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SELECTION AND REPLACEMENT OF BRIDGE EXPANSION JOINTS IN SEISMIC PRONE AREAS

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Abstract

Expansion joints on bridges are devices that enable relative displacements of the superstructure spans from the effects of temperature, traffic load and long-term effects. They are placed at the ends of the bridge, where they bridge the space between the superstructure and the abutment, while on very long bridges they are installed at all places where the superstructure breaks between individual sections of the bridge, in order to enable safe and unhindered traffic. They are the "weak points" of the bridge, as their "leakage" can seriously threaten the function of the bridge. In the seismic prone areas, encompassing seismic action in their design and selection is inevitable.

This paper will overview the types of expansion joints, design approach in their selection for new bridges and problems that may arise during their replacement in the rehabilitation process of existing bridges. Movements due to traffic load, seismic movements, movements due to long term effects of the deck (creep and shrinkage) and thermal movements will be considered. Based on practical examples, design for either no damage due to seismic action or partially damaged expansion joints for seismic action, will be contemplated.

Keywords: bridge, expansion joint, bearing, movements, earthquake, creep, shrinkage, temperature, traffic

1. Requirements, types and causes of defects of expansion joints

Expansion joints on bridges must sustain the loads and accommodate movements without causing failure to itself or other section of the structure. They must assure water does not enter the structure and accumulate in the joint, and they must be compatible with the waterproofing system of the roadway. They should allow smooth traffic flow while remaining safe for all categories of road users. Noise generated when crossing the joint should be kept to a minimum, especially if the bridge is located in a populated area. They should be easily accessible for inspection and maintenance [1] and regularly inspected and maintained to ensure that they continue to operate in accordance with all the requirements.

Guideline for European technical approval of expansion joints for road bridges specifies numerous requirements on expansion joint such are mechanical resistance, resistance to fatigue, seismic behaviour, movement capacity, cleanability, resistance to wear, watertightness, safety in case of fire, release of dangerous substances, safety in use, protection against noise, energy economy and heat retention, aspects of durability, serviceability and identification of products [2]. In this paper movement capacity and seismic behaviour will be overviewed and discussed.

According to typical movement ranges, expansion joints may be categorised as (i) joints for minimum movements of up to 20 mm (±10); (ii) joints for small movements of up to 40 mm (±20); (iii) devices for medium movements of up to 150 mm (±75); (iv) devices for large movements of up to 300 mm (±150) and (v) devices for very large movements over 300 mm (≥ ±150) [1, 3]. The new approach [2, 4] specifies families of expansion joints according to their principle of operating as described in columns left and middle of the Table 1. The right column of the Table 1 specifies equivalent joint types.

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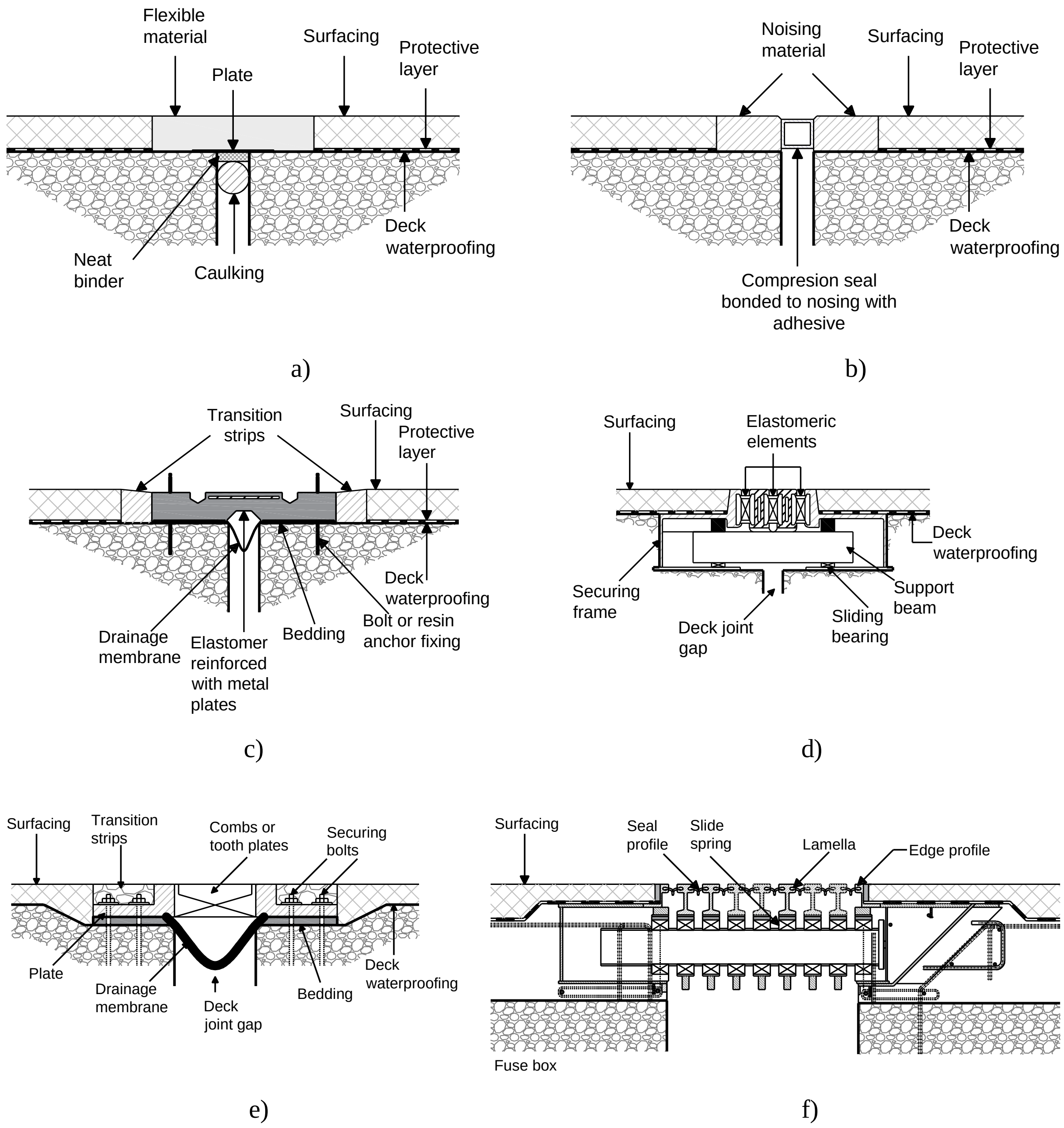
Table 1 – Families and types of expansion joints according to [2 & 4]

Joint family	Short description	Joint type
Buried expansion joints	This expansion joint is formed in place with components such as waterproofing membranes or an elastomeric pad to distribute the deformations over a wider width and support the pavement that runs continuously across the deck joint gap. The components of the expansion joint are located under the pavement.	Buried joint under continuous surfacing
Flexible plug expansion joints	An in-situ poured joint consisting of a band of specially formulated flexible material (binder and aggregate) that also forms the pavement and is held in place over the joint gap of the pavement by thin metal plates or other suitable components. The joint material is flush with the pavement surface.	Asphaltic plug joint
Nosing expansion joints	The gap between the edges prepared with concrete, resin mortar or elastomer is filled by a flexible profile, which is not traffic load carrying.	Nosing joint with poured sealant Nosing with preformed compression seal
Mat expansion joints	The expansion joint uses the elastic properties of a prefabricated elastomeric strip or pad to allow for the expected movements of the structure. The strip is attached to the structure with bolts. The subcomponent of the joint is flush with the running surface.	Reinforced Elastomeric
Cantilever expansion joints	The expansion joint consists of cantilevered symmetrical and asymmetrical subcomponents (such as comb or sawtooth panels) anchored to one side of the deck joint gap and interpenetrating to bridge the deck joint gap. The subcomponents are flush with the running surface.	Cantilever comb or tooth joint
Supported expansion joints	The expansion joint consists of one subcomponent flushed with the running surface, secured on one side by hinges and on the other (by a second element) by sliding supports, spanning the deck joint gap. The expected movement of the structure is enabled by sliding on the unattached side of the hinged substructure member, i.e., on the support element anchored to the substructure.	Not covered
Modular expansion joints	The expansion joint consists of a sequence of watertight subcomponents (in the direction of travel) consisting of motion-controlled metal girders supported by movable substructures that bridge the structural gap (i.e., cross girders, cantilevers, and current collectors). The metal girders are flush with the pavement surface.	Elastomeric in metal runners

Example of joint for small movements of up to ±20 mm is asphaltic plug expansion joint made of flexible bituminous material (thorma joint, Figure 1a). Nosing expansion joints permit a movement range of up to ±6 mm with poured sealant and up to ±20 mm with a performed compression seal (Figure 1b). Example of device for medium movements (although there are various sizes giving movement range of up to ±165 mm) is reinforced elastomeric expansion joints (Figure 1c). Movement range of elastomeric in metal runners expansion joints is up to ±40 mm for single element joint consists of a profiled elastomeric seal fitted between two metal runners, one fixed to each side of the deck joint gap. Multi element modular joints (Figure 1d) can accommodate much larger movements of up to ±480 mm. Cantilever comb or tooth joints (Figure 1e) have a movement range of up to ±300 mm which puts them, together with multi element modular joints, into to category of devices for very large movements.

If a regular expansion joint closes more than the design allows during an earthquake, severe damage to the joint and the bridge could result. This could be avoided by using fusible links (fusible box, Figure 1f), which act as a predominant predetermined breaking point and allow for a controlled failure.

Depending on the design of the fusible link, the link moves either vertically upward or horizontally in a specific, defined space. During seismic opening movements, the extended support bars protect the expansion joint from falling into the construction gap. After the earthquake, a quick and easy repair of the predetermined breaking points within the fuse box and its roadway surface is easily and quickly possible [5].



a) b) c) d) e) f)

Figure 1. Examples of expansion joints: a) bituminous, b) nosing, c) reinforced elastomeric d) elastomeric in metal runners, e) cantilever comb or tooth expansion joint, f) fuse box; reproduced based on [2 & 5]

During the use of the bridge, the expansion joints are exposed to various defects. Defects can be the result of eight main causes systematised in [6]: (i) *inadequate design*, i.e., in relation to the movements of the structure; (ii) *defects in the technical specifications*, such as insufficient adaptation to the service conditions or lack of connection between the joint and the rigid element; (iii) *defects in the production*, i.e., inadequate anti-corrosion treatment or incorrect geometry; (iv) *errors during installation*, such is for example incorrect definition of the neutral point of the joint or inadequate anchoring; (v) *lack of*

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proper maintenance resulting in accumulation of debris or moisture from vegetation on the deck and water leaks; (vi) *changes from the intended conditions of use*, such as a deck with a different long-term behaviour than predicted, settlement of abutments or foundations, a higher traffic load than expected; (vii) *environmental effects* such as higher or lower temperatures (which may already occur during device installation), freeze-thaw cycles; and finally (viii) *random impacts* due to natural events or human influences.

The studies summarised in the above-mentioned study [6] conclude that a large part of the costs in bridge management (up to 20% in some cases) is related to the repair and replacement of expansion joints. In addition, rehabilitation measures that result in disruption, slowing, or detour of traffic flow can cause inconvenience to users and significant indirect costs.

2. Design approach in seismic prone areas

In bridge design, thus in displacement calculation, it is necessary to assimilate temporary procedures of Eurocodes. For the total design displacement under seismic conditions in accordance with EN 1998-2, an adequate structural gap is required to protect critical or major structural elements from damage. The total value of the design displacement under seismic conditions d_{Ed} [7] is determined as follows:

$$d_{Ed} = d_E + d_G + \psi_2 d_T$$

where:

d_E is the design seismic displacement; d_G is the displacement due to the permanent and quasi-permanent actions measured over the long term (e.g. post-tensioning, shrinkage and creep for concrete decks); d_T is the displacement due to thermal movements; ψ_2 is the reduction factor for the quasi-permanent value of thermal action to be taken as 0,5.

In order to receive expansion joints without damages due to seismic action, they need to be select to undertake full design seismic displacement as described above. But this is reasonable only when seismic displacements are not very high. Namely, expansion joints are non-critical structural elements expected to be damaged due to other actions besides seismic action and changed few times in the design work life of bridge. Therefore, Eurocode gives correction of full seismic displacement with the recommended value of factor 0,4 d_E which means that local damage of the expansion joint will be admissible and damages under frequent earthquakes are still avoided. But damages due to seismic action should be predictable, without the need for immediate repair and with no influence to the emergency traffic safety.

Design requirements for expansion joints under seismic conditions consider the importance of the bridge and the expansion joint. A declaration of seismic performance is not required for buried and flexible plug expansion joints, while two main approaches with several subdivisions are provided for all other families of joints.

Movement capacity design is to be applied for bridges with small seismic displacements (i.e. $d_{Ed} \leq 200$ mm) allowing expansion joints with movement capacity (possibility to allow the displacement of the parts of the main structure) under serviceability conditions even during the earthquake for the total displacement d_{Ed}. When the design includes provisions limiting movements of the bridge, thus preventing the joint from being affected by seismic effects, no combination for seismic design situations exists (approach A1). The seismic design combination for approach A2 is selected for seismic actions with a high probability of occurrence or with smaller values for A_{Ed} [2].

For larger seismic displacements, $d_{Ed} > 200$ mm, former design according becomes uneconomic, so ***restricted movement and load capacity design*** is to be applied, accepting controlled damage for severe earthquakes (with a low probability of occurrence). Still, the damage under frequent earthquakes is to be avoided by providing structural gaps for long term creep and shrinkage effects plus appropriate fractions of the design seismic displacement (40%) and thermal movements (50%) [2].

Table 2 – Design requirements during and after design earthquake according to [2]

Design approa	**Requirements posed at the expansion joints**	**Actions to be considered during design earthquake**	**Load bearing capacity and serviceability after design earthquake**	**Expected repair work**
A	***Movement capacity design***			
A1	Movement capacity exists under serviceability condition even during the earthquake.	The expansion joint is not affected by seismic actions. Fundamental combination is used as per EN 1990.	The expansion joint is assumed to be resistant to any kind of effects after the design earthquake. Load bearing capacity and serviceability are as before the earthquake.	No repair work has to be applied.
A2	The seismic movement capacity of the joint exists for total displacement d_{Ed}	The resistance to static actions during the earthquake shall be checked for the frequent combination of actions: $C_{ULS\text{-}SEISMIC} = G_k$ "+" F_{ik} "+" $\boldsymbol{\psi_{1k}}$ [Q_{1k} "+" Q_{lk1} "+" Q_{tk1}] "+"A_{Ed} where ψ_{1k} = 0,4 is a combination factor for frequent value of a variable action; $A_{Ed} = d_E$ "+" d_G "+" $\boldsymbol{\psi_3}$ d_{Tk} is design seismic situation (imposed displacements for the derivation of internal forces); ψ_3 = 0,5 is the reduction factor for the quasi-permanent value of thermal action		
B	***Restricted movement and load capacity design***			
B1	No damage with reduced load bearing capacity and increased gap width during earthquake.	The resistance of load carrying structural elements shall be checked for the seismic design situation: $C_{ULS\text{-}SEISMIC} = G_k$ "+" F_{ik} "+" $\boldsymbol{\psi_{2k}}$ [Q_{1k} "+" Q_{lk1} "+" Q_{tk1}] "+"A_{Ed} where ψ_{2k} is a combination factor for quasi-permanent value of a variable action: $\psi_{2k} = \psi_3$ = 0,3 for B1 $\psi_{2k} = \psi_3$ = 0,1 for B2 $\psi_{2k} = \psi_3$ = 0,1 for B3 $\psi_{2k} = \psi_3$ = 0,0 for B4 After earthquake → $\psi_{2k} = \psi_3$ = 0,2 for B3 $\psi_{2k} = \psi_3$ = 0,2 for B4 on the joint $\psi_{2k} = \psi_3$ = 0,0 for B4 on the fuses G_k = self weight; F_{ik} = internal force – expansion joints may show internal forces from imposed displacements, rotations and/or prestress caused by e.g. compression or elongation, and/or relative movements; Q_{1k} = vertical traffic in lane 1, axle 300 kN; Q_{lk1} horizontal traffic direction, axle 120kN; Q_{tk1} horizontal perpendicular to traffic direction, axle 60kN	Load bearing capacity and serviceability are as before the earthquake.	No repair work has to be applied.
B2	Minor damages to secondary elements are allowed. Load carrying elements are allowed to have a reduced load bearing capacity and increased gap width during earthquake.		Load bearing capacity as before the earthquake.	Secondary elements shall be replaceable or repairable after the earthquake.
B3	Minor damage to structural elements or fusible devices due to a combination of reduced traffic load bearing capacity and increased gap width during earthquake.		The expansion joint is assumed to be resistant to frequent traffic loads according to EN 1990 after the earthquake and to fulfil all the ULS and SLS requirements after small repairs.	Small repairs on structural elements and fusible devices.
B4	Major damage to fusible devices and minor damage on the joint. Fusible devices should avoid or minimize damage on the structural elements of the bridge reducing at the mean time the required size of the expansion joint.		No remaining load bearing capacity and increased gap width. In the case of emergency traffic, the expansion joint shall comply with approach B3 load and the width of possible gaps shall be as a max 300 mm.	The possibility of permanent repair shall be described.

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3. Performance of expansion joints of the existing bridge

The bridge we consider below, with 17 spans of 24.5 m, an end span of 18.92 m and a total length of 435.42 m, was built half a century ago and was the subject of the student master's thesis [1]. The bridge deck is 3x3.5=10.50 m wide with 2.55 m wide corridors on the west side and 0.90 m on the east side. The total width of the bridge is 13.95 m. The span is a grill type girder concrete structure consisting of transversely prestressed reinforced concrete deck slab, post-tensioned main longitudinal T-section girders and transverse reinforced concrete beams. The grill type girders are connected to each other in continuous systems over three spans. In total, there are six continuous superstructure sections on the bridge, separated by expansion joints.

During examinations of the structure and laboratory tests of samples of the structure, numerous damages were found, especially to the protective layer of the reinforcement. In 2007, a project was launched to rehabilitate the bridge. First, the entire upper structure and then the lower structure of the bridge were repaired. A major part of the rehabilitation involved the restoration of the protective reinforcement layer. Using hydro demolition, the crumbling surface concrete was removed, the corroded reinforcement was cleaned, repair mortar was applied, and all concrete surfaces were coated with a protective layer of polymer cement coating, which prevented carbonation of the concrete and corrosion of the reinforcement.

The most demanding measure was the rehabilitation of the bridge deck. This involved the process of deepening the concrete by 2 cm, and then installing new reinforcement and concreting. Altogether 4 cm of new concrete was poured, 2 cm of concrete below the installed reinforcement, and 2 cm above it. The entire renovation process of the slab was carried out using the counterweight method, the most demanding renovation method in terms of time and technology.

After the completion of the repair work on the bridge deck, the installation of waterproofing and asphalt, expansion joints were installed. It should be noted that in the original rehabilitation project of 2007 reinforced elastomeric expansion joint with a total movement of 50 mm were foreseen (Figure 2a). The connection with the reinforced concrete structure was to be made with bolts, and the connection of the corridor with the pavement was to be welded.

However, in practice, these devices did not prove to be of high quality because they allowed water to penetrate the structure, so during the rehabilitation in 2012, it was decided to install flexible seamless expansion joints (asphaltic plug joints) with a total movement of 40 mm, made of highly polymerized asphalt, reinforced with anchor elements (Figure 2b). The advantage over other devices of the same type is the simplicity and speed of installation. And what was considered very important for rehabilitation, this device can be installed halfway, that is, one lane can always remain free for traffic.
Selected expansion joint consists of polymer-modified bitumen, structural reinforcement with a neoprene insert that allows the operation of the device (the length of the element is 1.5 m) and anchors Φ13 mm, a base coat (primer), bitumen tape for reinforcement, bitumen adhesive tape and foam rubber sealant insert.

The width of such an expansion joint is 400 mm and the depth is 80 mm with a possible displacement of 40 mm (+-20 mm), and it was considered suitable for new concrete bridges, viaducts and overpasses with a span of up to 40 metres. For old concrete bridges, where the rheology of the concrete is complete, the work of the span structure is 0.4 mm/1m (three times less than for new bridges). For this bridge, the work is 70 m x 0.4 mm/m = 24 mm, and it was assumed that a device that allows displacement of 40 mm is suitable.

But this solution turned out to be extremely bad after implementation. Because the contractor was late in procuring the equipment from Japan, the equipment was installed in December at a temperature of about 0ºC, in high humidity, and on a wet concrete slab, and subsequently the expansion joint leaked in almost all seven places where it was installed. This is because elastic expansion devices, which are made of bituminous mixes, require higher temperatures to bond aggregates and binders during installation.

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Asphalt mixture is installed only when weather conditions are favourable. Paving asphalt in the rain and on a wet surface is not allowed. During the production of the wearing layer, the temperature of the substrate and the air must be higher than 10ºC, and during the installation of the bonding and bearing layer higher than +5ºC. At higher temperatures, asphalt mixtures are prone to plastic deformation, including the appearance of rutting, which can cause considerable counter-impact forces at low temperatures, but also limit their use in areas with a moderate climate. In practice, asphalt expansion joints often fail at the joints to the pavement. This can lead to the formation of cracks and leakage of liquids, which is due to the extremely high hardness of the material at low temperatures.

The design of the bridge in accordance with modern European guidelines for the assessment of suitable expansion joints was carried out as a student master's thesis [1]. Design included bridge self-weight, additional dead load, traffic load, temperature effects, wind and seismic action and their relevant combinations. A grill model of the bridge consisting of beam elements in longitudinal and transverse direction, and spring elements for the bearings (elastomeric bearings without steel restraints which freely deform horizontally in all directions depending on the values of the horizontal and vertical reaction and enter the model via the defined stiffness of the springs) and KF connections for points with the same boundary conditions (the node at the upper end of the support has the same displacements and rotations as the node at the lower end of the support).

Effects of temperature are considered through: uniform temperature load: maximum temperature difference of the bridge (highest temperature – construction temperature $44-15=29°C$); uniform temperature load: minimum temperature difference of the bridge (construction temperature – minimum temperature $15-(-15)=30°C$); uniform temperature load for the selection of expansion joints and bearings (with an addition of ± 20°C which increased the maximum/minimum temperature difference of the bridge $30 + 20 = 50°C$ and $29 + 20 = 49°C$); non-uniform temperature load along the height of the concrete superstructure: the upper edge is warmer (negative value); non-uniform temperature load along the height of the concrete superstructure: lower edge warmer (positive value); with the simultaneous effect of uniform and non-uniform temperature components through eight combinations.

Seismic loading is determined by the response spectra for ground acceleration for the return period T = 475 years $a_g = 0.23\ g$, elastic non-ductile behaviour of columns without the possibility of developing plastic joints with the behaviour factor $q = 1.0$, structure importance factor 1.0 and soil category C. Multimodal analysis, combining eigenfrequencies and design spectra for the three directions of earthquake action, was applied.

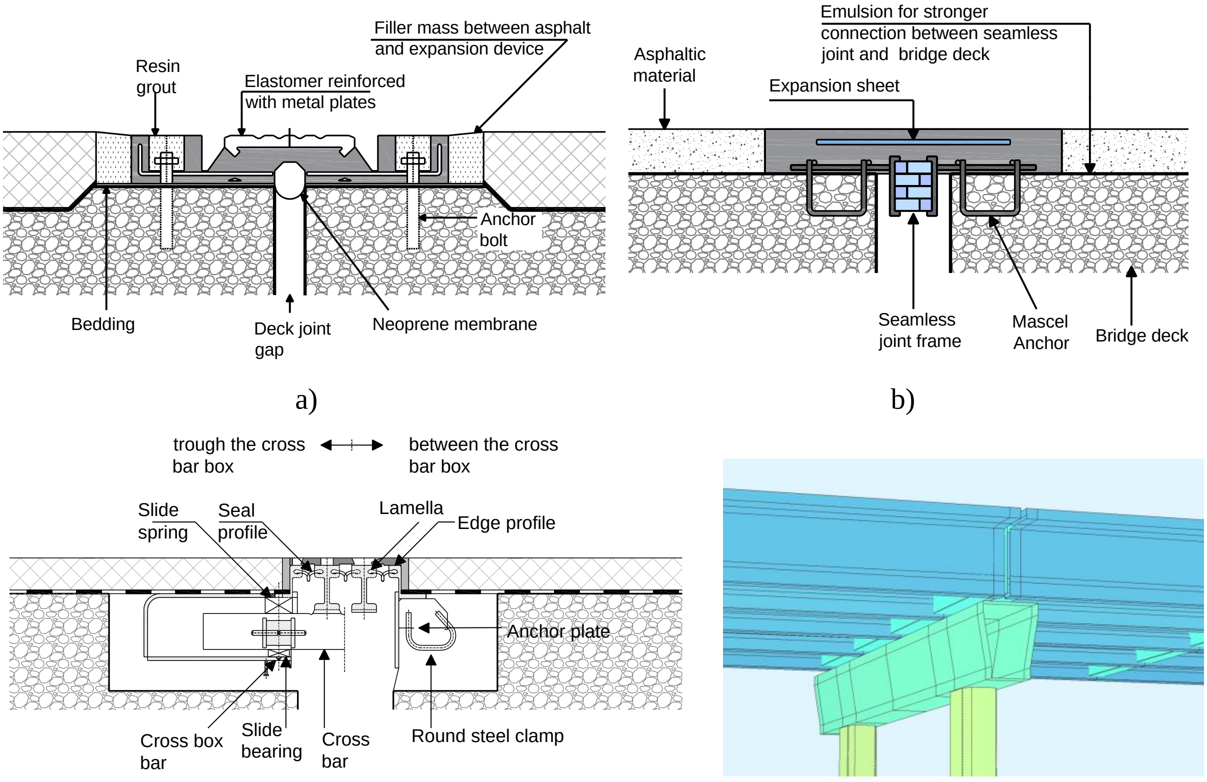
The displacements for the selection of expansion joints were determined in a combination of 40% seismic and 50% temperature action according to the EC8 guidelines, which allow damage to the expansion devices under severe earthquakes, while damage under frequent values can still be avoided, as explained in the previous chapter of this paper. Full temperature load displacements and full wind load displacements were calculated separately as well.

Based on the calculations, the largest horizontal displacements of about 56 mm in the longitudinal direction of the bridge were determined for the seismic combination. Based on the determined displacements, the type of expansion joint was proposed that would allow displacements of at least ± 60 mm in the longitudinal direction. Large transverse displacements, exceeding 40 mm at the first pier dilatations from both sides, should be covered with the appropriate expansion joint capability in the transverse direction (see proposed example in Figure 2c) or transverse restraint in the form of earthquake-resistant blocks would be required. Of course, it is necessary to assess and confirm the installation possibility of the selected device.

Bearings are selected for the relevant combination of vertical reaction and displacement at a particular bearing location. On the abutments and columns under the expansion devices, except for the central column, bearings are selected for the largest displacements of 75 mm, along the central spans of the entire bridge for spans between 50 and 65 mm, and in the edge spans for the smallest displacements of up to 25 mm.

This example shows how important and demanding the choice of expansion joints is in bridge rehabilitation. It should be based on knowledge of modern load requirements for bridge structures and of the expansion joint devices themselves and the current knowledge of how they work and perform during the use of bridge. But, replacing the expansion joint on the existing bridge also depends on moving capacity existing bridge poses and the space allowable for installation of the expansion joint.

Apart from the extremely important correct installation under appropriate climatic conditions, which was not suitable during the installation of the transition device foreseen in the rehabilitation project of the above bridge, the calculation in accordance with the modern earthquake design guidelines showed that these devices would not provide sufficient movement capacity during earthquake of frequent occurrence without damages and especially during serious earthquakes of low probability of occurrence.



a)

b)

c)

d)

Figure 2. Expansion joints for existing bridge: a) reinforced elastomeric expansion joint 50 mm selected by the original rehabilitation project, b) asphaltic plug joints 40 mm installed during actual rehabilitation process and c) elastomeric in metal runners girder grid expansion joint proposed by the valid contemporary seismic design of the bridge in the master's thesis, figures reproduced based on [8, 9 & 10]; d) section of the bridge model in the area of transversal beam at the supports

4. Expansion joint selection in the design of the new bridges

The following section considers the selection of expansion devices in the construction of two semi-precast prestressed concrete grillage type bridges. Both bridges span four spans 26+31+31+26 m, one of which is designed as a system of simply supported girders and the other as a continuous superstructure.

Models of the bridge consisting of beam elements in longitudinal and transverse directions and spring elements with a defined stiffness for the bearings and KF fixed connections for points with the same boundary conditions.

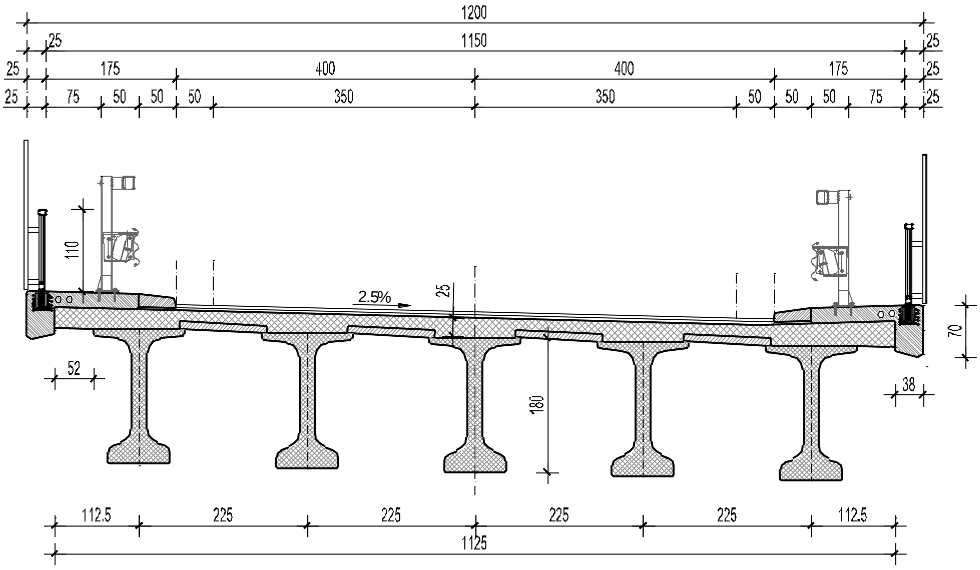
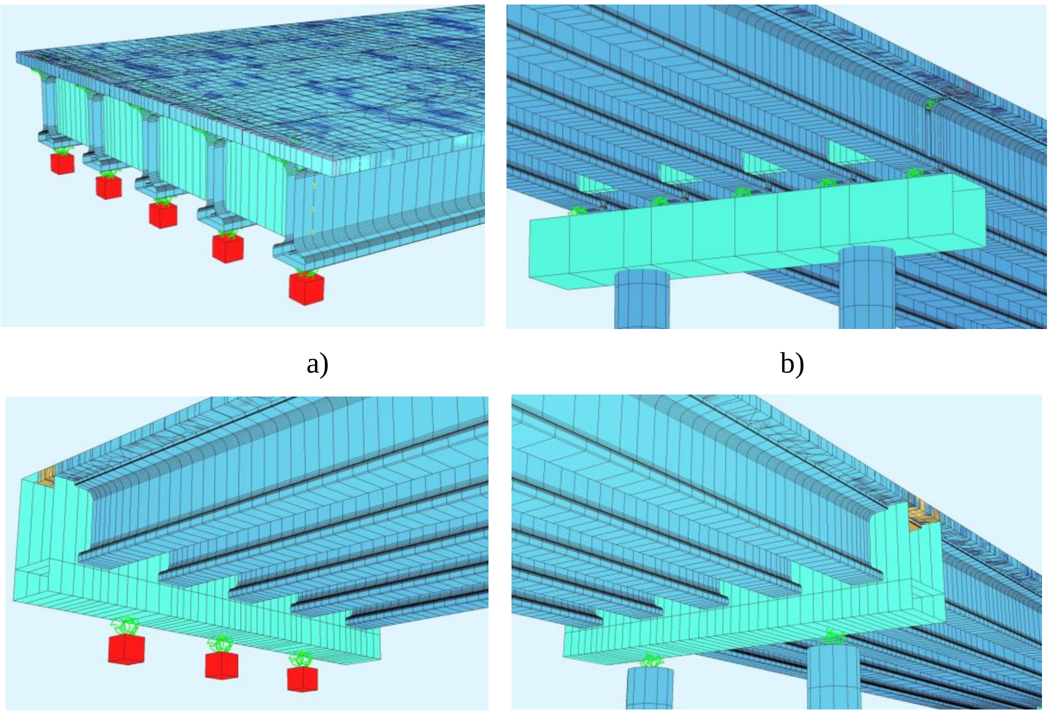


Figure 3. Cross section of case study bridges

The difference between the model of the bridge consisting of a series of girders and the bridge with a continuous superstructure is visible in the Figure 4. The simply supported girders have two cross beams above the piers, one for connecting left span main girders and one for the right span. The continuous superstructure consists of a common cross member at each pier. The first variant is easier to build, while the second is a more durable and robust construction. Expansion joints in both cases are provided above the abutments.



a) b)

c) d)

Figure 4. Extract from the bridge models in the software: a) set of simply supported girders supported at the abutment, b) set of simply supported girders supported at the pier, c) continuous superstructures supported at the abutment, d) continuous superstructure supported at the pier

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The design according to the Eurocodes includes the self-weight of the bridge, additional dead loads, long-term effects (creep and shrinkage), traffic loads, temperature effects, earthquake effects and their relevant combinations.

Creep and shrinkage were observed at all stages of bridge construction. The calculation of displacement due to these long-term effects was performed for a relative humidity of 80% and a temperature of 20 °C, with the end of the bridge's service life set at 50 years.

Traffic load is represented with the Model 1 from EN 1991-2 as a vertical load comprising both continuous and concentrated load and adequate braking and accelerating forces as a horizontal traffic load.

Uniform temperature load is considered as maximum temperature difference of the bridge (highest temperature – construction temperature $42-10=32°C$) and minimum temperature difference of the bridge (construction temperature – minimum temperature $10-(-18)=28°C$). Uniform temperature load for the selection of expansion joints and bearings increases the maximum/minimum temperature difference of the bridge by ± 20°C: $32 + 20 = 52°C$ and $28 + 20 = 48°C$).

For the multimodal analysis, combining eigenfrequencies and design spectra for the three directions of earthquake action, seismic loading is determined by the response spectra for ground acceleration for the return period T= 475 years $a_g = 0.241\ g$, elastic non-ductile behaviour of columns with the behaviour factor $q = 1.0$, structure importance factor 1.0 and soil category B.

For the calculation of the vertical, horizontal longitudinal and horizontal transverse reactions as well as the displacements in longitudinal and transverse direction, all relevant combinations of the above loads are considered. The displacements for the selection of expansion joints were determined in a combination of 40% seismic, 50% temperature action and 100 % long-term effects of creep and shrinkage according to the EC8 guidelines, which allow damage to the expansion joints under severe earthquakes, while damage under frequent values can still be avoided, as explained in the previous chapter of this paper.

The table 3 gives an overview of the results in terms of reactions and displacements for the selection of bearings and expansion joints.

For bridge composed of simply supported girders in each span, five reinforced elastomeric bearings are provided at each abutment (Figure 4a) and altogether ten bearings at the pier, five for the left and five for the right part of the superstructure (Figure 4b). In the longitudinal direction, displacements due to seismic loading are equal, within acceptable limits for these types of bearings and it could be considered that the bridge will “float” during an earthquake. In transversal direction displacements are of course the smallest at the abutments and the largest at the middle pier due to the expected vibration in the transverse direction of the bridge. For the selected bearings layout, expansion joints are to be selected to provide both longitudinal and transversal displacements during an earthquake.

Note that the horizontal stiffness of the bearings for the model is calculated based on the shear modulus, the area of the bearing surface, and the total thickness of the elastomer layers, while the vertical stiffness is calculated based on the elastic modulus, the area of the bearing surface, and the total thickness of the elastomer layers for selected bearing types.

In the case of the continuous bridge, where only two bearings movable in all directions are used at the abutment and on the piers (Figure 4d), the large response due to seismic loading in transversal direction (2135 kN) at the abutment required an additional middle bearing designed as a seismic transverse bearing (see Figure 4c). This bearing limited the movement in the transverse direction, so that the selection of the expansion joints was based only on the longitudinal movements.

This example shows that the final choice of expansion joint is highly dependent on the intended behaviour of the bridge system, which includes the arrangement of the selected bearings.

Table 3 – Selection of bearings and expansion joints in design of new bridges

Simply supported girders

position	**U1 EX. J**	**U1 B**	**S2 B**	**S3 B**	**S4 B**	**U4 B**	**U4 EX. J**
V_{max}		2295	3010	2750	3010	2295	
$H_{x,max}$		405	358	333	358	405	
$H_{y,max}$		235	335	430	335	235	
$d_{x,max}$	+ 63, -25	72	72	72	72	72	+ 63, -25
$d_{y,max}$	19	46	66	85	66	46	19
possible selection	D160* with 2 sealing elements	5x EB 400x500 (3000/74)	10x EB 450x600 (4210/74)	10x EB 450x600 (4210/85)	10x EB 450x600 (4210/74)	5x EB 400x500 (3000/74)	D160* with 2 sealing elements

*D160 stands for expansion joint for movement component rectangular to the gap axis of 130 mm according to [10].

**EB 400x500 (3000/74) stands for elastomeric bearing for the maximum load of 3000 kN and displacement of 74 mm according to [11]

Continuous Superstructure Bridge

position	**U1 EX. J**	**U1 B**	**S2 B**	**S3 B**	**S4 B**	**U4 B**	**U4 EX. J**
V_{max}		4315	8460	8605	8460	4315	
$H_{x,max}$		778	813	780	813	778	
$H_{y,max}$		(2135)	485	800	485	(2135)	
$d_{x,max}$	+ 87, -59	145	145	145	145	145	± 87
$d_{y,max}$	0	0	90	140	90	0	0
possible selection	D240* with 3 sealing elements	2x V2S5800 (74/158) ** + transverse restraint seismic bearing	2x V2S8500 (63/180)	2x V2S9500 (63/180)	2x V2S8500 (63/180)	2x V2S5800 (74/158) + transverse restraint seismic bearing	D240 with 3 sealing elements

*D240 stands for expansion joint for movement component rectangular to the gap axis of 195 mm according to [10] as the first lower D160 allows only 130 mm.

**V2S5800 (74/158) stands for seismic isolator/elastomeric bearing for the maximum load of 5800 kN, service displacement of 74 mm and seismic displacement of 158 mm according to [12]

5. Conclusion

After carrying out the overall design of the bridge in accordance with Eurocode standards, including seismic design in earthquake prone areas and calculation of displacement for relevant combinations of actions, the final choice of expansion joint should be the optimal solution in terms of performance, the cost of the equipment itself and its maintenance, additionally using an appropriate choice of design approach for the expansion joints.

For the bridges analysed in this paper and the selected expansion joints, this is the A1 approach for the transverse direction, where the movements of the bridge should be limited with anti-seismic blocks or seismic restraint devices, and the A2 approach for the longitudinal or transversal direction, which allows the seismic movement capacity of the joint for the total displacement d_{Ed} calculated for earthquakes with frequent values, that is, for seismic actions with a high probability of occurrence.

If the design of longer bridges under severe earthquakes will result in larger seismic displacements (i.e. $\mathrm{d}_{\mathrm{Ed}} > 200\mathrm{mm}$, see example bridge in [13]), then restricted movement and load capacity design B1-B4 approaches of expansion joints could be investigated. These approaches could also be beneficial for old bridges designed without seismic activity, when installing a new expansion joint for adequate seismic movement according to current seismic demands will not be possible.

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