Joint Sealing Practice for Longer Spans

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A foreseeable trend to longer span bridges together with the realization that there is a definite, causal relationship between certain identifiable types of premature bridge distress and ineffective sealing practices has led to the recent development and use of a number of interesting new sealing systems using the compression principle.

A photographic study of premature bridge distress has been accomplished in an attempt to better understand what is happening and what can be done to eliminate or at least minimize the problem.

A performance criterion for a sealing system has been established to assist bridge design engineers in the selection of an effective sealing system from the available candidates.

Typical sources and categories of movement phenomena on bridges are described and their importance underscored in long-span joint sealing practice. It is the responsibility of the design engineer to identify, describe and predict the magnitude of each of the types of movement that might occur at the joint interfaces on the structure.

Examples of current sealing systems and solutions in the United States and Europe are illustrated and discussed in terms of their performance capabilities.

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Recent comprehensive field tests in a number of countries have given an indication that in the light of present knowledge, we must face the fact that the poured-in-place mastics, thermoplastics and exotic field molded sealants do not have a sufficient performance capability for even the shortest spans. Indeed, they may have no place at all on a bridge regardless of length. The bridge sealing problem even in its simplest form is a complex one and is further complicated by the uniqueness of each structure so that no two structures have exactly the same performance need. Recently, responsible producers of field molded sealants have issued definitive literature restricting the use of these materials to only the very shortest of spans and for all practical purposes have eliminated their use on bridges.

Since few bridge designers would agree to the feasibility of standardizing the design of all bridges for reasons of economy, environment, aesthetics and a multiplicity of regional or local factors, we must recognize that insofar as the sealing problem is concerned, each bridge joint must be considered separately and its performance need rated according to the design of each structure.

In the past, much bridge construction consisted of spans of short length, such as 50 ft or less, whereas today, bridge design engineers are stretching out the lengths of many bridges to longer spans as design and construction techniques have been improved. It is difficult to find a common description of the difference between a short and long span other than a short-span bridge is one in which the live load governs the design, whereas a long-span bridge is one in which the dead load governs.

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Figure 1. Aesthetics problem: staining and discoloration.

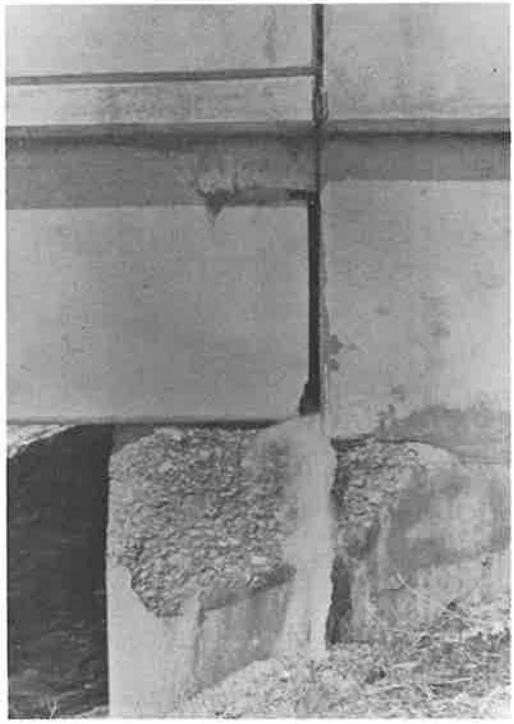

Figure 2. Typical salt brine deterioration of a bearing shelf with ice stalagmite illustrating hydraulics of freeze-thaw.

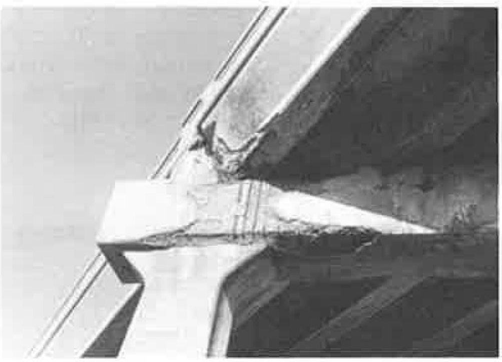

Figure 3. Typical salt brine deterioration of pier cap or bent with advanced corrosion of reinforcing bars; products of corrosion require 5 to 10 times as much space as original steel cross section with resultant popout.

Since the joint sealing problem is primarily concerned with arriving at a series of solutions to accommodate a wide spectrum of movement phenomena, for the purpose of this discussion, we will consider that a long-span bridge is one in which the longitudinal distance change between the deck slab ends, from pole to pole of movement, will exceed one inch.

DESCRIPTION OF THE PROBLEM

While it could appear to be elementary for a group of practicing engineers to review the categories of typical premature bridge distress, it may be well to have agreement on, or an understanding of, the problem if we are to expect any agreement on a given solution.

It is anticipated that much of the expensive maintenance cost of premature bridge distress related to ineffective joint sealing could be eliminated or certainly minimized if joints could only be sealed with some permanency. While the accompanying photographs show typical maintenance problems on bridges, it is recognized that environmental differences will place emphasis on certain types of distress being a serious problem in one geographic area that are not a cause for concern in another. Typical of this would be the salt brine deterioration of pier caps. Caution is to be observed however in generalizing that relatively balmy or mild climates would minimize the salt brine deterioration problem as compared to far northern environments inasmuch

Figure 4. Erosion attributed to salt brine and vibration from traffic loading.

as there now exists relatively new documentation which attests that this deterioration can be more severe in areas where there are more cycles of freeze-thaw. It may be that the salt brine deterioration of pier cap problems could be more severe in Virginia, Kentucky, Kansas, Missouri and similar latitudes than it is in Connecticut, New York, Michigan, Minnesota and Canada. To generalize, bridge joint distress may be considered to differ in type from one environment to another, rather than in severity.

Figure 5. Erosion with resulting traffic hazard attributed to concentrated attack of brine at the joints.

Figure 6. Corrosion of steel beam ends and bearings; balance of structure is unaffected.

Figure 7. Concentrations of stress at the curb line.

EXAMPLES OF TYPICAL PREMATURE BRIDGE DISTRESS CAUSALLY RELATED TO THE SEALING PROBLEM

In an attempt to better understand the cause and effect relationship between ineffective sealing practices and their effect on bridges and structures, a comprehensive photographic study of bridges was undertaken in the United States, Canada and a number of other countries which has given evidence that certain common categories of premature distress are widespread.

The photographs attempt to categorize the types of premature distress that can occur when the preformance capability of a sealant is exceeded (Figs. 1-13).

Figure 8. Crushing due to intrusion of high friction material.

Figure 9. A continuous span with a sliding plate joint is susceptible to crushing and stress concentrations at the curb line.

Figure 10. Evidence of stress relief attributable to pressure buildup from entry of foreign materials at midpoint of a bent.

Figure 11. Pressure generation from intrusion of foreign materials; loss of backwall support contributes to premature splitting—continuous spans can be more susceptible to this category of distress.

Figure 12. Pressure generation—wingwall is rotated 10 degrees to the left of center; on very warm days, wingwall rotates as much as 15 deg.

Figure 13. Pressure generation on a skewed joint—an older structure has been forced 12 in. out of alignment.

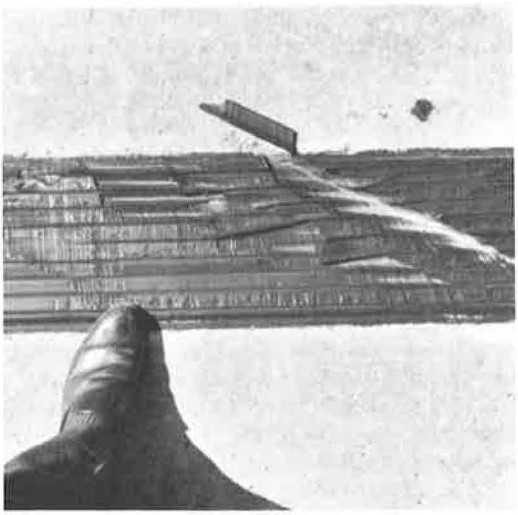

Figure 14. Typical attrition of an elastomeric surface under traffic, snowplows, stones, gravel, grit, and laitance.

PERFORMANCE CRITERIA FOR A SEALING SYSTEM ON LONGER SPANS

In light of the aforementioned typical bridge distress, it is considered that an effective joint sealing system must be equivalent to the following performance criteria:

1. It must have the capability to respond successfully to the many different types of movement that might occur on a specific bridge: straight distance change between the joint interfaces, racking distortion from the many variations of skews, horizontal, angular, vertical and articulating motion patterns, differential vibrations of slab ends, impact, warping and rotation effects, permanent changes in deck length, creep, plastic flow, etc.
2. It must have the capability of responding to the individual magnitudes of the various movements both singularly and when acting in concert.
3. It must seal out the entry of incompressibles, compressibles and all types of foreign material with a restraint producing potential, and guarantee that bearing seats, shelves, pier caps, bents, do not receive accumulations of these materials together with chemicals deleterious to steel and concrete's performance life.
4. It must seal out the entry of free water in a leakproof manner and assist in channelizing the water into the drainage system of the structure.
5. It must be capable of absorbing the various types and ranges of movement within itself without being extruded above or expelled from the joint opening.
6. With respect to the riding surface of the sealing system, it must be constructed of materials which have a capability to withstand wear and impact such as is produced from forces of repetitive and heavy traffic loadings coupled with ice, snow, slush, maintenance materials and incompressibles, the forces of abrasion from snowplow blades at low temperatures, and abrasive effects of sand, silt, small stones, gravel, grit, and laitance. Figure 14 shows typical attrition of an elastomeric riding surface.
7. It must be capable of performance in extremes of temperatures for the environments of each particular structure. Bridges in Alaska encounter -70 F, whereas bridges in the southwestern United States can build up deck temperatures of 150 F.
8. The sealing system must be constructed of materials that have a long outdoor service capability. All materials used must be relatively unaffected by sunlight, ozone, petroleum products, chlorides, deleterious chemicals from industrial smog, mainte-

nance chemicals, and cement alkalis, as well as tensile and compressive stress of long-term duration.

9. The surface of the sealing system should have provision for skid resistance if the device is of a longitudinal width greater than 8 in.

10. The sealing system should be easily capable of inspection and maintenance and have provision for adjustments to take into account one-time or permanent changes in the bridge deck length (positive or negative creep) as well as movements from pavement pressures, settling of abutments or other similar forces commonly brought to bear against decks and abutments.

11. The sealing system should allow relatively unrestricted movement of the bridge to relieve stresses due to temperature, creep, shrinkage and loading unless the bridge is designed to accept these categories of stress. Should a device produce excessive stress, it could be capable of ejecting a bridge from its bearing points or produce other undesirable forms of stress relief.

12. It should have a service life at least equal to the life of the deck surfacing and ideally to the life of the bridge. Short-lived sealing solutions should have provision for simple and easy replacement with minimal cost.

13. The sealing system should have good riding qualities and generate neither noise nor vibration due to traffic.

14. Wherein the joint opening exceeds 4 in. at the widest point of opening, the sealing system should provide adequate structural support for traffic loadings that are not subject to rapid attrition or wear.

15. The sealing system must be equally effective at the juncture of the pavement and curb, this being the critical area for sealing of the bridge.

16. The sealing system should be free of breaks or field joints within the line of a given joint. Where sections of elastomeric tubes are fabricated in pieces shorter than the actual length required, they should be factory vulcanized (Fig. 15).

DETERMINATION OF THE TYPE AND MAGNITUDE OF MOVEMENTS

With respect to solving the joint sealing problem, bridge design engineers must be able to make the following judgments:

1. Identify and describe the different types of important movement phenomena that will occur.
2. Predict with reliability the magnitude of each type of movement.
3. Insofar as progressively closing or opening joints are concerned, predict when this phenomenon will occur in the life of the structure.

Figure 15. Typical compression seal 180 ft long weighing approximately 1000 lb, free of any field fabricated joints.

SOURCES AND CATEGORIES OF MOVEMENT ON BRIDGES

Typical sources or categories of joint movement that occur on bridges and structures are as follows:

1. Straight thermal movement (longitudinal distance change between adjacent slab ends or joint interfaces). The current AASHO Guide Specifications suggest that we design in terms of $\frac{1}{8}$ in. of movement for each 10 ft of deck or span length in a temperature gap of 100 deg.
2. Racking movements of skewed joints (this pehnomenon obviously differs in complexity with each varying angle of skew).

3. Progressively closing joint openings.
4. Progressively opening joints.
5. Progressively decreasing stroke of joint movement.
6. Progressively increasing stroke of joint movement.
7. Vibratory movement from heavy traffic loadings, military vehicles, snowplow impact, etc.
8. Positive or negative creep: (a) viscoelastic flow, (b) drying shrinkage, and (c) grower aggregates.
9. Warping of slab ends from temperature differentials within slabs or structural members, orthotropic surface plates and subframing, etc.
10. Slab end rotation: (a) temporary rotation such as from heavy traffic loading at midspan, and (b) permanent rotation from progressive increase in dead load deflection.
11. Unloading of movement from one end of a deck slab to the other due to mechanical restraints such as frozen bearings and excessive friction.
12. Dual movements of different categories resulting from changes in direction in the line of a joint or from vertical to horizontal or a combination of both (skew joints changing direction at the curb).
13. Cross joints and variations of T junctures with their peculiar movements and stresses.
14. Vertical deflection movements at joint interfaces from loading cantilevered slab ends.
15. Articulating movement.
16. For longitudinal joints between adjacent structures, differential racking movement should be anticipated. In addition, differential vibration when one span is being loaded with traffic while the other is not, should be taken into account (Fig. 16).
17. Zero movement phenomenon. Evidence exists suggesting that certain compounds of elastomers and polysulfides can be relatively short lived if there is little or no movement involved in the exposure.

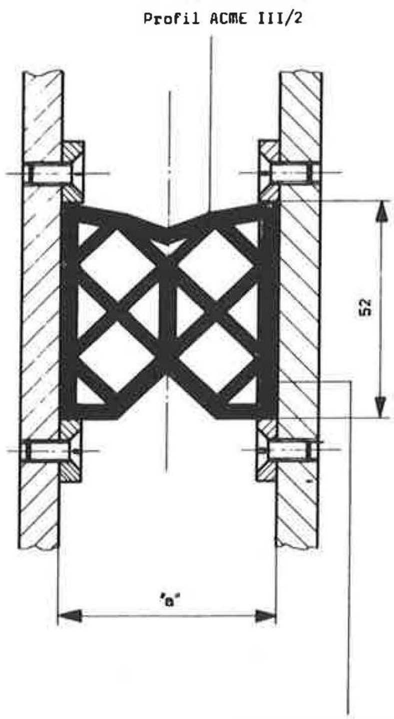

Figure 16. Swiss-German compression seal utilizing 5 mm of Teflon bonded to the elastomer and 5 mm of Teflon bonded to the steel interface of a longitudinal joint. Stops are affixed to top and bottom to resist floating or migration. Used to accommodate distance change between interfaces, differential longitudinal movement and severe vibration from traffic loading on longer spans.

While the above list covers may of the major sources and categories of movement found on bridges and structures, it is not construed to be all-inclusive. Environmental conditions in specific bridge locations should be thoroughly evaluated to search out all of the factors that could produce erratic movement such as wind, sun, and chill.

Whether the movement at the joints is 1 in. such as the case might be in a simple 80-ft long span, 14 in. for each joint which is the case on the new Severn Bridge in England for a temperature gap of only 60 deg, 22 in. anticipated on the Port Mann Orthotropic Bridge in Vancouver, B.C., or 72 in. which was predicted for the new Forth Bridge in Scotland, the movement must be accounted for in the design of the jointing and sealing system with an additional provision for some margin of safety.

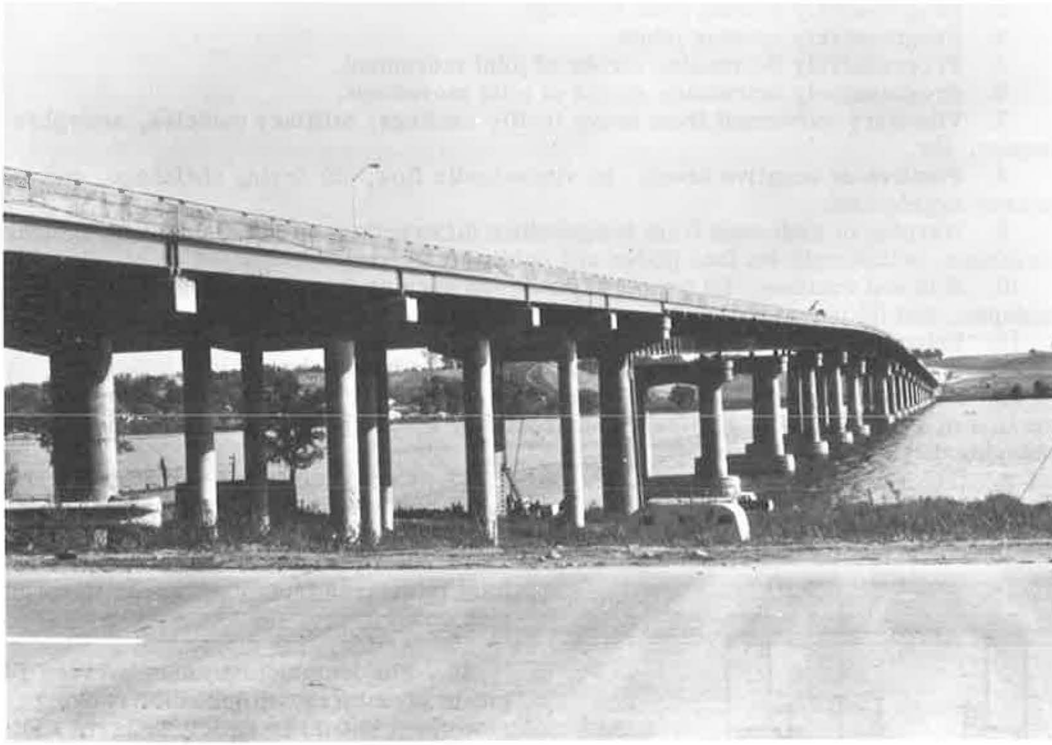

Figure 17. Leclair Bridge on I-80 over Mississippi River utilized 3-in. wide compression seals throughout.

Figure 18. Leclair Bridge—lubricating the joints and inserting the seals with a "pogo stick" inserter.

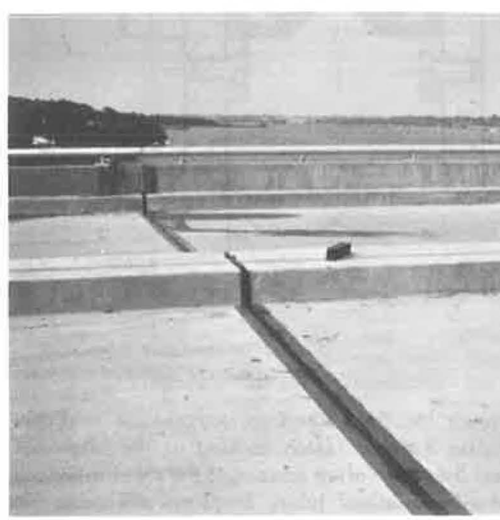

Figure 19. Leclair Bridge—seal is inserted in a single length free of breaks from outside balustrade through the deck, mall curb and to the other side.

Figure 20. Bernard F. Dickman Gateway Bridge (Poplar St.) at St. Louis. Orthotropic: weight of steel on main span, 13,000 tons; approximate cost of main span, $8 million; weight of one finger joint, 40 tons; approximate cost of finger joint, $25,000; movement at east joint, 11 in. (1365 ft); and movement at west joint, 8 in. (800 ft).

PRESENT PRACTICE FOR LONGER SPANS IN THE UNITED STATES

Monolithic tubular, compartmented, compression seals are being widely used on bridges and structures for small movements of from ½ in. to 3 in. (Figs. 17-19). Movements in excess of this would call for different practice. For most long-span bridge movement in excess of 3 in., slider plate and finger joints are being used with no attempt to seal these joints being made whatsoever (Figs 20-23).

Figure 21. Poplar St. Bridge under construction: finger joint at west abutment to handle 8 in. of movement—weight of finger joint approximately 40 tons; approximate cost, $250 per foot (100 ft wide). No attempt is made to seal joint.

JOINT SEALING PRACTICES FOR LONG SPANS

Obviously there are no fundamental differences in the sealing problem on bridges here or abroad assuming that the performance conditions are similar; however, in many countries, there are differences in general construction practices and policies that appear to affect the design or selection of a joint sealing system.

Construction is often accomplished by engineer-contractor type firms. A greater latitude in selection of the sealing system is enjoyed by the contractor who builds the bridge; however the legal responsibility

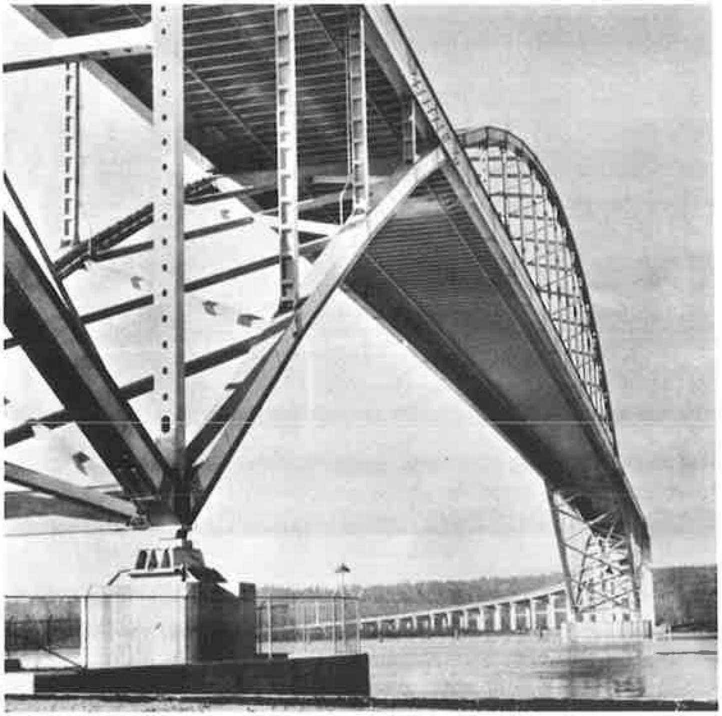

Figure 22. Port Mann Bridge, Vancouver, B.C. Orthotropic: weight of main and approach spans, 19,660 tons; length of continuous portion, 1920 ft; weight of expansion joint, 50 tons; approximate cost of expansion joint, $37,000.

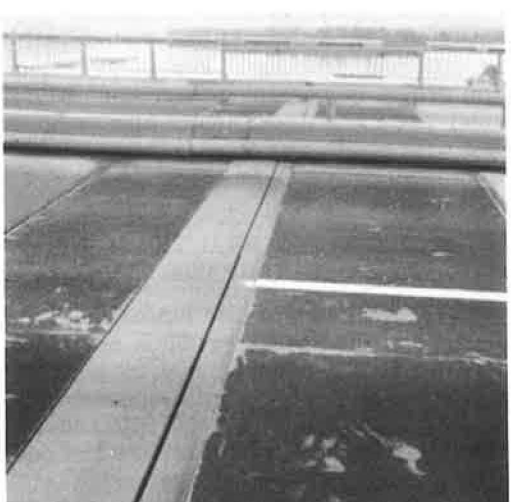

Figure 23. Port Mann Bridge: sliding plate joint of rolling link or chain type—anticipated movement, 22 in.; approximate cost, $700 per foot for a width of 54 ft. No attempt is made to seal the joint.

for maintenance of the joints is also mandatory. In many countries, the maintenance of joints is the contractor's responsibility for as much as 10 years.

European bridge designers have gone almost exclusively to continuous spans. The inevitable result is that they are left with only two joints—or on very long bridges—only a few joints, and so the sealing problem is magnified and must be dealt with in all of its accumulated magnitude.

There seems to be a generally accepted rule abroad that the individual joint openings regardless of how much movement is involved, must never exceed 50 mm (2 in.) at the widest time of opening. This in all likelihood is due to the relatively high percentage of bicycle traffic and greater amounts of small wheel diameter compact cars.

Permissible axle loadings seem to be somewhat higher and the tire diameters appear to be comparatively smaller than North American truck traffic. The dynamic effect of wheel impact on joint edges

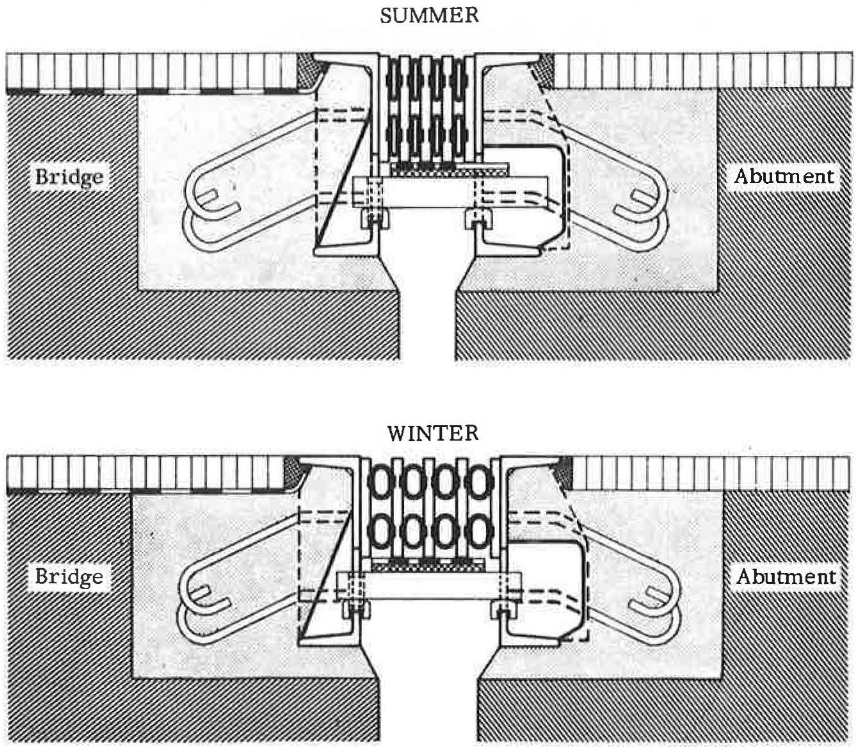

Figure 24. Stages of movement (80 mm)—System RUB.

is significantly greater and this is reflected by the rugged nature and thickness of steel cross sections on their armor-plated joint interface designs. This thickness is also justified by bridge designers as being necessary to absorb vibrations; it has a definite damping effect. Where bolts are used to hold sealing devices in place, the French place 7 tons of prestress per foot of joint, whereas the British suggest that not less than 12 tons per foot be applied. If armor plates are being held by supporting bars or lugs,

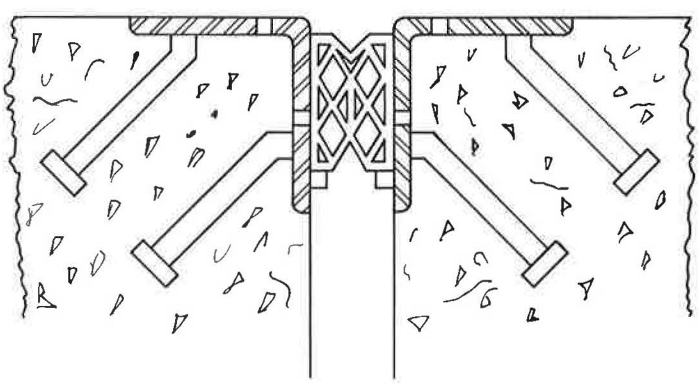

Figure 25. Sealing system for 1 to 2 in. of movement.

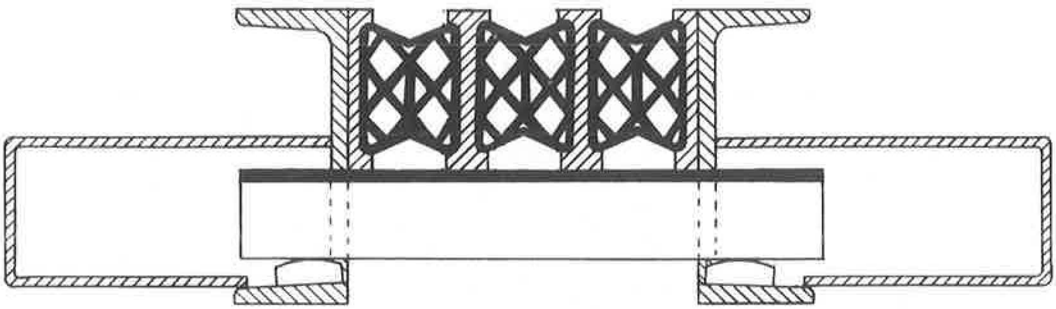

Figure 26. Sealing system for 4½ in. of movement.

they should be welded to the main reinforcement of the bridge and treated as a cantilever with no credit being taken for lug embedment.

It is an extreme rarity in Europe to see any serious attempt at sealing bridge joints without incorporating some rugged type of armor plating of the joint interfaces. The husky nature of these armor plating systems may give rise to question, but European designers attest to their absolute necessity for any permanency of joint sealing. It is felt that they can only seal with permanency where the interfaces have a long life expectancy.

It is the practice abroad to rate a sealing system's performance capability in terms of millimeters of movement while the American practice has been to talk in terms of percent of joint opening. It is suggested that the European system may be a more realistic one.

European designers think in terms of much greater design life than do Americans. German bridge designers have advised that they have an overall ultimate design life thinking in terms of 80 years of service. Obviously, many of the organic materials used in joint seals would be woefully inadequate in this respect but this is recogzined and when a sealing material or device is being considered by an engineer-contractor firm, its actual true performance life is taken into consideration.

The initial cost of joint sealing systems used in Europe today appears to be significantly greater than counterpart systems in North America. It may well be, however, that the cost over a 10-yr period of service is significantly cheaper. The European

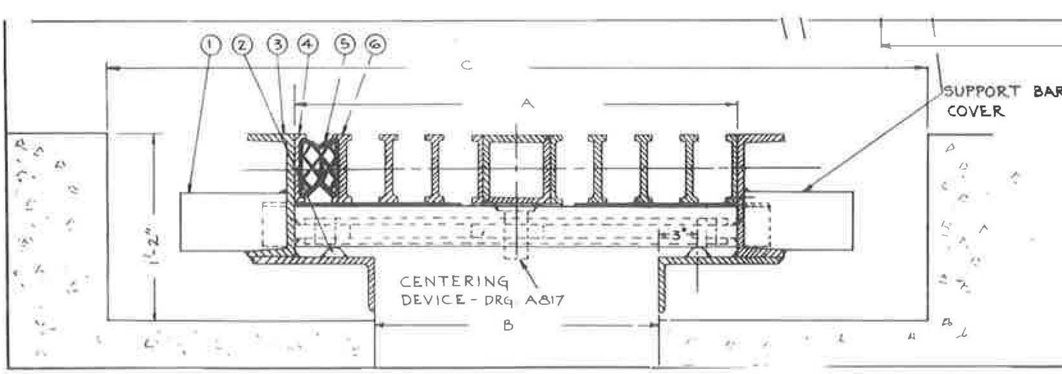

Figure 27. Modular sealing system for 12 in. of movement designed for Willamette River Bridge, Ore.

thinking is to build sophisticated, low maintenance, sealing systems of a predictable life initially, and so stretch out the maintenance-free life of the structure (Fig. 24).

TYPICAL AMERICAN SEALING PRACTICE FOR LONGER SPANS

In light of the previously established performance criteria for a joint sealing system on longer span bridges, some typical sealing solutions are shown in Figures 25 through 27.

Figure 25 illustrates a system which is now in widespread use throughout much of the United States, Canada and a number of other countries.

Figure 26 establishes a modular system by incorporating a series of standard seal configurations, each with a known movement capability. The appropriate number of seal cross sections are selected and separated by counter supported vertical steel plates to meet a performance need of $4\frac{1}{2}$ in., or whatever might be the requirement.

Figure 27 is a facsimile of a sealing system presently being used on a long-span bridge in Oregon with a movement prediction of 12 in. at each joint. While there would be no theoretical limit to the amount of movement that could be built into a sealing system, the above bridge sealing system is apparently the most versatile to date in the United States utilizing the principle of compression.