INSTALLATION OF EXPANSION JOINTS IN CABLE SUPPORTED BRIDGES – KEY CONSIDERATIONS AND ILLUSTRATIVE CASE STUDIES

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Abstract
The proper installation of sensibly selected, well designed expansion joints in bridges is a key factor in ensuring durability and minimising life-cycle costs. This is especially true for the large expansion joints generally required by cable supported bridges, which can present very significant challenges – for example, due to their size, which can make transport from factory to site and installation very difficult, or due to the connections to steel superstructures that more often arise in long-span bridges. By describing such challenges, and illustrating them with reference to appropriate case studies, this paper can enable designers and constructors of large cable-supported bridges to gain a deeper understanding of the associated challenges.

Keywords:
Expansion joint; cable-supported bridge; transportation; lifting; challenges.

1. Introduction

Deck expansion joints generally perform a critical function in bridges of any significant span length, by enabling the deck to expand and contract (due to temperature changes, creep, shrinkage, etc.), and otherwise move and rotate, as required by the bridge's design and loading. This is especially true of cable-supported bridges, which tend to have long spans and thus be subjected to correspondingly large movements and rotations at the ends of each span. As a result of their greater size and complexity, the expansion joints of cable supported bridges often present particular challenges for transportation and installation. Associated factors that should be considered in the specification, design, supply and installation of such expansion joints, to avoid or overcome such challenges, are described below.

2. Importance of proper expansion joint installation and general installation considerations

Of course, the proper long-term performance of an expansion joint depends on a number of factors, including selection of the optimal expansion joint type, the reliability of the specific model offered by the chosen manufacturer, and good design with use of optional features as may be appropriate. Proper installation is also critically important in ensuring the good long-term performance of any expansion joint, in a number of ways. But all too often, expansion joints are installed with insufficient care or expertise, as recognised by NCHRP Report 467 [1], for example, which broadly groups durability problems with modular expansion joints into four categories, one of which is "Problems that can be traced to improper installation".

Many other factors must be considered and checked during expansion joint installation. For example, a joint should be installed in such a way that all its parts are properly supported and will not be subjected to any unnecessary forces or damaging constraints. Its 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, with allowance for the future opening and closing movements 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. Other key points to be aware of and consider during installation works typically include:

- the watertightness of the expansion joint,
- the expansion joint’s proper alignment,
- the condition and proper functioning of any sliding surfaces, drainage channel or rubber seals,
- the condition and adequacy of corrosion protection, and
- the condition, flatness and waterproofing of connecting pavement / nosing.

If not properly installed, an expansion joint can suffer in many ways, including, for example, from

- mechanical damage from impacts during transport and installation or improper handling
- damaging constraint forces during structure movements
- inadequate ability to facilitate all structure movements and rotations
- contamination of sliding interfaces and other surfaces
- excessive loading from traffic, etc., or
- reduced ability to withstand static and dynamic loading.

Ensuring proper installation requires a good understanding of the subject. Therefore, expansion joint installation must be planned and carried out by competent and properly informed/inducted personnel, with all work planned and carried out under the supervision of a suitably qualified engineer who is familiar with the design and needs of the particular joint type. Supervision provided by the joint manufacturer may be the best solution and is generally to be recommended. This is especially true where, as is often the case, the bridge is scheduled to be opened (or re-opened) to traffic very soon after the completion of expansion joint installation – where there will be little or no opportunity to correct or improve sub-optimal installation.

3. Transportation challenges associated with very large expansion joints

The enormous size of the expansion joints manufactured for some large bridges can make transportation from the factory to the bridge very difficult. Challenges may include:

- awkward handling of bulky constructions at any stage in the transportation process
- road transport limitations due to weight, e.g. in crossing bridges
- road transport limitations due to dimensions, e.g. with over-length or over-width, perhaps requiring a police escort
- limitations relating to port cranage, or
- challenges in ship transportation, where transport in shipping containers or below deck may not be possible, perhaps necessitating shipping as bulk cargo which may take longer and offer less protection.

Significant transportation challenges were encountered, for example, in the case of the 24-gap modular joints manufactured in 2009 for the Incheon Bridge in South Korea, as illustrated by Figures 1 and 2.

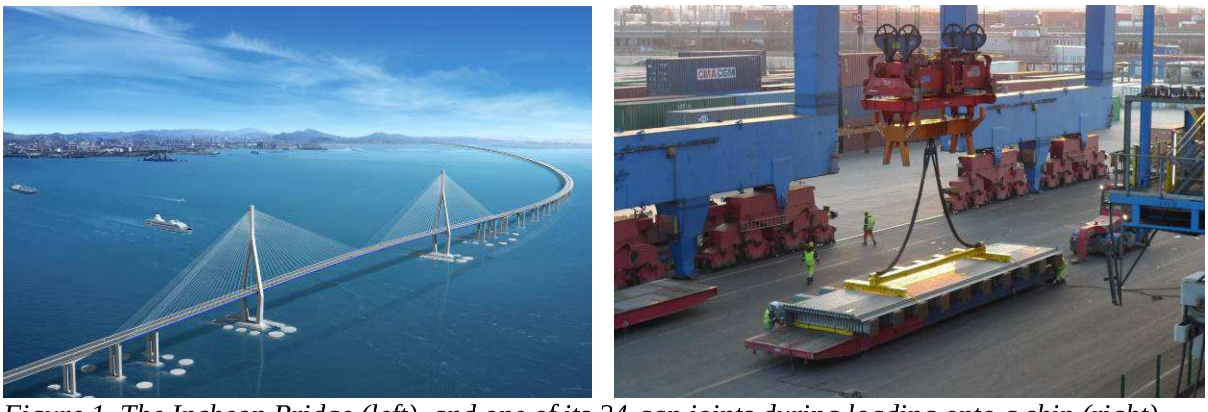

Figure 1. The Incheon Bridge (left), and one of its 24-gap joints during loading onto a ship (right)

Figure 2. Two 24-gap Tensa-Modular joints being sucured in a ship's hull for transport to site (left), and one of these during lifting into position on site (right)

To overcome such challenges, it may be possible – and should be considered – to design and fabricate very long expansion joints in parts, to be connected together on site. In the case of a modular joint, for example, this requires specialised butt-welding of the joint's transverse-oriented steel surface beams, insertion of rubber seals to span the gaps between the surface beams, and application of corrosion protection to the newly welded areas. It should be noted, however, that carrying out all this work on a bridge construction site – exposed to inclement weather and construction schedule pressures and perhaps using processes and equipment that vary from their very standardised, highly controlled factory counterparts – can only introduce an element of risk to the quality and durability of the fully installed joint, reducing its life-cycle performance and resistance to fatigue.

Possibilities may also be considered for designing and fabricating an expansion joint with parts which can be removed during transport to reduce height or increase robustness (e.g. removable rigid drainage channels) or to reduce width (e.g. partially removable support bar boxes of a modular joint).

Another possibility, requiring considerably more effort on site but perhaps overcoming an otherwise insurmountable transportation challenge, is to pre-assembly the expansion joint in the factory, de-assemble to suit transportation restrictions, and then re-assemble on site. This approach was taken, for example, in the case of the Run Yang – Nan Cha Bridge in China, which opened to traffic in 2005 with a main span of 1.49 km – one of the longest in the world. The bridge's construction required the use of exceptionally large modular expansion joints, at two bridge axes, to accommodate longitudinal movements of 2,160 mm. The expansion joints supplied each have 27 individual movement gaps, each gap facilitating 80 mm of longitudinal movement (as well as further movements and rotations). Due to their enormous size, each with a length of 16.25 m and weighing more than 55,000 kg, these joints were delivered in pre-assembled parts and re-assembled on the bridge deck to overcome the difficulties of transporting them fully-assembled from Europe to the construction site in China.

Figure 3. The Run Yang Bridge in China (left), and one of its 27-gap modular joints on site (2005)

Figure 4. Assembly of the Run Yang – Nan Cha Bridge's 27-gap Tensa-Modular joints was carried out on the bridge deck, greatly simplifying transportation to site

4. Challenges associated with lifting into position on site

Once delivered to site, expansion joints require to be lifted into position, often after being transferred from the point of acceptance to the appropriate location on the superstructure. This may be challenging but relatively straightforward, as in the case of the 22-gap modular joints manufactured in 2008 for the Chongming Bridge over the Yangtse River near Shanghai, images of which are shown in Figures 5 and 6.

Figure 5. The Chongming Bridge over the Yangtse River near Shanghai (left), and one of its 22-gap Tensa-Modular joints during transport to site (right)

Figure 6. Lifting in and installation of a 22-gap modular joint on the Chongming Bridge, 2008

In some cases, however, accessing the installation location on the deck and lifting into position can present significant access challenges – for example, if the joint's location on the superstructure is not accessible by truck or by road crane with the required lifting capacity – and may also present considerable safety risks which must be carefully mitigated. Such challenges are illustrated by the case of the 18-gap modular expansion joints manufactured in 2017 for the new Tappan Zee Bridge (officially named the Governor Mario M. Cuomo Bridge, see Figure 7) currently under construction near New York City, one of whose parallel structures has already opened to traffic. As specified by the bridge constructors, these expansion joints were required to be delivered from the factory in one piece, in spite of their enormous size – each 29 m long, 3.5 m wide and weighing 57,000 kg. Following road transport from the supplier's factory in Pennsylvania to the bridge's location on the Hudson River, on a truck with a 12-axle trailer and with a police escort (Figure 7), the expansion joint was lifted by crane from one end of the incomplete superstructure onto a raft, floating on the water 49 m below. The raft was then pulled, together with a second, floating crane, into position beneath the edge of the bridge deck at the appropriate deck axis. With the raft adequately secured, the floating crane was used to lift the expansion joint up onto the deck (Figure 8). The joint was lifted right into position in the previously prepared recess in the concrete deck with great efficiency; within 45 minutes of being lifted off the raft, the positioning of the joint had been finalized – a notable achievement for a full-length expansion joint of such dimensions.

Figure 7. The new Tappan Zee Bridge (left), and road transport to site with police escort (right)

Figure 8. Lifting of an 18-gap Tensa-Modular expansion joint (29 m long, 3.5 m wide and weighing 57,000 kg) onto the bridge deck from a barge on the river 49 m below, using a floating crane

5. Connection to the main structure – design and execution considerations

In designing an expansion joint, and executing its connection to a bridge superstructure, it is important to consider both the structural (load-transmitting) connection and the road surfacing connection.

The design of the structural connections between an expansion joint and the main structure at each side depends on whether the main structures are of steelwork or concrete – or more precisely, on whether the connections may be concreted or must be bolted/welded – a necessity that arises more often in the case of cable supported bridges, which are more likely than other bridge types to have steel superstructures.

Concreted structural connections are generally considerably easier to execute (both in expansion joint fabrication and on site) than steelwork connections. In particular, concreting allows a much greater degree of tolerance in terms of positioning, with the joint simply lifted into an oversized recess (Figure 9), but it does require reinforcement steel to be correctly placed in advance of concreting. It should be noted that expansion joint designs can have a serious impact on this constructability. For example, a joint whose design (e.g. with orthogonal shape) allows easy placing of reinforcement and concrete around it on a bridge deck (see Figure 9) will be less likely to suffer from poor installation than a joint whose design makes this site work complicated and difficult. An example of poor execution is shown in Figure 10, where cracking has occurred in the main structure beneath a modular joint's support bar where it enters the concrete structure – presumably due to poor placing and compaction of the concrete beneath the steel box in which the support bar is supported. To address the challenge of ensuring proper placing and compaction of concrete beneath such elements, the use of grouting in those locations may be considered – an approach which has found application in Japan, in particular, in the installation of modular expansion joints.

Figure 9: Connection to the main structure by concreting allows a great deal of tolerance in positioning, and an orthogonal expansion joint design can greatly simplify placing of rebar

Figure 10: An example of a poorly executed connection, resulting in cracking of the structure beneath a modular joint's support bar where it enters the main structure

Steelwork structural connections, in contrast to concreted ones, require a much higher degree of care and precision, both in terms of design and fabrication of the expansion joint and the connecting steelwork, and during installation on site. 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 structural connections, relative to concreted structural connections, typically include (as described by Jelenik et al [2]): uniqueness from an expansion joint design perspective; potentially uneven/poor load transmission to the main structure; greatly diminished accommodation of tolerances; less convenient design and connection of transportation and installation frames; increased access difficulties for workers during installation; distortion of steel and damaging of corrosion protection due to welding; and the need to apply corrosion protection to welded areas following installation, with implications for quality and durability. The relative complexity of steel connections relative to concrete ones is also illustrated by Jelenik et al, with examples such as those presented in Figures 11 and 12.

Figure 11. Installation of 7-gap and 14-gap Tensa-Modular expansion joints, side by side, during renovation of the Lillebaelt Bridge, Denmark (2002)

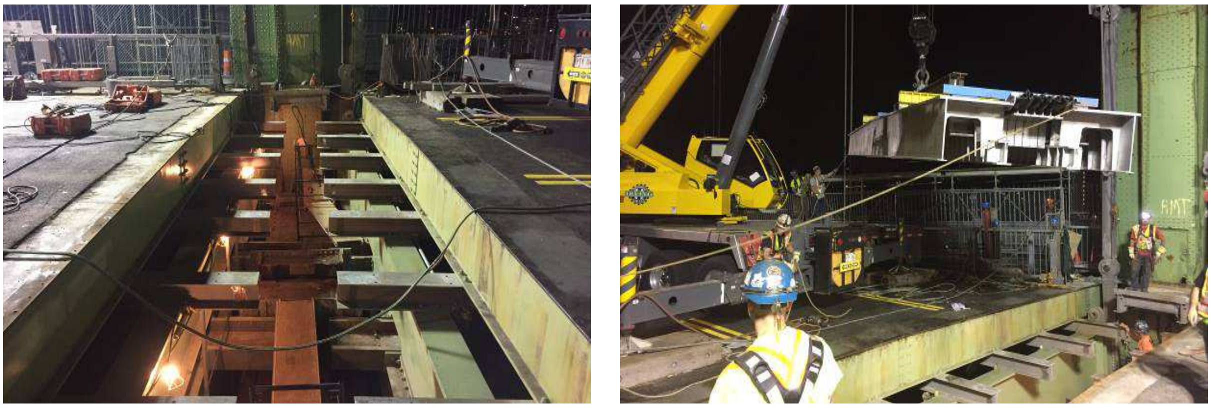

Figure 12. Installation of a 7-gap Tensa-Modular expansion joint during renovation of the Angus L. Macdonald Bridge in Halifax, Canada (2017)

The road surfacing connections between an expansion joint and the main structure at each side are generally asphalted or concreted, depending largely on whether the deck surface has an asphalt / bituminous surface and whether the structural connection (as described above) is concreted or bolted/welded. Where the structural connection is of the concreted type, the concrete may be extended right up to the driving surface or may alternatively leave room on top for asphalted road surfacing. In the case of asphalt surfacing connecting to the joint, the design of the joint's edge profiles should generally allow, by means of a suitable horizontal flange, for the connection of the superstructure's waterproofing membrane. Asphalted connections also require great care in compacting the surfacing along the edges of an expansion joint, to achieve proper compaction without damaging the expansion joint. To overcome this problem, consideration may be given to installing the expansion joint after the road surfacing has been applied right across the installation location, and then cutting out a recess into which the expansion joint will be placed and concreted.

6. Further installation considerations

Numerous further challenges may arise during installation of an expansion joint on a bridge, which must be considered in the design of the expansion joint and the main bridge structure. For example, the dynamic loading on an expansion joint from traffic should be limited in order to limit fatigue-related deterioration and other damage. For this reason, consideration should be given to making the surface level of an expansion joint slightly lower than the connecting road surface at each side (by between 2 mm and 5 mm in the case of asphalt, and between 1 mm and 4 mm in the case of concrete), which has been concluded by the EVAF research project, as reported by Lachiner and Hoffmann [3], to limit dynamic loading on the expansion joint and to reduce the risk of damage by snow ploughs.

It is also important to ensure that the connecting road surfacing will maintain the desired level for many years, and not become deformed or deteriorate due to traffic loading etc. – not only for the same reason of preventing unnecessarily high dynamic loading on the joint, but also for the surfacing's role in maintaining the watertightness of this critical part of the superstructure. This should not be an issue in the case of a concreted surface connection, but in the case of an asphalted surface connection, deformations can generally be expected to arise in due course unless suitable measures are taken to prevent them. Consideration may be given, for example, to strengthening the asphalt along the edges of the joint with mortar ribs or polymer concrete strips.

A task that can become a significant challenge in the case of cable stayed bridges, during installation of large expansion joints, is adjusting of an expansion joint's pre-setting. It is vitally important that the pre-setting of a joint is correct at the time of installation, to ensure that it will be able to accommodate all future opening and closing movements, including those due to temperature changes, creep and shrinkage of concrete, etc. Pre-setting is already a challenge to address properly in design, and adjusting on site can be especially challenging on long cable supported bridges because the width of the bridge's movement gap may change significantly on the day of the installation. Pre-setting brackets, which may be specially designed transportation beams (as shown in Figure 13), are generally used for this purpose, but the bridge's natural contraction or expansion (as day turns to night or night turns to day), where substantial enough, may also be used to adjust pre-setting.

Figure 13. Adjustment of pre-setting of a 23-gap Tensa-Modular joint (length 17 m, width 5 m and weight 55,000 kg) on the Queensferry Bridge, Scotland (left), and view from below (right)

7. Designing for the future with easily replaceable expansion joints

It can be very beneficial to consider future expansion joint replacement needs when equipping a bridge with expansion joints – especially in the case of steel cable supported bridges, which require large expansion joints with steelwork connections. In the case of expansion joints of the modular type, which are often required by cable supported structures, a "quick exchange" solution such as that described by Adam et al [4] has much to offer. As shown by the images in Figure 14, the originally installed expansion joint is designed to allow its mechanical part, with moving parts that are subjected to fatigue loading etc., to be replaced, while maintaining the parts of the joint that are connected to the main structure. This will enable, when the time comes to replace the joint at the end of its service life, to carry out this work quickly and easily, with an absolute minimum of impact on the bridge structure and on the traffic using the bridge.

Figure 14. 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

8. Conclusions

The challenges that can and often do arise in relation to the installation of expansion joints on cable supported structures are substantial. Indeed, the entire process of selecting, designing, detailing and delivering the optimal expansion joint solution for a cable supported bridge requires effective collaboration, early in the bridge design process, between a specialist expansion joint supplier and the bridge's designer and construction contractor. In particular, an understanding of joint-specific issues (during the construction stage and long term) on the part of the bridge construction team is very important, as is the timely consideration of the expansion joints' needs and of the implications of their use. Solutions such as "quick exchange" designs for certain expansion joint types can be supplied, and developed as required, by suitably experienced manufacturers, who can also provide the expertise needed to achieve the precision and quality required to ensure the serviceability and durability of expansion joints as installed. 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.

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