Modern bridge bearings and expansion joints for road bridges

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Abstract

Introduced in 2010 EN 1337 “Structural bearings” is nowadays a basic act intention of which is providing a good manufacturing quality and operation of modern bridge bearings. This act prepared during 17 years is a recapitulation of European experiences on this field. It was the first harmonized European Standard on construction products. Most of Standard parts are innovative as compared with old national ones. As bridge expansion gaps form discontinuities in pavement they cause dynamic and impact additional loads. It has influence on durability and reliability of bridge expansion joints which are often complex mechanical structures. Their quality depends on requirements fulfillment given in R&BRI Technical Approvals as well as in ETAG 032 Guideline. These requirements refer not only to assembly and installation precision of expansion joints but also to their fatigue resistance verification. Nonetheless, not only in Poland, more and more one can observe their damages and failures. Most of failures are related to the shape of surface noise reducing elements and method of their fastening.

Keywords: bridge bearings; bridge expansion joints; durability of bridge elements

1. Introduction

In recent decades one can observe a great development of modern structural designs for bearings, Block et al. (2013), and expansion joints in bridge structures, Ramberger (2002). Modern bridge bearings and expansion joints are at present rather mechanical structures but not construction ones as they were treated previously. So the
requirements for contemporary devices are greater and of another kind. And although due to lack of stress concentration and transferring the pressure on greater surfaces as in case of bearings, their damages rarely lead to bridge structure failure but can lead to faster wear of elements. It can provoke to worse supporting conditions of bridge decks and in final case even to blockade of displacements and rotations, Niemierko (2001). Also in case of expansion joints which are designed as totally tough the dynamic and fatigue effects can destroy them when a proper anchorage and assembly tolerances are not respected.

2. Bridge bearings

A bearing is an element of a bridge structure which determines the durability and reliability as well as its safety behavior. In the middle of last century many innovative bearing designs were invented. They are nowadays very popular in bridge engineering. Traditional concepts as rollers, rockers, pin steel plate and concrete hinges became historical solutions. Requirements for designing, manufacturing and installing bridge bearings have been completely changed. Besides of traditional steel grades in modern bridge bearings, we meet the materials not used in the past e.g. austenite steel, silicone grease, PTFE, composite materials as well as synthetic rubber and polyurethane.

Since the 1970s the Road and Bridge Research Institute (R&BRI) is responsible for the supervision, control and introduction to Polish bridge engineering of modern types of bearings. Till 2010 this task was fulfilled by approval tests being base for technical approvals issued by the Institute. After adopting EN 1337 as Polish Standard this activity was interrupted. But almost 40 years of prototype and new on Polish market bearings tests allow to form at the Institute the competitive center for modern bridge bearings quality and reliability assessment, Niemierko (1994).

2.1. Bearings’ standardization

EN 1337 “Structural bearings” is nowadays a basic act, intention of which is providing a good manufacturing quality and operation of modern bridge bearings. This act, prepared during 17 years, is a recapitulation of European experiences on this field. It was the first harmonized European Standard on construction products. Technical Committee CEN/TC 167 “Structural Bearings” was formed in 1989 under the presidency of Agostino Marioni (Alga, Milano). It gathered the best European specialists in this field representing universities, research institutes and bearings’ manufacturers. In total over 60 persons together with external experts were involved in this standard elaboration, Marioni (2006). EN 1337 is composed of 11 parts (Tab. 1) but only some of them (3-8) are harmonized.

<table>
<thead>
<tr>
<th>Part</th>
<th>Title</th>
<th>No. EN and year of validity</th>
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<tr>
<td>1</td>
<td>General design rules</td>
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<td>EN 1337-3:2006</td>
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<td>Roller bearings</td>
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<td>5</td>
<td>Pot bearings</td>
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<td>6</td>
<td>Rocker bearings</td>
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<tr>
<td>7</td>
<td>Spherical and cylindrical PTFE bearings</td>
<td>EN 1337-7:2004</td>
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<td>8</td>
<td>Guide bearings and restraint bearings</td>
<td>EN 1337-8:2007</td>
</tr>
<tr>
<td>9</td>
<td>Protection</td>
<td>EN 1337-9:1997</td>
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<tr>
<td>10</td>
<td>Inspection and maintenance</td>
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</tr>
<tr>
<td>11</td>
<td>Transport, storage and installation</td>
<td>EN 1337-11:1997</td>
</tr>
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</table>

In practice, after 2008 all of the most important national standards as DIN 4141, BS 5400 Part 9, AFNOR T -47 and CNR 10018 was replaced by EN 1337. Compatibility with harmonized standard is signed by CE mark. This sign is a certificate of bearing quality more valid than ISO 9001 Quality Assurance Certification. For CE mark receiving
the bearing’s manufacturer should present a certificate from notified body. The necessary condition is an approval of the manufacturer Factory Production Control (FPC) and the results of type-testing which are defined in relevant Parts of EN 1337. FPC should be carry out in regular periods and contain the following items:

- specification and verification of raw materials and components,
- control and routine tests during manufacturing according to the frequency specified in relevant parts of EN 1337,
- control and tests of finished bearings according to the frequency specified in relevant parts of EN 1337.

The most important innovative issues of EN 1337 are as follows:

- all types of bearings are designed on base of the limit state concept; especially with reference to Ultimate Limit State (ULS) as it was adopted in Eurocodes for structures,
- definition of characteristic resistance of materials (Tab. 2); design values comprise correspondent safety coefficients which can be defined by every CEN member state independently.

<table>
<thead>
<tr>
<th>Sliding material</th>
<th>Actions</th>
<th>( f_k ) (MPa)</th>
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</thead>
<tbody>
<tr>
<td>PTFE for main surfaces</td>
<td>permanent and movable loads</td>
<td>90</td>
</tr>
<tr>
<td></td>
<td>movable loads</td>
<td>90</td>
</tr>
<tr>
<td>PTFE for keys</td>
<td>temperature, shrinkage and creep</td>
<td>30</td>
</tr>
<tr>
<td></td>
<td>permanent loads</td>
<td>10</td>
</tr>
<tr>
<td>composite CM1</td>
<td>permanent and movable horizontal loads</td>
<td>200</td>
</tr>
<tr>
<td>composite CM2</td>
<td>permanent and movable horizontal loads</td>
<td>120</td>
</tr>
</tbody>
</table>

### 2.2. Characteristic of modern bearings

In respect of its design the modern bridge bearings are divided into: elastomeric, pot, spherical or cylindrical PTFE, guide and restraint (see Tab.1). All of these designs can contain sliding element composing of polished austenitic steel plate and PTFE dimpled sheet supplied with silicone grease for easing sliding and preventing an excessive wear of PTFE.

First elastomeric (rubber) bearings reinforced with steel grillage were used in France due to Eugène Freyssinet who patented this solution in 1954, Andrä and Leonhardt (1962); Topaloff (1964). Now steel plates are used for reinforcement. In Poland, the first application of reinforced elastomeric bearings (Fig. 1) was in 1963, Wasiutyński (1967). After more than 30-years of operation they have been removed and tested, indicating very good performance and characteristic, Niemierko (1996).

![Fig. 1. Sections of the first elastomeric (rubber) bearings in Poland after removal from bridge supports.](image)

In the 1980s successful results were received with polyurethane elastomeric bearings (Fig. 2), Niemierko (1991). Tests undertaken in R&BRI showed that besides their easier manufacturing, they present twice greater resistance in compression and greater durability. At present they are not competitive with neoprene elastomeric bearings as cost of their manufacturing is greater.
Elastomeric bearings can be anchored to surrounding structures or can be combined with sliding element allowing the greater displacement of bridge structure. This displacement can be also limited by use of supporting steel plates equipped with blocking cubes (Fig. 3).

Modern elastomeric bearings are characterized by enough great bearing capacity (Fig. 4) with plan dimensions reaching 1200 \times 1200 \text{ mm} and depth of 360 \text{ mm}, Block et al. (2013).

An original design is the application of fiber optics inside elastomer which allows to register changes in applied loads and compressive stresses, Chabert and Dauvilliers (1984). As elastomer are used synthetic (chloroprene, butadiene) rubber as well as natural ones. The most popular is neoprene patented in 1931 by Du Pont de Nemours. Often questionable is the durability of elastomeric bearing. The last tests and findings show that their working life, at the beginning assumed as 20 years, can be extended to 50 or more years, Price and Fenn (1983); Stanton and Roeder (1983); Burpulis et al. (1990); Itoh and Gu (2009); Aria and Akbari (2013). Sliding elastomeric bearings
started to be used in 1956 when polитетrafluoroethylene (PTFE) under the name of Teflon was patented by Du Pont. It can be used as directly vulcanized with elastomer (Fig. 5) or with sheets recessed in steel backing plate vulcanized with elastomer.

![Fig. 5. Section of sliding elastomeric bearing usually used for permanent displacements.](image1)

Pot bearing (Fig. 6) was for the first time used in 1959 in Germany, Eggert (1978). Its concept is based on elastomeric pad confined in cylinder by means of a close fitting piston and internal seal. This piston assures that the elastomer can be subjected to much greater pressure and can behave as a visco-elastic material. In addition as isolated from external influence of ozone and UV radiation, it can be made with natural rubber preserving good elasticity in low temperature.

![Fig. 6. Pot bearing with central key allowing for movement in one direction (a) and removed sliding plate (b).](image2)

In Poland first pot bearings with the R&BRI technical support were manufactured by PRInż Katowice at the beginning of 90s. Now pot bearings reach capacity of 200 MN with rectangular shape of elastomer pad or 120 MN and for circular one with diameter 2500 mm, Block et al. (2013).

![Fig. 7. Free sliding spherical bearing.](image3)
Spherical (Fig. 7) and cylindrical bearings are simply a kind of spatial articulation with contact surfaces covered by PTFE sheets. They can be combined with flat sliding element allowing horizontal displacements of bridge structure. The first spherical bearing was installed in Germany in 1966. In Poland they were used in the first incrementally launched bridge in 1987. Based on prototype tests undertaken in R&BRI in 1980s one of greater bridges over Vistula river was supported on 8 MN capacity spherical bearings of own production. Unfortunately after some month of operation in consequence of improper use of sliding elements the PTFE sheets had been destroyed, Niemierko (1992). One of the biggest in Europe spherical bearings are installed on two central supports of cable-stayed bridge over Vistula river in Plock, Niemierko et al. (2006). Bearings of 110 MN capacity had 2200 mm diameter of rotational element (Fig. 8).

![Fig. 8. Lowering of convex rotational element on concave backing plate of 110 MN capacity guided spherical bearing.](image)

Quite new design in modern bridge bearings are guide bearings and restraint bearings (Fig. 9, 10 and 11). They are treated as special devices and in view of their greater cost they are used only in justifiable cases, for example when typical bearings cannot be applied. In general they are not intended for transmitting vertical loading and bending moments but for allowance or blocking the displacements. They usually cooperate with bearings which transmit vertical loading.

![Fig. 9. Example of guide bearing; a – cross-section, b – axonometric view; 1 – sliding element, 2 – articulation.](image)

![Fig. 10. Example of restraint bearing; a – cross-section, b – axonometric view.](image)
2.3. Bearing’s installation

For statically indeterminate or curved and skew bridge structures it is important to install the bearings in accordance with design reactions rather than in accordance with geometrical layout of the deck. Even small changes in supporting levels can give a rise to great changes in reaction distribution. It should be provided the replacement or rectification of bearing by auxiliary plates. Uplift reactions should be rather avoided. In case of skew spans the fixed bearing should be installed in place where the greatest reaction is designed e.g. in obtuse angle not in acute one. On one support cannot be installed bearings with different compressibility. Final bearings should be installed after completion of whole bridge structure. It is not allowed to use the final bearings in bridge deck erection stages e.g. for incremental launching or before post-tensioning of prestressed concrete structure. For continuous multispans structures it is recommended to install a fixed bearing on one of intermediate supports (usually middle one). Such a solution allows using the expansion joints with smaller movement.

3. Expansion joints

Bridge expansion gaps form discontinuities in pavement causing additional dynamic and impact loads. They have influence on the durability and reliability of bridge expansion joints, which are often complex mechanical structures. Their quality depends on requirements fulfillment given in R&BRI Technical Approvals as well as ETAG 032 Guideline. These requirements refer not only to assembly and installation precision of expansion joints but also to their fatigue resistance assessment. Nonetheless, not only in Poland, more and more one can observe their damages and failures, Lachinger et al. (2014); Zimmermann, T. et al. (2014). Most of failures are related to the shape of surface noise reducing elements and method of their fastening. So it is recommended to extend the fatigue tests on expansion joints with surface noise reducing elements. In 2006 under EOTA was formed Technical Committee for unification of expansion joints requirements. In 2013 the work was finished with elaboration of Guideline for European Technical Approval of Expansion Joints for Road Bridges (ETAG 032, Tab. 3). Now it serves as a base for the issue of European Assessment Documents (EAD).

Table 3. Parts of ETAG 032.

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<td>3</td>
<td>Flexible Plug Expansion Joints (Fig. 13)</td>
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<tr>
<td>4</td>
<td>Nosing Expansion Joints (Fig. 14)</td>
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<td>5</td>
<td>Mat Expansion Joints (Fig. 15)</td>
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<tr>
<td>6</td>
<td>Cantilever Expansion Joints (Fig. 16)</td>
</tr>
<tr>
<td>7</td>
<td>SupportedExpansion Joints (Fig. 17)</td>
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<tr>
<td>8</td>
<td>Modular Expansion Joints (Fig. 18)</td>
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Buried Expansion Joints (Fig. 12) are used for displacements not greater as 25-30 mm. Flexible Plug Expansion Joints (Fig. 13) are generally used for gap displacement not greater as 40 mm. Both are executed directly on site.
Fig. 12. Buried Expansion Joint acc. to ETAG 032-2: 1 – buried expansion joint, 2 – pavement reinforcement, 3 – crack sealant, 4 – pavement, 5 – waterproofing, 6 – bridge deck, 7 – caulkling, 8 – abutment.

Fig. 13. Flexible Plug Expansion Joint acc. to ETAG 032-3: 1 – bituminous filling mixture, 2 – surface dressing, 3 – tanking, 4 – pavement, 5 – waterproofing, 6 – metal plate, 7 – fixing, 8 – caulkling, 9 – sealant, 10 – bridge deck.

Fig. 14. Nosing Expansion Joint acc. to ETAG 032-4: 2 – anchorage, 3 – seal part, 4 – edge profile, 5 – pavement.

Fig. 15. Mat Expansion Joint acc. to ETAG 032-5: 1 – pavement, 2 (left side) – sealant, 2 (right side) – transition strip, 3 – reinforcement, 4 – elastomer, 5 – anchoring.

Fig. 16. Cantilever (Finger) Expansion Joint with clamping device.
Nosing Expansion Joints (Fig. 14) are used for gap displacement not greater as 80 mm. Mat Expansion Joints (Fig. 15) are used for gap displacement not greater as 330 mm. Cantilever Expansion Joints (Fig. 16) are used for gap displacement from 80 to 800 mm. Supported Expansion Joint (Fig. 17) is composed of finger elements forming sliding plate one end of which is anchored and another is supported with sliding possibility on the opposite side of gap. The second plate with fingers serving for refilling the space between fingers of sliding plate is attached on this side of gap.

![Fig. 17. Supported Expansion Joint acc. to ETAG 032-7: 1 – sliding plate, 2 – fixe support base, 3 – sliding support base, 4 – holding down device of sliding plate, 5 – anchorage system, 6 – support, 7 – gutter, 8 – sliding support.](image)

Modular Expansion Joint (Fig. 18) gives the greatest movement possibility (over 800 mm). It is composed of subsequent beams with watertight sealants supported by crossbeams construction of which allow uniform expansion between beams.

![Fig. 18. Modular Expansion Joint acc. to ETAG 032-8; 1 – edge beam, 2 – centre beam, 3 – seal, 5 – joist box, 6 – prestress element, 7 – bearing, 8 – stirrup, 9 – crossbeam.](image)

Nowadays the most popular are nosing and modular as well as cantilever expansion joints, the latter also as supported ones. Some years ago environmental requirements put in evidence the noise limitation necessity. That was the reason of wide use of noise reducing elements combined mostly with nosing and modular expansion joints. These elements play a decisive role in health condition of whole devices. They are very vulnerable on dynamic and fatigue behavior. In ETAG 032 the problem of working life is treated as one of the most essentials. It depends on: traffic loads, imposed movements, frequency and number of cycles, as well as on fatigue resistance and wear of their components. It depends also on component’s replacement possibility and quality of installation. Declared by manufacturer, the product durability should be based on the durability categories considering acc. to EN 1337-2 (Table 4.5) number of trucks $N_{obs} = 0.5$ mln per year. There are 4 working life categories from 10 to 50 years. ETAG 032 distinguishes also 3 component’s categories depending on the possibility of their replacement: A (non-replaceable), B (replaceable with major obstruction of the traffic flow) and C (replaceable with minor obstruction of the traffic flow). The working life should be at least on the level of 10 years.

Before introducing to the market the new expansion joints should be verified during type tests in a notified laboratory. These tests are based on fatigue loading simulating traffic loads and movements $\geq 0.2$ mm/h due to thermal expansion or/and $\geq 0.6$ mm/s due to traffic loads. There are two load models with contact pressure of
0.8 N/mm² and 1.0 N/mm². The number of cycles depends on desired durability category: 10, 15, 25 or 50 years. In ETAG 032 (Fig. 19) and other national guidelines the requirements for installation admissible tolerances are given.

![Fig. 19. Admissible level differences in running surface; 1 – ideal surface line, 2 – running surface of the joint, 3 – expansion joint zone.](image)

In Poland, since 2008 especially on new motorways, we register many damages or failures with nosing and modular expansion joints. In most cases they were equipped with noise reducing elements. Some of them were damaged after only one year of service. The problem was with attachment of these elements to intermediate beams using improper bolts. This design didn’t respect requirements of PN-EN 1993-1-8 concerning joints subjected to vibrations, chocks or others dynamic actions. There are not allowed bolts with conic shape head. Also PN-EN 1090-2+A1:2012 do not advice threaded bolts with respect to effect of threads plastic behavior under dynamic loads.

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Marioni, A., 2006. The European Standard EN 1337 on Structural Bearings. 6th World Congress on Joints, Bearings and Seismic Devices Systems for Concrete Structures, ACI, September 17-21, Halifax, Nova Scotia, Canada