reprogramming is necessary if the list of repair types is changed.

CONCLUSIONS AND POLICY IMPLICATIONS

The model has revealed numerous important insights concerning bridge repair and replacement needs for state-owned bridges. These are as follows:

1. It is nearly always cheaper to repair than replace a bridge (except when widening is an option), provided a bridge has not become unsafe and beyond repair.
2. Wisconsin should replace between 27 and 38 bridges under state responsibility per year to the year 2000.
3. Wisconsin should let the average condition of bridges decline over the next two decades to take advantage of the remaining years of useful life in its bridges reflected in their age distribution. This conclusion assumes WisDOT always selects the least-cost option for repair and replacement work.
4. Major repair costs for concrete overlay work and new decks on steel deck girders and prestressed-concrete structures built after 1955 will increase substantially from the 1980s to the 1990s. The reason is that these bridges are reaching their midlife when significant repairs are typically required.
5. Implementation of the model has been achieved by involving key staff and decisionmakers in both the development and evaluation of the model as well as the results. Broad participation will be needed for both future applications and enhancements of the model.

ACKNOWLEDGMENT

We wish to thank Joe Dresser, George Gundersen, Wendy Fearnside, and Ken Leonard for their strong support for this work and also Don Flottmeyer, Cliff Benz, Jim Ziehr, Walter Scott, Jim Pautzke, and Tom Dobson for their valuable input. We also thank Michael Fitzpatrick of the New York State DOT for sharing his work with us.

The results, views, conclusions, and recommendations are solely ours and not necessarily those of WisDOT.

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Publication of this paper sponsored by Committee on Structures Maintenance.

Performance Specification for Bridge Deck Joint-Sealing Systems

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A performance specification, although an unconventional approach, can be an effective way to ensure that only high-quality bridge deck joint-sealing systems are designed and selected for use. History of the past decade, when these systems were first used to seal the gap between moving bridge ends, has shown that the systems have not always been as durable as they need be to fulfill their intended function over the life span of the bridge. Disappointing results can be attributed in part to the relative newness of their application and unfamiliarity of the producers with the demands of the task. More important, shortcomings can be traced to a selection procedure that relies mainly on low initial cost rather than quality. Without the application of uniform standards by which to measure performance, there can be no means to judge the relative merits of candidate systems. A well-designed performance specification can meet this need. Although it would be desirable to force producers to guarantee their system's quality over the long term, the concept is contractually and practically untenable. A specification that embodies performance criteria for products to comply with prior to, and just after, installation can go a long way to ensuring that only systems that have a good chance of success are selected.

Two decades ago, the traditional approach to providing for bridge end movements greater than 1 in was to construct open joints. With the increasing use of salt compounds to maintain bridge decks free of ice, steelwork and concrete substructures in the vicinity of the joints suffered extensive deterioration as the waterborne corrosive agents spilled through and splashed on these surfaces. Oftentimes drainage troughs were constructed beneath the openings to collect deck runoff and direct it, via a plumbing system, to discharge away from the bridge. Usually these collection systems rapidly became clogged with accumulations of road debris. They soon became useless and, on occasion, broke away from their supports as the load carried within them increased and bridge vibrations caused their connections to fracture.

Clearly, the solution to the problem was to devise a joint seal capable of spanning a moving gap while remaining watertight.

For small movement ranges not exceeding 2.5 in, these needs were met with the development and widespread use of the compression seal. These seals, which can be as large as 6 in², are open-webbed neoprene products. Inserted within steel-armored joint edges, these seals have compiled an impressively successful record of accommodating bridge movements while maintaining watertight joints. The width of a properly selected model cycles between 20 percent (in warm temperatures) and 80 percent (in cold temperatures) of the unstressed width.

Unfortunately, manufactured products designed to seal joints that move more than 2.5 in have not enjoyed the success of the compression seal.

A number of manufacturers have produced a variety of products and thrust them on bridge owners hoping that their selection and use will ultimately prove the product's quality and ability to do the job, which would subsequently lead to the product's gaining universal acceptance. In effect, the public's bridges have been used as a proving ground. Some products have been successful, while others, not so successful.

During the past decade, the products that have been widely used have been manufactured by a number of companies. These products functioned in a variety of ways, such as

1. Segmented seals bolted to the bridge deck and subjected to varying degrees of tension and compression,
2. Segmented seals bolted to the deck and subjected to relatively low stress, and
3. Continuous strips or glands contained within metal extrusions either bolted to, or embedded within, the bridge deck and subjected to relatively low stress.

By far, the most widely used products during the early application of these sealing systems were those in the first category. Because the great majority of the systems that have been applied accommodate movements generally 4 in or less, this presentation addresses only those systems, although the general concept of selection by meeting performance criteria applies equally well to models designed to handle larger movements.

FAILURES

The singularly most disappointing feature of proprietary sealing systems has been their lack of durability, mainly with respect to watertightness. This shortcoming has been due to many reasons, most notably leaking through joints of segmented systems.

As documented in a National Cooperative Highway Research Program report (1), several years ago a number of state and other highway agencies were canvassed for their experiences with the performance of proprietary systems then in place. Forty-one agencies responded to the survey and reported on a total of 580 installations. They reported that almost two-thirds had some form of problem, one-third leaked, one-fifth suffered surface scarring, one-tenth were noisy, one-tenth of the anchorages failed, and 3 percent of the seals ruptured. Reasons for the failures, as judged by those who responded from the reporting agencies, included improper product design, defective material, inadequate control of construction, and inability of the seal to accommodate bridge end movement.

NEED FOR PERFORMANCE SPECIFICATION

Bridges are products of the (owner) bridge engineer's imagination. Once the engineer selects a proprietary product for incorporation within a structure, then the manner in which the product functions to fulfill a certain role must be delegated to the product's designer and manufacturer. Of course, since manufacturers must compete for their share of the market, their survival depends on their ability to produce the product and offer it for use at the lowest possible price. Unfortunately, quality and low cost are not often coexistent. Consequently, the bridge engineer is confronted with a dilemma, for he or she cannot truly know the capabilities and reliability of the various manufactured products. In accepting a product for use, the bridge engineer must be guided by what he or she reads and believes in the manufacturer's literature and whatever performance record is available.

To compound the problem further, the manufacturer will not ordinarily be a party to a contract with the owner. The manufacturer is but a supplier. Contractual responsibility will lie with the installer--a contractor whose accountability for success or failure of the product may be difficult to enforce.

The answer to this dilemma appears to lie in the selection of products that can conform to a generic specification that embodies performance standards.

WHAT IS A PERFORMANCE SPECIFICATION?

End-result specifications are not currently widespread in contracts for highway and bridge construction in this country, although the use of modified forms of performance specifications for the selection of certain types of material is increasing. In the case at hand, the end results required of a sealing system are attributes such as serviceability, wearability, quietness, watertightness, and compatibility with the bridge structure of which it is an integral part. Criteria for these attributes must be stipulated and are required to be verified by a combination of testing and observation.

During the time that research was being conducted to determine the merits, feasibility, and features of a specification, it was learned that no domestic agency was then applying a performance specification in the selection of bridge deck joint-sealing systems.

CONCERNS WITH USE OF PERFORMANCE SPECIFICATION

It should be understood that the agency that employs the performance specification must be willing to relinquish to the manufacturer the positive aspect of that part of the project design that relates to the deck joint-sealing system. The manufacturer, after all, can only be required to ensure the performance of its own creation or selection. Although the owner may still have the prerogative to proscribe certain obviously undesirable features, he or she may no longer prescribe detailed features.

Ideally, for the performance specification to be an effective tool in judging the quality of proprietary bridge deck joint-sealing systems and the total construction, the evaluation should include a period of in-service performance. Requiring a standard of performance to be complied with during a postconstruction period is tantamount to demanding a guarantee or warranty. That is, an assurance of quality that entails the responsibility for repair or replacement in the event of failure.

At this point the dilemma surfaces, for, from the moment the contractor completes all work in the contract and the project is accepted by the owner, it is not hard to understand why he or she may not be willing to correct deficiencies that develop at some later time. First, the contractor did not design the product and, second, he or she will not be anxious to assume responsibility when the cause of failure may not be obvious.

However valid these arguments may be, there are legal ways to induce a contractor to make corrections at his or her expense, or the expense of the bonding company, if the product fails to perform to the satisfaction of the owner during a specified service period.

Many believe that, for a number of reasons, a demand for an in-service performance guarantee is not reasonable or practical. Basically, the objections focus on the argument that there are factors, such as the behavior of the total bridge structure and contiguous roadways, environment, and traffic loadings, that are outside the control of the manufacturer and contractor and that can adversely affect the performance of the joint-sealing system.

It is interesting to observe that, of the responses from cognizant representatives of the 41 reporting agencies, 78 percent commented that warranties did not appear to be possible or practical for a variety of reasons, including

1. The responsibility for satisfactory performance should be shared by all parties to the construction--designer, inspector, manufacturer, and contractor;
2. Reasons for nonperformance may be difficult to determine precisely, especially to the satisfaction of a court of law (those that quoted this as a reason were focusing on the difficulty in legally enforcing the clause);
3. Federal Highway Administration (FHWA) regulations prohibit the use of warranties in contracts of this nature; and
4. A warranty clause will result in higher bid prices.

It is also interesting to note that 56 percent of the respondents replied that performance specifications without a warranty clause were not sufficiently valuable to merit implementation. This view notwithstanding, the need for these products to comply with some form of performance standard has been established through experience. Moreover, the legitimacy of the above-cited contentions furnish powerful arguments against the application of in-service performance guarantees.

It is recognized that a performance specification without an in-service guarantee clause limits the verification of specified attributes to evaluations prior to, and during, construction. Nevertheless, it is believed that some form of performance specification, even one lacking the in-service guarantee feature, merits implementation and represents an improvement over the various specifying means that have been used to select proprietary bridge deck joint-sealing systems to date.

DESIRABLE INGREDIENTS OF PERFORMANCE SPECIFICATION

Proprietary bridge deck joint-sealing systems are manufactured by one company and installed by another. It thus makes sense that acceptance testing be applied to the manufactured product (preinstallation tests) as well as to the total construction (postinstallation tests). The optimum specification stipulates performance criteria that, in the end, can serve as an adequate gauge of the system's ability to function satisfactorily over the long term. The obvious difficulty lies in selecting criteria that are not unduly severe, which results in the qualification of only overly expensive systems, or, on the other hand, too lenient, which results in the acceptance of the unsuitable.

The initial steps toward developing a specification are to identify desirable functions and attributes of a successful joint-sealing system. The preinstallation tests should attempt to simulate service conditions to a practical degree. These tests are generally described as follows.

Specimens of finished components and the complete assembly will be subjected to a series of tests to determine the unit's ability to satisfactorily withstand extended cyclic motion over travel, skewed action, and water ponding (for leakage); to verify anchor bolt torque retention under traffic; to certify the integrity of tension splices of segmented cushion elements; and to establish the product's durability when exposed to temperature extremes. Specimens to be laboratory tested are to be assemblies that consist of the candidate seal model mounted on concrete slabs that simulate the actual bridge deck joint construction proposed for a specific project. The specimen will be fastened to a mechanical apparatus capable of imparting a relative motion to the slabs.

Because cyclic motion will be required to be delivered to the assembly through the concrete slabs, restrictions will be placed on the maximum tension (or horizontal shear) the device imposes on the slabs during the rated movement. In addition, the performance of the concrete during the cyclic tests will visually indicate whether such forces are harmful or not to the deck slabs.

It is a fact that, if seal surfaces and gaps are properly constructed, the noise level will not be objectionable, provided no parts of the assembly are loose, thereby introducing an additional source of noise through the contacting of such parts during traffic impact. It is impractical to attempt to simulate truck traffic over a test unit in the laboratory to record noise levels and then to equate such measurements to the unit after installation on the bridge. It is more impractical to expect an agency or joint manufacturer to build a dummy bridge to be used as a noise test site or to find an existing installation of the same model while the temperature is -30°F to conduct noise tests. Therefore, a proprietary product must also be assumed to be acceptable from a noise standpoint provided the prescribed gap widtn and ridable elevation difference are not exceeded.

After an agency accepts a proposed joint-sealing system on the basis of satisfactory test results during the preinstallation phase, the contractor must be permitted to perform the installation in whatever manner he or she deems best, with the implied concurrence of the manufacturer. This is the philosophy behind a true performance specification. Notwithstanding this philosophy, the contractor will be obliged to accomplish or avoid certain critical results during installation, provided the performance specification does not prescribe how these results are to be accomplished or avoided. An example of required installation procedures is as follows. The ridable surface of elements will be required to be set a specific distance below the adjacent roadway surface, and if systems are installed at temperatures beyond a permissible latitude from the midpoint of the design temperature range, the assembly must be compressed or stretched accordingly during installation to simulate the stressed dimensions of the unit at the installation temperature.

Once preinstallation tests are complete, the only field test recommended to be performed will be a water-ponding test for leakage.

The following are recommendations for specific performance provisions:

1. Cyclic motion: The specimen will be subjected to 5000 cycles of the full prescribed movement range at a period of about 1 min. Before the full test commences, a load-recording test will determine the force required to maintain the specimen at various positions of the full movement range.
2. Ponding: After 2500 cycles, and again at 5000 cycles, the surface of the specimen will be diked and ponded with water to a depth not less than 1 in for 9 h, remaining 3 h in each of three positions--fully compressed, fully stretched, and midpoint.
3. Temperature range: After a successful comple-

tion of the first ponding test, the specimen will be subjected to 10 cycles of the full temperature range prescribed. The specimen will remain at each temperature extreme for 30 min between cycles with the gap between slabs set at the appropriate dimension.

4. Splice test: Specimens of segmented systems will be tested in tension to rupture. The splices will be expected to be nearly as strong as an individual segment.

5. Bolt torque dissipation: In this test, anchor bolt systems will be tested for torque retention after a period of sustained vibrations. The specimen will be subjected to downward blows of 8000 lb applied in a rapid sequence to each side of the joint, which simulates high-impact wheel passages. After 50 000 consecutive blows, the torque will be tested and expected to be within 1 percent of the initial value. Also, the rigors of the test are not to have caused damage to, or loosening of, other parts.

6. Vehicular braking/traction test: A standard truck tire mounted on an axle and loaded with 8000 lb will be drawn across the specimen with the wheel locked, and then rolled back. This cycle shall be repeated 50 000 times with a period of 2 s.

7. Membrane puncture: This test is designed to determine a strip seal's capacity to resist puncture and pullout from retainers when the seal may be covered with granular debris. A rubber-tired ram apparatus will deliver 8000-lb downward blows at 5-s intervals to the center of a plate that covers the specimen.

8. Debris-expelling test: The seal will be examined after being loaded with granular debris and cycled 25 times between full-rated opening and 1.25 in for its ability to expel the entrapped debris.

9. Postinstallation testing: The only test proposed after construction is a water-ponding test for leakage. In this test, dikes will be constructed across the roadway and sidewalks, and water delivered through an unnozzled hose at the rate of 1 gal/min will flow continuously down the parapet face and across the sidewalk and curb face of the joint. The flow and ponding will continue for a period of 9 h, after which the underside of the entire joint will be examined for leakage.

CONCLUSIONS

In summary, then, observations of many installations over a significant time period lead us to conclude that, for the most part, proprietary bridge deck joint-sealing systems have not been performing as expected. They have been more successful in theory than in actual practice, where they are subjected to the rigors of traffic and the occasional unpredictable behavior of bridge structures. Ironically, the most important attribute for which these systems were designed--watertightness--has been the area in which most of the complaints originated.

Judging from the erratic performance of identical joint assemblies in different projects, the quality of workmanship in installing these sophisticated assemblies must play a critical role in their success or failure.

In today's competitive market, with some highway agencies specifying joint assemblies by name, there is little incentive for manufacturers to augment their design with any cost feature that would price them out of the market. If all joint products were held to a common set of performance ground rules, manufacturers would not only strive to improve their systems in order to comply, but they would be competing on an equitable basis and agencies would be afforded reasonable assurance of good performance at competitive prices. An effective performance specification, geared to stipulating desirable attributes verifiable to some extent by meaningful testing programs before and after installation, should be the solution to this problem.

Contractual restraints and practical considerations are such that the detection of those systems with desirable attributes, and elimination of those without, must be performed before an extensive in-service period. Consequently, it is only through a properly designed qualification program that the concept of a performance specification can be acceptable to all parties.

An important area for additional research concerns the further development of test criteria that can truly gauge a proprietary sealing system's quality. Judgment only has served to compile the criteria presented in this report. More empirical data are needed to equate the form, magnitude, and cyclical variation of laboratory-applied loads with the actual lifetime experience of a sealing system.

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Thermal Compatibility of Thin Polymer-Concrete Overlays

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Thin polymer-concrete overlays that provide low permeability and high skid resistance can be installed on bridge decks with minimal disruption to traffic and at about one-half the cost of alternative service-life-extending measures such as portland cement concrete overlays. Unfortunately, laboratory tests have indicated that the temperature changes to which bridge decks are typically subjected are sufficient to cause deterioration and eventual failure of the overlays placed in Virginia. The deterioration is caused by the development of stress in the bond between the concrete and overlay that results from differences in the moduli of elasticity and the coefficients of thermal expansion of the two materials. Thermally induced cracks have been noted in the overlay, the base concrete, and the bond interface—a majority of them in the medium least able to withstand the stress. Cracks in the overlay increase its permeability, and cracks in the base concrete or the bond interface lead to delamination of the overlays. It is estimated that a properly installed overlay prepared with either of the two polyester resins tested to date in Virginia will have a useful service life of at least five years, which, considering its ease of application, may be acceptable for bridges where it is difficult to close a lane to make a more permanent repair. A longer service life should be possible if more flexible resins are developed.