Optimising selection of critical bridge components - the bearings and expansion joints of the Viaducto Puerto de Santa Maria

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Summary

The highways serving the town of El Puerto de Santa Maria on Spain's southern coast were recently extended and improved, with the work including the construction of an elegant new highway viaduct. That proper attention was paid, not only to aesthetics but also to ensuring functionality, durability and value for money, can be seen in relation to the structure's critical mechanical components - its bearings and expansion joints. The care that went into the selection of these components is demonstrated by the fact that a single solution was not chosen to satisfy either the bearing or expansion joint needs of all locations. In fact, two types of bearing (spherical and elastomeric), and two types of expansion joint (modular and finger) were selected for use on the same structure – a rather uncommon degree of diversity. The resulting benefits are described, demonstrating the importance of attention to detail in this part of a bridge's design and construction.

Keywords: bridge; bearings; expansion joints; selection; installation; replacement; optimisation.

1. Introduction

The town of El Puerto de Santa Maria, on Spain's south coast close to the strait of Gibraltar, has a distinguished history, having been the launching point for Columbus' second voyage to America – a proud heritage which should be reflected in modern developments. A recent infrastructure project in the town demonstrates how design and construction work can be carried out to achieve a result that is not only attractive but also optimises functionality, durability and cost-effectiveness. The Viaducto Puerto de Santa Maria (Figures 1 and 2) is a new highway viaduct connecting to the region's A-4 and A-491 highways. The structure's designers and constructors showed an appreciation of the importance of careful selection of key components – in particular in relation to the mechanical components such as bearings and expansion joints which are far less robust than the main structure but subjected to tremendous fatigue loading and service movements during a lifetime of several decades. Rather than selecting a single type of bearing to satisfy the deck bearing needs at all locations, and a single type of expansion joint for both ends of the bridge, a mix of types was applied, as described below.

2. The structure's design

The viaduct has a total length of 440m, with 14 spans of approximately 30m each – the deck being supported by 13 intermediate piers and the abutments at each end. The deck's "fixed point" is at its mid-length, so the greatest movements experienced by the deck are at its abutments. The viaduct has a prominent horizontal curve at its centre, resulting in the need to facilitate transverse movements at each pier as the deck expands and contracts due to thermal effects.

Fig. 1: The Viaducto Puerto de Santa Maria – aerial view showing the structure's curve

Fig. 2: View of the viaduct from ground level, showing its attractive pier design

3. The structure's expansion joints

A bridge's expansion joints provide a continuous driving surface at each end of its deck, while facilitating deck movements which might result from temperature variations, wind, concrete creep, traffic etc. Expansion joints of different types offer varying capabilities and benefits. The Viaducto Puerto de Santa Maria requires expansion joints at its two abutments. Although the movements to be facilitated at each abutment are very similar, with 400mm (+/- 200mm) of longitudinal movement in each case, there were differences which made the use of different joint types desirable.

3.1 Expansion joints allowing easy replacement: The *Tensa-Flex* sliding finger joint

At one end of the viaduct, the horizontal curve of the deck at mid-span gives way to a straight deck at the abutment. As a result, the transverse and vertical movements of the deck at this location could be limited to just +/- 3mm and +/- 1mm respectively. This made the use of a finger-type expansion joint feasible, and this was considered in detail. Finger type joints can offer an attractive alternative to other types of large-movement joint, especially due to their relative simplicity and the low noise emissions from traffic crossing the continuous surface. However, their interlocking finger design means that, apart from longitudinal movement, they are relatively limited in the movements and rotations they can accommodate. Various types of finger joint offer different advantages. Cantilever finger joints, whose fingers cantilever out across the movement gap, are suitable for small movements (of up to approximately 300mm). Sliding finger joints, on the other hand, can accommodate much larger movements, since the tips of their fingers receive sliding support at the opposite side of the gap – reducing structural demands on the joint and its support structures.

Another defining requirement was for the expansion joint to have low depth, considering the pre-tensioning cable anchorages in the area. One type of sliding finger joint is the *Tensa-Flex* joint (see Figures 3 and 4) – a highly durable, easily replaceable joint that offers excellent watertightness and features strong anchorages (especially in comparison to, for example, a rubber mat joint).

Fig. 3: An installed Tensa-Flex expansion joint

Fig. 4: Schematic section of a Tensa-Flex joint

The *Tensa-Flex* sliding finger joint is a flexible steel and elastomer bonded system which consists of two asymmetric parts. Each part consists of individual elements of length just 500mm, making them easy to install and replace – for example, by hand as shown in Figure 5 below. The fingers of the upper part are pre-tensioned downwards and therefore apply a permanent pressure to the opposing sliding surface of the lower part. The system is anchored to a specially prepared concrete subsurface, and is therefore easily replaceable. Perhaps most significantly in many cases, the modular design of the system allows the individual elements of the joint to be replaced in a very short period of time (for example, in one night) on a lane-by-lane basis. It is also possible to only replace the joint under the lane with heaviest traffic, should this section of joint require replacement earlier than the rest.

The installation of the joint on a concrete surface, either on a new structure or where traffic management considerations do not demand a speedier return of the structure to full service, is shown in Figure 5.

Fig. 5: Positioning and securing of finger plates of a Tensa-Flex joint by hand, on a prepared concrete surface with waterproofing membrane

Fig. 6: Placing of Mini-Fly-Over traffic management system to minimise traffic disruption during installation of Tensa-Flex joints

If an existing expansion joint is to be renewed when it reaches the end of its lifetime, the Mini-Fly-Over system can be used to allow traffic to cross the site during the daytime, while the construction works are carried out at night-time on a lane-by-lane basis [1]. In this way, unhindered traffic flow during peak times can always be facilitated. The approach is shown in Figure 6.

The features of the Tensa-Flex system therefore make it particularly suitable for densely populated and heavily trafficked areas, where longitudinal movements of up to 800mm must be facilitated.

3.2 Expansion joints with exceptional flexibility: The *Tensa-Modular* joint

At the other end of the viaduct, the deck still has a slight horizontal curve and a significant transverse gradient of over 3.7% from one side to the other. At this location, the expansion joint had to be designed to accommodate larger transverse and vertical movements, of +/- 7mm and +/- 15mm respectively. A more flexible type of expansion joint was thus needed, and the Tensa-Modular joint was selected. This joint is characterised by its ability to facilitate very large longitudinal movements, and, in contrast to other types of modular joint, by its great flexibility while achieving this [2].

3.2.1 Very large longitudinal movements

Modular expansion joints can be designed to sustainably accommodate longitudinal movements of 2 metres or more, as demonstrated by the joints of the Tsing Ma Bridge in Hong Kong (Figure 7), which has a main span of 1377m. These joints have 25 gaps each and can thus facilitate movements of up to 2000mm. Having been installed in 1996, the joints have now been in service for almost two decades, and during this time have required only the replacement of control springs – a wear part which regulates lamella beam movements, distributing overall deck movements among the individual gaps between lamella beams.

Fig. 7: The Tsing Ma Bridge in Hong Kong – with deck movements facilitated by 25-gap Tensa-Modular expansion joints since 1996

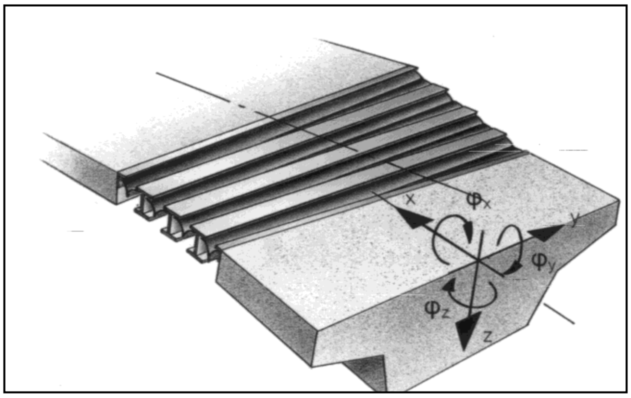

Fig. 8: The Tensa-Modular joint's great flexibility enables it to facilitate movements in all directions and rotations about any axis

3.2.2 Exceptional flexibility

Modular expansion joints can be designed to offer a level of general flexibility which is unmatched by any other type of joint. In addition to being able to accommodate enormous longitudinal movements, as described above, those with elastic control systems (such as Tensa-Modular) can also facilitate very significant transverse and vertical movements, and rotations about any axis (longitudinal, transverse or vertical), as illustrated by Figure 8. Such capabilities may well be required by a bridge's design and its movements, but even if they are not, the flexibility of the joint can still be of great value – for example, should unexpected movements arise, or should constraint forces develop due to blockage by a foreign object or similar. And the elastic nature of the joint's design significantly increases the joint's fatigue resistance and general durability.

4. The structure's bearings

A bridge's bearings are among its most critical components, ensuring the proper functioning of the structure as a static and dynamic system. They carry the weight of the bridge's deck while safely transmitting loads from a wide range of other sources (traffic, wind, seismic, etc.) and facilitating movements and rotations of the deck as may be required by the structure's design. Although some short-span structures can be designed without bearings, the inclusion of bearings in most large structures can be highly advantageous. The provision of joints, which can allow movements and/or rotations, in what would otherwise be a stiff, non-flexible structure, can substantially reduce the forces and bending moments arising within the structure. This results in considerably smaller cross-sections, less materials and reduced anchoring, and thus ultimately in improved constructability, lower overall construction costs and an aesthetically more pleasing structure.

There are numerous types of structural bridge bearing, each offering its own capabilities and benefits. The most popular include elastomeric bearings, pot bearings, disc bearings and spherical bearings, as well as various types of seismic isolator. In the case of the Viaducto Puerto de Santa Maria, both elastomeric and spherical bearings were used – with varying designs.

4.1 Bearings offering elasticity: *Lasto-Block* elastomeric bearings

The bearings supporting the viaduct's deck at its intermediate piers are typically required to carry loads of approximately 14,000 kN each. Elastomeric bearings were chosen for their elastic behaviour as the structure is situated in a seismic area. This type of bearing is less complex than other types, and can thus be expected to perform well for many years with little or no maintenance. The damping of structural vibrations they offer can not only protect the structure from seismic and other types of loading, but can also minimise noise. The elastomeric bearings also allow a certain amount of transverse movement at each pier as the viaduct's deck expands and contracts due to temperature changes because of the deck's horizontal curvature. Elastomeric bearings can allow some transverse movement by deformation alone, without needing an in-built sliding surface, and so are an attractive solution, especially when maintenance and durability are taken into account.

At the viaduct's mid-length, where the deck's "fixed point" is located, the deck is supported on 5 piers by elastomeric bearings as shown in Figures 9 and 10. These bearings consist primarily of large blocks of elastomer, reinforced by internal horizontal steel plates. They also feature external steel plates in their top and bottom surfaces, and separate anchor plates concreted into the connecting structures above and below. The bearings are securely fixed in position, both above and below, by keys recessed into the surface plates and anchor plates - a design which allows each bearing to be easily removed or replaced if the deck is lifted by just 15mm. The bearings thus allow horizontal deck movements only by means of elastic deformation of the elastomer, which is limited by design as appropriate – in particular, by the total additive height of the bearing's elastomeric layers. The bearings of the central three piers allow longitudinal movements of just +/- 40mm (and transverse movements of +/- 16mm), while the bearings of the adjacent piers, being further from the centre of the "fixed point", allow somewhat more (+/- 56mm).

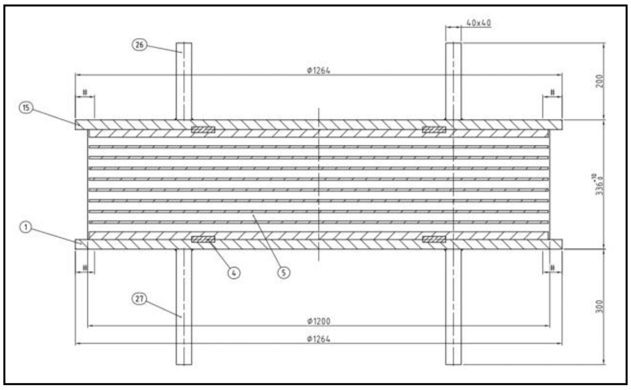

Fig. 9: Cross-section of an elastomeric bearing with anchor plates, which allows deck movements only by deformation

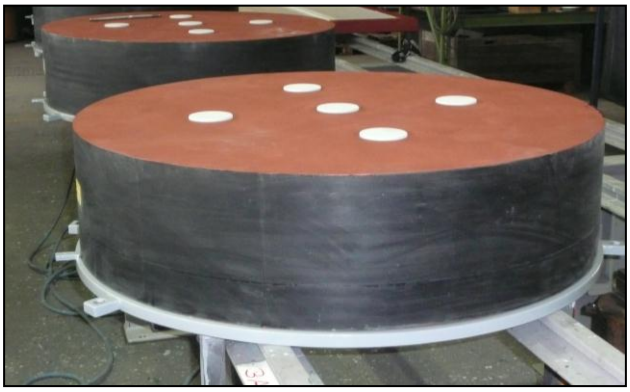

Fig. 10: An elastomeric bearing during assembly in the factory, showing the steel discs that key the bearing to the upper anchor plate

The bearings at the remaining piers, being yet further from the "fixed point" at the viaduct's mid-length, must accommodate yet greater longitudinal movements, increasing to +/- 190mm at the last pier at each end of the viaduct. Movements of such magnitude could only be facilitated by bearings with correspondingly large additive heights of their elastomeric layers, making the bearings prohibitively high, so the longitudinal movement capacity of these bearings was achieved by adding a sliding interface. The sliding interface is created by the addition of an extra steel plate between the bearing's upper surface plate and the anchor plate above, as shown in Figures 11 and 12. The additional steel plate can slide against the anchor plate, with this sliding facilitated by a lubricated PTFE disc on the upper surface of the additional steel plate and a stainless steel sheet on the lower surface of the anchor plate. Transverse movements at this sliding interface are prevented by a guide bar which protrudes from the upper surface of the additional steel plate on its central axis and slides within a longitudinal recess in the lower surface of the anchor plate.

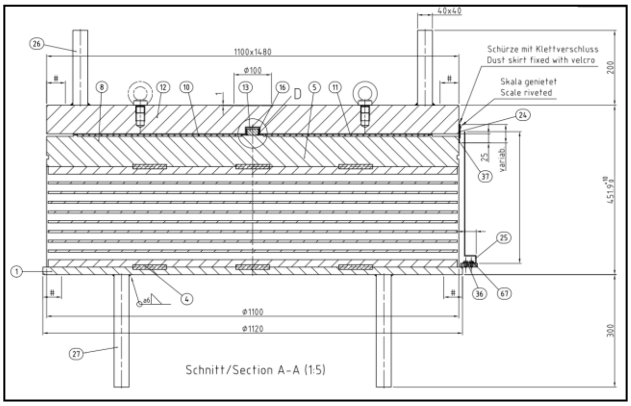

Fig. 11: Cross-section of an elastomeric bearing which allows longitudinal movements by sliding and transverse movements by deformation

Fig. 12: Installation of an elastomeric bearing on site, showing the stainless steel sheet on top which allows longitudinal sliding movements

4.2 Bearings for large loads and rotations: *Reston-Spherical* bearings

At the abutments at both ends of the viaduct, the requirements for the bearings were somewhat different than for those at the piers. It was necessary to prevent any transverse movement whatsoever at these locations where the driving surface connects to the approach roads, and it was also desirable to reduce the size of the bearings. Although elastomeric bearings can be designed to prevent transverse movements by the addition of vertical steel plates (with sliding interfaces) from top to bottom, this would be an ungainly solution for a large bearing with a height of 450mm or more (like the bearings at the piers next to the abutments). Therefore, an alternative type of bearing was selected for the abutments: spherical bearings. These are far more compact than elastomeric bearings, making the additional of guide bars across the full height of the bearing much more practical.

Spherical bridge bearings are based on the principle of a steel calotte, with the shape of a spherical cap (a portion of a sphere cut off by a plane), located within a concave-shaped lower steel part with a matching radius. The calotte can rotate freely within the lower part, thus enabling the bearing to efficiently facilitate large bridge deck rotations. Like other types, spherical bearings can be designated fixed, free sliding or guided sliding, depending on their ability to accommodate horizontal sliding movements or resist horizontal forces.

Spherical bearings are very strong and durable, consisting entirely of carbon steel, stainless steel and a sliding material such as PTFE above and below the calotte. The weakest part is the sliding material, so the strength and durability of the entire bearing depends on that of the sliding material. Therefore, the dimensions of the bearing can be greatly reduced by the use of an improved sliding material which can be subjected to higher stresses. Such a material is RoboSlide, a patented high-grade sliding material which was specially developed and certified for use in bridge bearings and expansion joints. This material, a modified ultra-high molecular weight polyethylene, offers much higher bearing capacity than PTFE, along with other advantages such as far superior resistance to wear and abrasion [2]. The use of such a sliding material enables spherical bearings to be designed and manufactured to carry truly enormous loads – such as those supporting the pylon of the Tran Thi Ly Bridge in Da Nang, Vietnam, two of which are each capable of resisting loads of 250,000 kN (2.5 times the weight of the Eiffel Tower). These bearings, shown in Figures 13 and 14 during assembly and installation respectively, are enormous, with their calottes having a diameter of approximately 3 metres - but they are considerably smaller than would be possible with any other type of bearing, with numerous advantages for procurement, installation and the bridge’s design [3].

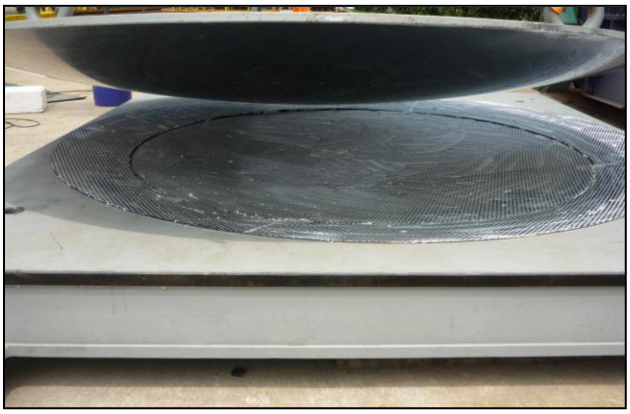

Figure 13: Assembly of a bearing for the Tran Thi Ly Bridge: Placing of calotte with convex surface onto lubricated lower concave part

Figure 14: Placing of two enormous guided sliding spherical bearings, side by side, to support the pylon of the Tran Thi Ly Bridge

To avoid the occurrence of constraint forces at the ends of the Viaducto Puerto de Santa Maria, it was desirable to have only one bearing preventing transverse movements at each abutment. This was achieved by means of a guided sliding bearing, as shown in Figure 15.

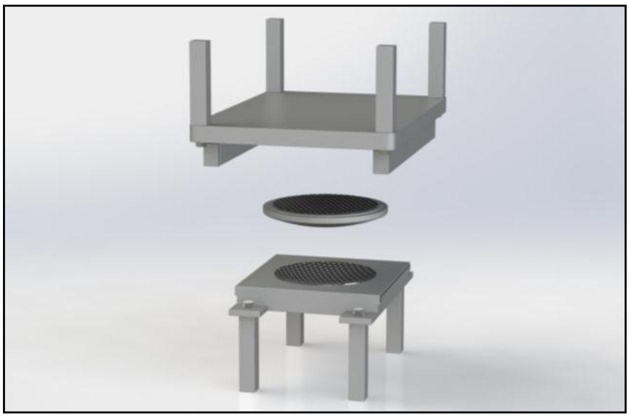

Fig. 15: Schematic representation (exploded view) of a guided sliding spherical bearing

Fig. 16: Free sliding spherical bearing as installed, showing reflection in sliding sheet

To minimise the maximum transverse movements that can arise across the deck's width at this location (resulting from thermal expansion and contraction of the deck's materials), it was decided to place that bearing at the centre of the abutment, beneath the deck's longitudinal axis. Since the deck is not stiff enough or stable enough to be supported by a single bearing beneath its centre, an extra spherical bearing was placed at each side. Again, to avoid constraint forces due to thermal expansion and contraction, these bearings were designed to be free-sliding, with a sliding interface facilitating all horizontal sliding movements, both longitudinal and transverse. One of these bearings is shown in Figure 16.

5. Conclusions

The construction of the Viaducto Puerto de Santa Maria in southern Spain demonstrates well how bridge bearings and expansion joints of different types can be used on the same structure, with significant benefits for procurement, installation, maintenance and renewal. Early consideration of the options available, with the support of a specialist supplier who can advise on the capabilities, benefits and optional features of a wide range of possible solutions, can enable product selection and design to be optimised. The attention to detail that was applied to this part of the Viaducto Puerto de Santa Maria's design and construction is very evident - an attention to detail that Columbus himself would probably have been proud of, in planning his voyages to America.

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