# THE MODULAR EXPANSION JOINT – UPDATE ON WHAT CAN TODAY BE EXPECTED OF IT

Gianni Moor, Thomas Spuler and Simon Hoffmann

**Biography: Gianni Moor**, born in 1968, received his civil engineering degree from the Swiss Institute of Technology in Zurich, Switzerland (ETHZ), and was later awarded an MBA degree by the Business School IESE (Barcelona, Spain). Today, he is Deputy General Manager and COO of Mageba Group, and CEO of Mageba USA.

**Thomas Spuler**, born in 1956, received his civil engineering degree from the Polytechnic of Brugg, Switzerland and is today CEO and Chairman of Mageba Group. He is a member of the European expert team for Road Bridge Expansion Joints (EOTA), and Chair of IABSE's Working Group 5 on bridge bearings and expansion joints.

**Simon Hoffmann**, born in 1972, received his civil engineering degree from the Technical University of Aachen, Germany, and PhD degree from BOKU University, Vienna, Austria. He is currently Technical Director of Mageba Group.

## ABSTRACT

The modular expansion joint can justifiably be considered the most versatile type of expansion joint available today, being widely used around the world to accommodate greater movements and rotations than other types. It is important that bridge engineers and owners are aware of what they can expect of a modern modular expansion joint, in order that they and their structures, and the structure's users, can be sure to benefit from the functionality and reliability they offer, and if appropriate, from the optional features now available. Armed

with such knowledge, and an updated understanding of what level of durability and testing that can (and should) be specified, expansion joint life-cycle performance and costs can be optimized, resulting in less maintenance and replacement effort, greatly reduced owner and operator costs, and less impact on bridge users and the environment.

**Keywords:** modular expansion joint; specification; features; benefits; durability; testing.

## INTRODUCTION

Bridge expansion joints are today subjected to greater demands than ever before, including higher traffic loading and greater tri-axial movements and rotations. Expansion joint technology must continually develop to keep pace with these increasing demands, and the expectations of bridge owners and operators that the life-cycle costs associated with expansion joints be always minimized – as should the traffic disruption caused during repair and replacement work. As expansion joint technology and manufacturer capabilities develop, bridge engineers and owners should be aware of what can be expected of a modern expansion joint, in order that they and their structures, and the structure's users, can be sure to benefit from the functionality and reliability they offer. With this awareness, and with an understanding of what level of durability and testing they can specify, engineers and owners can ensure that expansion joint life-cycle performance and costs are optimized, resulting in less maintenance and replacement effort, greatly reduced owner and operator costs, and less impact on bridge users and the environment.

This is illustrated below with reference to the modular expansion joint, which is widely used all around the world to accommodate greater overall movements and rotations than other types, and is thus arguably the most versatile type of expansion joint available today.

## THE TENSA-MODULAR EXPANSION JOINT

Modular expansion joints (**Fig. 1**) have a great deal to offer the designers and constructors of bridges everywhere, thanks to their ability to facilitate very large longitudinal movements and their great flexibility - no other type of joint can accommodate longitudinal movements of two meters or more while, where so designed, also facilitating movements in all directions and rotations about all axes. This has led to modular expansion joints being the preferred solution for many of the world's largest bridges in recent years, and to an increasing focus on performance standards and testing requirements for such joints by owners and engineers.

Modular expansion joints divide the total movement requirement of the superstructure among individual, smaller gaps. The gaps are separated by centerbeams, which create the driving surface and which are supported at regular intervals by support bars underneath.

The gaps are made watertight by means of rubber sealing profiles. *Tensa-Modular* is a modular expansion joint of the single support bar type (with every support bar supporting all centerbeams), with pre-stressed, free-sliding, bolted stirrup connections between centerbeams and support bars (see **Figures 2 to 4**). The support bars themselves are supported by a similar system in the joist boxes at each end. Rubber control springs, positioned in sets below the centerbeams, coordinate the movements of the centerbeams. This elastic system avoids constraint forces and reduces the effects of loading on the joint and on the main structure, extending the life of the entire system.

## SPECIAL MATERIALS AND OPTIONAL DESIGN FEATURES

In order to be able to optimally meet the widely varying needs of different structures, it should be possible to tailor a modern modular expansion joint to suit any particular set of demands and circumstances, with the selection of appropriate design features. A number of these, appropriate to the above-mentioned *Tensa-Modular* joint, are presented below.

## Materials

Of course, all materials used in the manufacture of a high-quality expansion joint should be of appropriately high quality and performance level. This is particularly true of the sliding materials that are used, typically paired with a stainless steel sliding partner, at each of the joint's sliding interfaces. PTFE is no longer the sliding material of choice in many cases, with modern UHMWPE alternatives such as *Robo-Slide* offering far greater strength and resistance to wear, and very often, lower friction[1]. Considering that an expansion joint's sliding materials are generally much more susceptible to damage and wear than the rest of the joint, the use of the best sliding materials available has great potential to minimize expansion joint maintenance and replacement work.

## Replaceability

Considering that expansion joints, being mechanical components and less robust than the main structure, will probably need to be replaced several times during the main structure's life, the costs of undertaking this work (including user costs due to traffic disruption, etc.), which are generally far higher than the original supply and installation costs[2], should be minimized. This can be done by designing the joint to be easily exchanged, e.g. with a *Quick-Ex* design or by the *Box-in-Box* approach (**Fig. 5**), which avoids the need to break out the parts of the joint that are concreted to the main structure[3].

## Use of Structural Health Monitoring (SHM) and the advent of "smart" expansion joints

SHM has much to contribute to bridge construction and maintenance in general, and to expansion joint installation, inspection, maintenance and replacement in particular[4]. With the advent of "smart" expansion joints, which feature integrated SHM sensors already when they leave the factory and whose SHM systems are capable of "learning" what deviations from normal readings are significant enough to warrant reporting or raising an alarm, another significant step forward has been taken[5].

## Further special design features

The most advanced modular expansion joints offer a number of further optional features which can improve functionality, performance and durability in many cases. The *Tensa-Modular* joint, for example, can be equipped / installed with features including:

- *Noise-reducing surface plates* ("sinus plates"), connected to the top surface of a modular expansion joint to create a continuous driving surface (**Fig. 6**), substantially minimizing tire impacts and the resulting noise as vehicles drive across the joint[6].
- *Hump seals* (**Fig. 7**), an alternative to the standard "v-shaped" rubber strip seals which seal the gaps between the joint's surface beams, optimized to introduce a self-cleaning action as the joint opens and closes and thus reduce maintenance and prevent damage[7].
- *Seismic protection features*, such as *Fuse-Box* (**Fig. 8**), which enable the joint to fail in a controlled way during an earthquake, minimizing damage to the joint and to the bridge and thus ensuring that the bridge, and the joint, can be returned to service as quickly as possible – most importantly for the emergency traffic that may need to use the bridge following an earthquake[8].
- *Asphalt-strengthening features*, such as *Robo-Dur*, which can minimize driving surface level changes at expansion joints, thus minimizing dynamic loading on the joint – which can be very significant, even in the case of minor rutting or settlement[9].

## LABORATORY TESTING

Laboratory testing of bridge components has an important role to play in verifying their long-term performance and thus minimizing their life-cycle costs. An expansion joint that offers better durability will, of course, need to be replaced fewer times during the bridge's life of 100 years or more, and it is during replacement works that the most significant costs of an expansion joint, to the bridge's owner and its users, arise[2].

The long-term performance of these critical bridge components should thus be a key factor in their selection and design. In North America, where the use of modular expansion joints has increased substantially in recent years, standards published and promoted by the American Association of State Highway and Transportation Officials (AASHTO) have taken on a leading role in terms of testing requirements for such joints in particular, with highly demanding testing defined to determine an expansion joint's suitability in a number of key areas. The 2002 report *Performance Testing for Modular Bridge Joint Systems*[10], published by the Transportation Research Board of the National Research Council, was issued as Report No. 467 of the National Cooperative Highway Research Program (NCHRP), and was based on research which was sponsored by AASHTO in cooperation with the Federal Highway Administration, United States Department of Transportation. NCHRP Report 467 includes specifications for various prequalification tests, including the *Opening Movement and Vibration (OMV) test* and the *Seal Push-out (SPO) test* (described below), which are included in AASHTO's LRFD Bridge Construction Specifications[11], Appendix A19.

### Testing of long-term opening/closing movements and resistance to traffic vibrations

The *Opening Movement and Vibration (OMV)* test[12] (**Fig. 9**) is carried out on a full-scale specimen of the modular joint type which is to be prequalified. It simulates, on the one hand, the opening (and closing) movements that can be expected to occur during a 75-year lifetime due to daily thermal cycles (i.e. one opening and closing cycle per day) – and thus features 27,400 cycles. At the same time, the test simulates the vibrations caused by traffic, with a 33 kN force applied to a centerbeam at high frequency for the entire duration of the opening movement testing. Inspection of the tested expansion joint after completion of the test allows the ability of the expansion joint to withstand these principal impacts to be evaluated.

**Testing of long-term seal strength and watertightness**

Following completion of the OMV test, the *Seal Push-out* (SPO) test[12] (**Fig. 10**) is carried out. This test assesses the strength of the connection of the elastomeric seals to the centerbeams which support them, and thus indirectly tests the ability of the joint to remain watertight. The failure mechanism tested is the pushing out of a seal under wheel loading which is transferred to the seal due to the collection of debris between the centerbeams above the seal. Since the SPO test is carried out on the same joint which has already been subjected to the rigors of an OMV test, it simulates the weakened condition with respect to movements that a seal may exhibit after many years of service, making it a more demanding and a more realistic test of performance and durability.

**Fatigue testing**

Fatigue testing of modular expansion joints is also specified in AASHTO's LRFD Bridge Construction Specifications, Appendix A19, with the testing based on another, similarly established NCHRP report, No. 402[13]. This presents a practical test procedure for the determination of the fatigue resistance of critical details in the joint's construction. The onerous testing required simulates the fatigue-inducing movements and stresses of a service life on a full-scale section of a joint which contains all critical members and connections. It involves the subjecting of expansion joint specimens to an enormous number of load cycles, and its complexity increases with the complexity of the expansion joint itself. For a highly developed and particularly flexible type of modular joint such as *Tensa-Modular*, fatigue testing can be especially demanding[14].

Although the testing is specified in great detail by NCHRP Report 402, one critical aspect is not clearly defined: the number of load cycles to which each test specimen must be subjected. It is clear, however, that the number of cycles must correspond to a point above the appropriate S-N curve (which plots S [stress] against N [number of cycles to failure]) for a specific so-called *detail category*, as given in Figure 2.5 of NCHRP Report 402 (**Fig. 11**).

The detail categories can be thought of as a ranking of the severity of the stress concentration associated with the geometry of the detail (e.g. a connection), with each detail category being a grouping of components and details having essentially the same fatigue resistance. AASHTO LRFD Bridge Design Specifications (7th edition, 2014) define Categories A to E', Category A being the best, and represents the fatigue performance of each by means of an S-N curve as shown in Fig. 11. As can be seen from the curves, the number of cycles (N) that can be withstood by a detail at any particular stress range increases rapidly as the detail category improves.

In selecting the stress (S) and number of cycles to failure (N) to be applied during testing, the question arises: Should a relatively low number of cycles be applied at a high load level, or a much higher number of cycles at a lower load level? It is certainly desirable to limit the number of cycles in order to limit testing time and cost, but what point on the appropriate curve is optimal? To answer this question it is useful to note that each defined S-N curve has a horizontal part, shown by the dashed line, which indicates a *Constant Amplitude Fatigue Threshold* (CAFT). This makes the S-N curves of the detail categories analogous to the S-N curve, featuring a fatigue limit, of the steel material from which they are primarily made (**Fig. 12**). When the applied stress on such a curve reaches the fatigue limit, the number of cycles to failure suddenly appears to approach infinity. In other words, at stresses below the fatigue limit, fatigue failure will never occur. Therefore, it makes sense to conduct testing, where possible, with parameters that are taken from the flat part of the S-N curve (and from the left-hand end of the flat part in order to limit testing time). Such testing, in the so-called “infinite life regime”, indicates that an infinite number of load cycles could be applied without failure as long as loading levels do not exceed the corresponding value that has been applied in testing.

It is desirable for an expansion joint’s details to be recognised as belonging to a high category, as it provides confidence in the long-term performance of the expansion joint and enables fatigue design requirements to be satisfied by less cumbersome, more easily installed and maintained expansion joints. Category A is typically only applicable for very simple details such as base metal with no welds or structural connections, so Category B is the best that can be hoped for in relation to connections of any sort. In fact, the NCHRP Report 402 specifies that a centerbeam / support bar connection with a stirrup should be classified as Category D – unless a higher category is proven by infinite life regime testing.

The manufacturer of the *Tensa-Modular* joint, having committed to carrying out fatigue testing in accordance with AASHTO requirements, made arrangements to do so at America’s leading institute in this field, the ATLSS Engineering Research Center of Lehigh University, Pennsylvania. Being convinced that Category B was achievable and appropriate for this detail, the company decided to conduct the testing with the objective of proving this. After extensive discussions with ATLSS, involving complex technical considerations such as real-life deviations from the idealised S-N curves mentioned above and considering the specifications of various American states, it was concluded that testing should consist of six million load cycles for each specimen – although the S-N curve for Category B indicates a figure of just three million at the point where the curve becomes horizontal. This is because the curves were plotted based on a statistical probability of 50% that a value would fall below a curve, but a higher degree of confidence is desired. In order for just 5% of the results represented by a normal distribution to fall below the figure of three million indicated by the S-N curve, that figure is increased by a factor of two times the standard deviation, which is evaluated by a factor of two. In effect, this introduces a much higher degree of statistical certainty to the testing; a bell-curve centred on the target value of three million load cycles (as it would be if that was the number of cycles chosen for testing) would allow 50% of the values to fall below the target figure, and thus to fall within the "finite life regime", but a bell-curve centred on a target value of six million cycles evaluates just 5% to fall below the target figure, with 95% falling within the "infinite life regime". In statistics, and thus statistics-based testing, an allowance for 5% (1 in 20) of values to fall outside proposed limits without compelling the statistician to consider these values particularly significant has been a key aspect of probability theory since Sir Ronald Fisher, the father of modern statistics, first championed the standard in 1925. In relation to the fatigue testing of modular expansion joints, the factor of two is specified, for example, by Washington State Department of Transportation, one of America's leading authorities in this field.

In accordance with AASHTO requirements, at least ten S-N data points are required to confirm that values consistently fall above the appropriate curve on the S-N graph. In the case of the *Tensa-Modular* joint, the test specimens were tested under constant amplitude fatigue loading at a nominal stress range of 110 MPa (16 ksi), corresponding to the CAFT for AASHTO Category B (much better than the Category D specified by the standard in the absence of such testing). The testing was completed successfully, with the fatigue resistance of all details being verified by testing of ten specimens as specified, each subjected to six million load cycles without any fatigue cracking. It can thus be concluded that Category B is achievable, and that modular expansion joint manufacturers should be able to demonstrate that their joints can achieve that category in equivalent testing – with a factor of two similarly applied to the number of load cycles indicated by the appropriate detail category curve in order to reduce the probability of “finite life regime” failures from 50% to 5%.

**Seismic testing**

It is clearly sensible for owners of bridges in seismically active areas to be satisfied, before investing in and installing a particular type of modular expansion joint, that the joint can be expected to survive an earthquake of a specified intensity. But even if the bridge is in a non-seismic area, evidence that a specific type of joint has survived extreme seismic testing can provide great confidence in the joint’s quality, strength and durability. An example of such testing of the *Tensa-Modular* expansion joint, in accordance with the testing protocols of the California Department of Transportation (Caltrans), is presented by Moor et al[12]. A full-scale modular expansion joint with seven gaps and four support bars was connected to powerful actuators which would cause large, rapid longitudinal and transverse movements (**Fig. 15**). A series of 17 tests was carried out, with varying conditions and requirements. One test, for example, consisted of ten movement cycles with a velocity of 1000 mm/second, with longitudinal movements or 450 mm and transverse movements of +/- 250 mm arising, and with rotations about every axis. These factors varied for the other tests, allowing an overall picture of the performance of the joint during a range of seismic events to be assessed.

## CONCLUSIONS

As described by Spuler et al[2], the total life-cycle costs of a bridge’s expansion joints – including for design and manufacture, installation, maintenance, and replacement of the joints, and other costs such as those resulting from the traffic disruption caused by replacement works – are typically many times the original supply and installation costs – making those original costs “insignificant” in that context. It is thus very important that adequate attention and expenditure are devoted to the procurement and proper installation of well-designed, high-quality joints. By being aware of the functionalities and optional features that are available on the expansion joint market, and the quality level that can be expected (as verified by testing, for example), bridge owners and engineers can ensure that their structures, and the structures’ users, benefit accordingly from improving technology and manufacturer capabilities.

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## FIGURES

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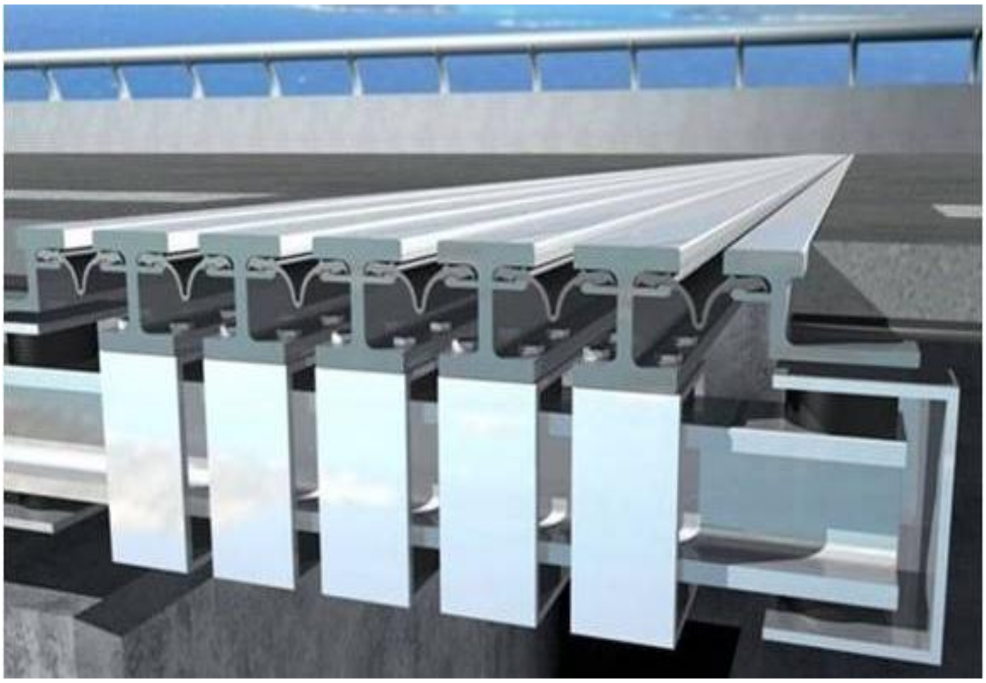

**Fig. 2−A Tensa-Modular expansion joint (cross section at a support bar), showing stirrup connections to centerbeams.**

**Fig. 3−Installation of a Tensa-Modular expansion joint in a concrete bridge deck.**

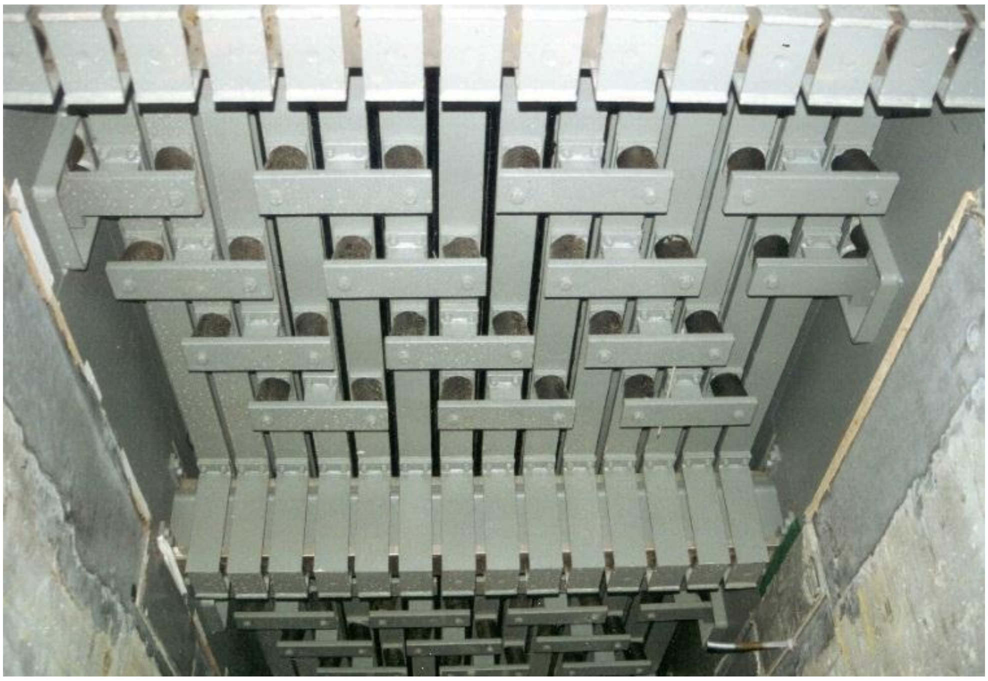

**Fig. 4−An installed Tensa-Modular expansion joint, viewed from below.**

**Fig. 5−"Box-in-box" method for modular joint renewal: Lifting in of new part consisting of a centerbeam and connected support bars, complete with boxes.**

**Fig. 6−"Sinus plates" on a modular joint minimize impacts and vibrations and thus minimize noise and improve durability.**

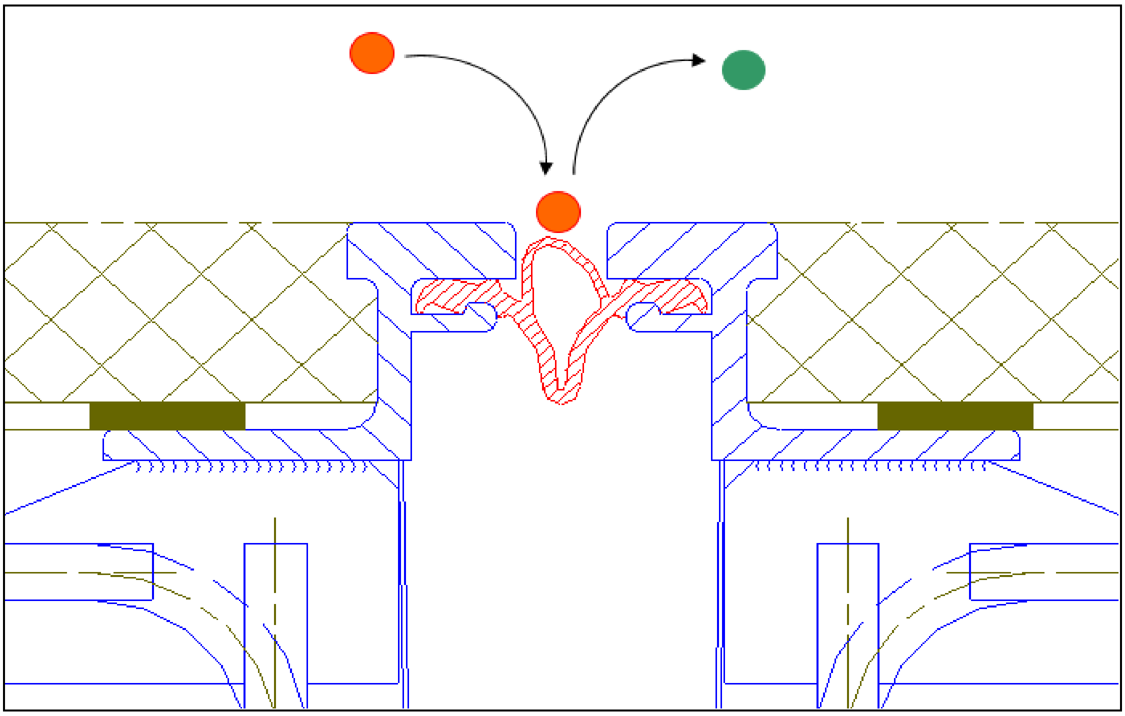

**Fig. 7−Hump seals fill out the gaps, keeping them clean, reducing noise and increasing pedestrian comfort.**

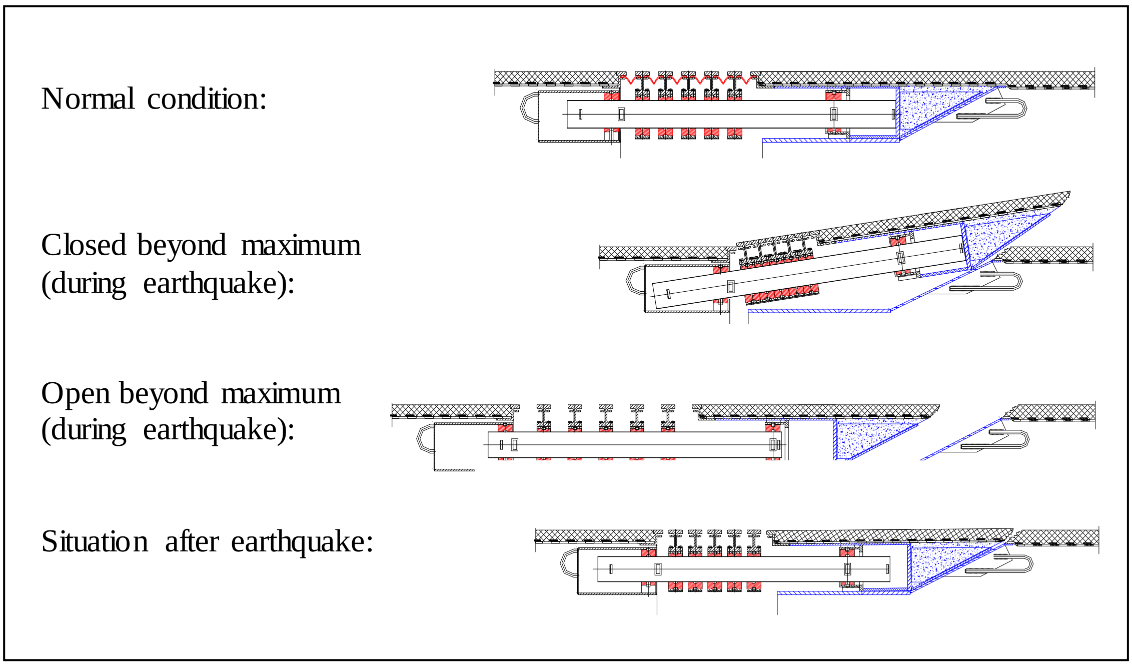


**Fig. 8-Principle of the Fuse-Box seismic protection system for expansion joints.**


**Fig. 9−Opening Movement and Vibration (OMV) Test per NCHRP Report 467.**

**Figure 10−Seal Push-Out (SPO) test in accordance with NCHRP Report 467.**

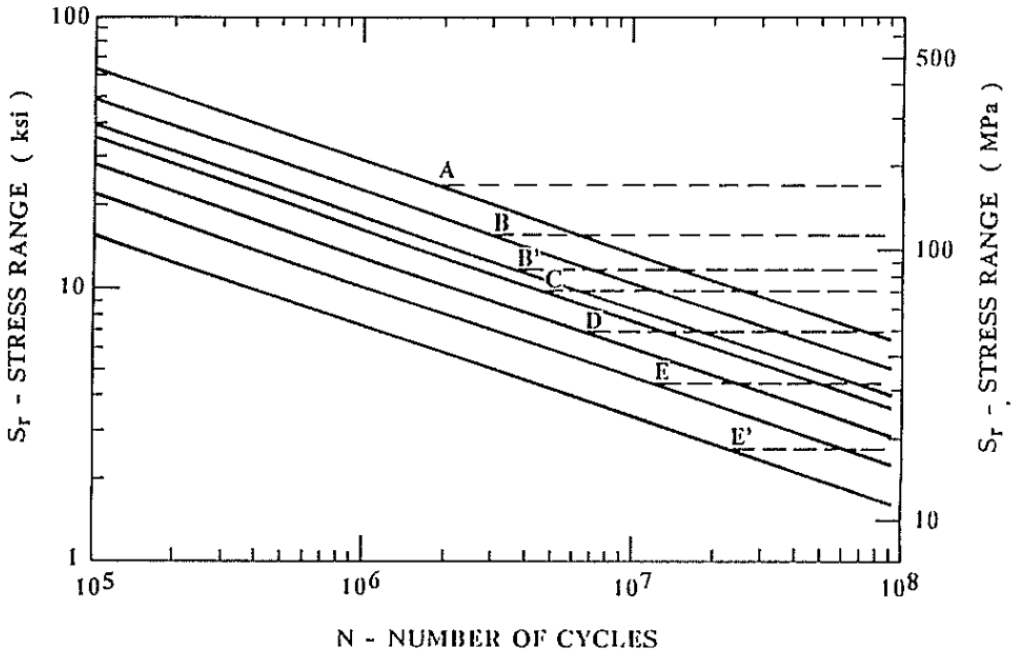


**Fig. 11−AASHTO S-N curves for all detail categories (Fig. 2.5 of NCHRP Report 402).**

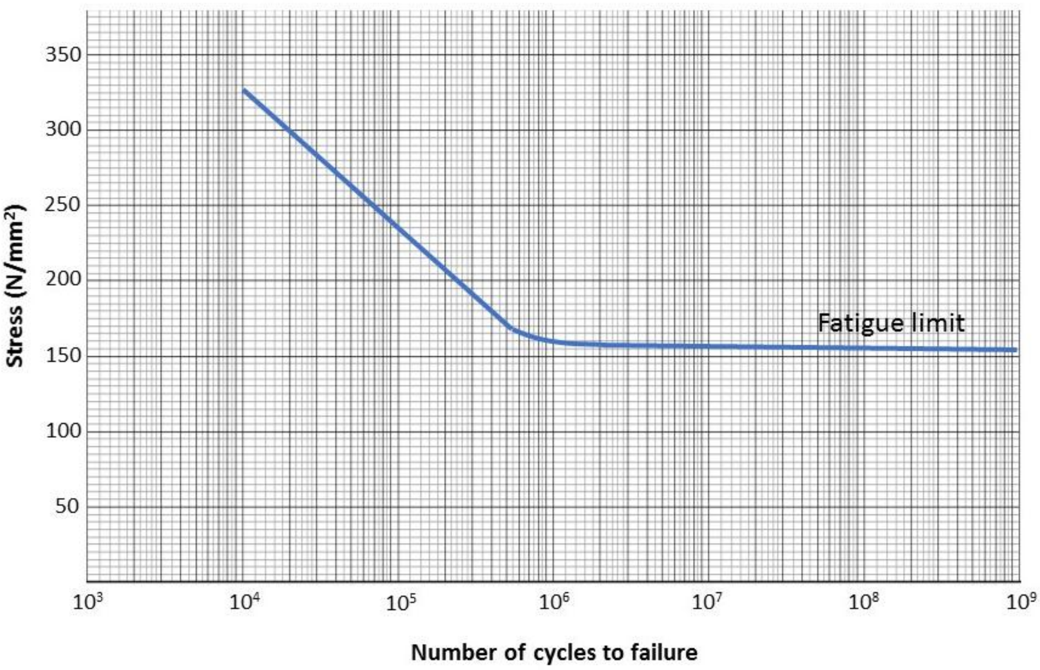


**Fig. 12−S-N curve for a typical steel.**


**Fig. 13−Fatigue testing of *Tensa-Modular* joint – test rig at ATLSS / Lehigh University.**


**Fig. 14−Fatigue testing of *Tensa-Modular* joint – one test specimen.**

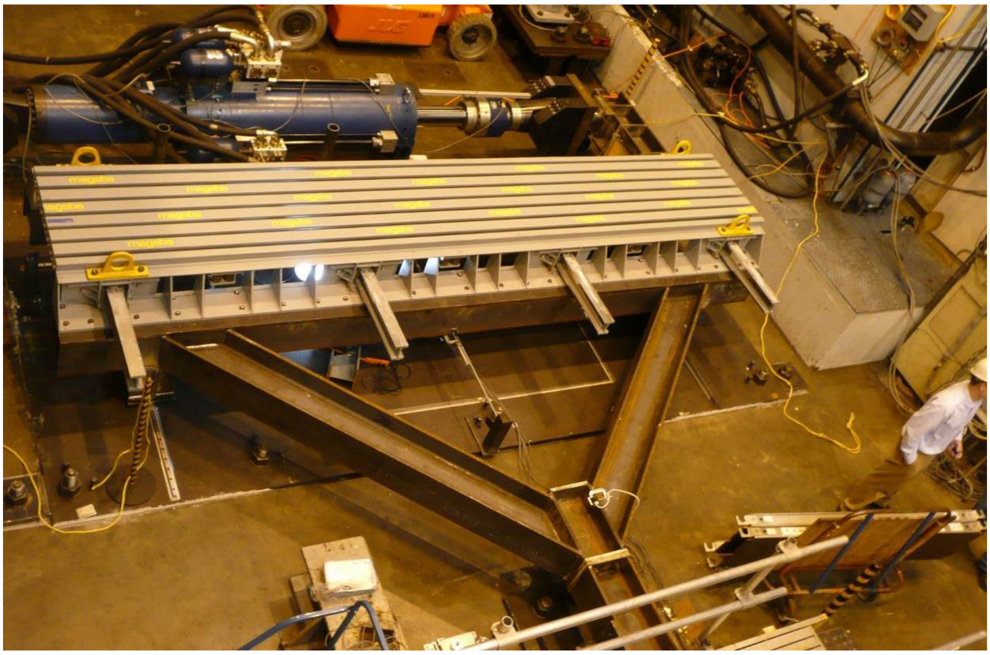

**Fig. 15−View from above of seismic testing as carried out per CALTRANS protocols.**