SOME REFINEMENTS IN EXPANSION JOINT SYSTEMS

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Testing and performance inadequacies of the widely used compression seals can be eliminated to a large degree by the use of mechanically locked seal elements. Rehabilitation techniques for expansion joints on older structures utilizing strip seals, low-stress sealing glands, and special low-profile elements are discussed. Major improvements in the rubber cushion concept are advanced, such as armoring for protection against snowplows and attrition, new curb and gutter techniques utilizing weldments for multidirectional changes, and lowering of detrimental force transmission. Improved modular systems for very large movements, methods of raising existing systems to meet asphalt overlay requirements, field splicing techniques utilized in lane-at-a-time reconstruction, and important noise reduction developments for urban environments are evidenced in case history evaluation.

•WIDE experience with preformed neoprene compression seals over the past decade on many thousands of bridges throughout the world has left no doubts regarding the advisability of mechanically locking the seal element between armored interfaces and that this refinement is strongly indicated as the way for bridge design engineers to go in the direction of seal design.

For an extensive period of time the writer has served as chairman of a special task group in ASTM that has had the mission of producing an acceptable national specification for the bridge compression seal industry. This task group includes the major producers, users, installers, and state highway department testing authorities, all knowledgeable in the testing of these compression seals. After years of work and a great many meetings, drafts, and redrafts, the committee is still not in agreement because of the vagaries of the recovery tests and the complete lack of a sound method of calculating the true limit of safe compressibility of a seal configuration.

What this means is that we apparently have been seeking something very hard to find: We expect a bridge compression seal, extruded from an organic material and subjected to long-term compression, to continue to recover and retain a functional level of residual compression when we already know there will be a time-dependent, gradually increasing loss of pressure. The complexities of different seal configurations, unavoidable changes in web thickness, and the need for a sufficient amount of internal web structure to resist traffic-activated vertical forces all complicate the problem for testing engineers.

By adding the fail-safe ingredient of mechanically locking the seal element to the joint interface, engineers can now specify with confidence the seal configuration shown in Figure 1 because most problems currently symptomatic of neoprene compression bridge seals would be eliminated. Specifically, mechanical locking

1. Eliminates concern for the problem of long-term pressure decay of the seal element;
2. Eliminates the argument over a seal's limit of safe compressibility;
3. Handles movements in excess of its design stroke, free of overstress;
4. Continues to perform successfully regardless of time-dependent, unanticipated joint width changes;

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5. Ends forever any possibility of intrusion of foreign material by establishing and maintaining a permanent, impervious locking contact with both joint interfaces;
6. Ensures performance against unusual dynamic vertical forces due to live loading, hydrostatic pressures, etc.;
7. Offers performance in near-cryogenic environments, since the practical limit of performance of neoprene stops at -20 F when used as a compression seal;
8. Facilitates much narrower joint widths than any other sealing concept, including basic compression sealing, which requires a 20 percent safety factor in width not required in the corner locking systems; and
9. Provides much lower overall cost.

REHABILITATION OF BRIDGE DECK FINGER JOINTS WITH STRIP SEALS

Finger or comb joints can be restored in a leakproof manner using strip seals. The old fingers are sawed out by means of a moving guided torch, after which the steel extrusions are welded at the desired elevation where the protruding fingers have been cut off. Figure 2 shows one lane with the steel extrusions welded in place. The adjacent extrusions will then be butt-welded in an impervious manner, end to end. The strip seal element then is placed a lane at a time in a continuous strip across the joint and up through the curb in a leakproof installation (Figure 3).

Bolting the Strip Seal Extrusions

A method of bolting the steel extrusions to the deck is shown in Figure 4. Bolt-hole tabs are welded to the steel extrusions, extending back into the deck as far as is necessary for good structural practice. The seal element is installed after both steel interfaces are securely fastened down, after which the asphalt overlay is placed using the steel extrusions as an end dam.

Rehabilitation of Bridge Deck Slider Plate Joints With Strip Seals

Strip sealing systems are now being widely used to repair sliding-plate joints where a new asphalt overlay is being installed over the old decks.

The slider plate is cut off by means of a moving torch and then rewelded in place to re-form the desired joint opening. The strip seal extrusions can then be welded or bolted to the reconstructed steel joint opening a lane at a time, after which the neoprene strip seal element can be installed in one piece across the deck, making it a leakproof installation.

Field Installation of Strip Seal Element

Figure 5 shows field installation of the strip seal element after all construction work is complete. This is accomplished by using a tool shaped like a tire iron, which rotates the locking lugs of the gland into their mating receptacles. This is an important feature of a sealing system because replacement of damaged glands could become necessary in case of fire or vandalism.

Skewed Joint Movements With Strip Sealing Systems

Strip sealing systems offer good performance for even the most extreme angles of skewed joints. Many hundreds of installations of strip sealing systems are now operating

Figure 1. Typical mechanical locking of the seal element.

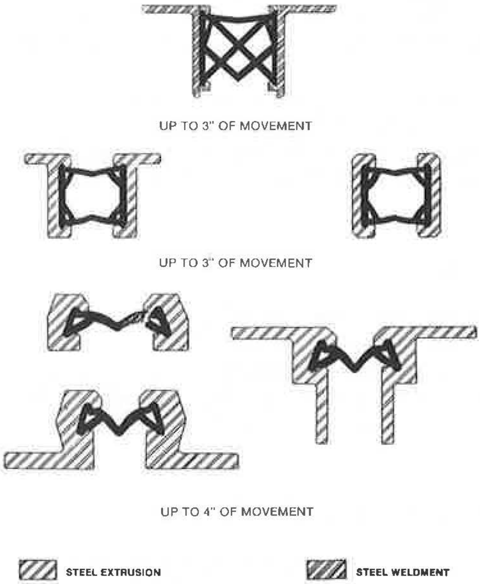


Figure 2. Seam-welded steel extrusion replacing old finger joint.

Figure 3. Installing strip seal element in one piece, a lane at a time, for 100 percent leakproofing.

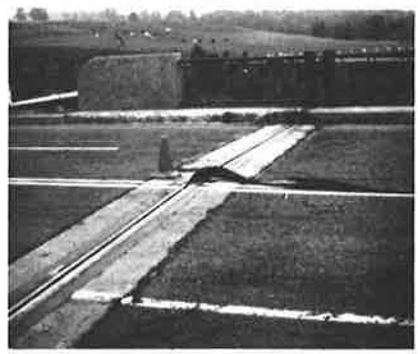


Figure 4. Bolting strip seal armor to bridge deck.

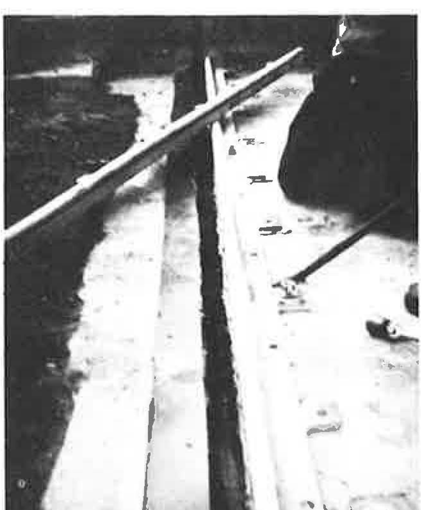


Figure 5. Field installation of strip seal gland.

successfully in service on new and rehabilitated bridge decks around the world—Germany, France, Holland, Belgium, England, Austria, Africa, portions of the new Bosporous Bridge in Turkey, as well as a number of installations in Canada and, more recently, in the United States.

As an example of the low forces attainable in a skew, at an angle of 45 deg, tests show the ability to absorb ±1 to 1½ in. (25 to 38 mm) vertically to its axis and ±1 to 1½ in. in the direction of its axis. The shear force occurring in the longitudinal direction of the seal at a deformation of 1³⁄₁₆ in. (30 mm) will be 235 lb/ft (3.33 kN/m).

Differential Height Problems at Opposing Interfaces

There are occasions where opposing interfaces are constructed at different times and under differing conditions of vertical load, creep, time-dependent variations in crown, etc., that could result in an unpredictable difference in height (Figure 6). The strip seal system, with the seal element capable of being installed at any time, coupled with very low working stress, is an ideal solution for sealing problems of this type.

Interchangeability of Strip Seal Elements for Unanticipated Movement

Should unanticipated permanent movements occur in a bridge structure far in excess of design calculation, one merely has to change the size of a strip sealing gland. This not-too-infrequent problem, whose principal cause is excessive creep-shrink in post-tensioned structures, has often been solved with strip seals in this manner by using the next-larger gland.

A NEW ARMORED RUBBER CUSHION SEALING SYSTEM

Confirming the necessity for armor-plating of rubber surfaces that will be subject to traffic loadings is the newest design of low-stress gland-type rubber cushion sealing shown in Figure 7. Significant features of this design are

1. A one-piece sealing gland that extends the full width across the joint, compared to conventional 4-ft (1.22-m) lengths;
2. A low-cost, replaceable sealing gland;
3. Movement ranges up to 3 in. (76 mm);
4. Total armoring of the rubber cushion; and
5. A very low cyclic stress transmission to the structure.

New Low-Profile Mechanically Locked System

Figure 8 shows a compartmented, mechanically locked seal element with a low profile specifically designed for low height requirements such as are necessary for overlaying old existing bridge decks.

The system, when subjected to an extreme movement test, does not pull out of engagement at 7 in. (178 mm) of elongation (Figure 9).

Very low forces are transmitted to the structure using low-profile seal elements compared to most heavy-duty bridge compression seals.

PROTECTION AGAINST SNOWPLOWS, STUDDED TIRES, AND OTHER WINTER MAINTENANCE CONDITIONS

Lowering the System Below the Riding Surface

Typical examples of snowplow, studded tire, and tire chain winter damage are shown

Figure 6. Strip seal system has capability of accepting extreme changes in interfacial elevation.

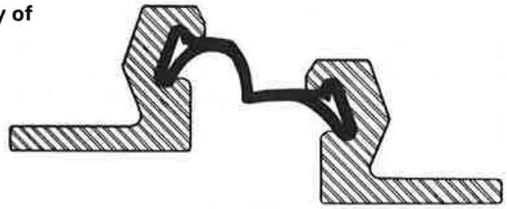


Figure 7. Armored rubber cushion sealing system.

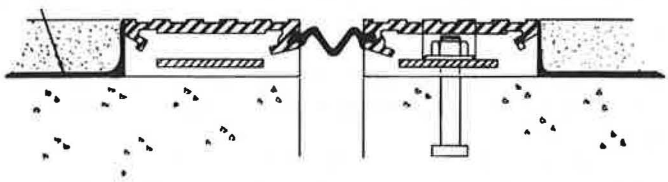


Figure 8. Low-profile mechanically locked sealing element.

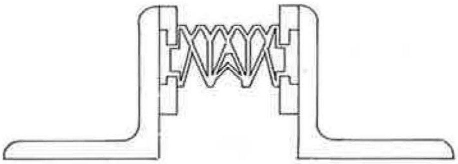


Figure 9. Low-profile system subjected to extreme elongation.

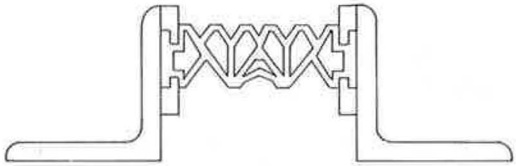


Figure 10. Damage to seals incurred during winter conditions.

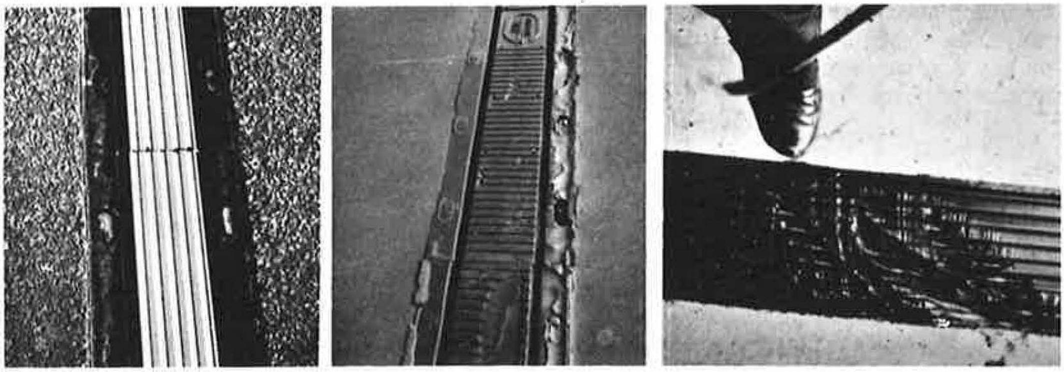
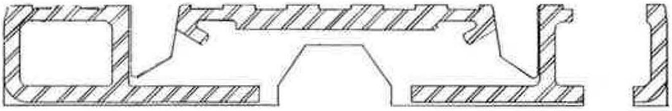


Figure 11. New fully armored rubber cushion system offers 100 percent protection of neoprene against snowplows and studded tires.



in Figure 10. The normal wearing away of the asphalt riding surface adjacent to the expansion joint exposes the edges of the jointing system to the damaging effects of plows, and synthetic rubber at low temperatures is highly susceptible to attrition. Because of this, rubber cushions lacking snowplow protection should be installed below the riding surface to anticipate this time-dependent change in elevation.

Protecting or Armoring of the Rubber Cushion

Most manufacturers of rubber cushion sealing systems are alert to the problems of winter damage, and a number of methods of incorporating snowplow protection are now becoming available. Since there are few environments in North America where snow is not encountered at least occasionally, it appears that it would be good business judgment for all of these systems to encompass at least some snowplow protection in their design.

Figure 11 shows a new design using armor to protect the center portion of the neoprene, which at low temperatures takes on the consistency of brick cheese insofar as its resistance to attrition is concerned. Its entire wearing surface is protected by the addition of a high-strength, corrosion-resistant aluminum extrusion that serves as both a wear plate and a fastening component.

IMPROVEMENTS IN THE RUBBER CUSHION SEALING CONCEPT

The use of molded rubber cushion expansion joints, various types of which have existed for the past 30 years, has been greatly impeded and their general acceptance by bridge engineers around the world discouraged to a large degree by the difficult problem of their high incidence of leaking, particularly at the curb and gutter area.

Most designs of molded sections, by reason of conventional practical rubber production techniques, are restricted to sections 4 to 6 ft (1.2 to 1.8 m) long. Furthermore, there are probably no 2 curb and gutter configurations that incorporate the same design on any 2 adjacent bridges. As a result, there are a great many leaking rubber cushion expansion joint systems.

Prefabricating Curbs by Means of Welding

Advances in design of curb and gutter treatments are shown in Figures 12 and 13, where the units are joined by a series of welded connections.

The appropriate solution is detailed by shop drawings, then factory prefabricated by means of miter cutting and welding them together to fit the exact contours of the curb. Figure 13 shows a factory-prefabricated unit incorporating 3 vertical and horizontal bends.

Greatly Reduced Cyclic Stresses in New Designs of Rubber Cushion Systems

The new rubber cushions shown in Figure 14 have been intentionally redesigned to achieve the lowest possible cyclic working stress attainable in keeping with good structural design. Tests have validated that the forces at full tension-compression have now been lowered to approximately 500 lb per linear foot (7297 N/m), a highly desirable reduction from earlier designs of these rubber cushion systems for this 4-in. (102-mm) range of movement.

Ideally, a sealing system should transmit zero stress to the structure, since the designer of a bridge often has no control over the selection of the device to be used on

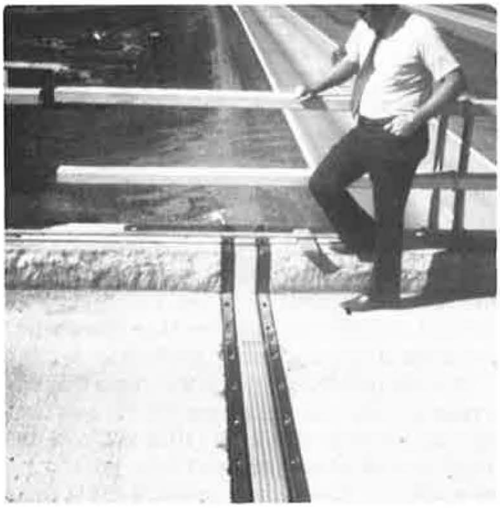


Figure 12. Completed installation of factory-prefabricated curb section.

Figure 13. Factory-prefabricated unit incorporating vertical and horizontal bends.

Figure 14. Improved rubber cushion system incorporating low cyclic stress.

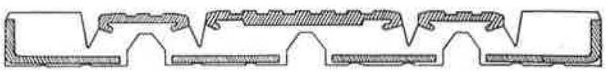


Figure 15. Urato Bay Bridge at Kochi, Japan, incorporates modular system at main-span joint.

Figure 16. Urato Bay Bridge 4-tube system located at midspan for 10.4-in. (264-mm) movements.

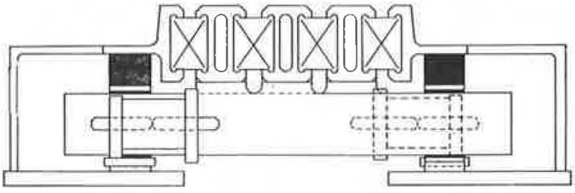
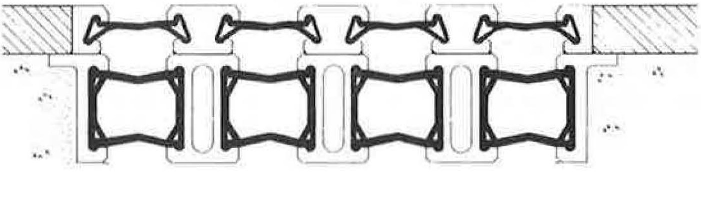


Figure 17. Using strip seal component to elevate existing systems for new overlay.



the bridge. Systems that produce very high cyclic stress can be harmful to the structure, and therefore the designer should be aware of the availability of armored rubber cushion systems in the larger movement category of 4 in. (102 mm) and over that incorporate this most desirable stress reduction.

IMPROVEMENTS IN MODULAR SEALING SYSTEMS FOR LONG-SPAN POST-TENSIONED BRIDGES

The use of improved modular systems as a solution for accommodating large movements and rotation between the span ends on very long, free-standing, post-tensioned concrete box-girder bridges has begun to attract the attention of bridge designers.

The recently completed record-shattering 754.5-ft (229.97-m) box-girder span soaring over Urato Bay in southern Japan (Figure 15) incorporates in the juncture of the 2 cantilevered sections at midspan an expansion jointing system like that shown in Figure 16. This system permits horizontal movement along the axis, providing for the expansion and contraction plus concrete creep. It also positively permits shear movements and rotations and maintains very low friction sliding values since PTFE to stainless steel sliding surfaces under permanent precompression of 4 kips (17.8 kN) are incorporated in the spring-loaded mechanism at each end of every support bar joist.

Some designers have previously used drop-in spans or continuous prestressing in the center. However, an expansion joint system of this type permits the superstructure to accommodate all types of movements, thus eliminating the need for complicated and expensive bearing devices over the main piers. It also results in no moment at midspan, thus making the structure as light as possible.

In view of the success of the design of Urato Bay Bridge, it is the opinion of the writer that span lengths can go much further, possibly 1,000 to 1,500 ft (300 to 450 m), assuming the inevitable development of the durable lightweight concrete that will be necessary to their becoming economically and technically feasible. Urato Bay Bridge utilized conventional concrete, with only 10 percent of the design load over the main piers being live load. Reducing the dead load would substantially cut the amount of material and greatly simplify the design of these attractive and welcome longer spans.

Adjusting the System for New Overlay Requirements

With so many thousands of modular systems being placed in service during the past decade and their obvious ability to outlast not only the deck surfacing but the deck itself, there is often a requirement to raise the system to accommodate the height of a new concrete or asphalt overlay.

Figure 17 shows the method of superimposing small steel extrusions on top of the original separation and edge beams by means of welding and installing strip seal extrusions over the existing tubular seal elements. This can be done very inexpensively and quickly, 1 lane at a time, using standard strip seals. The steel extrusions can be simply and securely fastened a lane at a time under heavy traffic, followed by the installation of the strip seal in the same manner. The writer cannot envision a situation where material and labor could be more effectively used to produce such an ideal solution as is available in the method shown in Figure 17.

Provisions for Future Widening of the Bridge Deck

Increasing traffic often dictates that existing in-service bridges be extended or widened. Provision should be made in the basic design of expansion jointing systems for this future possibility.

The hollow steel separation beams that are components in these improved systems lend themselves nicely to tying together in a lane-at-a-time manner, with the incorporation of steel dowels making a rugged splicing tie between the opposing members

Figure 18. Splice components.

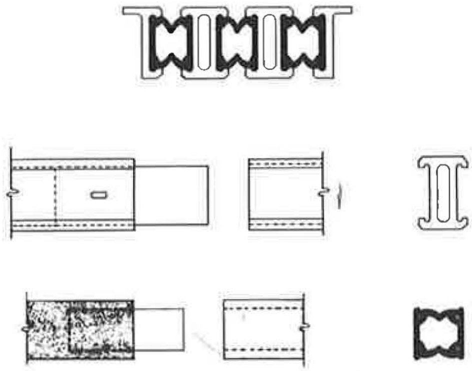


Figure 19. Sliding spring and bearings in normal position under precompression.

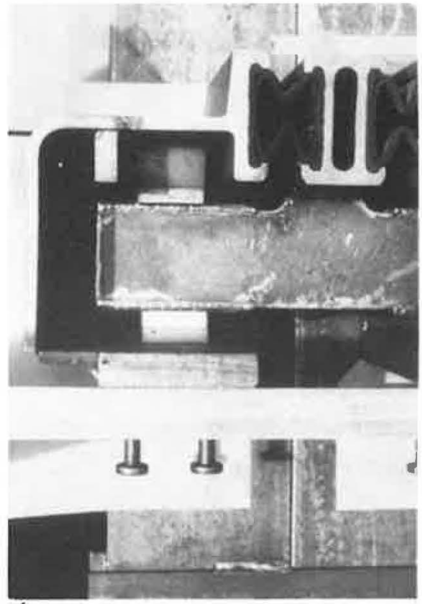


Figure 20. Spring-bearing mechanism performing satisfactorily under rotation.

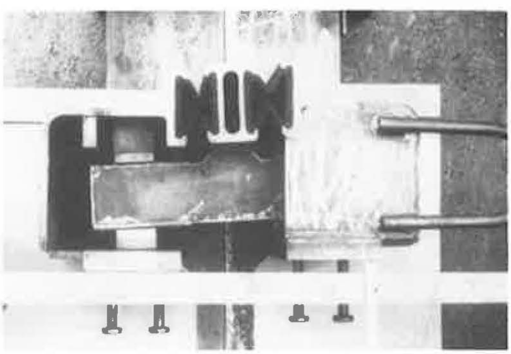


Figure 21. Unusually curved joint in Cologne-Bonn Airport upper departure level structure sealed with single-tube system.

Figure 22. Old seal element.

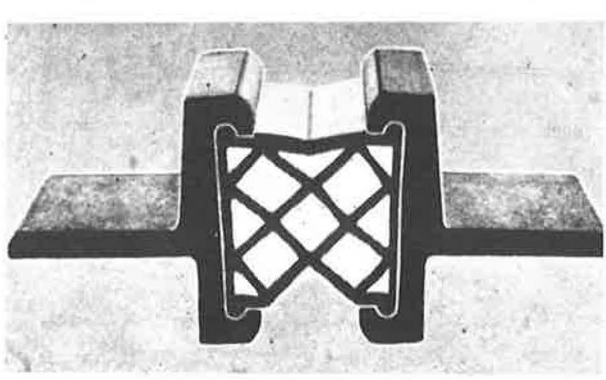


Figure 23. Improved seal element.

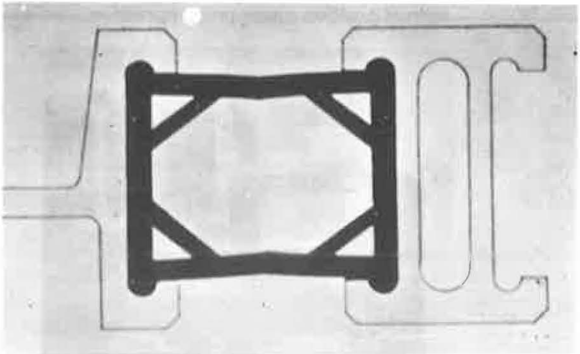
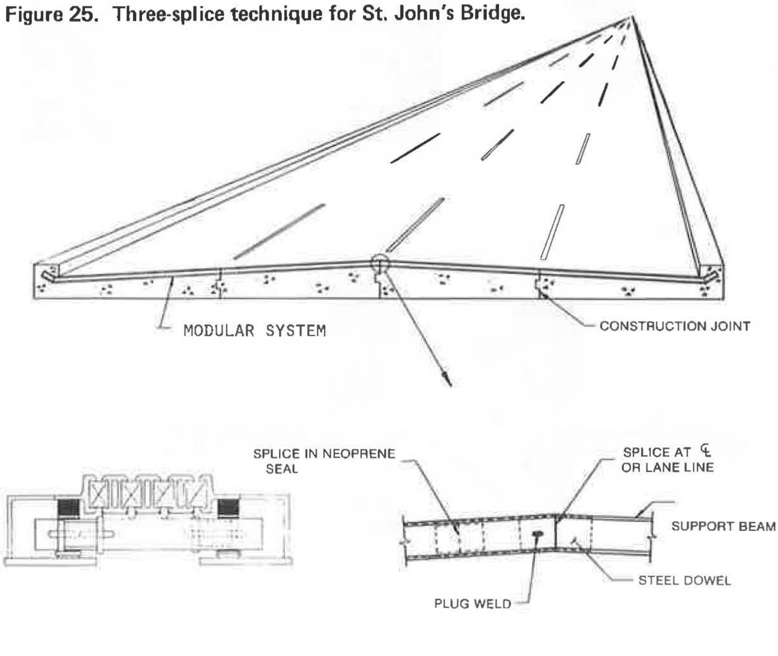


Figure 24. St. John's Bridge in Portland, Oregon, received new expansion joints.

Figure 25. Three-splice technique for St. John's Bridge.



(Figure 18). The seal elements can either be removed and replaced with longer lengths to be continuous across the deck or they can be effectively spliced by vulcanizing.

Rotational Capability

The new longer span, thinner, and more elastically responsive structures coming off the drawing boards of the current generation of bridge designers have posed a challenge to expansion joint designers. Because of this design trend, the ability to withstand extreme rotation of the span ends is a must. This capability is incorporated in a sliding urethane spring-bearing mechanism located at either end of the support bar joists, as shown in a test situation in Figures 19 and 20.

Figure 19 shows the sliding spring in 4 kips (17.8 kN) of compression at the top of the support joist and the sliding bearing in normal support position underneath. It can be seen from the type of test in Figure 20 that the flexibility of the spring-bearing arrangement easily accepts the shifts in forces without losing contact and in a manner that is in no way deterimental to the performance of the system.

Unusually Curved Joints Can Be Effectively Sealed

A typical example of the excellent lateral design flexibility of these systems is a severely curved joint that reverses its direction at the ends of 2 spans of the upper-level structure of the Cologne-Bonn airport (Figure 21). The spans were post-tensioned, and because of structural economics this unusual joint configuration was the best possible solution, all things being considered.

At an early period in its design life, a webbed seal element such as shown in Figure 22 was used. However, the very high working stress in the seal under full compression, high force transmission to the structure, and actual extrusion of the seal in some cases during full joint closure resulted in switching over to a relatively hollow seal (Figure 23). The need for internal webbing is no longer present when a mechanically locked seal is used and is, in fact, a deterrent to the service life of the seal element.

Typical Rehabilitation of Venerable Old Structure

The majestic and colorful St. John's Bridge in Portland, Oregon (Figure 24), designed by the late D. B. Steinman and opened to traffic over 40 years ago, recently had its old finger expansion joints removed and replaced with systems that incorporate a movement capacity of up to 10.4 in. (264 mm). The passage of time and increasing traffic loads had taken their toll to the point that county engineers made the decision to extend its service life by incorporating sound, maintenance-free expansion joint practices.

Because of heavy traffic, a design requirement was that the system be installed in lane-at-a-time widths (Figure 25), which complicated the reconstruction but was an absolute necessity. Connection details have now been engineered that will make the finished system perform similarly to a single-length assemblage.