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SMALL-MOVEMENT EXPANSION JOINTS FOR ROAD BRIDGES – MODERN LOW-DEPTH SOLUTIONS THAT OFFER CONSIDERABLE BENEFITS WHEN INSTALLED ON EXISTING STRUCTURES

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Abstract: Considering the repeated need to replace expansion joints in bridge structures, solutions that facilitate relatively easy renovation and replacement, or that are relatively easy to install on an existing structure to replace an expansion joint of another type, are particularly valuable. Two low-depth expansion joint types that fulfil this need are described – one a single-gap joint with steel edge profiles embedded in polymer concrete, the other a polyurethane flexible plug joint. Armed with an understanding of these expansion joint types, bridge owners and engineers will be better able to make informed decisions when selecting and using small movement joints in their structures – especially in relation to minimizing disruption to traffic and impacts on the structure during expansion joint replacement works.

1 INTRODUCTION

A bridge's expansion joints are likely to need to be replaced several times during the bridge's service life, and a very large part of the life-cycle costs relating to a bridge's expansion joints – particularly when considering indirect/consequential costs such as traffic disruption – is due to these replacement works. Replacement of bridge expansion joints today still typically involves a significant amount of demolition and reconstruction of the bridge deck. For example, with reference to Figure 1, installation of the very durable single gap joint shown on the left to replace the old, much less durable joint shown on the right would require breaking out and pouring of concrete. But this can be avoided in many cases. For maintenance of the innumerable number of bridges around the world with low-movement expansion joints, installation-friendly expansion joint solutions are available that can minimize effort, costs and traffic disruption in many cases – primarily by minimizing or avoiding the need to break out concrete of the main structure.

Figure 1: The use of standard robust single gap expansion joints such as that shown on the left to replace low-depth joints such as that shown on the right typically requires breaking out and pouring of concrete

2 THE HIGH COSTS OF EXPANSION JOINT REPLACEMENT WORKS

A bridge's expansion joints are typically among its most important components, but as a result of their main function – to accommodate structure movements and rotations while maintaining a safe and watertight driving surface for traffic – they are generally far less robust than the main structure and thus need to be replaced a number of times during the life of the main structure. The costs of replacement throughout the main structure's life are hugely significant as a proportion of the total life-cycle costs of the bridge's expansion joints, to the point that studies by influential authorities in the United States and the United Kingdom concluded that the initial cost of supply and installation pf a bridge's joints is insignificant in relation to the life-cycle costs of poorly performing joints – especially considering not only the direct financial costs of the work but also the indirect / user costs resulting from traffic diversions and disruption etc. (Spuler et al. 2012).

2.1 The Direct Costs of Expansion joint Replacement

The direct cost to the owner of the replacement works that are required at the end of the service life of a particular joint can be very significant. At any rate, due to the costs of site mobilisation and traffic management, and the limitations on progress imposed by the need to keep traffic flowing on the bridge, the costs are likely to be much higher than the initial supply and installation works that were carried out when the bridge was under construction. The costs of replacing a joint on an existing bridge are estimated by Braun (2011) to be about three times higher than the initial installation costs, when the work is scheduled with pavement renovation activities, or between five and six times higher when the work is carried out on its own. Data from an actual bridge gives a further indication of the magnitude of such costs; in 2006, the direct cost to the owner of the replacement of a single 9-gap modular joint on the Anzac Bridge in Sydney Harbour was "conservatively estimated at 5 million Australian dollars" (Ancich and Chirgwin 2006).

2.2 The Indirect / User Costs of Expansion joint Replacement

The user costs associated with a bridge's expansion joints result primarily from the disruption to traffic that is caused by joint maintenance or replacement works. The assessment of these costs requires the estimation of such factors as the number of vehicles and occupants which will suffer delays, the average length of delays, the cost per hour per vehicle or occupant, and increased fuel consumption. User costs will therefore vary greatly from one structure to another, but an indication of their magnitude is again given by the above-mentioned data relating to the Anzac Bridge in Sydney, where it was estimated that, in addition to the previously mentioned direct costs to the owner, "community savings (associated with traffic disruption, increased travel times, increased pollution, etc.) of 10 million Australian dollars" could be realised by avoiding replacement.

3 MINIMIZING REPLACEMENT COSTS BY MINIMIZING THE AMOUNT OF MAIN STRUCTURE THAT MUST BE REMOVED AND REPLACED

Considering the high costs associated with expansion joint replacement works, as described above, it is clear that in order to minimize the life-cycle costs of a bridge's expansion joints during the life of the bridge, the number of joint replacement exercises required during that life must be minimized – by the use of joints of suitable quality and durability, and appropriate attention to inspection and maintenance activities. But even the best designed and fabricated, most durable expansion joints must be replaced sometimes, so solutions that minimize the effort required when the time comes should be considered.

A major part of the work involved in replacing a bridge's expansion joints is associated with breaking out and removing the existing joint, at least to the extent required to install the new joint. And following this process, and placing of the new joint in the created recess, substantial work and time is generally required to secure the new joint in place, by concreting or welding, and filling the rest of the recess that is not filled by the new joint itself. Where concreting work is required, the installation schedule relies on the availability of concrete and must allow time for the concrete, once poured, to cure before surfacing work such as asphalting can take place.

Considering the time and effort required to carry out this work – and more importantly, the resulting impacts on traffic – it is clear that an approach to expansion joint replacement that minimizes the time and effort required for removal, and for securing the new joint and refilling the created recess, can be very beneficial. In the case of a concrete (or steel) superstructure with asphalt/bituminous surfacing, such as that shown in Figure 1 (right) or Figure 2, a solution that completely avoids the need to break out concrete or steel, and then locally reconstruct the superstructure, can greatly reduce the overall time and effort and the associated impact on traffic. If the new joint requires only removal of existing joint and asphalt within the depth of the asphalt surfacing, as shown in Figure 2, the potential benefits are very substantial.

Figure 2: If installation of a new expansion joint as a replacement for an old existing joint, such as that shown on the left, requires the removal of existing joint/structure only within the depth of the structure's asphalt surfacing, as shown on the right, the work can be substantially accelerated

As an added benefit, the environmental impacts of the work – such as noise, dust, and the additional fuel consumption and exhaust fumes emitted by traffic that is inconvenienced by the work – can also be substantially decreased by solutions that make this possible.

Two examples of such solutions are presented in the following sections.

4 ROBUST SINGLE-GAP JOINTS WITH STEEL EDGE PROFILES EMBEDDED IN POLYMER CONCRETE

Considering the key issues of durability and reliability, robust single gap joints such as the *Tensa-Grip* joint shown in Figure 1 (left) have a great deal to offer and should always be considered for use where small movements arise. However, this type of joint, with its steel anchor loops for concreted connection to the main structure, typically requires breaking out of concrete, and concreting in place, when installed to replace an old joint on an existing structure. The joint type shown in Figure 3, however, has a much lower depth. The steel edge profiles of the joint are anchored in high-strength polymer concrete, which is strong enough to secure the edge profiles of the joint to a suitably prepared concrete substructure without reinforcement. This enables their dimensions, and in particular their depth, to be greatly reduced – so much so, in fact, that this type of joint can typically be installed within the depth of a bridge's asphalt surfacing. This means that considerably less of the existing structure needs to be broken out, resulting in less construction effort, less wastage of materials and less noise. Indeed, breaking out of more than the surfacing may be highly undesirable or impossible in certain cases, for instance where a girder is in the way or where the steel bars of reinforced concrete would need to be cut, weakening the structure. Whatever the existing joint type, it is only necessary to remove the joint to a depth of approximately 60 - 80mm (likely to involve no breaking out of concrete or placing of reinforcement) and ensure a clean, solid subsurface to which the polymer concrete can bond (Figure 4, left).

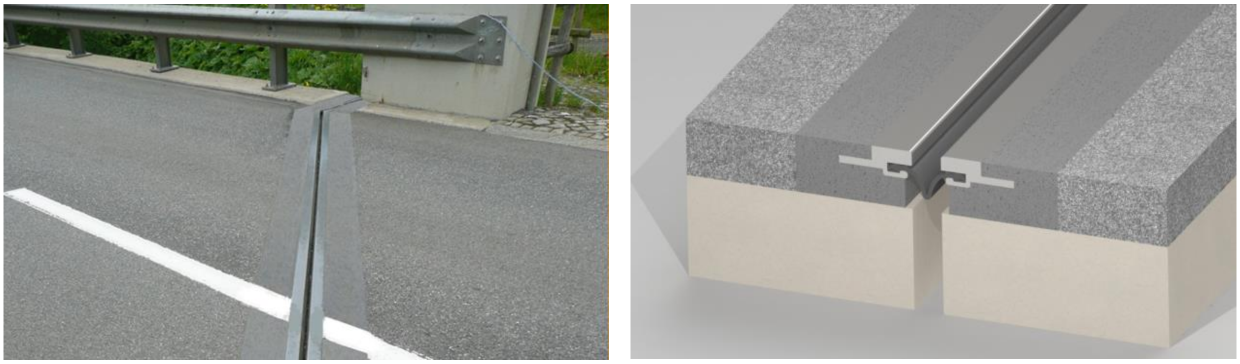


Figure 3: A *Tensa-Crete* single gap expansion joint, with anchorage in high-strength polymer concrete

Figure 4: When installed on an existing structure to replace an old expansion joint, the anchorage in polymer concrete minimises break-out (often requiring only removal of the old joint and asphalt surfacing) (left) – far easier and less disruptive than a joint requiring anchorage in normal concrete (right)

This type of joint can also be equipped with surface plates if desired (Figure 5), reducing noise and vibrations under traffic. Single-gap joints with such surface plates can typically be used to accommodate service movements of up to 100 mm, while joints without surface plates are generally used for movements of up to about 80 mm – depending on the applicable design code.

Figure 5: The type of joint shown in Figure 3 may also be equipped with noise-reducing surface plates, minimizing impacts, vibrations and the resulting noise under traffic

The strength of this type of joint has been proven in testing (Figure 6), with the test specimen featuring noise-reducing surface plates – which introduced moment effects that made the test far more demanding than it would be without surface plates. Fatigue testing of this joint type, which in effect constitutes a cantilever finger joint, is specified by the demanding Austrian standard RVS 15.04.51 (Federal Ministry for Transport, Innovation and Technology, 2010). Having withstood two million load cycles at the specified loading level (with downward and upward forces of 31.6 kN and -9.5 kN respectively), the downward forces were increased incrementally to achieve failure; only after a total of 2.44 million load cycles, with the downward force increased to 110.6 kN, or 3.5 times the specified value, was failure finally reached.

Figure 6: Testing of the joint shown in Figure 3 (incl. noise-reducing surface plates as shown in Figure 5)

In addition to being much stronger than regular concrete, the polymer concrete used also cures very quickly, gaining the strength needed to support traffic loading within a matter of hours (typically 4 to 6 hours, depending on temperature and humidity). As a result of these advantages, the use of this type of joint not only reduces the construction effort and time requirements, but can also reduce to a minimum the impact on traffic using the structure while the works are carried out.

This type of joint maximizes the use of pure steel for strength and durability, without any moving or sliding parts. The strip seal between the steel profiles is more prone to damage but its use is unavoidable, so its suitability must be carefully assessed and its reliability verified. A typical standard “v-shaped” seal is shown in Figures 3 and 7. The correct performance of the seal depends on the precise dimensioning of the extruded elastomer seal and of the recess in the steel beam into which it is inserted. A secure and watertight connection is ensured by five contact points, precisely matching the shape of the recess as shown on Figure 7 (right). This design, without any mechanical fixings, enables the sealing element to be replaced with relatively little effort should the need ever arise.

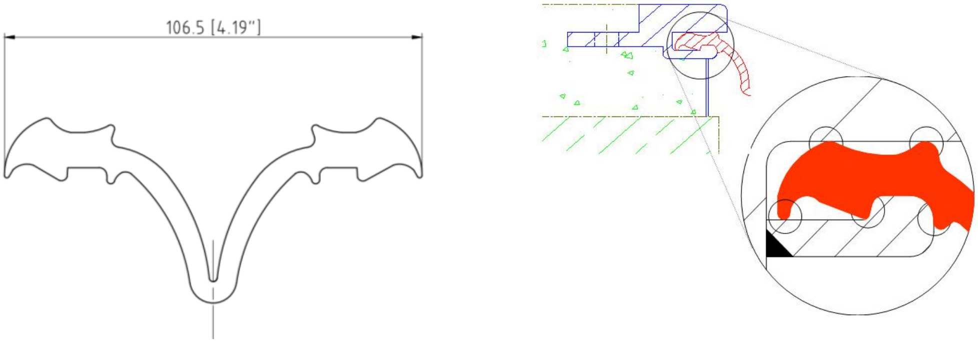


Figure 7: Cross-section (left) of a standard “v-shaped” strip seal of the joint type shown in Figure 3, and the design of its ends (right) – a critical detail in ensuring the strength, reliability and watertightness of the strip seal’s connections to the joint’s steel edge beams

A so-called “hump seal”, which is the same in most respects but features an additional hump, is shown in Figures 5 and 8. The hump is asymmetric and designed to maintain its height as the joint opens and closes, ensuring its effectiveness while never protruding above the driving surface. The hump keeps the joint gap free of dirt and debris, pushing such material up and out each time the joint closes. In addition to providing this self-cleaning service, the hump increases the resistance of the joint to leaks which can result from piercing of the rubber, by providing a second line of defence against such damage. And finally, it fills out the gap, reducing noise under traffic and the difficulties that might be experienced by pedestrians, for example with high heels, as they cross the joint.

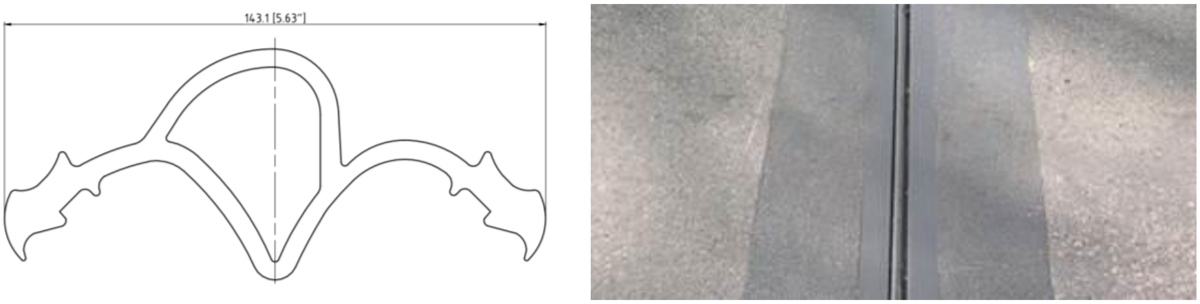


Figure 8: A “hump seal”, similar to the v-shaped seal shown in Figure 7 but featuring an additional hump which fills out the gap – keeping it clean, reducing noise under traffic and increasing pedestrian comfort

As noted above, the elastomeric seal is the part of a single gap joint which is most susceptible to damage or loss of performance (all other parts being solid steel). Two laboratory tests which can be used to verify reliability and performance are described below.

- The Seal Push-Out (SPO) test (Spuler et al. 2011), in accordance with AASHTO LRFD Bridge Construction Specifications (AASHTO 2017), subjects the seal to loading which simulates that which might arise under traffic should the seal become packed with dirt and debris. This test is carried out after completion of an Opening Movement Vibration (OMV) test, in accordance with the same standard, which simulates the daily thermal opening and closing movements, and the vibrations from traffic, of a 75-year service life – and thus tests the strength of the seal and its connections to the steel profiles in a somewhat “weakened” state.
- The watertightness of sealing profiles, again following deformations that introduce an element of durability to the test, can be verified in accordance with German standard TL/TP FÜ (Federal Ministry for Traffic, Construction & Urban Planning, 2005). This involves testing of watertightness after a period of stressing to 120% of design movements in longitudinal and transverse directions.

Through successful testing in accordance with such standards, it can be shown that the “weakest link” in the single gap joint of any particular manufacturer is anything but weak.

5 POLYURETHANE FLEXIBLE PLUG JOINTS – THE MODERN, FAR SUPERIOR ALTERNATIVE TO ASPHALTIC PLUG JOINTS

Flexible plug expansion joints, which create a completely closed, absolutely flat driving surface across a structure’s movement gap, offer various benefits over other small-movement expansion joint types. The continuous, flexible surface results in high driver comfort and very low noise under traffic, while also eliminating discomfort and safety risks for pedestrians and cyclists. Furthermore, the way the joints are constructed, by pouring freshly mixed material in situ, facilitates transport and handling and makes expansion joints installable in sections, lane by lane, with any desired shape or longitudinal profile (e.g. with intersections or upstands).

Figure 9: The *Polyflex-Advanced* polyurethane flexible plug joint offers numerous advantages over plug joints of the traditional asphaltic type, including strength, durability and geometric flexibility

However, flexible plug expansion joints made from traditional asphaltic materials have long been plagued with durability problems, especially at low or high temperatures. Inconsistent quality due to improper mixing and incorrect temperature during installation (high temperatures required) also frequently cause problems. To overcome such shortcomings while retaining the aforementioned benefits, the design of the flexible plug expansion joint has been optimized, utilizing superior materials and incorporating improved support and connection details. This type of expansion joint, as shown in Figure 9, is described below.

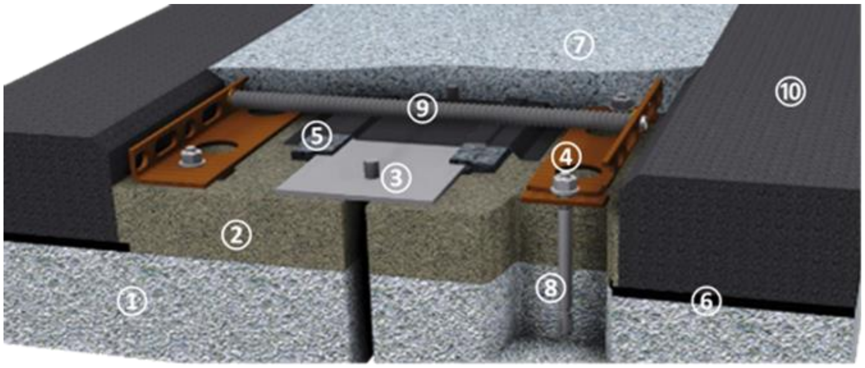
5.1 Design and Characteristics of the PU-based Flexible Plug Joint

Instead of the asphaltic material traditionally used to form the driving surface of flexible plug expansion joints, this modern flexible plug expansion joint uses a specially selected, solvent free, highly durable polyurethane (PU) material. The PU material originally used, which was adapted for road expansion joint requirements, had a long history of use as waterproofing for roofs, and has been constantly improved over the years. The material has shown test values of 650% elongation before breaking (compared to 350-400 % for standard rubber), which enhances durability and makes the material an ideal choice for use in expansion joint systems.

With perforated steel support elements incorporated in the design (Figure 10), the joint can withstand long-term traffic loading and braking and reaction forces while accommodating significant structure movements, at both very low and very high temperatures. Total movements of up to 100 mm (4 inches) have been accommodated on various bridges in several countries in successful operation since 2007.

In addition to its exceptional elasticity, the special PU material used offers enormous tear resistance, with a tear strength of 20 N/mm². It typically has a tensile strength of 14 N/mm², a density 1.05 g/cm³ and a Shore A hardness of approximately 65. It is highly resistant to wear and environmental and chemical influences, and thus offers an exceptionally long lifespan. In fact, its service life is typically substantially longer than that of connecting roadway surface materials.

The joint is fully functional in the temperature range –50°C to 70°C (–58°F to 158°F) – a major improvement over asphaltic plug joints. It is also very versatile, with virtually any common joint shape possible – e.g. with upstands (Figure 9), skew angles and T-shaped or X-shaped junctions.



1 Main structure
2 Polymer concrete base
3 Bridge plate across gap
4 Perforated steel angle
5 Sponge rubber
6 Bridge waterproofing
7 Special PU material
8 Anchoring
9 Stabilizing bar if needed
10 Road surfacing

Figure 10: Illustration showing the main elements of the described PU flexible plug expansion joint

Installation is relatively easy, compared not only to asphaltic plug joints but also to expansion joints of other types. With no large, heavy parts, lifting plant is not required, and the poured material adapts to suit the dimensions of the prepared recess. The two-component PU material is mixed from complete packing units at ambient temperatures, minimizing the risk of suboptimal mixing and installation. Processing is possible at temperatures from 5 °C to 35 °C (41 °F to 95 °F), virtually independent of humidity, and the curing time is relatively short, depending on temperature – e.g. just a few hours in warm conditions.

In the context of bridge maintenance, in particular – when the joint is installed to replace an existing one – the benefits of the joint's use are even more pronounced. The joint can typically be laid within the depth of a bridge's asphalt surfacing, avoiding the need to break out any concrete etc. With only minimal amounts of an existing structure to be removed, and quick installation and short material curing times, the new joint can be installed quickly, economically and reliably. The speed of installation (e.g. with a joint fully replaced and trafficable within a day) minimizes impacts on traffic. If required, impacts on traffic can be further reduced by installing the new joint lane by lane. In phased installation, the already cured PU material of a previous stage is chemically reactivated by the fresh material, creating a high-strength bond. The same chemical reactivation of previously cured PU material also enables minor damage to an existing polyurethane joint to be easily repaired, simply by pouring fresh material onto the damaged area.

5.2 Installation of the PU-based Flexible Plug Joint

The installation of a PU flexible plug expansion joint of the type referred to above to replace an existing joint is described below. The recess is prepared by removing as much of the existing structure as is necessary to create the minimum space required while ensuring an adequately strong, stable structure to which the new joint's materials can bond and transfer forces (Figure 11, left).

The recess is then sandblasted as required to ensure proper adhesion of the expansion joint materials, and cleaned. Where applicable, deck waterproofing membrane can be extended into the recess, enabling a watertight connection to be created.

Formwork is then placed as required to retain the poured material. This may simply take the form of a sheet of Styrofoam® or similar, placed in the bridge gap. As appropriate, a suitable primer is then used to ensure proper bonding and polymer concrete is poured to form the base (Figure 11, right).

Figure 11: Removal of old joint/surfacing as needed (left) and forming of polymer concrete base (right)

The recommended *Robo-Flex* polymer concrete cures naturally, requiring only protection from the elements and from damage. Curing time depends on ambient temperature (at 15°C, approx. one hour). The supplied steel angles are anchored to the prepared surface at each side of the movement gap (Figure 12, left), and the supplied coverplate is placed across the gap. When all is prepared and confirmed, with the recess free of debris etc., the PU material can be poured and precisely levelled to the final level of the connecting surfacing (Figure 12, right).

Figure 12: Fixing angles to polymer concrete base (left) and precise levelling to road surface (right)

5.3 Testing of the PU-based Flexible Plug Joint

5.3.1 Testing in Connection with the Awarding of a European Technical Approval (ETA)

In advance of the awarding of a European Technical Approval, with validity across the European Union, extensive testing and certification was carried out by the *Bundesanstalt für Materialforschung und –prüfung* (BAM), Berlin, by the *Prüfamt für Verkehrswegebau* of the Technical University of Munich (TUM), and by the MAPAG testing institute, Austria. The individual tests conducted included:

- Testing of Bond Strength of the PU Material
- Mechanical Resistance Testing
- Fatigue Resistance Testing
- Movement Capacity Testing
- Watertightness Testing
- Measurement of Level Differences in the Surface
- Skid Resistance Testing
- A rutting test (see below)

Testing was also carried out on the joint's components to establish durability characteristics as follows:

- Resistance to chemicals such as oil, fuel and de-icing agents per EN ISO 175
- Temperature-based ageing: Extreme-temperature tests according to ISO 4664 and EN 13687
- Ageing resulting from UV-radiation and weathering: Long-term tests to TR010
- Ageing resulting from ozone: Test according to ISO 1431
- Freeze-thaw test to EN 13687 Part 1

Details of the main tests are provided by Moor et al (2018). For example: The rutting test was carried out, at 60°C, in accordance with EN 12697-22. The pictures in Figure 13 show the enormous difference in performance between traditional asphaltic plug joint material and the PU material of the described expansion joint.

Figure 13: Comparison of flexible plug materials after rutting test per EN 12697-22 at 60°C.
(Left: Common asphalt plug after 100 cycles. Right: PU material of described joint after 30,000 cycles)

As a result of this testing, the expansion joint was awarded a European Technical Approval (ETA). This ETA covers joints of this type that accommodate SLS movements of up to 135 mm, with a thickness of 60 mm and an initial width of 1100 mm. All types are designed for a vertical displacement of +/- 10 mm, permitting bridge bearing replacement work to be carried out without damaging the joint.

5.3.2 Additional Testing for Cold Climates

Since the use of spiked tyres in winter driving conditions is still common in some areas, testing was carried out, at the VTI-Linköping testing institute in Sweden, to verify resistance to such demands. The test was performed in June 2015 according to EN 12697-16A, and demonstrated excellent resistance, with an abrasion value of AbrA = 0.1 to 0.2 ml. By comparison, traditional asphaltic surfacing with a value of less than 20 ml would be classified as "very good".

6 CONCLUSIONS

For maintenance of the innumerable number of bridges around the world with low-movement expansion joints, installation-friendly expansion joint solutions such as the single gap joint with steel edge profiles bedded in polymer concrete, and the modern flexible plug joint with polyurethane (PU) surface, enable demolition and reconstruction of the connecting superstructure to be completely avoided. Since both of these expansion joint types can typically be installed within the depth of a structure's road surfacing (e.g. asphalt or similar), installation of either type typically does not require partial breaking out of superstructure concrete or steel, or reconstruction thereof, and impacts on deck waterproofing can also be avoided. The old expansion joint is simply removed to the extent required to make space for the new joint, a suitable bedding surface is ensured/created as necessary, and the new joint is poured/installed. As well as minimizing impacts on the main structure, which is generally preferable and sometimes very important, and minimizing environmental impacts of the work, this greatly reduces the time required for the replacement project and thus minimizes the cost to the owner and disruption to traffic. Careful consideration of these issues when choosing expansion joints can thus by very beneficial – for the owner, for the environment, and for the bridge users who would be inconvenienced by avoidable repair and replacement activities.

REFERENCES

AASHTO (American Association of State Highway and Transportation Officials). 2017. *LRFD Bridge Construction Specifications, 4th ed.*, Washington, USA.

Ancich, E. and Chirgwin, G. 2006. Fatigue Proofing of an In-service Modular Bridge Expansion Joint, *Proc. 6th World Congress on Joints, Bearings & Seismic Systems for Concrete Structures*, Halifax, Nova Scotia, Canada.

Braun, C. 2011. Die Differentialbauweise in Brückenbau. *Brückenbau Construction & Engineering, Issue 1 – 2011*, Verlagsgruppe Wiederspahn, Wiesbaden, Germany.

Federal Ministry for Traffic, Construction & Urban Planning. 2005. *Technical delivery and inspection specifications for watertight expansion joints of road and foot bridges* (German specification TL/TP-Fü). Bonn, Germany.

Federal Ministry for Transport, Innovation and Technology. 2010. *Austrian specification RVS 15.04.51 – Bridge Equipment - Expansion Joints*. Vienna, Austria.

Moor, G., Baillés, B. and Pakniat, P. 2018. Modern flexible plug expansion joints with polyurethane surface – Far superior to the traditional asphaltic type. *10th International Conference on Short and Medium Span Bridges*, Quebec City, Quebec, Canada.

Spuler, T., Ancich, E., Savioz, P. and O'Suilleabhain, C. 2011. Developments in modular expansion joint technology – codes and testing in Australia, America and Europe. *Proc. 8th Austroads Bridge Conference*, Sydney, Australia.

Spuler, T., Loehrer, R. and O'Suilleabhain, C. 2012. Life-cycle considerations in the selection and use of bridge expansion joints. *Proc. 18th IABSE Congress*, Seoul, South Korea.