparatus. All bolts and screws were removed for the remainder of the test. A total of 70,664 repetitions was applied during this test.

The last phase of the project included 2 weeks of impact testing. The concrete bridge slabs were jacked up approximately 1 cm to create a difference in elevation between the expansion joint headers. Because of the geometry of the circular test track, certain joints with elevation differentials would be affected by clockwise rotation, whereas others would be affected by the counterclockwise direction (see Figure 2). The testing apparatus was run counterclockwise for 50 hr. It was intended to accumulate 50 hr of clockwise rotation as well; however, after 28 hr of rotation, one of the dual-wheel assemblies on the apparatus failed and the test was stopped. A total of 116,864 repetitions was achieved during this phase of testing. Although the testing ended prematurely, a total of over 260,000 repetitions was achieved. The numbers exceeded the original proposal of 250,000 repetitions.

BRIDGE JOINT CONFIGURATIONS

A graphic representation of each bridge joint system tested in this program is shown in Figures 3–7 in which the dashed line on each joint system represents the original joint profile.

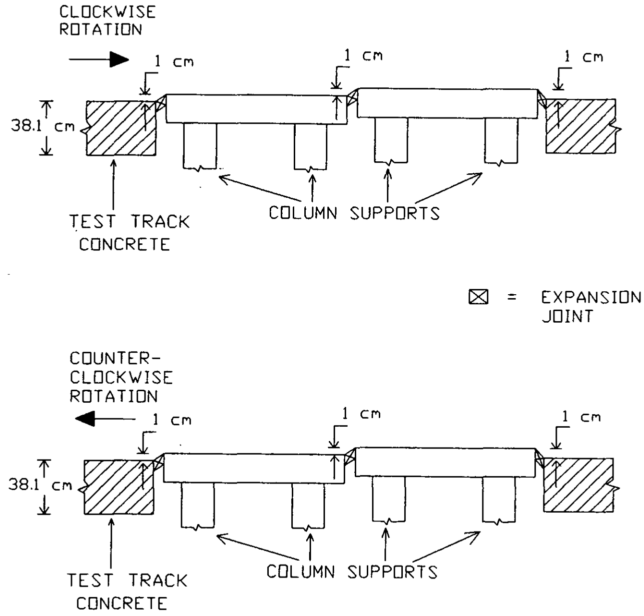

FIGURE 2 Impact test diagram.

The irregular profile under the dashed line shows the damage or wear from the test.

Bridge Joint A

The configuration of Bridge Joint A consisted of two steel armor angle retainers with a sinusoidal anchoring system of No. 4 rebar. Each steel angle retainer was anchored into a nosing of elastomeric concrete approximately 15.2 cm wide by 6.4 cm deep. A primer was used to enhance the bond between the nosing material and the concrete bridge slab, as well as between the nosing material and the steel angle. The square bridge seal, a dense foam material with longitudinal grooving on each vertical face, was bonded to the steel angle retainers with an epoxy. The foam seal allowed for elongation of approximately 20 percent, and the elastomeric concrete yielded an average compressed strength of 8867 kPa.

Bridge Joint B

Bridge Joint B consisted of two-cell neoprene bridge seal seated between a nosing of soft polymeric concrete approximately 7.6 cm wide by 2.5 cm deep on each side. The neoprene seal had small protruding fins running longitudinally down each side and was bonded to the polymeric concrete nosing with an epoxy adhesive. The seal was pressurized against the polymeric nosing until the adhesive curing was complete and allowed for an ultimate movement range of ±50 percent. The polymer concrete was a pourable self-leveling material that required no primer and had an initial set time of approximately 1 hr.

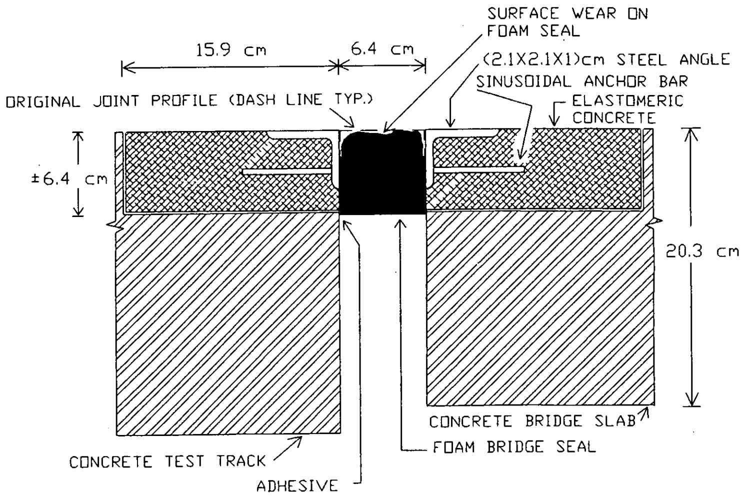

FIGURE 3 Bridge expansion joint system: Joint A.

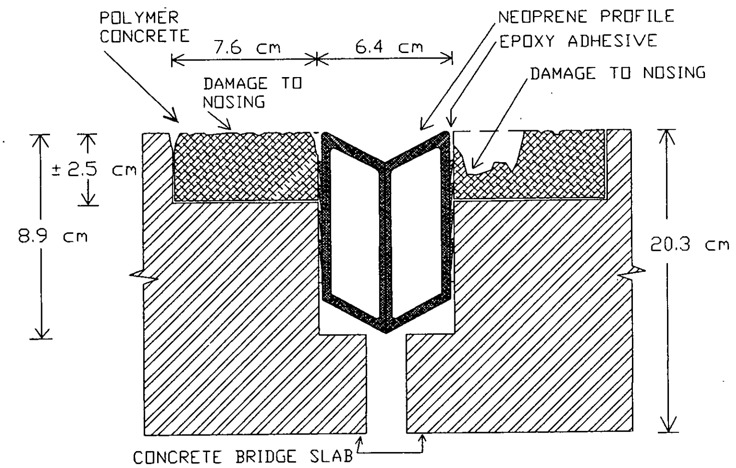

FIGURE 4 Bridge expansion joint system: Joint B.

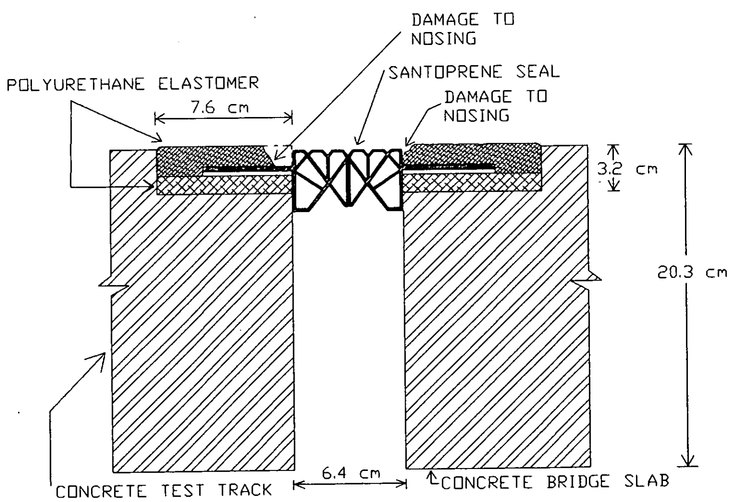

FIGURE 5 Bridge expansion joint system: Joint C.

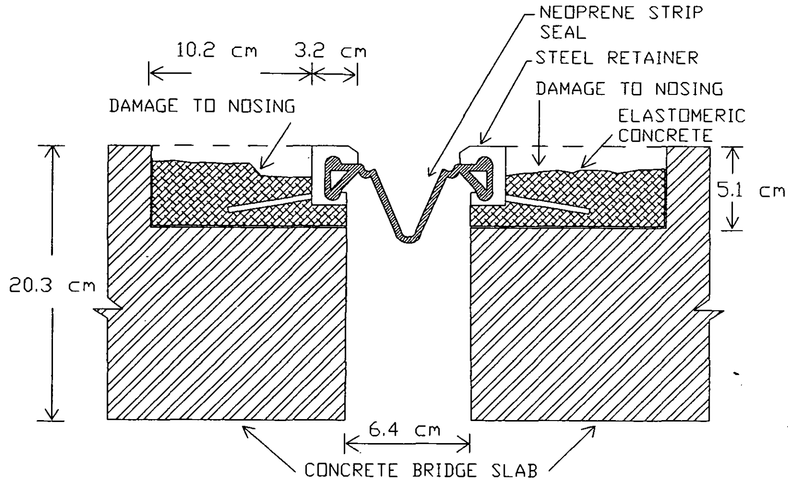

FIGURE 6 Bridge expansion joint system: Joint D.

Bridge Joint C

Bridge Joint C consisted of a winged, multicell Santoprene compression seal with the wings imbedded in a header of polyurethane elastomer concrete approximately 7.6 cm wide and 3.2 cm deep. An elastomer bond coat was used between the seal wings and the various layers of the elastomer concrete header. The Santoprene seal allowed for elongation in excess of 300 percent and the wings used slotted holes for additional bonding and load transfer. The elastomer concrete nosing had an initial cure of approximately 4 to 6 hr.

Bridge Joint D

Bridge Joint D consisted of two steel retainer bars anchored on each side with an angled bar 1 cm in diameter in a soft elastomeric concrete nosing, approximately 12.7 cm wide by 5.1 cm deep. A V-shaped neoprene strip seal was seated in the retainer bar and bonded with an epoxy. The strip seal was designed to accommodate horizontal movement up to 10.2 cm. The elastomeric concrete nosing material took approximately 2 hr to cure and yielded a compressive strength of 15 169 kPa after 7 days.

Bridge Joint E

Bridge Joint E consisted of two elastomeric concrete nosings, each approximately 5.1 cm wide by 2.5 cm deep, separated by a compressed form-backer rod and a sealant of poured elastomer. A polymer conditioner was required for proper bond between the elastomeric concrete nosing and the concrete test track, as well as between the elastomeric concrete nosing and the poured elastomer seal. The seal, poured to a depth of approximately 0.6 cm over the center of the backer rod, required heat lamps for proper cure. The joint material required approximately 4 hr for initial cure. It was designed to accommodate an elongation of approximately 25 percent.

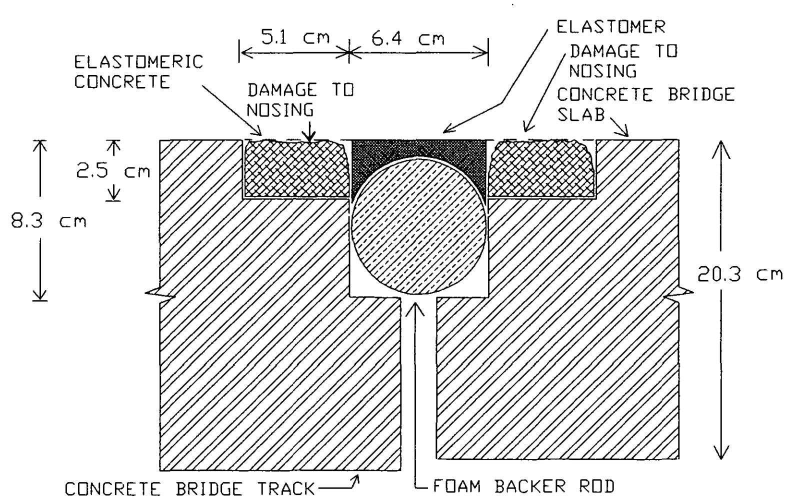

FIGURE 7 Bridge expansion joint system: Joint E.

TEST RESULTS

Bridge Joint A

After 600 repetitions of wear testing, the foam seal of this joint developed slight markings and collected small pieces of burnt rubber from the tires. After approximately 35,000 repetitions, the markings developed into slight scratches that continued to form throughout the normal wear test. Some slight separation between the foam seal and the armor angle occurred with depths of approximately 0.3 cm. At the conclusion of all testing, the foam seal exhibited some grooving and separation along the steel angle bond line to a depth of approximately 0.6 cm. The elastomeric concrete exhibited only slight signs of wear throughout the entire testing, exposing some small aggregate. The steel angle retainers exhibited no problems.

The joint performed satisfactorily throughout the test program. The minimum SLE for this joint is

$$\frac{260{,}450}{44{,}715} = 5.8 \text{ years}$$

Bridge Joint B

The polymer concrete nosing of Joint B showed signs of wear during the early stages of the normal wear test. The wear increased with the development of large, deep cracks and incipient spalling throughout the header material after approximately 44,000 repetitions of normal wear testing. The abrasion test brought spalling of the header material and separation of the bond between the polymer concrete and the concrete test track, with resulting gaps approximately 0.3 cm to 0.6 cm wide. Small gaps also appeared in the bond between the neoprene seal and polymer concrete nosing. During the impact testing large bits of polymer concrete broke off at the nosing. A liquid polyuria material was applied to the damaged areas of the polymer nosing in an attempt to repair the damage and reseal the bonds. The repair material seemed to perform fairly well throughout the remainder of the impact testing (approximately 90,000 repetitions). However, by the end of all testing, numerous cracks had developed in the repair material.

The SLE for this joint, as a result of early nosing failure, is

$$\frac{40{,}000}{44{,}715} = 0.9 \text{ years}$$

The SLE for the nosing material repaired with the polyuria patch is

$$\frac{90{,}000}{44{,}715} = 2.0 \text{ years}$$

Bridge Joint C

The elastomer concrete nosing displayed only slight wear during the normal wear test, with a slight collection of debris noted in the grooves of the seal. The abrasion test brought continued minimal wearing of the elastomeric nosing, with a small crack observed at the end of this phase (approximately 144,000 repetitions). The Santoprene seal collected a large amount of debris in the top grooves, but it did not appear to be damaged. The early portion of the impact testing revealed signs of spalling in the edge of the elastomeric nosing. A small piece (approximately 1.9 cm long) broke away at the seal-nosing bond line after approximately 243,000 repetitions. On further impact, larger chunks of the nosing material broke off; the largest of these was approximately 15.2 cm long. Other signs of incipient spalling also were noted on both sides of the joint. The Santoprene seal resulted in slight wear, with a 5.1-cm tear in the seal wing at the bond line between the wing and the seal body.

The initial signs of nosing material failure yield an SLE of

$$\frac{144{,}000}{44{,}715} = 3.2 \text{ years}$$

The occurrence of more severe deterioration of the nosing material and winged seal gives a cumulative SLE of

$$\frac{243{,}000}{44{,}715} = 5.4 \text{ years}$$

Bridge Joint D

The soft elastomeric concrete header material in Joint D exhibited moderate wear during early stages of the normal wear test. There was a 0.3-cm groove by the end of that testing, after approximately 74,000 repetitions. The nosing material continued to wear down during the abrasion test to a depth of approximately 1.3 cm below the riding surface. The elastomeric concrete material was repaired at the end of the abrasion test because of concern that the tires might be damaged on the sharp edge of the retainer bar. The impact testing resumed and the header material quickly spalled to its earlier state. It was then removed and replaced for the remainder of the testing (approximately 116,000 repetitions) with a more heat-resistant elastomeric concrete that appeared to hold up well. The retainer bar assembly and neoprene seal showed little or no sign of wear during the testing program.

The classification of extreme nosing material wear as an early stage of failure gives an SLE of

$$\frac{74{,}000}{44{,}715} = 1.7 \text{ years}$$

The new higher heat-resistant nosing material performed satisfactorily for the period that it was in place for testing, yielding a minimum SLE of

$$\frac{116{,}000}{44{,}715} = 2.6 \text{ years}$$

Bridge Joint E

After approximately 6,000 repetitions, Joint E failed in bond between the elastomeric concrete and the elastomer seal. It was determined that the joint material was improperly installed and the joint was removed and replaced. The normal wear test proceeded with slight signs of wear and separation of the bond between the elastomeric concrete and the elastomer seal after approximately 112,000 repetitions. During the abrasion test, this bond separation continued to grow to approximately 0.3 cm in depth, and the elastomeric concrete nosing began to wear down. Signs of spalling appeared on the surface of the nosing material. During the impact test, a complete separation between the elastomeric concrete and the elastomer seal occurred in the areas of tire contact. Slight spalling and increased wear also were noted in the elastomer concrete nosing.

The SLE for this joint, as a result of early debonding and wear, is

$$\frac{112{,}000}{44{,}715} = 2.5 \text{ years}$$

CONCLUSIONS

Time and cost are major obstacles in the testing of new system technology for bridge joints under the effects of full-scale loading. To date, most full-scale testing has occurred only through the installation of new products on actual Interstate bridges. Although these applications certainly provide the most realistic results, monitoring programs can require years to gather enough load-cycle information to prove or disprove a joint product. In addition, routine inspection of the joint applications can be impractical or virtually impossible because of heavy traffic volumes. Costs for such tests can prove excessive because of material quantity and maintenance-of-traffic requirements, and can continue to increase if the products being tested fail prematurely and require replacement.

The full-scale accelerated testing apparatus in operation at the University of Central Florida has proven to be a timely, cost-effective means of testing bridge joint systems. The joint applications require placement of only a few linear feet of material and can be observed and inspected daily. The field observations of various component deficiencies experienced during this testing program are consistent with actual deficiencies and problems encountered in live applications. Specifically, live field applications of Bridge Joints B and C were inspected during the testing program. Both joint products were located on heavily traveled Interstate routes in central Florida with similar conditions to those in the test simulation. In each case, the bridge joints exhibited wear deficiencies identical to those experienced on the test track. Both Bridge Joint B applications—actual and test track—exhibited wearing and spalling of the nosing material and a debonding of the nosing material to the bridge seal. Both Bridge Joint C applications exhibited cracking and spalling of the nosing material over the seal wings under impact loading. In addition, the simulated life durations calculated during this program are consistent with information collected from field observations and maintenance reports. It can be concluded that test results are relevant and representative of actual conditions.

Several consistencies in the various joint deficiencies also were observed. First, several of the joint applications revealed that the bond line between the seal and the nosing material is a weak link in the joint system. The bonding of soft, pliable materials to rigid epoxy bonding agents appears to be susceptible to the movements encountered under impact and cyclic loading. Second, the softer nosing materials appear to accommodate impact loading acceptably but are less resistant to excessive wear and abrasion than the harder materials. Conversely, although the harder materials are more wear resistant, they appear to be brittle and susceptible to spalling under impact loading. Steel armored headers obviously were the best component for resisting impact load if the anchorage systems were properly seated in the nosing material. Third, all nosing materials required precise mixture and placement techniques to ensure their intended performance. There seemed little room for error with any of these materials, as witnessed by the fact that Bridge Joint B debonding problems resulted from improper surface preparation and Bridge Joint E had to be removed and replaced early in the testing program because of improper placement.

Finally, it should be noted that the full-scale accelerated testing afforded the bridge joint manufacturers the opportunity to identify weaknesses in their products and to make improvements to their systems. As a result, the physical characteristics of Bridge Joint C have been modified and the chemical properties of Bridge Joint D nosing material were adjusted as discussed.

It can be concluded that full-scale accelerated testing for bridge joint systems is a timely, feasible method of obtaining realistic results. The determination of proper individual component characteristics to be included in a given bridge joint system must be based on site-specific criteria such as location, joint movement requirements, and characteristics of local traffic.

Recommendations for future testing include these observations: Temperature sensors should be installed on the bridge slabs to measure temperature variations during operation. Strain gauges may be placed on the joint nosing to measure strains or stresses. Measurement can be undertaken with a system of computerized data acquisition already at the UCF test track facility.

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