

# Developments in modular expansion joint technology – codes and testing in Australia, America and Europe

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**Abstract** Great advances have been made in modular expansion joint technology since this most versatile type of joint was invented forty years ago, and the use of such joints, especially on very large bridges, has increased steadily. As a consequence, national standards have been written and continually developed to keep up with this technology, in order to ensure that the great potential of this type of joint is fully realised. Key contributions towards the development of these standards have been made by the engineering communities of Australia, America and Europe in particular, governing the design, manufacture and testing of the joints. Commentary on these contributions is presented, with reference in particular to the testing requirements of various national standards.

## Introduction

Modular expansion joints have a great deal to offer the designers and constructors of large 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 metres 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 the responsible authorities around the world.

## Europe

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. The greatest advances were made by a Swiss company that was able to benefit from the highly developed Swiss engineering industry of the time. A technology sector consisting of world-leading companies such as Asea Brown Boveri, and highly respected and well funded institutions such as the Eidgenössische Materialprüfungs- und Forschungsanstalt (Swiss Federal Laboratories for Materials Testing and Research or EMPA), made Switzerland a likely location for the development of such technology at that time.

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, 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 have a wealth of nationally recognised literature and experience on which to base his 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 lamella beam of the joint was supported by its own support bars) subsequently gave way to the single support bar system (whereby all lamella beams are supported by each support bar, thus reducing the number of support bars required) (Fig. 1).

**Multiple support bar system (1970)**



**Single support bar system (1990)**



**Fig. 1.** Development from multiple support bar to single support bar system

### ***The first national standards with international influence***

The new type of expansion joint quickly became popular in other European countries, and in particular in Switzerland's northern and eastern neighbours, Germany and Austria. Sharing a language and strongly developed engineering and transportation sectors, the Swiss technology was quickly adopted by these countries where the great potential benefits of the new joint were recognised. In order to maximise the efficiency of developing industries and the benefits of emerging technologies to their economies, national standardisation boards were established to regulate many engineering products and services, and the supply of bridge expansion joints was no exception. The German standard *TLTP-Fü* [1] was first released in 1992, and quickly became a benchmark internationally. That the standard is considered by the German authorities to have reached the appropriate level to adequately regulate the design and fabrication of expansion joints is indicated by the fact that the last revision of the code already dates back to 2005.

This well-established code 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.

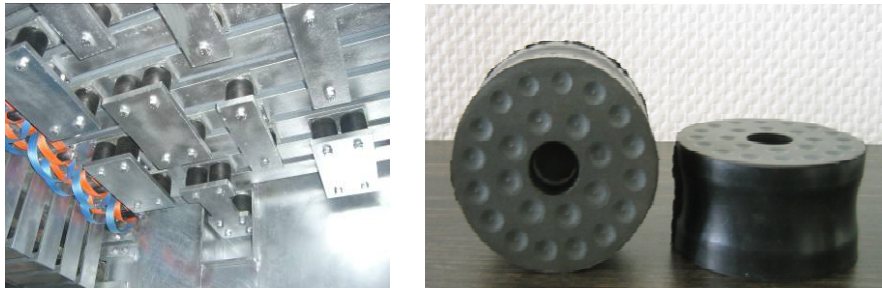
The Austrian standard *RVS* [2], which came into effect for all Austrian highway structures in 1999, regulates the design and fabrication of several types of joint which are favoured on Austrian highways, including both modular joints and finger-type joints. The requirements relating to modular joints are comparable to those contained in the German equivalent.

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 of some systems which allow the lamella beams to slide across the support bars below, and the elements which control the gap widths between the individual lamella beams as the whole joint opens and closes. 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 lamella beam 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.

### *Ongoing developments*

The pioneering role played by European engineers did not cease with the development of these first standards, however. The world's manufacturing hub for modular expansion joints has stayed in central Europe, with suppliers from this region still maintaining an edge over international competition to this day. Designs and techniques have been continually refined, and highly advanced materials, such as the ultra high molecular weight polyethylene (UHMWPE) sliding materials which can now replace the traditionally used polytetrafluoroethane (PTFE) in large joints thanks to their exceptional performance [3], have been developed. These improvements (such as those shown in Fig. 2) allow the joints to continue to perform well in spite of the increasingly imposing demands of the bridges constructed by an equally ingenious bridge construction industry.



**Fig. 2.** New generation design and materials in modern modular expansion joints

The ongoing harmonisation of standards across the European Union, a process by which national standards of member countries will be replaced by a single standard across the Union, will in the coming years result in a new standard for bridge expansion joints, which is expected to combine best international practice in expansion joint design and construction, and become a reference for expansion joint technology worldwide.

But the modular joints story would not be limited to Europe – their benefits lead to their becoming increasingly popular around the world, prompting new standards to be developed by authorities in other parts of the world, including America and Australia.

## **America**

The use of modular expansion joints has also increased substantially in North America, and this is reflected in the advancement of national standards. In fact, standards promoted and published by the American Association of State Highway and Transportation Officials (AASHTO) [4] 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. That a greater degree of testing is required in the United States may result from the fact that this type of joint does not yet have as long a history and as strong a manufacturing base as in Europe, where the authorities have enough positive experience of the established suppliers to give confidence in their products without requiring extensive full-scale testing. Such confidence 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" [5] was issued as Report No. 467 of the National Cooperative Highway Research Programme (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 very 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 the NCHRP Report 467 of 2002 sought to address the needs for performance testing of modular joints in general, the 1997 NCHRP Report 402, "Fatigue Design of Modular Bridge Expansion Joints" [6] 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 specifications 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 Design 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 proposed test programme for the typical fatigue testing of a joint, to be carried out in 2011, is presented in Table 1.

Lamella Beam: Nr.:	Stress range MPA	Load Cycles n	Frequency 1/s	Time d
1	300	300 000	2	
2	300	300 000	2	2
3	250	500 000	2	
4	250	500 000	2	3
5	160	2 000 000	3	
6	160	2 000 000	3	8
7	150	3 000 000	3	
8	150	3 000 000	3	12
9	150	3 000 000	3	
10	150	3 000 000	3	12
Total:				37 days

**Table I.** Overview of fatigue testing in accordance with NCHRP Report 402

Such a series of tests can require over a month of non-stop use of a test rig, and the testing facilities which are widely recognised as being capable of conducting the testing are very few. This means that such testing, if properly conducted, is very expensive (costing in excess of USD 100,000), and must be planned well in advance to allow the facilities to be reserved and the testing to be conducted within the timeframe of a project.

### ***Testing of daily opening movements, vibrations from traffic and seal strength***

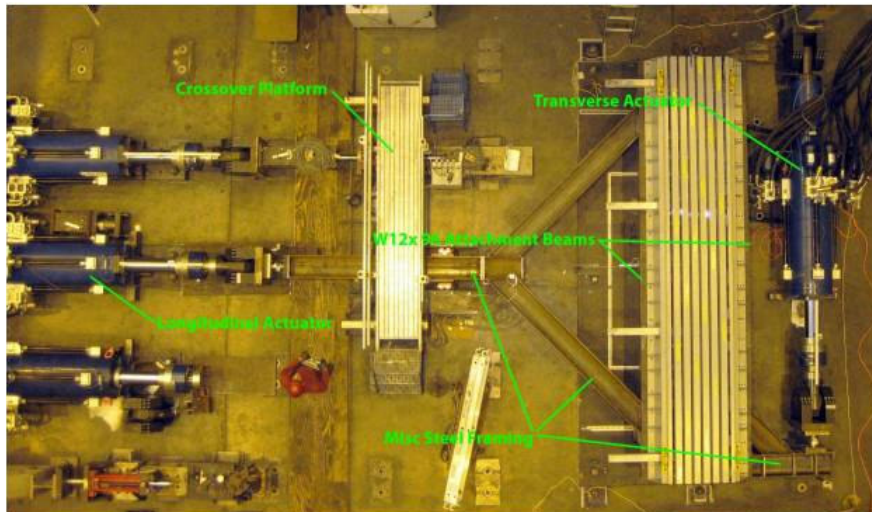
Following the publication in 1997 of NCHRP Report 402, which addressed fatigue performance only, the need remained for a second report to address all other aspects of the performance of modular joints. In 2002, the above-mentioned NCHRP Report 467 was issued, commenting on the contribution of Report 402 in addressing fatigue problems and noting: "The research described in this report focussed 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 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 33kN force applied to a lamella beam 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.

Following completion of the OMV test and all evaluations, the SPO test is recommended. This test assesses the strength of the connection of the elastomeric seals to the lamella beams 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 lamella beams above the seal. The SPO test is carried out on the same joint which has already been subjected to the rigours of an OMV test, and thus simulates the weakened condition that an elastomeric seal may exhibit after years of service.

### ***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 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 most 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 (Fig. 3). A series of 17 tests was carried out, with varying conditions and requirements, as presented in Table 2. Test No. 14, for instance, consisted of 10 movement cycles with a velocity of 1000mm/second, with longitudinal movements of 450mm and transverse movements of +/- 250mm 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.



**Fig. 3.** View from above of conducted seismic testing

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



**Table 2.** Overview of seismic testing conducted in December 2010 in accordance with Caltrans requirements

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

### *The implementation of these testing requirements*

The specific requirements for such testing for a bridge construction project, and the approval of results, is generally the remit of the relevant state transportation agencies, who may require independent third party verification by an approved testing company or laboratory. Consequently, no single certification body is authorised 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 Design Specifications [6]), the amount of effort it will take to fulfil 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 for a project in one state may not be accepted in another state. And while engineering judgement 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.

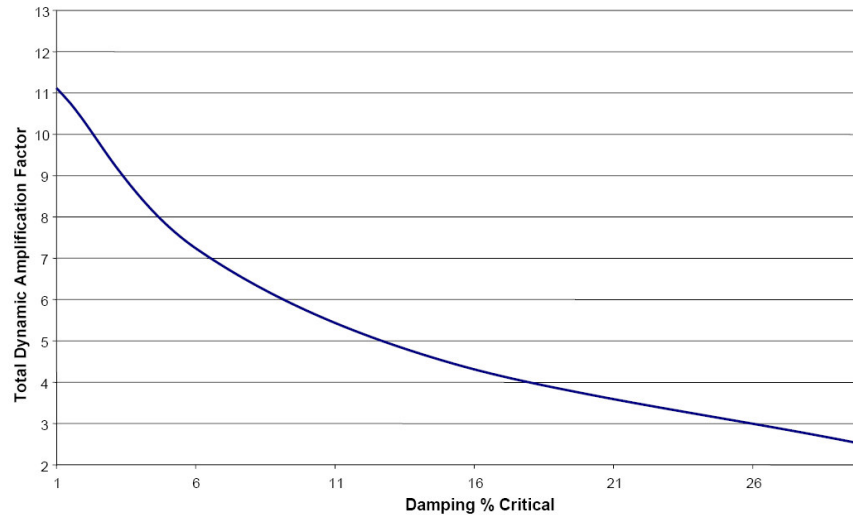
## **Australia**

In Australia, the development of standards has also developed strongly in recent years, building on the experience of the existing standards in Europe and America among others. Thanks to modern computer technology and methods of assessment of dynamic behaviour, new possibilities can be explored by researchers and developers of modular joints. A particular development relates to the dynamic load allowance, which is critical to the assessment of the joint's performance under dynamic loading. The Australian bridge design code [7] notes that the dynamic load allowance for modular expansion joints should be determined from specialist studies. The quality specification B316 [8] of the Roads & Traffic Authority (RTA) of New South Wales has taken this requirement literally and is now, arguably, the most demanding in the world in this regard. This specification has set new standards worldwide and was recently recommended to international road authorities by Swedish researchers [9]. The B316 specification was developed following an extensive measurement program where the structural dynamics of an in-service joint were identified experimentally for the first time. Also, for the first time, a translational (whole body) mode was identified as was a measured dynamic amplification factor (DAF) of 4.6. The significance of this measured DAF value cannot be understated as virtually every design code at the time throughout the world used a value around 1.7. The RTA's specification B316 has now set 2.5 as the default value for the DAF and it is this relatively high default DAF value that distinguishes B316 from other design codes. The relatively high value can be attributed to the coupled centre beam resonance phenomenon [10], in-phase excitation and the practical limitations of providing damping above 15% of critical.

A number of modular joints have now been supplied to this specification in several Australian states. Post-installation measurements undertaken of the single support bar design joints in the Karuah River Bridge on the Pacific Highway

confirmed that the specification was not conservative [11] [12]. This is also supported by Steenbergen [13], who found that DAF values higher than 2 occur easily and that these values are much higher than those prescribed in current bridge design codes.

In further support, experimental research by Ancich [14], which reported on the calibration of finite element models of both single support bar and multiple support bar design modular joints using experimental modal analysis and strain gauge data, accurately reproduced the empirical vibrational modes and dynamic strains of the operational 'as built' joints of two structures – the Anzac (single support) and Taree By-Pass (multiple support) bridges, accurately predicting the DAFs associated with the examined modular joint structures. Transient 'virtual dynamic truck pass-by' analysis runs were carried out on the 'as built' models to assess the sensitivity of the DAF to damping. Figures 4 and 5 show the resulting trend for both the single support bar and multiple support bar modular joints.



**Fig. 4.** Dynamic amplification factor (DAF) in relation to damping at Anzac Bridge

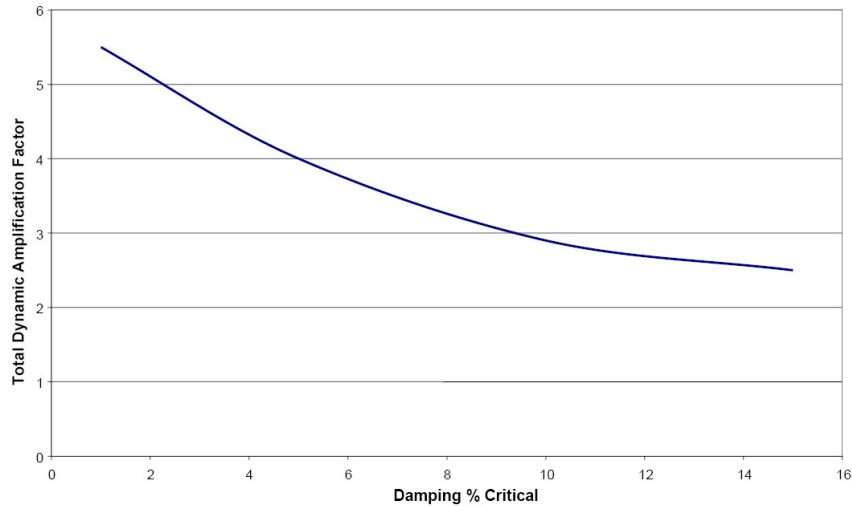


Fig. 5. Dynamic amplification factor (DAF) in relation to damping at Taree By-Pass

## 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, and are shaped by the development of standards to take the best of what already exists internationally, adapting it for the particular circumstances of the region. This is particularly true in the case of the specification of design input variables such as the dynamic amplification factor, and testing of joints before fabrication and use. Such demands 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. Testing, in regions where requirements are very onerous, comes at a high price, often costing many tens of thousands of dollars. It also places high demands on scheduling of design and manufacture of joints for a specific project, if months of testing is to 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 particular if the supplier cannot demonstrate many years of successful experience. The cost of testing is in any case 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. However, an alternative to costly project-specific testing may be found in detailed design assessments, for example using dynamic finite element modelling studies, calibrated using experimental modal analysis and strain gauge data on dynamically similar installed modular joints, to allow a wider range of analysis and thus, a better understanding of the complex non-linear dynamic behaviour of these structures.

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. However, in spite of such regional differences, there exists worldwide a wealth of information, research and experience relating to the modular expansion joint, of which advantage should be taken in the drafting, and regular updating, of regional standards.

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