Expansion joints for ever longer, lighter bridges

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Summary

The drive to construct bridges with ever longer spans, using ever less materials and resources, presents challenges for the suppliers of key bridge components such as the expansion joints which must provide a continuous driving surface at the ends of the structure's deck. Not only will the longitudinal movement range of the joints increase, but the flexibility of the joint to accommodate the more frequent and unpredictable movements of a less robust bridge deck must also be ensured. Durability also becomes a more critical consideration as a result of the increased movements and reduced robustness, and the design of the joints, and the materials used in their fabrication, must reflect this. It is important that bridge designers and constructors have an understanding of these issues, and of the implications of their designs for the expansion joints whose performance will be a significant factor in the constructability and life-cycle costs of the bridge.

Keywords: *Expansion joints; bridges; long spans; large movements; flexibility*

1. Introduction

As bridge engineers continue to push the boundaries of what can be achieved using continually developing techniques and materials, bridges become ever more impressive, achieving longer spans despite using less material. This ongoing development is important for us as an industry and for our natural environment, and is a key element of what defines us as engineers, but it also presents challenges for the supply chain partners whose products must likewise develop to keep up with this progress. This is especially true in the case of the expansion joints which are placed at the ends of a bridge's deck to provide a driving surface for traffic while enabling the bridge deck to move under the influence of thermal effects, creep, shrinkage, wind, traffic, seismic effects and other factors.

2. The demands on modern bridge expansion joints

As bridge deck spans increase, the maximum movements which must be accommodated by the expansion joint at each end also increase, to the point where some structures require joints which will accommodate movements of two metres or more. And as the deck is designed to be lighter, the secondary, frequent movements of the bridge also increase, as the effects of non-seasonal influences become more significant for the less robust structure. A light bridge deck will move more due to wind, traffic and short-term temperature changes (for example, as the sun goes behind a cloud) than a heavy one, with the result that the total accumulated movements which must be accommodated by its expansion joints increase greatly and can result in a modern slender bridge moving several hundred kilometres during the lifetime of its expansion joints.

At the same time, traffic continues to increase, presenting another challenge. Assuming a bridge carries just 6,000 vehicles a day on each traffic lane, the total design traffic volume per lane during an expansion joint's working life of 40 years will be likely to exceed 200 million axle loads. This enormous figure indicates why fatigue is a major issue when designing durable expansion joints.

The combination of such greatly increasing movements and loads on the expansion joints of modern bridges requires suppliers to continue to improve the performance of their products and develop new ways of satisfying the sometimes exceptional demands.

3. Improving expansion joint technology

Modern expansion joint technology and the capabilities of suppliers are continually developing to satisfy the demands placed by modern bridge engineering, as described below for the cases of two expansion joint types which are very often used in the construction of long-span bridges: the modular joint and the finger joint.

3.1 Modular expansion joints

Modern modular expansion joints are often best suited to satisfy the movement demands of today's exceptional bridges, in particular due to their ability to facilitate very large longitudinal movements of the bridge deck, and their great flexibility while achieving this, allowing also transverse and vertical movements of the deck as well as rotations about any axis. However even modular joints face a number of particular challenges in the case of bridges whose expansion joints are subjected to extreme movements (either movement capacities or accumulative movements) and/or extreme loading (resulting from exceptionally large traffic volumes etc). A number of special features which can help overcome these challenges are outlined below.

3.1.1 Special sliding materials

The sliding material normally used to facilitate the sliding of the moving parts of an expansion joint could not withstand the extreme movements of some expansion joints, and a suitable alternative must be specified. A material which meets modern demands is for instance *Robo®Slide*, as shown in Figure 1. This is a high grade sliding material with excellent abrasion resistance and very low friction characteristics. Tests carried out on this material showed that the material is far more durable than PTFE (with virtually no signs of wear after a sliding distance of 20 km), and more than twice as strong in compression.

Fig. 1: Special high-grade sliding materials

3.1.2 Asymmetrical control system

The symmetrical control systems generally used in modular expansion joints to regulate the widths of the gaps between the joint's lamella beams do not suffice when the movement capacity becomes very large, due to the friction and other forces which arise as the joint opens and closes. To overcome this problem, and ensure that the movement of the joint will be evenly distributed among the joint's individual gaps, an alternative, asymmetrical control system has been developed. This incorporates a staggered layout of the control springs, with the number of springs being increased at one end of the joint to counteract the build-up of friction forces. Figure 2 shows the underside of a joint with such a system.

Fig. 2: Asymmetrical control system

3.1.3 Highly durable control springs

The control springs which regulate the gap width between a joint's lamella beams are subjected to additional loading when installed in an expansion joint that must facilitate extreme movements, and must be adapted to suit. For instance, the rubber mixture of Mageba's control springs has been optimised to improve overall performance and durability by a factor of 2.5, as verified by testing at an independent institute (Figure 3).

Fig. 3: Testing of Mageba's 4th generation control springs at -20°C

Fig. 4: Noise-reducing "sinus plates" on a modular joint

3.1.4 Noise reduction

Noise generated by traffic crossing a modular expansion joint can be significant, especially in the case of large joints on busy bridges with high traffic speeds. Suitable surfacing to reduce the noise generated becomes a requirement in many cases, for instance on elevated highways in populated areas.

A solution which incorporates the fixing of profiled steel plates (so-called "sinus plates" due to their shape) is shown in Figure 4. These plates eliminate straight edges perpendicular to the direction of travel, and ensure that vehicles travelling over the joint continuously grip the surface, greatly reducing the noise generated by traffic on the joint.

Noise measurements carried out on different structures by an independent body have shown that modular expansion joints with sinus plates are significantly less noisy (up to 70% less noise generated by traffic) than other types of expansion joint [1].

3.1.5 Anti-skid protection

As the span of a modular expansion joint increases, so too does the distance a vehicle will have to travel in crossing the joint with reduced ability to brake, especially in wet weather conditions. Large expansion joints therefore require some form of surface treatment to improve tyre grip. A proven anti-skid surface, for example, is *Robo®Grip*, as shown in Figure 5. This is a five-layer laminate coating that is applied cold in liquid resin form. It was originally developed for aircraft carrier ships of the British Royal Navy, where high friction and durability under extreme conditions is required. This special surface treatment results in a friction coefficient μ of up to 0.9 and guarantees at least μ = 0.5 over its full service life, even under the most adverse traffic and weather conditions. It is also resistant to pollution and ultra-violet radiation.

Fig. 5: Lamella surfaced with anti-skid coating

3.1.6 Earthquake protection features

Depending on their location, bridges can also be affected by earthquakes, which can result in the destruction of the bridge's expansion joints and possibly severe damage to the bridge structure itself. Serious damage to a large bridge can have very serious consequences for an area which has recently been devastated by a earthquake, as its function as a lifeline to the area takes on great importance in such circumstances – in facilitating the evacuation of the affected population and access to the area by emergency services. A feature, known as *Fuse®Box*, which allows the connection of an expansion joint to the main structure to break in a controlled manner in the event of an earthquake, is shown in Figure 6. This system permits the expansion gap to close during an earthquake without being destroyed, and to settle afterwards in such a way as will allow emergency vehicles to travel across the joint. Such a system therefore facilitates essential activities such as emergency services, evacuation and reconstruction in the aftermath of an earthquake.

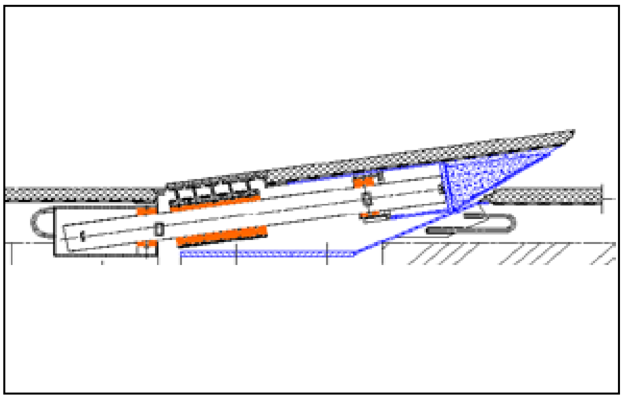

Fig. 6: Fuse®Box system for seismic events

3.2 Finger expansion joints

Finger type expansion joints offer an attractive alternative to other types of joint, especially due to their relative simplicity and lower number of moving parts, and low noise emissions from the passage of traffic across the continuous surface. However, apart from longitudinal movement, they are relatively limited in the movements (in any other direction) and rotations (about any axis) they can accommodate. Various types of finger joint have been invented and continually developed to exceed the capabilities of the past, with improved confidence in their performance and durability.

3.2.1 Cantilever finger joints

Where movement requirements are relatively small (typically a few hundred millimetres or less), a simple cantilever finger joint can often be used. This type of joint, as shown in Figures 7 and 8, has no moving parts, and is therefore an ideal candidate where low maintenance effort is a key consideration.

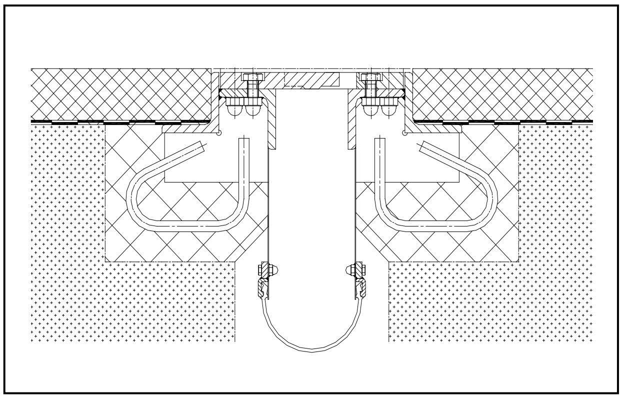

Fig. 7: Cantilever finger joint – cross-section

Fig. 8: Cantilever finger joint – as installed

3.2.2 Sliding finger joints

When larger movements must be accommodated, an alternative finger joint can be used: the sliding finger joint. Contrary to the cantilever finger joint, the finger plates of the sliding finger joint receive sliding support at the tip of each finger.

The sliding finger joint is an asymmetric construction consisting of complementary "male" and "female" parts. The female part consists of a steel plate with fingers bolted on top, which is fixed at one side of the expansion gap. The male part is an opposing plate with protruding fingers which is fixed at the other side of the gap. As the bridge deck expands and contracts, the fingers of the male part slide longitudinally between the fingers of the female part, always maintaining contact with (and receiving support from) the base plate of the female part below. Sliding finger joints can therefore facilitate relatively large expansion and contraction movements.

The male finger plates of a sliding finger joint are pre-tensioned downwards to ensure that their fingers remain in permanent contact with the opposing sliding surface below. Thus rotation of the joint, for example due to settlement of an abutment, can be facilitated, and the fingers of the joint will not protrude above the carriageway surface, or spring up, even under heavy over-rolling traffic. Furthermore, sliding finger joints can be used if the bridge has a longitudinal slope and the sliding bearings supporting the bridge deck are installed horizontally, as the resulting vertical movement of one section of deck relative to the other as the joint opens and closes can be accommodated by the joint’s flexibility.

Since the fingers that span the expansion gap act statically as simply supported beams (without any cantilever effect), relatively simple anchoring of the joint is possible. The flexible and shock-absorbing effect of the pre-tensioning also reduces the impact of loading and therefore protects the bridge structure underneath from fatigue-related problems. Finally, the design also enhances driver comfort and reduces noise to a minimum.

Two types of sliding finger joint, which differ primarily in the way the pre-tensioning downwards of the finger plates is achieved, were considered. One type, the steel/elastomer bonded variety, utilises the elasticity of the elastomeric block from which the fingers protrude to ensure a downward tendency in the fingers. The modular construction of the joint, with parts generally being liftable by two men, makes installation, maintenance and replacement relatively straightforward. This type of joint is shown in Figures 9 and 10.

Fig. 9: Sliding finger joint (steel/elastomer bonded system)

Fig. 10: Tensa®Flex Sliding finger joint (steel/ elastomer bonded system) – during installation

The second type, using primarily steel parts, achieves the pre-tensioning downwards of the finger plates by means of stainless steel springs below the plates. This type is shown in Figures 11 and 12, and is referenced in Section 4.2 below.

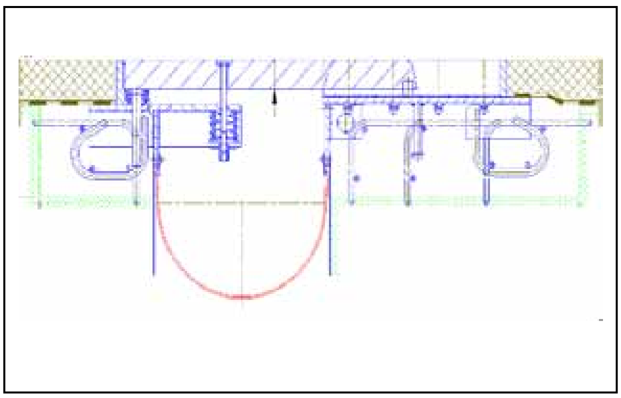

Figure 11. Sliding finger joint (steel system)- Cross-section

Figure 12. Sliding finger joint (steel system) – As – installed

4. Examples of recently installed joints on exceptionally long-span bridges

The recent delivery of exceptionally large expansion joints, both modular and finger types, for remarkable bridge structures in Asia and America, is described below. This will serve to illustrate the current capabilities of leading joint suppliers, and to sensitise bridge designers to the challenges presented in the supply of such components.

4.1 Modular expansion joints of the Incheon Grand Bridge, South Korea

At 12.3km long and with a main cable-stayed span of 800m, the Incheon Grand Bridge (Figure 13) was opened in October 2009 as one of the five longest cable-stayed bridges in the world. The modular expansion joints of the bridge's main span each have 24 gaps, allowing longitudinal movements of up to 1,920mm. The joints feature Robo®Slide high grade sliding material, an asymmetrical control system, advanced highly durable control springs and Robo®Grip anti-skid surfacing (refer to Section 3.1 above), and a Robo®Control structural health monitoring system [2].

Fig. 13: The Incheon Bridge, South Korea

Although fabrication of such large modular expansion joints is not unprecedented, what made the supply of these joints exceptional in the supplier's experience was the transport of the completely assembled joints from the factory (in Europe) to the other side of the world (Figures 14 and 15), while previously supplied mega-joints, including 27-gap joints supplied in 2003 for the Run Yang Bridge in China, were assembled on the bridge to overcome the challenges of shipping such enormous structures (Figure 17).

Fig. 14: Road transport from the factory in Austria of a joint for the Incheon Bridge

Fig. 15: Sea transport of joints from Europe to South Korea

Fig. 16: Installation of a joint on the Incheon Grand Bridge, South Korea

Fig. 17: Assembly on site of world-record 27-gap modular joints for the Run Yang Bridge, China 2004

4.2 Sliding finger joints of the John James Audubon Bridge, Louisiana, USA

The John James Audubon Bridge, currently under construction over the Mississippi River, will be the longest cable-stayed bridge in the Western Hemisphere when it opens later in 2011. The bridge has in recent months been fitted (Figure 22) with expansion joints that will allow exceptionally large movements for the preferred sliding finger type of joint. The largest joints are designed to facilitate longitudinal movement of up to 1,240mm, believed to be unprecedented for this type of sliding finger joint. These movement requirements presented a particular challenge for design and fabrication [3], resulting in the taking of a number of non-standard measures. These included: mechanical straightening of the fingers of the sliding plates, to achieve the required straightness (Fig. 19); pre-assembly of a joint, prior to application (after disassembly once again) of corrosion protection, to ensure that all parts would come together and interface as intended (Fig. 20); and assembly of the specially designed drainage system on site (Fig. 21). The successful completion of the project, with installation of the joints early in 2011, showed that even movements in excess of one metre can now be facilitated by this type of sliding finger expansion joint.

Fig. 18: The Audubon Bridge, Louisiana, USA

Fig. 19: Mechanical straightening of the fingers of a sliding finger plate

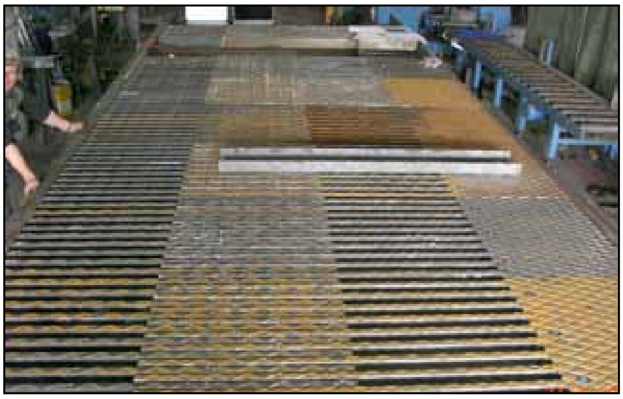

Fig. 20: Pre-assembly of a joint, prior to application of corrosion protection

Fig. 21: Connection of drainage channels to joints after placing on a support frame

Fig. 22: Lifting into position of the second expansion joint at one bridge axis

5. The importance of early consideration of expansion joint needs

In some cases, little consideration is devoted in the early stages of a bridge's design to the expansion joints it will require. But as bridge spans become ever longer, and decks become lighter, it becomes increasingly important to consider expansion joint selection during the preliminary design phase.

It is of course important to define the demands to which the expansion joint will be subjected, and to ensure, if necessary in discussion with an experienced manufacturer, that this will not present major difficulties for supply. This assessment should not be limited to just the bridge's longitudinal movements and designer or owner preferences, but should consider all other relevant factors such as: transverse and vertical movements; rotations about every axis; the frequency of such movements and rotations; the cumulative movement during the lifetime of the joint (including micro-movements which can occur due to wind or traffic, and due to thermal changes when the sun's warmth is temporarily blocked by a cloud); and the nature of the movements (whether they are sudden and irregular, or gradual and predictable). When these factors have been assessed, such issues as choice of sliding material can be properly considered, and it can be confirmed whether the best materials available can be expected to satisfy durability requirements. If they can not, then this should be recognised and accepted, and suitable allowance made for maintenance and replacement, or another solution should be sought – issues which should certainly be considered early in the design process.

Once the type of joint which can optimally satisfy the structure's needs has been identified, and allowance made for the costs of supply and installation of this type, it is important to ensure that the bridge deck is designed to receive the selected joint, with correctly sized block-outs and bridge gap. Inappropriate design of the bridge deck can limit access to the underside of the joint and cause difficulties with inspection and maintenance at a later stage, so early consideration of these issues can avoid changes to approved plans, or even adaptations to the bridge deck on site.

6. Conclusions

Exceptional bridge structures, designed and built by a construction industry that continues to push the boundaries of span and performance for such structures while at the same time always striving for greater cost-effectiveness, require carefully selected and detailed key components such as expansion joints to support their design. Suppliers of such components therefore play an important role in supporting the aspirations and achievements of the wider bridge construction industry – enabling bridges to be built ever longer and lighter, while not compromising on the quality of important mechanical components.

References

[1] SPULER, T., MOOR, G., O'SUILLEABHAIN, C., "Expansion joints with low noise emission", *International fib Symposium*, Amsterdam, May 2008.

[2] SPULER, T., MOOR, G., O'SUILLEABHAIN, C., "High performance expansion joints for the Incheon Grand Bridge", *International commemorative symposium for the Incheon Bridge*, Incheon, Korea, September 2009.

[3] SPULER, T., MOOR, G., O'SUILLEABHAIN, C., "Worlds largest sliding finger joints for the Audubon Bridge", *33rd IABSE Symposium*, Bangkok, September 2009.