



Testing of key bridge components to ensure good life-cycle performance

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Abstract

The proper long-term performance of key bridge components such as bearings, expansion joints, dampers and seismic isolators is an important factor in the life-cycle quality control of new and existing bridge infrastructure. Laboratory testing of these components in accordance with national and international standards can very helpful in ensuring good performance, but the testing that can find application is very varied, as demonstrated with reference to sample completed testing procedures – illustrating the benefit of consulting with an experienced practitioner as required.

Keywords: Testing; bridge; bearings; expansion joints; dampers; seismic isolators; durability.

1. Introduction

The proper long-term performance of critical structural components such as bearings, expansion joints, dampers and seismic isolators is vitally important in maximising long-term performance of bridges and other structures in which they are used. It thus plays a significant role in minimising the life-cycle costs of such structures, not only in terms of direct and indirect financial costs resulting from repair and replacement work, but also with respect to the disruption caused to the structure's users during the work [1] [2]. In the case of a bridge's expansion joints, for instance, the initial cost of supply and installation is considered by some authorities to be "insignificant" relative to the future costs of maintenance and replacement should the joints perform poorly [1].

A good way of ensuring that these key components will perform well throughout a long bridge service life is to conduct laboratory testing prior to use, in accordance with national or international standards. It should be noted that, although testing of anti-seismic devices is focused on performance during an earthquake rather than on durability, it is relevant for the life-cycle performance of the bridge infrastructure in which the devices are used as they will help ensure the bridge's survival of such an event, extending its life cycle in this way.

The wide range of testing that may be applied to key structural components is illustrated below with reference to important internationally recognised testing procedures for components of various types.

2. Approaches to testing

Testing of key bridge components can take various forms or approaches, each of which may be most appropriate in certain cases, where permitted by regulations and specifications [3]. First, it can involve testing of full-scale, functioning specimens or of critical individual parts. It can also be carried out on specially produced specimens in a laboratory, or on project-manufactured specimens as installed in a structure. And it can be project-specific, with testing of components that will actually be installed, or can take the form of type testing in accordance with a specific standard, which once completed on a particular specimen may be valid for other specimens of similar design. Such type testing can be very extensive, requiring a lot of time and money.

Unfortunately, another approach to testing is often to ignore it completely. Perhaps due to the costs and challenges associated with testing, or a lack of awareness of the benefits such testing can provide or the appropriate type of testing to specify, an appropriate level of testing is often not required by bridge construction and component procurement contracts. While this may save some initial expense and even reduce delivery time in some cases, the advantages of verifying good performance by such means can far outweigh the costs.

3. Testing of bridge expansion joints

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. Laboratory testing can thus play an important role in ensuring the durability and proper functioning of an expansion joint type/make, especially where this cannot be demonstrated by the supplier based on experience or other means.

Testing of expansion joints is a broad topic, with testing varying widely depending on the type of joint in question. This is illustrated below by reference to testing that relates to two very different types – the large-movement modular joint and the small-movement flexible plug joint.

3.1 Testing of modular expansion joints

The most extensive and demanding testing relating to any type of expansion joint in widespread use today is probably that relating to the modular joint (Figures 1 and 2). The most comprehensive suite of tests [3] is that contained in the Bridge Construction specifications of the American Association of State Highway and Transportation Officials (AASHTO) [4], which includes, in its Appendix A19, specifications for tests as described in Sections 3.1.1 to 3.1.3 below. Section 3.1.4 refers to seismic testing requirements that also find application across the United States and around the world – those of the California Department of Transportation.



Figure 1. The modular expansion joint divides a bridge movement gap into a number of small gaps

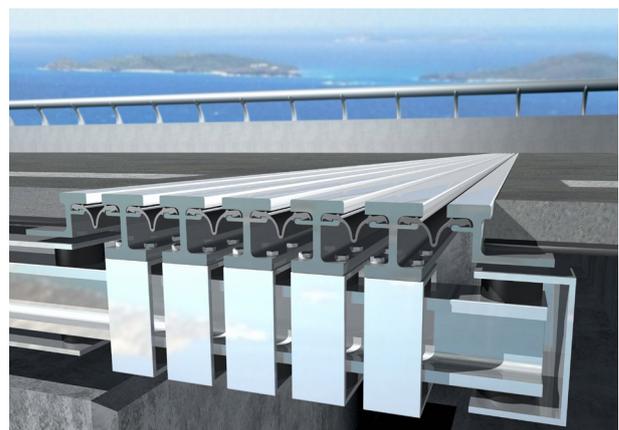


Figure 2. The Tensa-Modular joint has a “single support bar design”, with each support bar supporting all moving “centerbeams” on surface

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

The *Opening Movement & Vibration (OMV)* test (Figure 3) 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 life due to daily thermal cycles (one opening / 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 full duration of the opening movement testing. Inspection of the tested specimen after completion of the test allows the ability of the expansion joint to withstand these principal impacts to be evaluated.

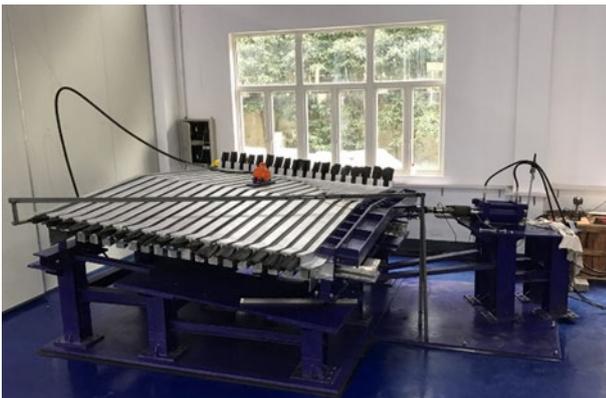


Figure 3. *Opening Movement & Vibration Test*

3.1.2 Testing of long-term seal strength and watertightness

Following completion of the OMV test, the *Seal Push-Out (SPO)* test (Figure 4) is carried out. This test assesses the strength of the connection of the elastomeric seals to the centerbeams that support them, and thus indirectly tests the ability of the joint to remain watertight. 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.



Figure 4. *Seal Push-Out Test*

3.1.3 Fatigue testing

The fatigue testing specified by AASHTO enables the fatigue resistance of critical details in the joint's construction to be determined. 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 (ten data points required) 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; testing of this type of joint over a 16-month period in 2012 and 2013 (Figure 5), for example, verified the fatigue resistance of all details by testing of ten specimens, each subjected to six million load cycles under constant amplitude fatigue loading at a nominal stress range of 110 MPa [5].



Figure 5. *Fatigue testing of Tensa-Modular joint*

3.1.4 Seismic testing

The ability of a particular type/make of modular joint to withstand the high-speed, violent type of movements that can arise in an earthquake may be verified during expansion joint selection by ensuring that the joint type has been successfully subjected to seismic testing. The only currently available internationally adopted guideline for seismic testing of expansion joints is that of California Department of Transportation (CALTRANS) – but even these are not entirely realistic in their simulation of actual seismic ground movements, since they are based on smooth sinusoidal motions rather than erratic seismic ones. Sinusoidal input is appropriate for overall dynamic behaviour identification (stiffness, damping, etc.), but does not provide an accurate identification of the peak force characterisation under seismic ground movements. In fact, some such ground movements result in peak forces that are almost double those resulting from equivalent harmonic (e.g. sinusoidal) inputs. As a result of this shortcoming of the testing protocols, it might be recommended to conduct additional seismic testing using simulated actual earthquake movements. An example of the application of CALTRANS guidelines, with additional testing based on actual recorded movements from major earthquakes and increased movements, is presented in Figure 6. This shows testing in 2010 of a 7-gap joint at the Center for Advanced Technology for Large Structural Systems (ATLSS) at Lehigh University in Pennsylvania. Two series of 17 and 19 tests were carried out, with varying conditions and requirements, as described by Spuler et al [3]. Test No. 15, for instance, consisted of 14 movement cycles with a velocity of 1100 mm/s, with longitudinal movements of 665 mm and transverse movements of +/- 400 mm arising, and with rotations about every axis. These factors varied for the other tests, allowing the performance of the joint during a range of seismic events to be assessed. Following completion of this testing, and after inspection of the joint confirmed that it had not suffered any significant damage, CALTRANS could be satisfied that the expansion joint type met their seismic testing requirements.



Figure 6. Seismic testing of a 7-gap modular joint at ATLSS Center, Lehigh University, PA, USA

3.2 Testing of flexible plug joints

Another type of high-performance expansion joint for which extensive testing applies is the polyurethane (PU) flexible plug joint. The *Polyflex-Advanced* expansion joint (Figures 7 and 8), for example, offers all the benefits of the asphaltic plug joint, including smooth, safe, low-noise surface, great adaptability and easy installation, but offers greatly improved strength, elasticity and durability, resulting in much less maintenance and far more reliable watertightness. The joint's material offers consistent behaviour at both high and low temperatures, and excellent resistance against rutting. And installation is also easier and less prone to error, with the two-component compound being mixed at ambient temperatures.



Figure 7. Modern flexible plug expansion joints of polyurethane (PU) offer far better performance and durability than the traditional asphaltic type

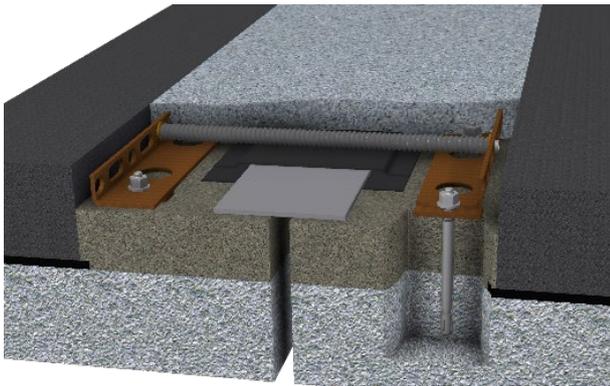


Figure 8. Typical design of a Polyflex-Advanced PU flexible plug expansion joint

Testing of this type of joint may include [6]:

- Testing of bond strength of the material;
- Assessment of ageing and temperature characteristics of the PU material;
- Mechanical resistance testing;
- Fatigue-resistance testing;
- Movement capacity testing;
- Measurement of surface level differences;
- Skid resistance testing;
- Testing of flexible plug material for resistance to ageing etc.;
- Testing for use in very cold climates;
- Testing of resistance to rutting and abrasion.

This testing is clearly entirely different from that associated with expansion joints of the modular type, demonstrating the dependence of applicable testing on the type and design of expansion joint.

4. Testing of bridge bearings

Laboratory testing can also play an important role in the verification, prior to selection and use, of the proper functioning and durability of a structure's bearings. This may be particularly useful or necessary in case of very large bearings, extreme load combinations or special bearing designs. Testing can be used, for example, to verify the results of static design calculations and to confirm that the bearing responds and functions as expected under actual loading conditions. It can also serve to establish the loading limits to which a bearing can be subjected before failure, and the precise failure mechanism that then arises – enabling weak points in the design to be identified

and addressed, and safety factors in case of an earthquake, for example, to be increased.

A key type of test, for all bearing types, is that of a bearing's ability to support/resist the forces, both vertical and horizontal, for which it has been designed. For very large bearings/forces, this can require an enormous test rig such as that shown in Figures 9 and 10.



Figure 9. A large bearing test rig with a vertical capacity of 100,000 kN (external view)



Figure 10. Internal view of the test rig shown in Figure 9, showing ability to apply transverse forces or allow movements

This testing rig was used, for example, to test bearings manufactured in the late 1990s for the Øresund Bridge, which connects Denmark and Sweden – with bearings subjected to vertical test loads of up to 90,000 kN, with simultaneous horizontal forces of up to 10,000 kN or displacements of +/- 200mm also possible.

Apart from such testing of load-bearing capacity and ability to facilitate movements, the testing that may be applied to any particular bearing is strongly dependent on the bearing type. This is demonstrated, for instance, by the European standard EN 1337 [7], which, in harmonising pan-European regulations governing bearing design, quality control and certification [8], defines the testing to which bearings must be subjected, depending on the bearing type. For example, elastomeric bearings must be tested, among other things, for: tensile strength; elongation at break and hardness before and after artificial ageing; minimum tear resistance and compression set; and ozone resistance. As part of the initial certification process, they must also be subjected to a pressure test with 2×10^6 load cycles and an applied stress of 25 N/mm^2 , and the pressure stiffness/pressure modulus before and after must be verified. Of course, tests such as these would not apply e.g. for pot, spherical or disc bearings. An example of the type-specific testing to which a pot bearing might be subjected is presented in Figure 11, which shows low-temperature testing of the restoring moment (rotation stiffness) of the bearing – which depends on that of the rubber pad at its heart.

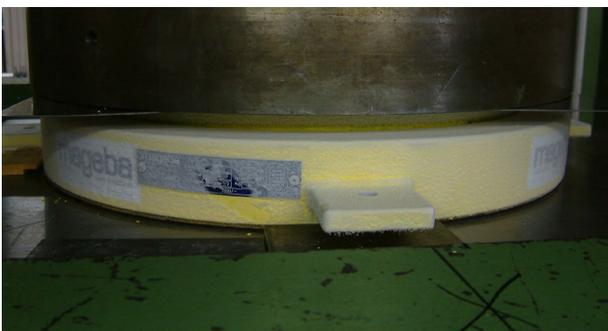


Figure 11. Low-temperature testing of the restoring moment of a pot bearing

Testing may be conducted on an entire bearing, or be limited to specific bearing parts – such as the sliding interface of a sliding bearing in evaluating its ability to accommodate long-term sliding movements, and the friction forces that will be transmitted across the bearing to the supporting structure. An example of the results of such testing, which can apply to sliding bearings of any type, is shown in Figure 12, based on long-term (50 km accumulated sliding distance) performance testing of a particular tribological system at various temperatures.

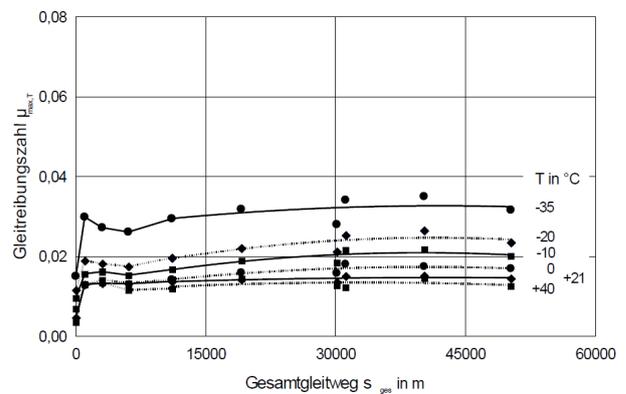


Figure 12. Results from testing of sliding interface design/materials, with Robo-Slide UHMWPE sliding material, at temperatures from -35°C to $+21^{\circ}\text{C}$. The graph correlates friction to accumulated sliding distance (50 km tested)

The comprehensive testing required by EN 1337, or alternative equivalent standards, can thus provide not only a high degree of confidence in a bearing's proper functioning and durability, but also further information which can be of great value in the design of connecting structures.

5. Testing of seismic isolators

In the same way that the European standard EN 1337 introduced a common standard across Europe for structural bearings, the standard EN 15129 [9] introduced a common standard for anti-seismic devices. EN 15129 regulates the design, production quality control, testing and certification of most types of anti-seismic device – including seismic isolators such as Lead Rubber Bearings (LRB), High-Density Rubber Bearings (HDRB) and Curved Surface Sliders (CSS – also known as Pendulum Isolators). This is described by Moor et al [10], while also describing the first testing of any

seismic isolation systems in accordance with EN 15129, at the European Centre for Training and Research in Earthquake Engineering in Pavia, Italy. The successful full-scale testing of two Lead Rubber Bearing isolators (Figure 13) and four Curved Surface Slider isolators (Figure 14) paved the way for certification with the CE label, verifying conformance with the applicable norm.

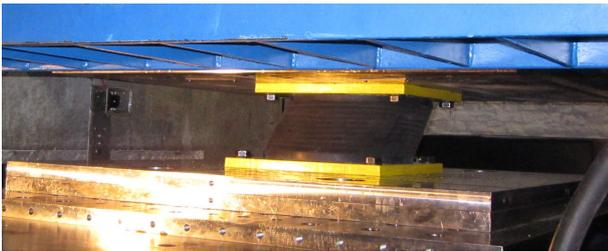


Figure 13. Testing of a lead rubber bearing (LRB) isolator in accordance with EN 15129. Two LRBs were subjected to a total of 28 tests with 74 cycles, with vertical loads ranging between -3450 kN and +1150 kN, and displacements of up to +/- 250 mm at velocities of up to 1.634 m/s



Figure 14. Testing of a curved surface slider per EN 15129. Four isolators were subjected to a total of 64 tests with 192 cycles, with vertical loads of -8000 kN to +1150 kN, and displacements of up to +/- 259 mm at velocities of up to 275 mm/s

As another example, testing of LRBs, at room temperature and at temperatures as low as -30 °C, according to North American standards (AASHTO GSSID [11] and the Canadian bridge design code CAN/CSA-S6 [12]), is described by Mendez et al [13]. An example of a graph showing results from this testing (hysteresis loops correlating force and displacement) is shown in Figure 15.

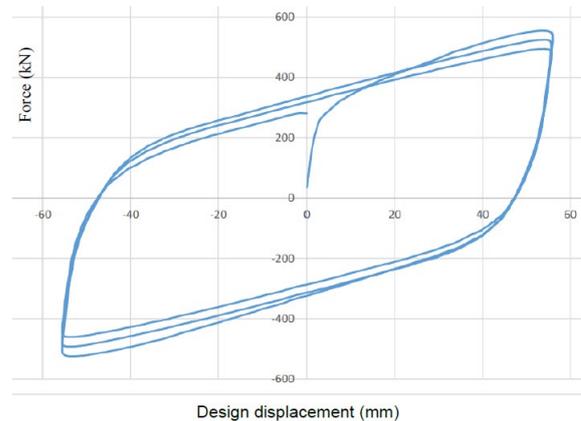


Figure 15. Hysteresis loops from testing of LRB at low temperature of -30 °C

6. Testing of seismic dampers and shock transmission units

The design, quality control, testing and certification of Fluid Viscous Dampers, Fluid Spring Dampers and Temporary Connection Devices (TCDs – more commonly referred to as Shock Transmission Units, STUs) is also governed in Europe by EN 15129 [9]. An example of the application of this code's testing (and design) requirements is provided by Baillés et al [14], in relation to the seismic shock absorbers (dampers) developed for use on the high-speed rail viaducts of the AVE Granada Line in Spain. A representation of the solution is shown in Figure 16, which indicates (circled) the fuse device that was incorporated in the design. Testing of the damper itself is shown in Figure 17; separate testing of the fuse element, also in accordance with EN 15129, was conducted separately.

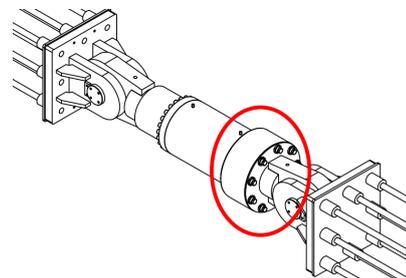


Figure 16. Representation of seismic damper, featuring a fuse device (circled), as developed for the AVE Granada high-speed rail line in Spain



Figure 17. Prototype damper during testing at Politecnico di Milano, Italy

7. Conclusions

Laboratory testing can play a very important role in the lifecycle quality control of new and existing infrastructures, by helping ensure the quality and durability or performance of a structure's key components – such as its bearings, expansion joints and seismic protection devices. Due to the wide range of such devices available, testing requirements can be very varied. But proper consideration should always be given to verifying performance by testing in accordance with comprehensive and applicable standards. While such testing comes at a cost, the advantages of verifying performance in this way can far outweigh the costs. And as well as providing confidence in durability and/or performance, testing can also provide valuable information for use in planning and design work. Due to the complexity of the subject area, it may be helpful to consult with a practitioner with suitable in-depth experience in the application of design and testing requirements.

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