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MODERN FLEXIBLE PLUG EXPANSION JOINTS WITH POLYURETHANE SURFACE – FAR SUPERIOR TO THE TRADITIONAL ASPHALTIC TYPE

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Abstract: A new, much improved type of flexible plug expansion joint has been developed, with a polyurethane surface, which offers a number of substantial advantages over the traditional bituminous type. It offers all the benefits of the asphaltic plug joint – including smooth, safe, low-noise surface, great adaptability and easy installation. However, it overcomes the numerous disadvantages and challenges that have always plagued asphaltic plug joints. It offers greatly improved strength, elasticity and durability, resulting in much less maintenance and far more reliable watertightness. Installation is far easier and less prone to error, with the two-component compound being mixed at ambient temperatures. For these reasons and others, this type of joint should be considered for use in bridge construction where low-movement expansion joints are needed, and, in particular, in bridge maintenance.

1 INTRODUCTION

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 1: A Polyflex-Advanced flexible plug expansion joint

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 (non-asphaltic) materials and incorporating improved support and connection details. The result – the Polyflex-Advanced expansion joint (Figure 1) – is described below.

2 DESIGN AND CHARACTERISTICS OF THE PU-BASED FLEXIBLE PLUG JOINT

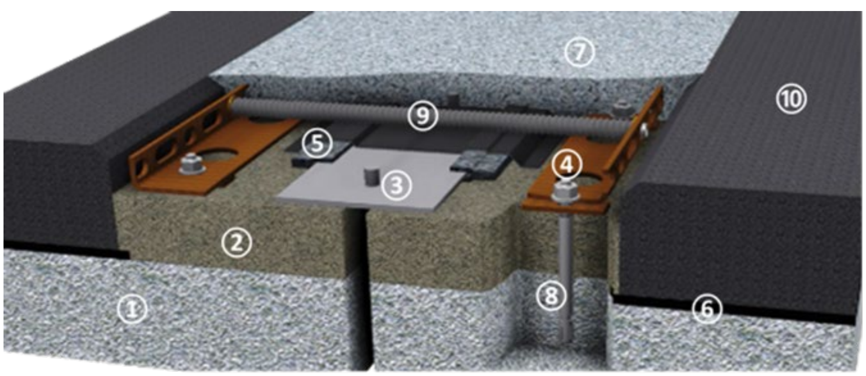
Instead of the asphaltic material traditionally used to form the driving surface of flexible plug expansion joints, this modern flexible plug expansion joint uses a specially selected, solvent free, highly durable polyurethane (PU) material.

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 2), 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 in several countries on various projects 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 3), 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 2: 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.

Figure 3: Upstands can be easily created

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 replaced during a night shift), with new joints being trafficable within just a few hours in warm conditions, 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.

3 INSTALLATION

The installation of a PU flexible plug expansion joint of the type described 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 to ensure an adequately strong, stable structure to which the polymer concrete base material can bond and transfer forces (Figure 4).

Figure 4: Removal of old joint/surfacing as needed

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 (Figure 5).

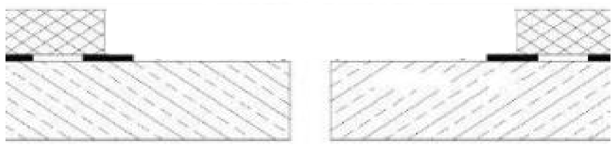


Figure 5: Arrangement of ends of waterproofing membrane in recess

Where a suitable base must be created (in the absence of an appropriate surface following breaking out of the old joint), formwork is then prepared to retain the fresh base material. This may simply take the form of a sheet of Styrofoam® or similar, placed in the bridge gap. A suitable primer is then used, if necessary, to ensure proper bonding, and polymer concrete is poured to form the base (Figure 6).

Figure 6: Forming polymer concrete base

The recommended *Robo-Flex* polymer concrete (if required) 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 7), and the supplied coverplate is placed across the gap.

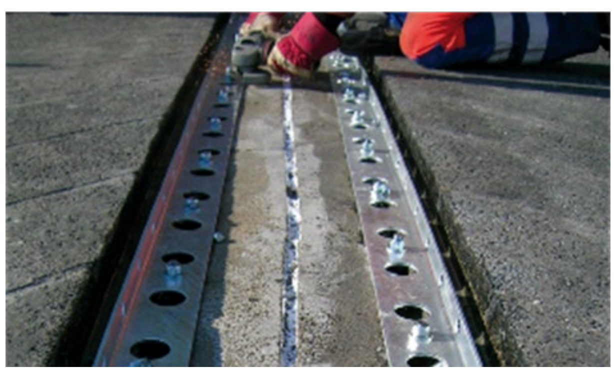


Figure 7: Fixing angles to polymer concrete base

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 8).

Figure 8: Precise levelling of material to road surface

4 TESTING IN CONNECTION WITH AWARDING OF EUROPEAN TECHNICAL APPROVAL (ETA)

In connection with 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.

4.1 Testing of bond strength of the PU material

The tests included verifications of bond strength on various surfaces such as concrete, polymer concrete, steel and asphalt. The recorded values were very high, even at low temperatures, demonstrating excellent resistance to de-bonding and thus also excellent resistance to leaking.

4.2 Assessment of ageing and temperature characteristics of the PU material

The ageing and temperature characteristics of the PU joint filling mixture were evaluated at the BAM institute in Berlin, after ageing for 3030 hours (Figure 9). The evaluation, based on ISO 4664, was carried out at temperatures of -60°C to +250°C. Both the complex modulus |G*| and the loss factor tan δ demonstrate very good dynamic mechanical behavior for the declared temperature range of -40°C to +60°C.

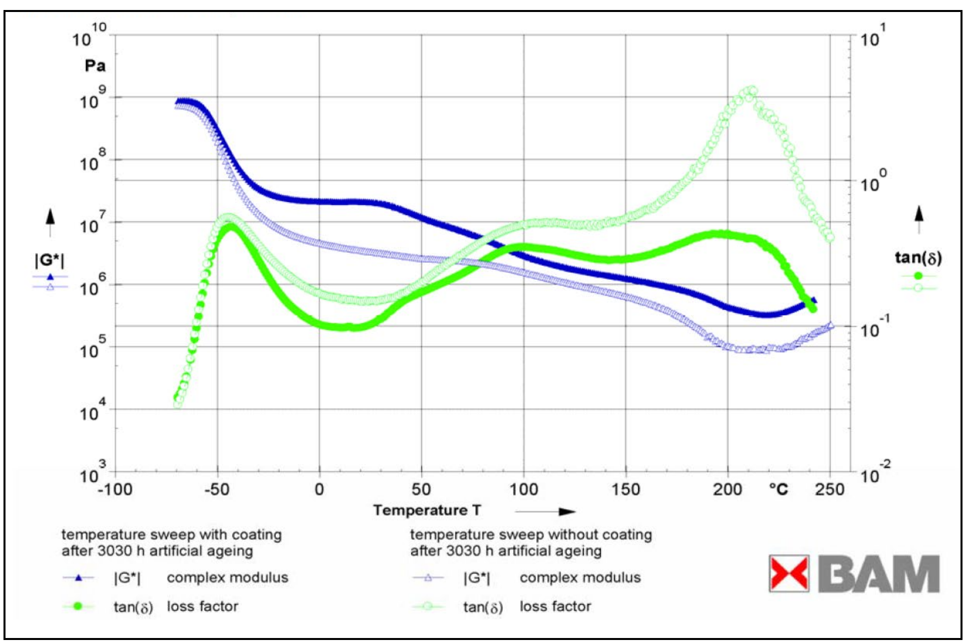


Figure 9: Assessment of temperature characteristics of the PU joint filling mixture at BAM institute, Berlin

4.3 Mechanical resistance testing

At the TUM institute in Munich, a full-scale assembled joint specimen, in the maximum opening position, was subjected to a test load of 150 kN via a pneumatic tyre (Figure 10). The contact pressure was 0.94 MPa, the temperature was 23°C and the specimen length was approximately 1 m. The test was carried out in accordance with the Austrian standard RVS 15.04.51 and the appropriate European Technical Approval Guideline (draft ETAG 032, Part 3, Annex 3M Method a), and recorded deformation after loading and any subsequent recovery curve. In the test, deformations of max. 0.5 mm were recorded immediately after unloading, and within one hour of unloading, a complete elastic recovery of the surface had occurred, with no damage detected.

Figure 10: Mechanical resistance testing

4.4 Fatigue resistance testing

A second full-scale joint specimen was then subjected to further testing at TUM, Munich. The test involved repeated rolling over by a pneumatic wheel, at an elevated temperature of 45°C, in accordance with draft ETAG 032, Part 3, Annex 3M Method b. The contact pressure of the pneumatic tyre was 1.0 MPa, and the number of overpasses was 3030, with 30 of these executed with an additional 10% of horizontal load to simulate braking forces. After the test, no de-bonding or cracking was observed, and the test was passed, with only temporary 0.5 mm deformations under full loading. On the basis of experience in Europe with the same testing procedure for asphaltic plug joints and various national regulations, this successful high-temperature testing would support a 15-year service life categorization.

In addition, a rutting test was carried out, at 60°C, in accordance with EN 12697-22. The pictures in Figure 11 show the enormous difference in performance between traditional asphaltic plug joint material and the PU material of the described expansion joint.

Figure 11: 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)

4.5 Movement capacity testing

To evaluate the movement capacity of the full-scale joint specimen, a test was performed at the BAM institute in Berlin, in accordance with draft ETAG 032, Part 3, Annex 3N. The complete declared movement range, from maximum elongation to maximum compression, was tested, with temperature varying synchronously to the relevant deformation state between -40°C and +60°C. During the test, reaction forces and deformations were recorded.

The specimen was also subjected to 7,500,000 sinusoidal cycles, with an amplitude of 1 mm, at ambient temperature and a frequency of 5 Hz. In addition, dynamic properties were voluntarily tested at -40°C. The dynamic behaviour of the material was shown to be excellent, with the specimen showing no irregularities or signs of fatigue after the testing.

4.6 Watertightness testing

After successfully passing the aforementioned movement testing, the specimen was subjected to a watertightness test at the BAM institute in Berlin. At the maximum opening position of the joint, water was applied to a level of 30 mm above the highest point of the joint and maintained at that level for six hours. After the test, no signs of leakage could be found under the specimen.

4.7 Measurement of level differences in the surface

The flatness of the specimen was checked prior to the above-mentioned tests, to verify that any deviations in surface level from an ideal connection line between the pavement at each side (in the unloaded condition) are not greater than 5 mm – in accordance with the Austrian standard RVS 15.04.51 and the relevant ETAG. After loading, greater deviations are permitted, but these must not exceed 10 mm. Verification checks were carried out, both during and after the previously described fatigue and movement tests. The results were positive, with a maximum level increase of +6 mm and a maximum level decrease of -5 mm being recorded. See Figure 12.

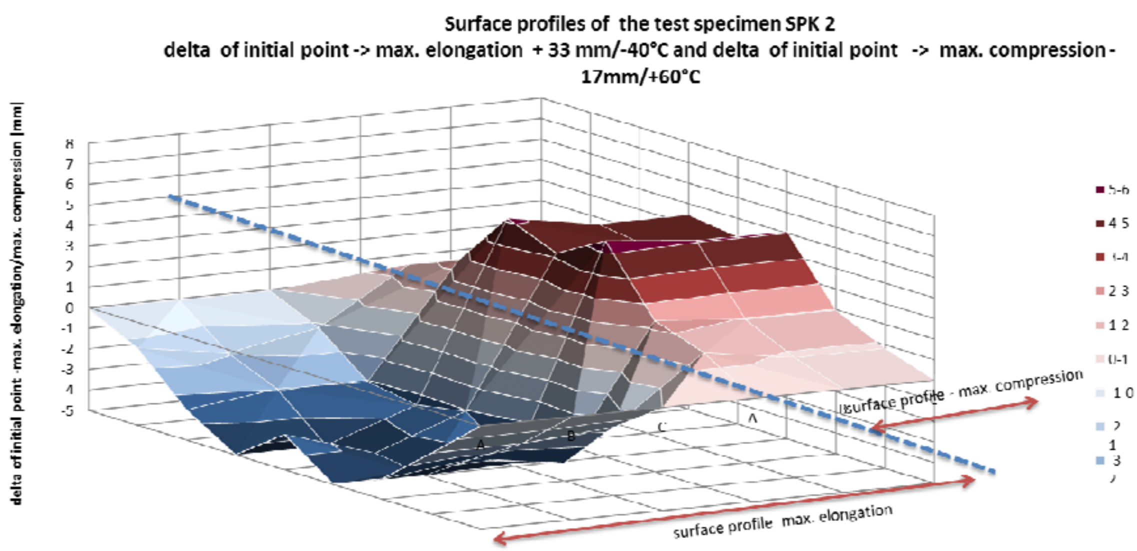


Figure 12: Measurement of deviation from ideal connection line across joint in maximum opened and maximum closed position, at the BAM institute, Berlin

4.8 Skid resistance testing

The full-scale specimen was subjected to skid resistance testing with a portable skid resistance pendulum tester as described in EN 13036-4, using the CEN rubber slider for carriageways and the 4S rubber slider for footpath areas.

4.9 Further testing

Testing was 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: Various tests according to EN 13687 Parts 2, 3 and 5
- 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

4.10 Resulting European Technical Approval

As a result of this testing, the expansion joint has been 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 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 APPLICATION EXAMPLES

6.1 Welland Canal Lock 2 Road Bridge

The Welland Canal connects two of North America's great lakes, Lake Ontario and Lake Erie. It has eight locks, which enable the level difference of approximately 100 m between the two lakes to be negotiated in safety. A bridge at Lock 2 carries Niagara Regional Road 83 across the canal, with one section of the bridge rising when required to allow ships to pass as they transport roughly 40 million tonnes of cargo along the canal. During a major bridge renewal project in 2017, new PU flexible plug expansion joints of the type described, for SLS movements of 30 mm, were installed at four structure axes. A typical cross section, for the carriageway section of several joints, is presented in Figure 13. This shows how the polymer concrete base of just 30 mm thickness connects to the bridge deck's waterproofing membrane, easily and reliably ensuring watertightness beyond the extents of the expansion joint itself.

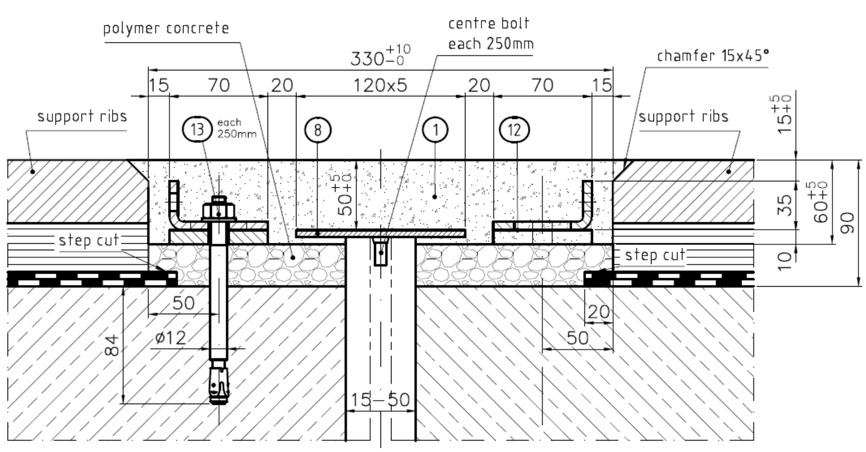


Figure 13: Cross section of new PU-type carriageway joint at Welland Canal Lock 2 Road Bridge

6.2 Kugelstein Railway Bridge, Austria

The use of polyurethane flexible plug joints is not by any means confined to road bridges and pedestrian/cyclist areas – they also find application in railway structures, as demonstrated by the installation of this type of joint in the recent renovation of the Kugelstein Bridge in Austria. As shown by the cross section in Figure 14, the PU joint is covered by a standard railway bed protection mat, and connects with the superstructure's waterproofing membrane. A key reason for the selection of this type of joint – apart from its durability, ease of installation and so on – was its great adaptability in forming joints of different shapes, e.g. with vertical upstands as shown in Figures 15 and 16.

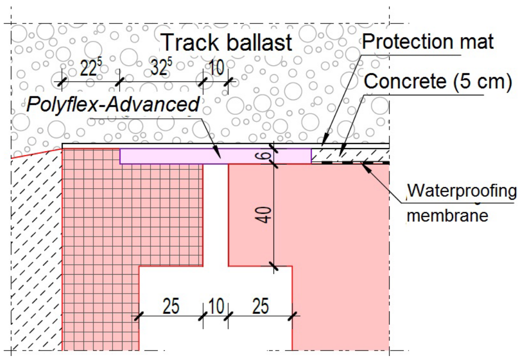


Figure 14: Cross section of railway joint (dimensions in cm)

Figure 15: PU flexible plug joint as placed, showing formwork for upstand at one end

Figure 16: Upstand at end of railway joint following removal of formwork and placing of protection mat (black) and track ballast (stones)

This project represents a vote of confidence – well founded to date – in this joint type by the Austrian railway authorities, considering the high level of reliability demanded of products used in railway bridges due to the great disruption to rail traffic that would be associated with the premature replacement of an expansion joint beneath an important railway track.

6.3 Henry Hudson Parkway, New York – 95th Street Off-Ramp

A project was implemented for New York City Department of Transportation (NYCDOT) in late 2014, with the replacement of an old small-movement expansion joint at the 95th Street off-ramp (southbound) of the Henry Hudson Parkway in Manhattan's Upper West Side. The joint, of the type described in this paper, was installed in two phases: One lane in November and the second a month later (see Figure 17). The same program was followed for both lanes. On the first day, the traffic lane was closed in the morning and the old joint was removed, and then the surfaces were sandblasted and the steel angles and anchors were installed. The next day, the special PU material was poured and levelled, and the lane was opened to traffic in the afternoon. Considering the cold temperatures due to the time of year and the resulting longer curing time required, steel plates were placed across the joint to protect the still-curing material during the first hours of service. Subsequent inspections have shown that the joint has performed very well under traffic, with no signs of wear and tear or ageing (Figure 18).

Figure 17: Existing expansion joint after removal of one particularly deteriorated section

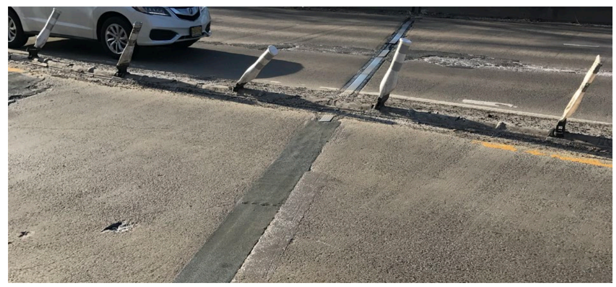


Figure 18: After two years in service on this very busy road, the new joint is still in perfect condition

7 CONCLUSIONS

The Polyflex-Advanced expansion joint, with its flexible polyurethane surface, offers all the benefits of the traditional asphaltic plug joint, but with greatly improved strength, elasticity, durability and reliability, and further advantages such as greater movement capacity, uniform material behavior at very high and very low temperatures, and easier installation at ambient temperatures. The speed of installation and curing of the material is particularly beneficial when the joint is installed on an existing structure to replace an old expansion joint. This modern plug-type expansion joint is thus likely to be increasingly used in the years to come in the construction and maintenance of bridges and tunnels.

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