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The particular challenges of expansion joint installation in steel bridges – Case studies

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Abstract. How a bridge's expansion joints are connected to the main structure is an important detail, with relevance not only for ease of installation and replacement but also for durability and long-term performance. In the case of steel bridges – or more accurately expressed, in the case of connection to steel surfaces – the challenges tend to be greater than with concreted connections. With steel connections, special attention is required in the design of the expansion joints, and considerably more effort and precision is required on site during installation work. This paper shall describe the particular challenges, and illustrate these, and ways of addressing them, with reference to steel bridge construction and renovation projects.

1. Introduction

Expansion joints are critically important bridge components, and how they are installed in a structure is important in a number of ways. Of course, the suitability of the connection as designed is of primary importance in ensuring that loads are properly transferred, but the quality of the connection, as designed and executed, is also of great importance in ensuring the durability and long-term performance of the components and the structure as a whole. Connection of expansion joints to concrete bridges is relatively straightforward, as concrete can very often be poured around the joints' anchorages, allowing a high degree of flexibility and tolerance without any impact on load transfer or long-term durability. In the case of steel bridges, however, the connection of a steel expansion joint directly to a steel structure often allows little or no such tolerance. Steel surfaces must generally be perfectly flat and flush with each other to ensure even transmission of loading without undesired moment forces or distortion, and in the case of bolted/screwed connections, anchors/bolt holes must be perfectly aligned with each other across each connection interface. While expansion joints may be specially designed and detailed to accommodate greater tolerances as specified, such measures require considerable additional design and fabrication effort, impacting on supply costs.

These challenges, and how they may be addressed, are described and illustrated below with reference to various steel bridge construction and renovation projects.

2. Connection of expansion joints to bridge structures – general

In principle, an expansion joint should be installed in such a way that all its parts are properly supported and will not be subjected to any unnecessary forces. Its presetting, or gap width at the time of installation, must be appropriate for the gap width of the structure at that time, considering the prevailing structure temperature etc., with allowance for the future opening and closing movements

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that the joint must accommodate. And any designed pre-tensioning within the joint should be as designed, without increase or decrease due to lack of proper levelling. This will ensure that the joint's durability and performance will be unimpeded by installation-related deficiencies, enabling it to perform well for many years.

Design and fabrication of an expansion joint for installation in a concrete bridge deck (i.e. with concrete connection) generally allows great installation tolerance, with the expansion joint simply lifted into a block-out / recess that can be over-sized as desired to ensure the joint does not clash with the superstructure. As long as any reinforcement steel (which can generally be bent out of the way if necessary) is not in the way, the expansion joint can then be freely, easily and precisely positioned in the correct position, at the correct height and with the correct longitudinal and transverse gradients. Furthermore, since the edges of the joint can be individually freely positioned for connection at both sides of the bridge movement gap, the expansion joint can be installed with a complete lack of undesired distortion or twist, and adjustment of presetting is easy and precise. The installation tolerance offered by concrete connection is illustrated in Figure 1, for two common types of expansion joint.

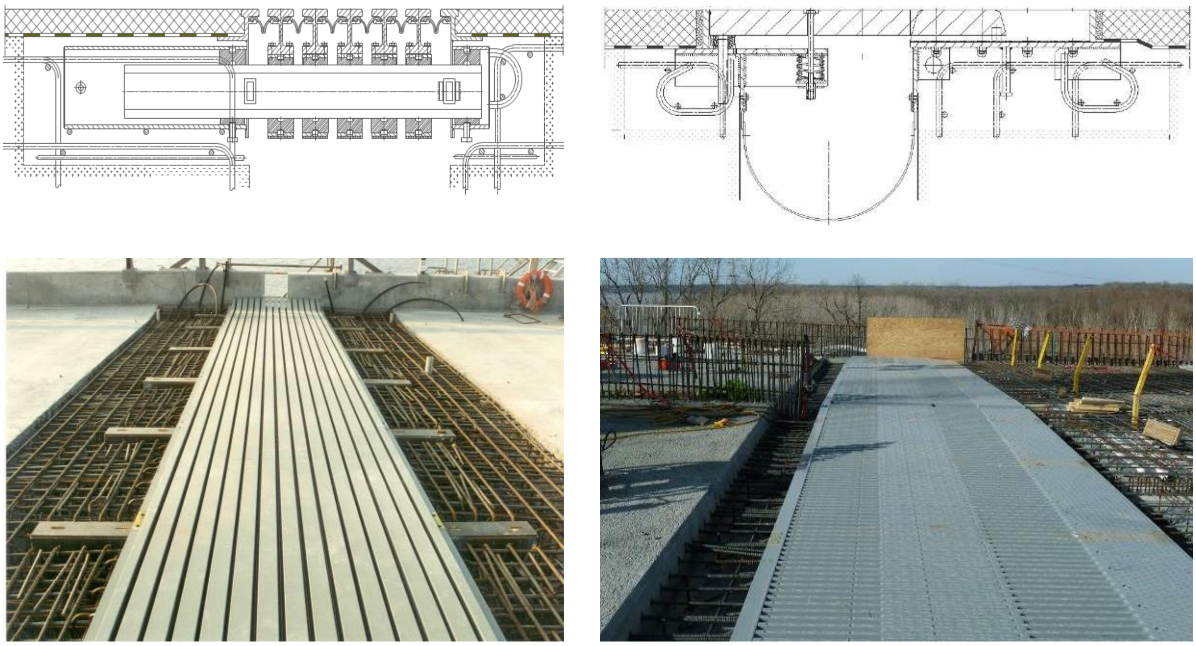

Figure 1. Connection of a bridge's expansion joints to the main structure by concreting allows a great degree of tolerance in terms of positioning, with the joint simply lifted into an oversized recess, as shown by these cross section sketches and photos (Left: Modular joints. Right: Sliding finger joints).

3. Connection of expansion joints to steel bridge superstructures – typical challenges

Design and fabrication of an expansion joint for installation in a steel bridge deck (i.e. with steel connection) generally requires more attention to detail and greater effort than would arise if the deck was of concrete. And installation of the expansion joint on site then also typically requires more effort and care.

Connection of expansion joints to steel structures may often be achieved by welding or bolting. Bolting offers advantages in terms of installation (especially, for example, in the case of galvanized steel) and replaceability, but this approach requires yet more precision / allows yet less tolerance than welding, and bolting generally requires significantly more space to transmit a specified load than welding – making bolting impractical in some circumstances. And as a rule, achieving a desired level of quality control is considerably more laborious with welded connections than with bolted ones.

The particular challenges of steel connections include:

3.1. Uniqueness
Steel connections are always non-standard from an expansion joint design perspective, and generally unique, so they require special solutions to be developed and implemented for every structure / joint.

3.2. Load transmission to the main structure
Without the load-distributing benefits of an intermediate "layer" of concrete between the expansion joint and the main structure to which it is connected, load transmission at connection points tends to be much more highly focussed as point/line loads, increasing design and execution challenges locally in these areas. This is especially true if connecting steel surfaces are not perfectly flat and parallel with each other, resulting in yet higher point loading and undesired torsions or bending moments.

3.3. Accommodation of tolerances
The installation tolerance described in Section 2 above associated with concreted connections does not apply in the case of steel connections. Not only does this increase the challenge of installation on site, and the difficulty of constructing the steel superstructure to receive the expansion joint exactly as designed, it also increases the effort required to fabricate the expansion joint precisely as designed, with a complete lack of distortion.

3.4. Transportation and installation frames
Connection of transportation and installation frames, which must often be designed to facilitate on-site adjustment of presetting (depending on the bridge structure's temperature at the time of installation, etc.), is less straightforward in the absence of anchor loops/studs of the type typically available for this purpose on a joint designed for concrete connection. In the case of concreted connections, such frames can simply be welded to the anchor loops/studs, and cut off at the time of installation – but in the case of steel connections, connection points are more limited, and must be either precisely designed for bolted connections or, where simpler welded connections are used, must be smoothened and treated with corrosion protection following installation. Furthermore, steel connections often require specially designed installation/positioning frames, tailored to the particular steel structure to which the joint is to be connected – a considerably more demanding aspect than arises with a concrete connection.

3.5. Accessibility during installation
Connection to a steel superstructure, especially by welding, typically requires a much higher degree of access for installation workers than does connection by concreting. Such access must be ensured in the design of the superstructure and of the expansion joint – if, indeed, it can be accommodated at all.

3.6. Distortion due to welding
Care must be taken when installing an expansion joint by welding to avoid distorting the joint or the steel structure to which it is connected, and to avoid damaging adjacent corrosion protection etc.

3.7. Subsequent application of corrosion protection to welded areas
Since steel which is to be welded must be clean, without any corrosion protection applied to the welding area, corrosion protection must subsequently be applied to the entire welded area following completion of welding. Not only does this require effort, it also introduces a new durability / quality control issue, since site-applied corrosion protection may not offer the same long-term protection as the factory-applied equivalent.

4. Examples of steel-connection expansion joints in major bridge structures
Some of these challenges are illustrated by the following images showing examples of installation of large expansion joints with steel connections in major bridge structures around the world.

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Figure 2. Installation of 7-gap and 14-gap *Tensa-Modular* expansion joints, side by side, during renovation of the Lillebaelt Bridge, Denmark (2002).

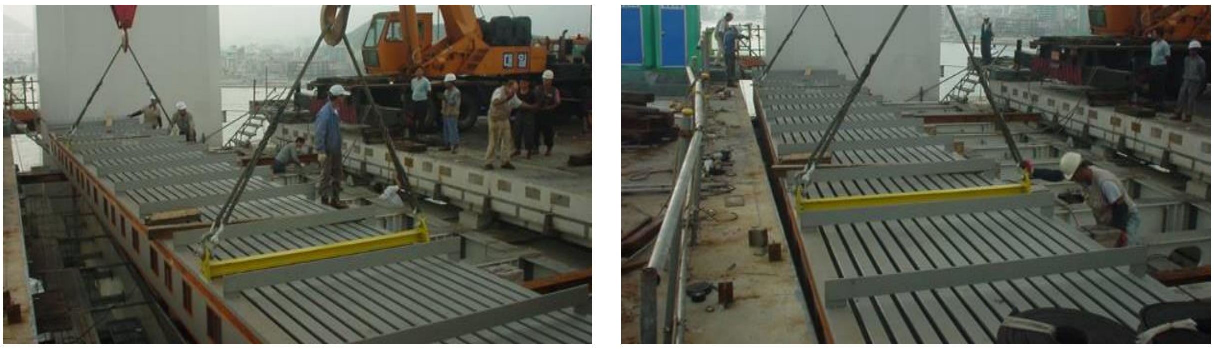

Figure 3. Installation of a 15-gap *Tensa-Modular* expansion joint during construction of the Guangan Bridge, Busan, South Korea (2002).

Figure 4. Installation of a 24-gap *Tensa-Modular* expansion joint during construction of the Incheon Grand Bridge, South Korea (2008).

Figure 5. Installation of a 12-gap *Tensa-Modular* expansion joint with noise reducing “sinus plates” on its surface on the Köhlbrand Bridge, Hamburg, Germany (2016).

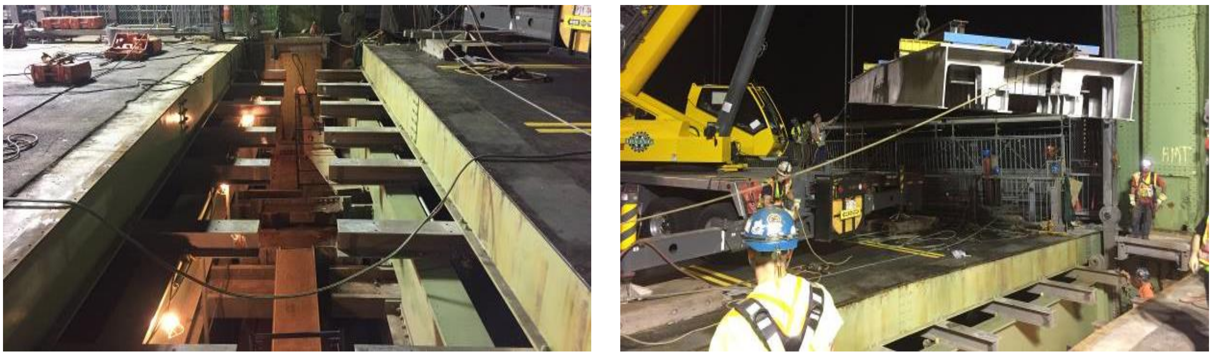

Figure 6. Installation of a 7-gap *Tensa-Modular* expansion joint (featuring noise-reducing “sinus plates” on its surface during renovation of the Angus L. Macdonald Bridge in Halifax, Canada (2017).

Figure 7. Replacement of *Tensa-Finger* sliding finger expansion joints with movement capacities of up to 2700 mm in the Verrazano Narrows Bridge, New York, USA (2017).

5. Expansion joint solutions that can avoid the need for steel connections on steel bridge decks

In some cases, the use of a particular type of expansion joint solution can avoid steel connection difficulties and challenges of the types described and illustrated above. A number of such solutions are presented below.

5.1. Expansion joint solutions that are designed for easy future replacement/renewal, retaining the existing connections to the main structure

A number of expansion joint solutions have been developed which enable the main dynamically-loaded part of an expansion joint to be replaced without replacing the parts which are connected to the main structure at each side and not subjected to dynamic loading, and which therefore will likely not need to be replaced. Such solutions can be particularly beneficial in steel bridges, as it is these connections to a steel bridge that are especially challenging and problematic.

5.1.1. The "Box-in-Box" solution for modular joint renewal

Where a modular joint on a bridge requires to be replaced, the "Box-in-Box" method may be used in certain circumstances. This method involves cutting short sections out of the existing joint's edge beams at each support bar, and cutting the top plate off the boxes at each end of each support bar. This enables the joint's mechanical structure, consisting primarily of its centerbeams and support bars, to be lifted out and replaced with a similar construction which also features new boxes on the ends of the support bars. When the new construction is lifted into place, the new boxes are secured inside the existing boxes, hence the method's name. This method requires that the existing joint is suitable in certain ways – in particular, with boxes that are large enough to receive fully functional new boxes. The method is illustrated in Figures 8 to 10, and described further by Spuler et al [1].

Figure 8. Renewal of a *Tensa-Modular* expansion joint by the "Box-in-Box" method: Removal of rubber seals and steel centerbeams; Cutting of edgebeams; and removal of transverse support bars.

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Figure 9. “Box-in-Box” method (cont.): Lifting in of new structure consisting of centerbeams and support bars; Welding of new box inside old box; Concreting of spaces between new and old boxes.

Figure 10. “Box-in-Box” method (cont.): Reinstatement of edgebeams where cut (with recesses for rubber seals); Insertion of rubber seals; Reinstatement of road surfacing – if needed, one lane at a time.

5.1.2. The “Quick-Ex” solution for modular joint renewal

The “Quick-Ex” (or “quick-exchange”) solution for replacement/renewal of a modular expansion joint is similar to the “Box-in-Box” method described above, but far easier to carry out when the time comes to replace the joint thanks to the designing of the existing joint to facilitate the renewal process. All parts that will need to be removed to enable the joint’s mechanical structure to be replaced are bolted/screwed in place and can thus be easily removed, without cutting of steel or damaging the bridge’s road surfacing or waterproofing. Then, the new mechanical structure can be lifted into place and secured by bolting, without any need for welding or concreting. The impact on the bridge and on traffic are thus kept to an absolute minimum. The approach is illustrated in Figure 11, and described in more detail by Adam et al [2].

Figure 11. A Tensa-Modular expansion joint as specially designed for easy future renewal by means of the “Quick-Ex” method – maintaining the joint’s connections to the main structure.

5.2. Expansion joint solutions that do not have steel at connection interface
Connection of an expansion joint to a steel structure can be relatively unproblematic if the joint does not have steel at the connection interface – for instance, as illustrated by the following low-movement solutions that may be applied to any type of structure, especially during renovation work.

5.2.1. Flexible plug expansion joints
Modern flexible plug joints, such as the *Polyflex* joint (Figure 10) which primarily consists of a poured polyurethane compound, are far superior to the traditional asphaltic type as noted by Moor et al [3].

5.2.2. Single-gap joints with polymer concrete forming high-strength bond to main structure
Single-gap joints that have their steel edge profiles anchored in freshly poured quick-drying polymer concrete offer great tolerance in positioning the steel elements of the joint and avoid any need for welding or bolting. An example of such a solution is the *Tensa-Crete* joint shown in Figure 11, which has numerous benefits when used to replace old existing joints as described by Spuler et al [4].

Figure 12. Poured polyurethane flexible plug joints such as the *Polyflex* joint offer many advantages over the traditional asphaltic type.

Figure 13. Single-gap joints with polymer concrete anchorage, such as *Tensa-Crete* joints, offer many benefits for joint replacement works.

6. Conclusions
For reasons as mentioned in Section 3 above, and as illustrated in Section 4, the challenges arising when expansion joints are to be connected to a steel bridge are very varied, and the situations arising are very often unique. While certain types of expansion joint do not have steel on their connection surface, which can reduce connection effort and introduce a significant element of tolerance/flexibility for fabrication/construction and installation work, these tend to have limited applicability – particularly in relation to the magnitude of movements these components can accommodate. Where steel connections are required, great care and attention to detail are needed in developing and implementing the solution, as are extensive knowledge of the technical challenges arising and in-depth experience in the development of suitable solutions. The potential for problems to arise during installation on site should be recognised, with adequate time allowed for installation, and all appropriate measures taken, in consultation between the bridge designer, the bridge constructor and the expansion joint supplier, to minimise the risks and ensure a satisfactory long-term solution.

References
[1] Spuler T, Moor G and O'Suilleabhain C 2013 Renewal of modular expansion joints - an innovative approach that minimises impacts on traffic and on the main bridge structure *Proc. IABSE Conf. on Assessment, Upgrading and Refurbishment of Infrastructures* Rotterdam
[2] Adam S, Spuler T and Hoffmann S 2018 The quick-exchange expansion joints of the Köhlbrand Bridge in Hamburg *Proc. 40th IABSE Symposium* Nantes, France
[3] Moor G, Baillés B and Pakniat P 2018 Modern flexible plug expansion joints with polyurethane surface – far superior to the traditional asphaltic type *Proc. 10th International Conference on Short and Medium Span Bridges* Quebec City, Quebec, Canada
[4] Spuler T, Moor G and O'Suilleabhain C 2012 Renewal of small movement expansion joints with minimum break-out and time requirements *Proc. 6th International Conference on Bridge Maintenance, Safety and Management (IABMAS 2012)* Stresa, Italy