Verification of quality and performance of modular expansion joints – America's leading role in full-scale product testing

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ABSTRACT: Laboratory testing to verify the functionality, performance and durability of bridge deck expansion joints has become increasingly important in recent years. Nowhere has the demand for such testing been stronger than in the United States, where a comprehensive range of standards specifying highly demanding testing has been published. The testing is described, and the consequences of the unnecessary requirement for such testing are discussed, enabling recommendations to be made regarding project-specific requirements for testing.

INTRODUCTION

Modular expansion joints have a great deal to offer the designers and constructors of cable supported bridges everywhere, thanks to their ability to facilitate very large longitudinal movements and their great flexibility [1] - no other type of joint can accommodate longitudinal movements of two meters or more while 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.

HISTORICAL BACKGROUND

In Europe, where the modular expansion joint was invented four decades ago, the joint type achieved its first widespread popularity and the technology improved accordingly. In those early days, the regulation of the design and manufacture of bridges in general was quite well advanced, establishing the basis for the development of standards for bridge components such as expansion joints. Until suitable standards had been established, however, the duty to confirm suitability of an expansion joint for use in a bridge was largely left to the responsible bridge engineer, who did not yet have a wealth of nationally recognized literature and experience on which to base the decision.

But the lack of national standards for the new type of joint did not stifle its growth in popularity across Europe, with early successes encouraging rapid development of the technology. Indeed, the multiple support bar system (whereby each centerbeam (lamella beam) at the surface of the joint was supported by its own support bars) subsequently gave way to the single support bar system (whereby all centerbeams are supported by each support bar, thus reducing the number of support bars required and increasing flexibility) – see Figures 1 and 2.

Figure 1 - Multiple support bar system (1970)

Figure 2 - Single support bar system (1990)

The new type of expansion joint quickly became popular in Switzerland, Germany and Austria – countries which shared a language and strongly developed engineering and transportation sectors. In order to maximize the efficiency of developing industries and the benefits of emerging technologies to their economies, national standardization boards were established to regulate many engineering products and services, and the supply of bridge expansion joints was no exception. The German standard TL/TP-Fü [2] was first released in 1992, and quickly became a benchmark internationally. This well-established standard applies where demands are unparalleled in certain respects, on the country's extensive Autobahn (motorway) network - on many parts of which no speed limit applies, and where modular joints are used almost exclusively. The Austrian standard RVS [3], which came into effect for all Austrian highway structures in 1999, regulates the design and fabrication of several types of joint which are favored on Austrian highways, including modular joints. The requirements relating to modular joints are comparable to those contained in the German equivalent.

As a key element of their evaluation and acceptance procedures, the authorities of both Germany and Austria issue general approvals to suppliers of modular expansion joints who demonstrate, following assessment, testing and inspection, that all aspects of the design and manufacture of the expansion joints satisfy the requirements of their codes. Awarding of such a general approval makes the seeking of further approvals from the same authorities on a project-specific basis unnecessary, saving a great deal of effort for those manufacturers that frequently supply the joints to these markets. The requirements are very demanding in general, but full-scale testing of complete expansion joints is not required. Instead, testing is limited to the parts and components of a joint which can be expected to prove problematic. These would include, for example, the sliding bearings and sliding springs (Figures 3 and 4) of some systems which allow the centerbeams to slide across the support bars below, and the elements which control the gap widths between the individual centerbeams as the whole joint opens and closes (Figure 5) [4].

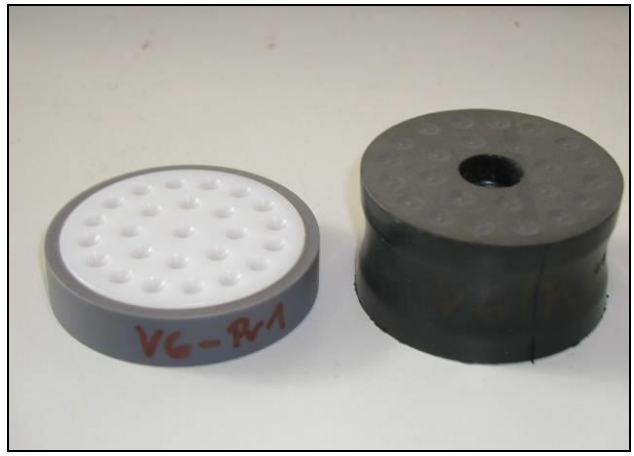

Figure 3 – A sliding bearing and a sliding spring of a modern modular expansion joint – used as a pair (above and below beam) to control the position of a centerbeam or support bar while allowing it to slide

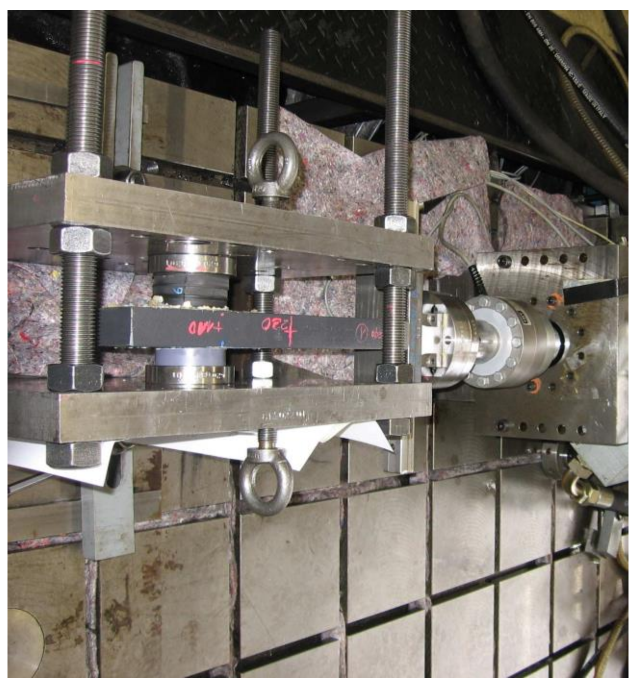

Figure 4 – Testing of a sliding bearing and sliding spring pairing (featuring *RoboSlide* sliding material) over a total sliding distance of 120 km

Figure 5 – Testing of the control springs (4 no.) of a modern modular joint at -4 °F (-20 °C). These control the movements of a joint's centerbeams relative to each other, ensuring that no gap becomes too wide

If the steel members themselves are made from single rolled sections rather than welded, they can be relied upon to perform as designed, making testing of these parts unnecessary. However, sections of a centerbeam are often butt-welded together – either in the factory to achieve a change of gradient, or on site to assemble a joint which was transported in parts for logistical reasons. Testing of such butt welds is therefore also necessary in order to achieve the above-mentioned national general approvals.

Because the modular expansion joint was developed in the region, in close cooperation with the responsible national authorities, the standard of the joints being designed and manufactured by local suppliers improved in line with expectations, as verified by national approval systems, so laboratory testing of complete full-scale joints was never deemed necessary. But as the joint type, thanks to its many advantages, became increasingly popular in other parts of the world which could not benefit from this extensive experience, authorities had to develop ways of ensuring that their needs would be met. Nowhere was this done more extensively than in the United States, where national standards now include a comprehensive range of laboratory tests.

FULL-SCALE TESTING OF MODULAR JOINTS – AMERICA TAKES THE LEAD

The use of modular expansion joints has increased substantially in North America in recent years, and this is reflected in the advancement of national standards. In fact, standards published and promoted by the American Association of State Highway and Transportation Officials (AASHTO) [5] took 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, including fatigue performance, daily movements, traffic vibrations, elastomeric seal strength, and performance during a seismic event. Such testing is intended to give bridge owners and engineers confidence in the products being installed on their structures – confidence which was clearly not widespread in the United States in 2002 at any rate, when a key report was published by the Transportation Research Board of the National Research Council. This report, entitled "Performance Testing for Modular Bridge Joint Systems" [6] 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. The foreword of this highly influential report states: "Many of these devices provide marginal performance, resulting in failures in the structural support and sealing system. Substantial maintenance is generally necessary to keep these devices operating. In many instances, these joints perform so poorly that they are removed and replaced prematurely. To assist transportation agencies in the selection and installation of these systems, performance requirements are needed". This statement explains why onerous testing was considered necessary to bring the standard of modular expansion joints used in the United States up to a satisfactory level. The same report goes on to define performance requirements, and to present performance test specifications, and guidelines relating to materials, fabrication and construction, which are recommended for use in the prequalification and acceptance of such systems to meet these requirements.

TESTING OF FATIGUE PERFORMANCE

Before NCHRP Report 467 of 2002 addressed the need for testing of modular joints in general, the 1997 NCHRP Report 402, "Fatigue Design of Modular Bridge Expansion Joints" [7] had assessed the particular case of fatigue performance. As noted by Report 467: "When the root cause of an overall failure is a failure of the structural supports (i.e., the centerbeams and the support bars), it is usually the result of fatigue cracking. Research was previously conducted on this problem, and fatigue design and testing specifications were proposed in NCHRP Report 402. It is believed that implementing the design and testing specification proposed in NCHRP Report 402 can substantially reduce the occurrence of fatigue cracking".

Report 402 presents a practical test procedure for the determination of the fatigue resistance of critical details. The onerous testing required by this report, and consequently by AASHTO's LRFD Bridge Construction Specifications, 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. Ten data points are required, gained from a series of tests to determine the number of load cycles to which the joint can be subjected before failure occurs. Using these data points, an S-N curve is plotted, correlating stress (S) to number of load cycles withstood (N) on a logarithmic scale. This enables the fatigue performance of the joint during an extended lifetime to be determined. The testing, performed in Lehigh University, Pennsylvania, USA, is shown in Figure 6.

Such a series of tests can require over six months of non-stop use of a test rig, and the testing facilities which are widely recognized as being capable of conducting the testing are very few. This means that such testing, if properly conducted, is very expensive, and must be planned well in advance to allow the testing to be conducted within a project's timeframe.

Figure 6 - Fatigue testing of joints (yellow) per NCHRP Report 402

TESTING OF DAILY OPENING MOVEMENTS, VIBRATIONS FROM TRAFFIC AND SEAL STRENGTH

Following the publication in 1997 of NCHRP Report 402, which addressed fatigue performance only, the need remained for a second report to address all other aspects of the performance of modular joints. In 2002, the above-mentioned NCHRP Report 467 was issued, commenting on the contribution of Report 402 in addressing fatigue problems and noting: "The research described in this report focused on the remaining performance problems". Two types of test are defined, which are recommended to be required for prequalification for use on a project: the Opening Movement Vibration (OMV) test and the Seal Push Out (SPO) test. The tests are carried out on a full-scale section of the modular joint type which is to be prequalified. The OMV test (Figure 7) 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 one closing movement 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.

Figure 7 - Opening Movement Vibration (OMV) Test per NCHRP Report 467

Following completion of the OMV test and all evaluations, the SPO test (Figure 8) is recommended. This test assesses the strength of the connection of the elastomeric seals to the centerbeams which support them, and thus indirectly tests the important ability of the joint to remain watertight. The failure mechanism identified and tested is the pushing out of an elastomeric seal under wheel loading which is transferred directly to the seal due to the collection and compaction of debris between the centerbeams above the seal. The SPO test is carried out on the same joint which has already been subjected to the rigors of an OMV test, and thus simulates the weakened condition that an elastomeric seal may exhibit after years of service.

Figure 8 - Seal push-Out (SPO) Test in accordance with NCHRP Report 467

TESTING OF SEISMIC PERFORMANCE

With its history of destructive and sometimes devastating earthquakes, it is not surprising that the state of California plays a leading role in the development of technology to withstand seismic events, with bridge components such as expansion joints falling under the remit of the California Department of Transportation (Caltrans). Although Caltrans has not yet published a formal specification to define the required seismic testing of a modular joint, the current level of testing required to gain Caltrans approval was recently applied during testing conducted in December 2010, at the Center for Advanced Technology for Large Structural Systems (ATLSS) at Lehigh University in Pennsylvania. A full-scale modular joint with seven gaps and four support bars was connected to powerful actuators which would cause large, rapid longitudinal movements and transverse movements (Figure 9). A series of 17 tests was carried out, with varying conditions and requirements, as presented in Figure 10. Test No. 14, for instance, 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.

Following completion of this testing, and after inspection of the expansion joint confirmed that it had not suffered any significant damage, Caltrans could be satisfied that the expansion joint type meets current Caltrans seismic testing requirements.

Figure 9 - View from above of conducted seismic testing

Dynamic Test #	Initial Cell Width (mm)	Initial Rotation (radian) about			Max. Displacement (mm)		Max. Velocity (mm/sec)	# of Cycles
		Vert. Axis	Trans. Axis	Long. Axis	Long.	Trans.		
TP1-1	10	0.000	0.000	0.000	450	0	25	10
TP1-2	6.5	0.000	0.000	0.000	500	0	25	1/2
TP1-3	78	0.000	0.000	0.000	-420	0	25	1/2
TP1-4	10	0.000	0.000	0.000	0	±250	25	10
TP1-5	10	0.000	0.000	0.000	450	±250	25	10
TP1-6	10	0.000	0.000	0.000	450	0	1000	10
TP1-7	10	0.000	0.000	0.000	0	±250	1000	10
TP1-8	10	0.000	0.000	0.000	450	±250	1000	10
TP1-9	10	0.012	0.067	0.010	450	0	25	3
TP1-10	10	0.012	0.067	0.010	0	±250	25	3
TP1-11	10	0.012	0.067	0.010	450	±250	25	3
TP1-12	10	0.012	0.067	0.010	450	0	1000	10
TP1-13	10	0.012	0.067	0.010	0	±250	1000	10
TP1-14	10	0.012	0.067	0.010	450	±250	1000	10
TP1-15	10	0.000	0.000	0.000	450	0	25	3
TP1-16	10	0.000	0.000	0.000	0	±250	25	3
TP1-17	10	0.000	0.000	0.000	450	±250	25	3

Figure 10 - Overview of conducted seismic testing

THE IMPLEMENTATION OF THESE TESTING REQUIREMENTS

Although the development by American authorities of laboratory testing specifications has been comprehensive, the application of testing requirements has been less uniform. Even within the United States, the specific requirements for such laboratory testing for a bridge construction project, and the approval of results, is generally the remit of the relevant state transportation agencies, which may require independent third party verification by an approved testing company or laboratory. Consequently, no single certification body is authorized to approve the applicability of successful testing for projects right across the United States. This very often makes the process of complying with project specifications in different states an uncertain one for suppliers. While testing may be required for a project (perhaps only indirectly, by virtue of the fact that it is called for by Appendix A19 of the AASHTO LRFD Bridge Construction Specifications [5]), the amount of effort it will take to fulfill the requirement may be very difficult to estimate without lengthy discussions with the specifying engineer. Successful testing in accordance with NCHRP Reports 402 or 467, which may have been previously accepted by one authority, may not be accepted by another. And while engineering judgment may allow the applicability of a previously conducted test to be extended to the particular design of joint required for a certain project, such arguments may be accepted in some states and rejected in others. The resulting lack of certainty increases the risks for suppliers and thus the cost of participation on a project – costs which must ultimately be borne by the project itself. Clear indications at an early project stage of the requirements for testing, and how previous testing may be considered sufficient, will thus help to considerably reduce the effort and expense of acquiring modular joints for a project, or avoid later lack of agreement on what new testing can be expected.

CONCLUSIONS

Expansion joints are arguably the parts of a bridge upon which the highest demands are placed, being relatively light compared to the rest of the structure, yet highly stressed and subject to intense fatigue loading. This is especially true of the modular joint, due to its exceptional flexibility and complex movement capabilities. National standards which regulate the design and manufacture of modular joints have developed in various parts of the world in recent decades – each with its own philosophy and particular focuses. These appear to be significantly influenced by the experience gained in the manufacture and use of the joints in the region. The requirements for full-scale laboratory testing of joints before use on a bridge structure are particularly onerous in regions where the authorities' experience of the joints, perhaps as a result of poorly designed and fabricated products, is not positive. Such testing comes at a high price, and places high demands on scheduling of design and manufacture of joints for a project, if months of testing must be planned, arranged and completed before fabrication of the joints which are to be supplied.

On the other hand, the assurance that the testing can provide to the bridge owner that the delivered expansion joints will be fit for purpose can be of great significance in certain circumstances. Such testing provides confidence where such confidence cannot otherwise be earned – for example, where new or improving suppliers cannot demonstrate the performance and durability of their joints from many years of "real life testing". In such cases, standardised testing enables suppliers to demonstrate the quality of their products in a relatively short time, and thus qualify for new contracts. And although expensive, the cost of testing is likely to be much less than the cost, both direct and macro-economic, of greater maintenance and repair effort and early replacement of a poorly performing joint. Such testing can therefore serve an important purpose in many instances, in particular in those markets where a high premium is placed on minimising the long-term costs, to the bridge owner and to society, of a bridge's expansion joints.

As is often the case in the engineering profession and the wider world, varying degrees of regulation and specification are appropriate to ensure an acceptable standard of supplied products in different markets. It should be recognised that an approach which is suitable for one region may not be optimal for another. While full-scale laboratory testing of modular expansion joints has much to offer, experience in the European markets where the modular joint has its origins shows that expensive, time-consuming full-scale testing is not necessarily appropriate. If the ultimate goal of an engineer in specifying such testing is to provide confidence in the ability of the supplier to design and manufacture an expansion joint which will fulfil the structure's requirements, alternative ways of providing this confidence should be considered. In particular, the track record of established manufacturers in supplying comparable expansion joints for similar structures offers valuable evidence of suitability. Indeed, it can be readily argued that evidence of years of reliable performance on an actual bridge, while subjected to real traffic and other loading, is far more compelling than any combination of laboratory tests, which can at best only approximate real-life conditions. The careful consideration of such issues can avoid unnecessary or overly demanding laboratory testing, saving considerable expense and, in some cases, valuable project completion time.

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