Flexible plug expansion joints – Benefits of polyurethane versus bituminous

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Abstract

A 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. The *Polyflex®Advanced* expansion joint offers all the benefits of the asphaltic plug joint, including smooth, safe, low-noise surface, great adaptability and easy installation. However, it overcomes 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 also far easier and less prone to error, with the two-component compound being mixed at ambient temperatures. For these reasons and others, this joint should be considered for use in bridge construction and, in particular, in bridge maintenance.

Keywords: flexible plug expansion joint; polyurethane; non-bituminous; installation; maintenance; replacement; durability; ETAG 032.

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 unsurpassed driver comfort and extremely 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 expansion joint

However, flexible plug expansion joints made from traditional bituminous materials have long been plagued with durability problems, not performing as well, long term, as joints manufactured primarily from steel in factory conditions. Continuous dynamic loading and braking/acceleration forces from vehicle wheels, year after year, cause stresses in the material, resulting in cracking, loss of watertightness and general deterioration – impacts that would only be exacerbated by improper preparation on site and incorrect temperature during installation (typically approx. 180 °C / 350 °F required).

To overcome these shortcomings while retaining the aforementioned benefits, the design of the flexible plug expansion joint has been optimized, utilizing superior (non-bituminous) materials and incorporating improved support and connection details. The result – the *Polyflex®Advanced* expansion joint (Figure 1) – is described below.

2 History and background

Traditional bitumen-based flexible plug expansion joint materials suffer from several disadvantages. At low temperatures, for instance, the material used is generally very stiff, causing de-bonding and resulting in leaking, while at high temperatures, the material becomes weak and tends to deform plastically. Inconsistent quality due to improper mixing and incorrect temperature during installation (high temperatures required) also frequently cause problems. As a result of such disadvantages, asphaltic plug joints are subject to various limitations. For example, they should generally not be installed in highways and locations with frequent acceleration and braking, such as in the vicinity of bus stops, traffic lights etc., and they should not be used in railway bridges under stone ballast. And in general, the functionality and durability of asphaltic plug joints has often been found from experience to be unreliable.

In Switzerland, investigations carried out in cooperation with EMPA (the Swiss Federal Laboratories for Materials Science and Technology) showed that the bitumen quality being used for such joints varied considerably, with substantial effects on joint functionality and durability. Small changes in the chemical composition of the raw materials led to big reductions in expansion joint quality. As a result, construction project clients and expansion joint manufacturers became increasingly concerned about the ongoing suitability of the systems for use. A demand developed for a flexible plug system using plug material that could be produced by the expansion joint supplier, or that could at least be acquired from a materials supplier in the required quality.

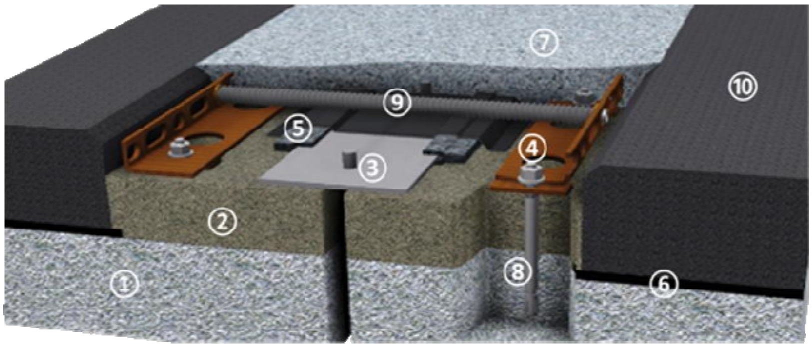
3 Design and characteristics of the PU-based flexible plug joint

Instead of the bituminous material traditionally used to form the driving surface of flexible plug expansion joints, the *Polyflex® Advanced* 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/mm^2. It typically has a tensile strength of 14 N/mm^2, a density 1.05 g/cm^3 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.



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 a typical Polyflex®Advanced expansion joint

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. Due to its good performance at low temperatures, the material can be used in very cold climates. 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 (Figure 4).

Figure 3. Upstands can be easily created

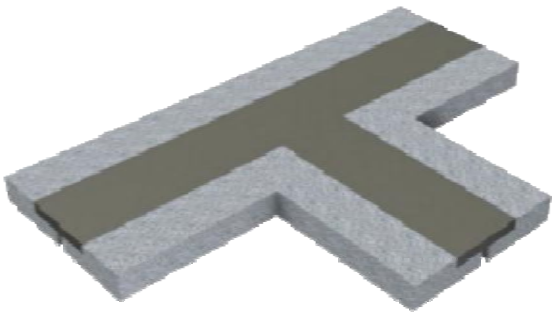


Figure 4. Junctions such as T- or X-shape possible

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 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.

3.1 Summary of advantages and benefits

- Exceptional long working life, longer than adjacent surfaces
- Highest possible driver comfort
- No noise from crossing traffic due to surface that is flush with adjacent road
- Watertight
- Maintenance-free (no cleaning required)
- Quickly installed lane-by-lane with minimal impact on traffic, quick curing
- Installation within a wide temperature range (5°C to 35°C / 41°F to 95°F)
- Wear-resistant, no mechanical wear parts
- No rutting, high resistance to abrasion (e.g. from braking traffic)
- Damage to the joint can be easily repaired by reactivation of the PU material
- No recess for anchorage in structural concrete necessary
- Surfacing (asphalt or concrete) can be applied continuously before joint installation
- Any horizontal bend in the joint possible
- Any curb / sidewalk detail possible
- Low reaction forces
- Cold processing and easy handling with preset mixing ratio minimizes risk of mixing errors
- Resistant to environmental influences and acids, bases, chlorides, etc.
- Smooth surface ideal for pedestrian areas (e.g. in airports and railway stations)

4 Installation

The installation of a *Polyflex®Advanced* expansion joint 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 (Figures 5 and 6).

Figure 5. Cutting of surfacing across the joint

Figure 6. 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 7).

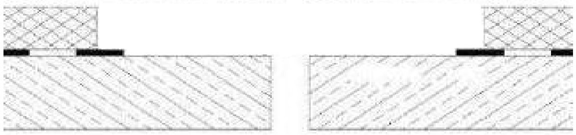


Figure 7. Arrangement of ends of waterproofing membrane in recess

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 (Figure 8) and polymer concrete is poured to form the base (Figure 9).

Figure 8. Application of primer to substructure

Figure 9. 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 surface of the prepared surface at each side of the movement gap (Figure 10), and the supplied coverplate is placed across the gap, centred above it, as shown in Figure 11.

Figure 10. Fixing angles to polymer concrete base

Figure 11. Fixing of angles, and plate across 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 (Figures 12 and 13).

Figure 12. Placing of PU material

Figure 13. Precise levelling of material to road surface

5 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.

5.1 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.

5.2 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 14). The evaluation, based on ISO 4664, was carried out over a temperature range from -60°C to + 250°C. Both the complex modulus |G*| and the loss factor tan δ demonstrate very good performance for the declared temperature range of -40°C to +60°C.

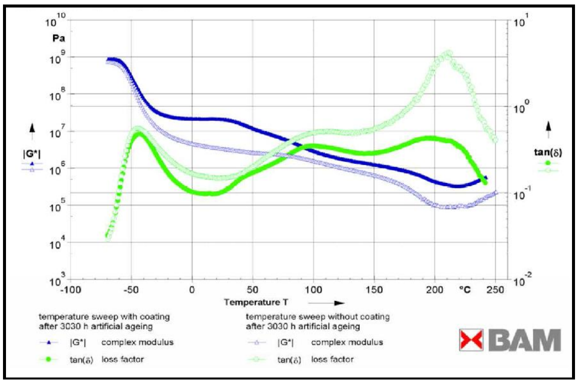


Figure 14. Assessment of temperature characteristics of the material at the BAM institute

5.3 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 15). 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 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 15. Mechanical resistance testing

5.4 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.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 16 show the enormous difference in performance between traditional asphaltic plug joint material and the *Polyflex® Advanced* material.

Figure 16. Comparison of flexible plug joint materials after rutting test acc. to EN 12697-22 at 60°C (Left: Common asphalt plug material after 100 cycles. Right: Polyflex® Advanced after 30,000 cycles)

5.5 Movement capacity testing

To evaluate the movement capacity of the full-scale joint specimen, a test was performed at the BAM institute in Berlin (Figure 17), 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.

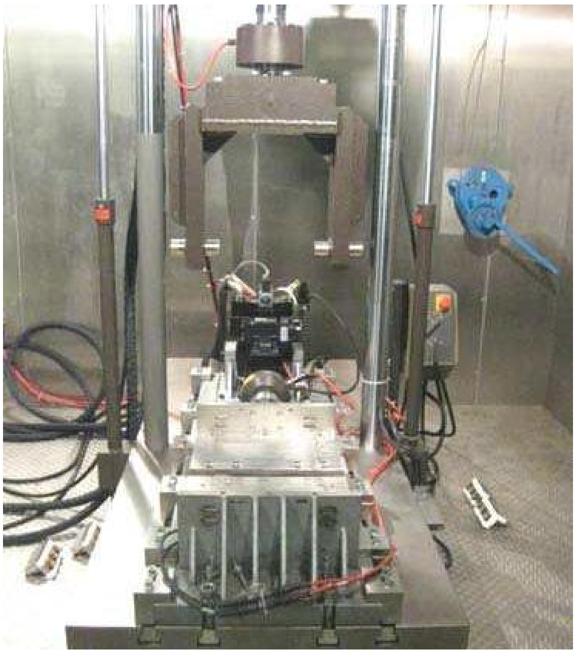


Figure 17. Movement testing at -40° to +60°C

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.

5.6 Watertightness testing

After successfully passing the aforementioned movement testing, the full-scale specimen was subjected to a watertightness test at the BAM institute in Berlin (Figure 18). 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 or moisture could be found under the specimen.

Figure 18. Verification of watertightness (at maximum opening position of joint) following movement capacity test

5.7 Measurement of level differences in the surface

The flatness of the full-scale specimen was checked prior to the above-mentioned tests, to verify that any deviations in the level of the driving surface from the ideal connection line between the two adjacent pavements (without any imposed horizontal deformations and in the unloaded condition) are not greater than 5 mm – in accordance with the Austrian standard RVS and the relevant ETAG (Figure 19).

After loading, greater deviations are permitted, but these must not exceed 10 mm. Verification checks were carried out during and after both the fatigue and movement tests as described above. The results were positive, with a maximum level increase of +6 mm and a maximum level decrease of -5 mm being recorded.

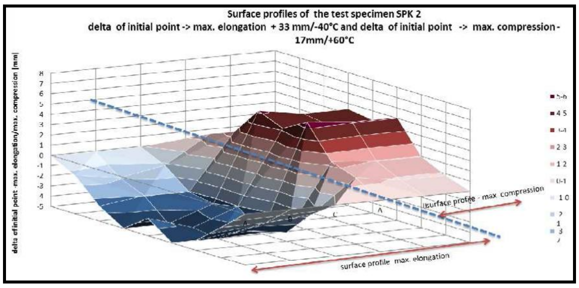


Figure 19. Measurement of deviation from ideal connection line across joint in maximum opened and maximum closed positions

5.8 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.

5.9 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 (3030 hours) to TR010
- Ageing resulting from ozone: Test according to ISO 1431
- Freeze-thaw test (with thaw salt) according to EN 13687 Part 1

5.10 Resulting European Technical Approval

As a result of this testing, the expansion joint has been awarded a European Technical Approval (ETA). This ETA (Figure 20) covers joints of this type that accommodate longitudinal movements (SLS) of up to 135 mm (90 mm expansion and 45 mm compression), 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.

Authorised and notified according to Article 10 of the Council Directive 89/106/EEC of 21 December 1988 on the approximation of laws, regulations and administrative provisions of Member States relating to construction products

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OIB Member of EOTA

European technical approval **ETA-12/0260**

(English translation, the original version is in German)

Handelsbezeichnung *Trade name*	POLYFLEX® Advanced PU
Zulassungsinhaber *Holder of approval*	Reisner & Wolff Engineering GmbH Terminalstraße 25 4600 Wels Austria
Zulassungsgegenstand und Verwendungszweck *Generic type and use of construction product*	Elastische Belagsdehnfuge für einen nominellen Dehnweg von 15 mm – 135 mm *Flexible plug expansion joint for nominal movement capacity of 15 mm – 135 mm*
Geltungsdauer vom *Validity from*	26.07.2012
bis zum *to*	25.07.2017
Herstellwerk *Manufacturing plant*	Auflistung der Herstellwerke festgelegt in der technischen Dokumentation *Comprehensive list of manufacturing plants laid down in technical documentation*

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Figure 20. European Technical Approval

Further national approvals have also been awarded. For example, an approval issued by NEXCO (the West Japan Highway Administration) on the basis of specially completed testing have validity right across Japan.