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A Half-Century of Involvement with Joints and Bearings and Some Lessons Learned

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From shortly before the entry of USA in World War II and to the present, I have been continuously involved in the design, testing, manufacturing and observation of the performance of joints of all types from pavements to bridges and bearings of all types from the old rockers to elastomeric, pot, disc and then to earthquake isolation concepts. Starting out with load transfer devices buried in concrete pavement joints for state highways and airfield pavements to field molded sealants and then compression seals, the design trend in pavements has been from longer 100 feet panels (30m) to relatively short panels of 15' (4.5m). This has greatly simplified the sealing problem since the distance changes between joint interfaces of shorter length panels obviously are much less in creep-shrink and thermal volume change.

With respect to bridges, the design trend has been reversed going from relatively short decks (40' (12m)) to longer and longer spans greatly complicating the sealing problem. It was in this confused design period that the writer worked towards developing sealing and bearing systems for every conceivable type pavement or bridge structure. Some lessons learned during the past 50 or more years, are the subject of this paper.

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INTRODUCTION

Sealing of Pavement Joints from 1945 - 1960

Most of the early attempts to seal 100' (30m) long pavement joint panels with field molded sealants of that era were a dismal failure. Variations of rubber and asphalt materials proved inadequate to handle the movements of the 78 foot long (23.8m) State of New Jersey pavement panels or the New York or Illinois 100 foot (30m) concrete slab length design. Other states incorporated slightly shorter length slabs in their pavement design, but the movement was just too much for the existing sealant compounds of that era to work effectively. During the late 1950's, the writer was asked to accompany an inspection team surveying the performance of various types of load transfer devices from one end to the other of the entire New York Thruway. It was astonishing to observe that not one single cement concrete pavement joint on the entire New York Thruway (100 foot panels - 30m) which incorporated field molded sealants of the rubber asphalt and polysulfide types was performing as intended in spite of the claims of manufacturers for 200% - 400% elongation as defined in ASTM and Federal specifications. It was this eye opening experience in 1955 which laid the groundwork for the introduction of the preformed neoprene compression seal.

Experiments with the Compression Principal - 1958 - 1960

The writer and Thomas Bowman, after considerable experimentation with various formed in place sealants, attempted to include the compression principal into liquid applied sealants by developing a material that when poured into a typical joint, would quickly skin over and then begin a period of foaming which tended to place that material initially at least into compression. While the short term result was impressive, it was difficult to control the foaming action so that the sealant would mound up over the joint surface of the pavement. Later it developed that the resultant sealant plug was lacking in the necessary durometer and elongation properties for long term performance.

With the compression principal still in mind, we then began to experiment with various extruded rubber shapes such as round tubes, box shaped and chevron shaped tubes which finally evolved into a rectangular shape that included a cross braced internal web design, a recessed folding top and a pointed bottom that was necessary for insertion into the joint. In an attempt to use the finest rubber in the state of the art at the time, we decided upon Neoprene because of its proven outdoor performance properties most of which were in successful use in electrical power line construction.

The Fuller Road Test - 1960

In an attempt to confirm our laboratory and design thinking, five 12' (3.6m) long joints were installed in a cement concrete pavement of Fuller Road in Albany, New York by the writer and T.C. Bowman in the Fall of 1960 with these new experimental extruded compartmented neoprene extrusions. As a control, polysulfide sealants were used on the adjacent pavement lane so that a clear comparison of performance could be made. The neoprene seals were continued up through the right angle curb so that the performance at these directional changes could be observed as well.

Condition surveys, in the Spring of 1961, indicated a clear performance superiority of the neoprene seals over the polysulfides. The State of New York, faced with wholesale failures of field molded sealants all over the state, issued a directive that the neoprene compression seals could be substituted as an alternate to field molded sealants if the comparative costs were in their favor. The result was that contractors switched over to neoprene compression seals on an extensive basis.

Early Experience with Neoprene Seals - 1961 - 1962

In their first year of wholesale usage, a number of failures occurred primarily from the lack of quality in the neoprene extrusions since there existed no field proven specification. A number of rubber firms who had quickly addressed themselves to its manufacture neither cared nor had any conception of what constituted quality in a neoprene extrusion. To make things worse, no one at that time really knew what constituted quality in a neoprene compression seal.

In one case where 12 feet (3.6m) wide pavements were being constructed, the first lane in the summer and the second in late fall, it became apparent that the compression seals placed in the summer placed pavement became loose in the winter where as the seals placed in the cooler time of the year stayed in compression nicely during the winter. They were placed in 60' (18.3m) long pavement panels and the original joint width was 3/8" (10mm). 11/16" (17mm) wide seals were installed in these joints and it was observed that the pavements constructed in the hot summer exhibited a total joint width change of 3/8" to 1/2" (10mm to 13mm) which was a combination of high temperatures, shrink and thermal movement. The seals that came loose were replaced with wider 13/16" (20mm) seals and they worked well through that next winter season.

The lesson learned here has long been remembered by the writer particularly as these seals began to see use on concrete bridge decks later on, is that in the sealing of joints particularly on concrete structures, one must always be cognizant of the as placed temperature width of the joint opening.

The Del Mar By Pass Test - 1963

As the extruded neoprene seals began to completely take over the sealant needs of New York State, considerable static from the field molded sealant fraternity had such a sobering effect on research personnel of the New York State Department of Public Works, that to settle the argument once and for all, they began to organize one of the most comprehensive full scale tests of sealing systems in the history of highway construction.

In June of 1963, some 37 different types of pavement seals representing the products of 21 manufacturers were installed on the Del Mar Bypass near Albany, New York under the supervision of the New York State DOT Bureau of Physical Research. Only manufacturers were permitted to install their sealants and each sealing product was allotted 5 transverse contraction joints to seal. Every conceivable type of field molded polysulfide, polyurethane, cold poured rubber asphalt, hot poured rubber asphalt, latex with extender, adduct rubbers, liquid neoprene and tar based sealant together with preformed silicone, EPDM,

polyurethane foam and preformed compartmented neoprene seals in the state of the art was installed.

In 1961, 1963, 1964 and 1965 a series of interim reports were published by the New York State DOT Bureau of Physical Research all highly favorable to preformed compartmented neoprene seals. Then came a final report (1) in December of 1968 which concluded that after ten years of research and field experience with sealers "their investigation has revealed that preformed neoprene is the only sealer that preformed satisfactory for more than 3 years". The report indicated that while they had experienced some compression set in some of the seals, that it was attributed to the fact that too small of a seal was used and their pavement design for contraction joints was then modified to require a 5/8" (16mm) wide as constructed contraction joint and a 1-1/4 (32mm) wide compression seal. The Del Mar Bypass test was followed by tests in numerous other states and authorities such as Pennsylvania, Ohio, Michigan, Minnesota, North Dakota, Florida, Nebraska, Colorado and Kentucky with similar conclusions.

Bridge Compression Seals

In 1962, we had begun to bond two pavement sized compression seals side by side to obtain the greater width needed for bridge expansion joints and subsequently commenced to extrude them as one single extrusion. It then became known that bridge engineers who were also experiencing very high failure rates with field molded sealants began to see the wisdom of switching over to these large compression seals. The first bridge size compression seal was installed on a bridge near Albany, New York and the second on a bridge in New Jersey. Michigan followed and subsequently over a period of time, virtually every state in the union began their use as well as many Canadian Provinces. Of course different manufacturers began to enter in to and contend for this vast new market and inevitably early failures began to surface for a great variety of reasons but primarily due to premature compression set.

Ultimately a good preformed compression seal specification was arrived at primarily due to the efforts of the State of Minnesota DOT Research Department. The number of manufacturers levelled off with only a few capable of meeting this new rather difficult specification and the field performance significantly improved in terms of compression set resistance.

The lesson learned here was that all organic materials, when subjected to prolonged tension or compression, will be affected by a change in shape or compression set. The degree of deformation or compression set is a function of the severity and elongation of the tension or compression force which that device is subjected to. The originators of neoprene claimed that like a bearing pad in compression which has a demonstrated long life in service, that a neoprene seal would last just as long. What they did not know or understand at that time was that when a cross braced compartmented compression seal is squeezed in compression, its internal webs which supply the pressure are actually bent in tension and this was the root cause of many of the early field failures. Obviously, the quality of the rubber compound in the extrusion also played a part but the principle of a compression seal whose internal webs are bent in a tensile mode for long periods of time must face up to a relatively short service life.

Bayshore (2) of the State of Michigan Research Department then reported a measured loss in pressure for compression bridge seals of as much at 70% - 80% in just 2 years which for all time changed the predicted life of a compression seal to something less that we as its originators hoped it would be. Some researchers even today lay claim to its effectiveness under ideal conditions as ten years. Strangely enough, the remaining seals in the original 1960 Fuller Road were still performing effectively after a 30 year period of time.

The lesson learned here was that since all compression seals would incur compression set regardless of the quality of the vulcanizate, that it would be best to use a very high type of adhesive to install them rather than a lubricant adhesive which was then in wide use. Bridge compression seals are today installed with excellent adhesives which have tended to extend their performance life to some degree. Cerrating of the compression seal walls to improve their bond strength has also been resorted to by some manufacturers.

We made attempts to switch pavement compression seals over to higher type adhesives but since some members of the industry chose to continue on with lubricant type, it still prevails in use today.

Mechanically Locking of Compression Seals

With the knowledge that bridge compression seals in particular needed every possible chance to perform as a leak proof joint, we began to introduce mechanically locked seals as shown in Figure 1. This was a significant improvement over plain bridge compression seals but a bit more costly to fabricate so they did not catch on well in North America because some suppliers were still arguing that their particular vulcanizate was of such high quality that there was no need for mechanical locking.

Strip Seals

In early 1970, with the full realization that the compression principle of sealing joints on bridges tended to be short lived, the writer introduced to North America what today is known as strip sealing. Adapted from German thinking, the product of the mind of Waldemar Koster, the strip seal represented a marked departure from bridge compression sealing then in wide use as well as more economical methods. Steel extrusions were introduced which at that time were only available from hot press firms in Germany. The process was to heat a steel billet to white hot temperatures, dip it in powdered glass for lubrication and then force it through glass dies into the desired shape. Figure 2 illustrates the type of extrusions that we introduced into the market in the early 1970's. They caught on like wildfire and today they still virtually control the North American market after 20 years in wide usage.

There are however some serious problems with strip seals and one lesson learned here has to do with the difficulty in maintaining tolerance controls in the steel extrusions as well as tolerance controls in the neoprene rubber extrusions. The resultant problem was either a difficulty in installing the extrusions in the steel claws or what was much worse, a tendency to looseness with the neoprene rubber extrusions working free in field service. High performance adhesives were then introduced but this does not entirely solve the problem. Another problem is the ripping or cracking of the neoprene rubber extrusions in field service which is probably due to the stiffening of the rubber at lowered temperature. Also the very deep fold in the rubber extrusions which with 3" - 4" (75mm - 100mm) movement sealing glands comes close to 4" - 5" (100mm - 125mm) and tends to attract large quantities of incompressables which cannot be ejected. Ice buildup over the top at lowered temperatures tends to damage the seals under high speed repetitive truck loading.

Molded Elastomeric Rubber Cushion Systems - 1968 - 1980

From the period of about 1968 to 1980, molded elastomeric rubber cushion tension compression seals came into very wide usage. Originally introduced by the General Tire an Rubber Company, they became so overwhelmingly popular that many bridge engineers absolutely refused to consider the use of anything else.

The lesson learned here was that if you wanted to be in the bridge seal business in the 1970's, you had to come up with a rubber cushion of some type. Very strong patents had been obtained which made the entry of competition next to impossible without inviting a major patent law suit by a very large rubber firm.

The first and original rubber cushion device is illustrated in Figure 3. A second is shown in Figure 4 and these two systems dominated the bridge market for well over a decade however the introduction of a second type resulted in costly litigation which lasted for many years.

These devices worked fairly well structurally however very high stresses were at work during their tension and compression phase of movement. Bolts tended to work loose, these large moldings tended to delaminate from their imbedded metal plates and snow plows reeked havoc with them if they were even slightly exposed to traffic. The most serious problem was that they leaked badly at the juncture of each molding even though they were of tongue and groove design and installed under compression. The curb and gutter connections tended to leak very badly particularly on skewed joints and this problem, after it became fairly well known in the trade, tended to initiate their demise. However a great many of them were installed on North American bridges and some of them are still in service today.

The writer whose firm produced a rubber cushion joint attempted to encourage the rest of the industry involved to install a continuous sheet of rubber underneath the rubber cushions from curb to curb but to no avail. It remains a question still today with these rubber cushion devices which were so overwhelming popular for a decade or so, whether they would still be in use if the installation of a rubber sheet underneath would have solved their leaking problem.

Rubber Cushion Strip Seal Systems

The Felt Products Company in the late 1970's introduced a modified rubber cushion system which incorporated rubber end dams together with an integral rubber sealing gland that was bolted into place over a prepared blockout in the bridge deck. This system was installed in sections 4' (1.2m) long with end flaps at each end to end connection. Essentially the field problems were the same as the previously introduced rubber cushions such as snow plow damage, etc. Because of the relatively short lengths, they leaked profusely. The writer introduced two similar versions with molded lengths up to 10' (3m) to minimize the number of joints but even so, they leaked at the end to end connections.

The lesson learned here was that molded sections installed with relatively short pieces in the field all tend to leak regardless of the type of connection. The primary function of a bridge expansion joint is to prevent leaking of deleterious chlorides on to the substructural elements below and so all of the rubber cushion systems have since gone completely out of use because they failed to accomplish this fundamental task.

Movement Related Failure Modes

As our structures and spans have become thinner, lighter in cross section (hollow boxes as compared to massive sections), and the economies from post-tensioning have been realized, the old historical movement data accumulated by local bridge design offices is often inadequate and outdated. These new more modern designs no longer enjoy the safety factor of thermal inertia or thermal lag and the thinner members tend to permanently shorten in creep-shrink in a magnitude that has surprised many experienced bridge designers. In fact, some of our newest, most technically exciting bridge structures have experienced total rupture of the expansion joints that have literally been torn apart in less that 2 years service.

It must be remembered that temperature gradients within the mass of newly placed bridge members vary widely by as much as 50 degrees F (28 degrees C) due to hydration which is a function of type and amount of cement, thickness of cross section, temperature of mixing water, surrounding air and from insulation. Other factors such as overall geometry of the bridge cross section, latitude and altitude, orientation of the bridge axis with respect to the sun, time of day and season, cloudiness or turbidity of the atmosphere, diurnal variations in ambient temperature, wind speed, nature and color of deck surfaces with respect to solar radiation absorptivity, emissivity and surface convection coefficient, thermal and physical properties of the constituent materials in the bridge, thermal conductivity, specific heat and density, ad infinitum.

It would be next to impossible with such a variety of variables for the average designer of bridges to make any accurate value judgement so it behooves those charged with the care of public funds to utilize healthy movement safety factors. It is the writers considered judgement that the following movement provisions are in the safe range for North American structures based on a 100 degrees F (56 degrees C) range of temperature environments:

1/8" (3mm) of movement for each 10' (3m) of deck length for thermal. Add 100% for creep-shrink and other phenomena.

Movements Other Than Thermal

Rubber cushions and most other types of sealing systems are designed to take a given amount of movement after which they will fail. A great many bridge authorities tend to disregard this or fail to provide for long term movements other than thermal and the expansion joint supplier tends to be blamed for failures which many times are not completely his fault.

Your attention is called to the interesting work of Moulton entitled "Observations of Highway Bridge Movements and Their Effects on Joints and Bearings" reported to the 1983 Session of the U.S. Transportation Research Board (3). In a comprehensive measurement study of movements other than thermally induced, on hundreds of bridges throughout 39 states and 4 Canadian provinces, vertical and horizontal abutment displacements averaging from 3.7 to 6.9" (94mm to 175mm) were recorded (Figure 5, Table 1) which is enough to damage or destroy any concept of bearing or expansion joint. In Figure 5, Table 2 we see average vertical and horizontal pier movements being in the area of 2.5 to 5.1" (63 to 129mm), and while these extra movements over thermal resulted in a multiplicity of other failure mode phenomena, 34 actual cases of damage occurring to the bearings were recorded (Figure 5, Table 3).

If Professor Moulton's summary is valid, the present movement rating practices of those 39 states and 4 Canadian provinces studied should result in future damage to bearings in the magnitude of 17% of their bridges. Figure 5 illustrates the magnitude and causes of these movements and the lesson learned here by the writer which came rather late in his career would have saved a small fortune in replacing and rebuilding bridge expansion joints in service which were way under designed for the actual movements that came. These movements which added to the thermal coefficient, tore apart many mechanical expansion joints. Another lesson to be learned here based on Professor Moulton's findings is that rather husky extra movement potential, which unfortunately costs a lot more money, should be added to the thermal prediction for all bridge expansion joint requirements.

Aluminum Armored Expansion Jointing Systems for Smaller Movements

From the period 1975 to 1985, the use of aluminum as the structural component for bridge expansion joints came into wide usage. High strength aluminum manufactured to grade ASTM 6061-T6 or its equivalent was the material of choice by most manufacturers. Figure 6a and Figure 6b denote some of the configurations that were used. Normally neoprene extrusions were used however in some of the colder climates, natural rubber came into use. Some type of locking claw similar to steel armored strip seals would be used to fasten the rubber component to the aluminum extrusion.

While they looked good in the installation process, were light and easy to handle in the field, they somehow did not have the damping properties of steel and many of them came loose from their fastenings particularly if expansion bolts were used.

The crowning feature of aluminum was its apparent resistance to corrosion as compared to steel used in expansion joints. These aluminum extrusions were often treated with factory applied anodized coating which made them even more resistant to oxidizing effects.

One of the disadvantages of aluminum learned from use in the field was attributed to its coefficient of thermal expansion which is roughly three times that of concrete or steel. Figure 7 illustrates the problem which shows a rather substantial gap in the aluminum edge armor of an in service expansion joint. The two pieces of the aluminum extrusion were bonded in the concrete end to end to form the edge armor of the system. It is obvious however that the marked difference in the expansion coefficients of the concrete and aluminum resulted in this leaking crack at the very edge of the expansion jointing system. This crack was a working crack that allowed the penetration of deleterious chlorides into the deck ends and substructural components of the bridge which defeats the whole purpose of a sealed expansion joint.

The inherent disadvantages of at least some of these aluminum armored systems as compared to steel tended towards the declining use of aluminum for bridge expansion joints in USA so that today they are rarely used. The advantage of aluminum in corrosion resistance apparently could not overcome the much lower cost of galvanized or painted steel at least in the view of the various manufacturers who addressed themselves to the making of bridge expansion joints so that today, few if any aluminum expansion joints are being marketed.

<u>Aluminum Armored Expansion Jointing Systems for Larger Movements</u>

Larger movement aluminum expansion jointing systems came into being around the late 1970's and continued on for about a decade or so. The same advantages and disadvantages of aluminum armoring still prevailed as in the case of smaller movement aluminum armored systems. Figures 8 and 9 illustrate two popular aluminum modular systems.

The system in Figure 8 incorporated neoprene rubber extrusions that served as riding surfaces which exposed this rubber to very serious snow plow damage in service. It is also a demonstrated field problem for any rubber component subjected to heavy traffic as a wearing surface that there is inevitably a pattern of attrition that will occur in the heaviest traffic pattern as can be seen in Figures 10 and 11. Attrition to rubber is particularly noticeable in lower temperatures when the rubber stiffens. Many bridge decks are subjected to rather large