Minimisation of maintenance-related disruption to bridge serviceability by the use of the right key structural components

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Abstract

Maintenance of bridges, and of their key components, is a major cause of disruption to traffic, whether it be for the purposes of inspection, regular maintenance and repair, or – most significantly, in the case of key components such as expansion joints – during replacement works. Ways in which such disruption to traffic can be minimised are presented, including maximising the performance of key components through proper selection, installation and maintenance, and minimising disruption during replacement of components by the use of optimised designs and methods.

Keywords: Bridge; bearings; expansion joints; seismic isolators; dampers; traffic disruption; performance; durability.

1. Introduction

Disruption to traffic on bridges should always be minimised, considering the enormous accumulated financial costs and other impacts of traffic congestion and diversions. A significant cause of disruption to bridge traffic is the maintenance, repair and replacement work required by their key structural components – their bearings, expansion joints, seismic isolators and dampers. Therefore, care should be taken to maximise the long-term performance of such components, as described in Section 2. And considering the great disruption to traffic that can be caused by component replacement work in particular, consideration should be given to using components that are designed for easy replacement, or for easy installation in an existing structure, as described in Section 3.

2. Limiting disruption by maximising performance of key components

Poorly performing components require more maintenance and repair, and may need to be replaced much earlier, than ones that perform well – and this can impact strongly on bridge users. In the case of expansion joints, for instance, some authorities consider the initial cost of supply and installation to be insignificant in relation to the long-term costs of poorly performing joints, considering in particular the user costs resulting from traffic disruption etc. [1]. In the case of bearings and seismic isolators, traffic can be affected by bridge lifting during replacement works, and bearings, isolators and dampers or STUs that do not support/protect a bridge as required can have devastating consequences, making the bridge unusable for an extended period.

2.1 Selecting the most appropriate key components for use

In order to minimise maintenance-related disruption to a structure's serviceability throughout its life cycle, it is essential to ensure the proper long-term performance of its key components. An important step in achieving this, of course, is to select the most appropriate key structural components for use. This requires consideration of many factors, including, for example, those outlined below.

2.1.1 Selection of the most appropriate general component type

A basic question that must be addressed at some point in the bridge design process – and the earlier the better – is what general type of key component should be used and allowed for in the bridge design. In the case of expansion joints, should they be e.g. of the single gap, mat, cantilever finger, sliding finger, flexible plug or modular type? In the case of bearings, should they be e.g. of the pot, spherical, elastomeric, disc or roller type? In the case of seismic isolators, should they be e.g. of the LRB, HDRB or pendulum type? The choice depends on many factors, not least of which should be the life-cycle performance that can be expected of each in the circumstances, and the likely impact on traffic during maintenance and replacement works. Therefore, it can be very beneficial for bridge designers to obtain guidance from a specialist supplier who can advise on the pros and cons of each type – especially where non-standard requirements arise [2].

2.1.2 Details of a supplier's specific design and optional features for that type

Having selected a general type, the pros and cons of the specific models of different manufacturers should be assessed, because design details, quality and durability can vary greatly. For instance, a modular expansion joint of the single support bar type, such as *Tensa-Modular* with its elastic design, offers far better long-term performance than other types. Optional features that can help ensure a longer service life can also vary greatly – as demonstrated for instance, in the case of the *Tensa-Modular* joint, by the *Fuse-Element* feature, which can be incorporated to help the joint, and the bridge, to avoid serious damage in an earthquake, limiting or avoiding disruption to traffic [3]. Shock absorbers / dampers can also be equipped with a protective fuse feature [4], ensuring their performance when required and limiting unnecessary disruption to traffic.

And of course, knowing that a particular supplier is capable of developing tailored solutions to satisfy special requirements can be very useful – a need that arises all too often, as demonstrated, in the case of bearings, by Baillés et al [2].

2.1.3 Supplier experience and track record with that component type

It is most important that the ability of the selected component, as designed and fabricated by the selected manufacturer, to withstand the loads and movements to which it will be subjected during a long life on a structure, should be verified in advance of its use. The best verification of this is a strong track record on the part of the supplier, with evidence of satisfactory performance of the component over many years on structures which place similar demands on the component.

2.1.4 Laboratory testing

Laboratory testing also serves a useful purpose, and can be very extensive – for instance, the testing required of modular expansion joints by American standards [5], and especially that relating to fatigue resistance [6]. The role of such testing in ensuring good life-cycle performance is explored for various types of bridge component by Mendez et al [7].

2.1.5 Specification of requirements to apply during component design

It is of course important to define the demands to which the component will be subjected, and to ensure that this will not present major difficulties for supply. This assessment should include the magnitude of all loads, movements and rotations, the frequency and nature of these, and the value of relevant cumulative movements during the lifetime of the component. The component's ability to withstand the environment in which it is located, and any irregular occurrences that may arise, such as earthquakes, should also be considered.

2.1.6 Quality control during design and fabrication

A comprehensive QA/QC system, for example in accordance with ISO 9001, and approval of design and manufacturing processes in association with the issuing to suppliers of national general approvals to supply the product in a certain country without further evaluation, can also provide confidence in the ability of a particular supplier to provide a product of the required quality.

2.2 Ensuring proper installation

The importance of proper installation to the correct functioning and durability of key components should be fully appreciated. For example, a component should be installed in such a way that all its parts are properly supported and will not be subjected to any unnecessary forces. It must be able to facilitate all design movements and rotations. And if applicable, its pre-setting at installation must be right for the condition of the structure at that time, considering the prevailing structure temperature, with allowance for any future movements that the component must accommodate. Many other factors must also be considered and checked. It is thus important that the installation of key components is supervised by a competent person who is familiar with the design and needs of the particular component type. Supervision by the manufacturer may be the best solution and is generally to be recommended.

It should also be noted that component designs can have a serious impact on constructability. A well-conceived component that is designed with constructability in mind is likely to present fewer challenges and problems during installation, perhaps resulting in better long-term performance.

2.3 Ensuring proper inspection and maintenance

Proper inspection and maintenance are essential for the long-term functioning of key bridge components, but unfortunately, these activities often do not get the attention or resources they deserve, resulting in durability and other problems. Avoiding inspection and maintenance work to save money is generally counter-productive, as this is liable to lead to far higher repair costs in the future, and earlier component replacement – with a much greater impact on traffic.

3. Minimising disruption during replacement of components

A very large portion of the total component-associated disruption to traffic during a bridge's service life is that caused during component replacement work. This disruption can be greatly reduced by using components and methods that have been designed to minimise disruption. A number of such solutions are described below.

3.1 Expansion joint solutions

Replacement of a bridge's expansion joints can be a major cause of traffic disruption, since it involves removing and replacing part of the bridge's driving surface, making some impact on traffic on an otherwise in-service bridge unavoidable. However, expansion joint types and replacement methods have been developed to help minimise such impacts, such as those described below.

3.1.1 The single-gap joint with polymer concrete anchorage

Single gap joints, with steel edge profiles and rubber seals connecting them, offer a very robust solution for small movements (in general, 80mm or less of longitudinal movement). Single gap joints typically have loop anchors for concreting into place, but when installed to replace an old joint on an existing structure, the alternative type shown in Figure 1 offers major advantages. This type, which simply anchors its low-depth edge profiles in high-strength polymer concrete, can generally be placed within the depth of any existing asphalt road surfacing, making it unnecessary to break out concrete; the existing joint is simply removed to the extent required (e.g. down to the top of the existing concrete substructure). As well as saving such demolition and reconstruction work, with resulting time savings, impacts on the main structure are minimised, which may be significant for structural reasons. Thanks also to the quick-drying nature of the polymer concrete, the road can be re-opened to traffic more quickly than would be the case with a concreted single gap joint. Further details are provided by Spuler et al [8].

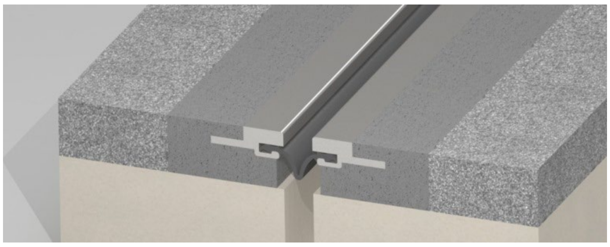

Figure 1. Illustration of a Tensa-Crete joint – low-depth and with polymer concrete anchorage

3.1.2 The polyurethane (PU) flexible plug joint

Another small-movement solution that offers great advantages in minimising disruption to traffic during installation is the modern polyurethane (PU) flexible plug joint (Figures 2 and 3). This offers all the benefits of the traditional asphaltic plug joint, including smooth, safe, low-noise surface, great adaptability and easy installation, but with greatly improved reliability, strength, elasticity and durability. Like the single gap joint with polymer concrete anchorage, this type of joint requires minimal removal of existing structure, and can typically be placed within the depth of a road's asphalt surfacing – greatly reducing installation time (thanks also to the PU material's short curing time) and thus minimising impacts on traffic. This is especially so because the joint can be easily placed in short sections, e.g. one lane at a time. Further details are provided by Meng et al [9].

Figure 2. A Polyflex-Advanced flexible plug expansion joint as installed

Figure 3. Installation of this low-depth joint on an existing structure typically requires no breaking out of concrete and can be carried out lane by lane

3.1.3 The rubber/steel sliding finger joint that can be installed by hand and lane by lane

For larger movements, where a sliding finger expansion joint is desired, a joint that does not require substructures or edge profiles can offer great benefits for traffic management. With no prefabricated full-length parts (its driving surface being composed of short finger plates), such a joint can be installed in short sections, e.g. lane by lane, enabling traffic to be facilitated at all times. Figures 4 and 5 show such a joint, of composite steel/rubber design, and images from its installation. Further details are provided by Spuler and Moor [10].

Figure 4. The Tensa-Flex sliding finger joint is fabricated from steel and rubber, with the finger plates pre-stressed downwards to remain in contact with the supporting surface at all times

Figure 5. Placing finger plates by hand

3.1.4 The *Mini-Fly-Over* traffic management solution for lane-by-lane installation

Where even replacement of an expansion joint on a lane-by-lane basis, with full-time lane closure, would cause too much traffic disruption, the *Mini-Fly-Over* system (Figure 6) can be used to allow traffic to cross the site when needed. Construction work then proceeds during night-time lane closures. In this way, unhindered traffic flow during peak times can always be facilitated. The approach involves bridging across the construction area with large steel plates, which in effect form a rudimentary sliding finger joint – the fingers of the main plate interlocking with and sliding between the fingers of a smaller partner plate. The plate surface is flush with the road surface, so traffic can flow freely and comfortably across the site at an appropriate speed. This solution was developed to reduce traffic disruption to an absolute minimum during the installation of joints of the previously described *Tensa-Flex* type, to replace old joints of a different type, in a highway viaduct that carries approx. 100,000 vehicles per day, and the solution, and the replacement project (Figure 7), are also described by Spuler and Moor [10].

Figure 6. The Mini-Fly-Over system can be used to allow traffic to cross the site during the day, making even this lane open to traffic when needed

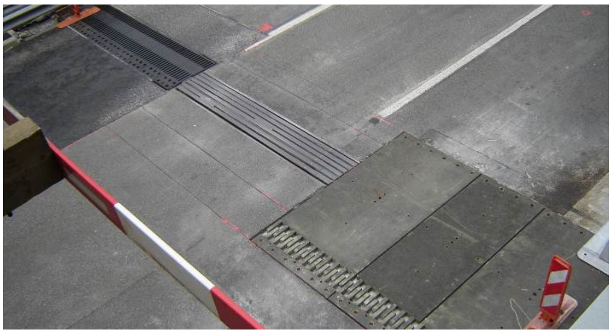

Figure 7. Three-lane carriageway during replacement of old modular joint (centre) with new Tensa-Flex joint (left) using Mini-Fly-Over (right)

3.1.5 The *Box-in-Box* method for renewal of modular expansion joints

Since the parts of a modular joint that are concreted in are not subjected to dynamic loading, it will not be necessary to replace those parts in most cases when a joint needs to be renovated. Retaining those parts, e.g. using the *Box-in-Box* method, can then save the effort of breaking out the concreted-in parts and the traffic disruption caused while the structure is partially demolished and reconstructed. The modular joint's design includes *centerbeams,* which create the driving surface, and *support bars,* which span the bridge gap, supporting the centerbeams. The ends of the support bars connect to the main structure at each side of the bridge gap in "boxes" which allow movement and rotation as required. Where geometry allows, the joint's new replacement part can be supplied with new boxes, which can be inserted into the old, retained boxes of the old joint, and secured there. The method is shown briefly in Figures 8 and 9, and further details are provided by Spuler et al [11].

Figure 8. View of retained substructure following removal of the dynamically loaded mechanical part of the old modular joint

Figure 9. Lifting in of the new replacement part, consisting of centerbeam(s) and support bars etc., complete with "boxes" on ends of support bars

3.1.6 The *Quick-Exchange* solution for renewal of modular expansion joints

Yet easier than the *Box-in-Box* method described above for renewal of modular joints is – if it has pre-designed into the existing expansion joint – the *Quick-Ex* (quick exchange) approach. This approach does not have the effect of minimising impacts on traffic or on the bridge structure at the time of first installation, but rather at the time of future replacement works. The design of a *Quick-Ex* Tensa-Modular joint will enable, when required, the joint's mechanical structure, consisting primarily of its centerbeams and support bars, to be easily replaced without any need for cutting or welding on the joint or any impact on the main structure. It will not be necessary to break out concrete, or damage asphalt or deck waterproofing, and therefore will also not require placing of these materials to reconstruct the deck. The moving parts of the joint are simply unscrewed, lifted out and replaced – far more quickly than would otherwise be possible, with an absolute minimum of impact on traffic. The design and approach are illustrated by Figures 10 and 11, and described in more detail by Stefan et al [12].

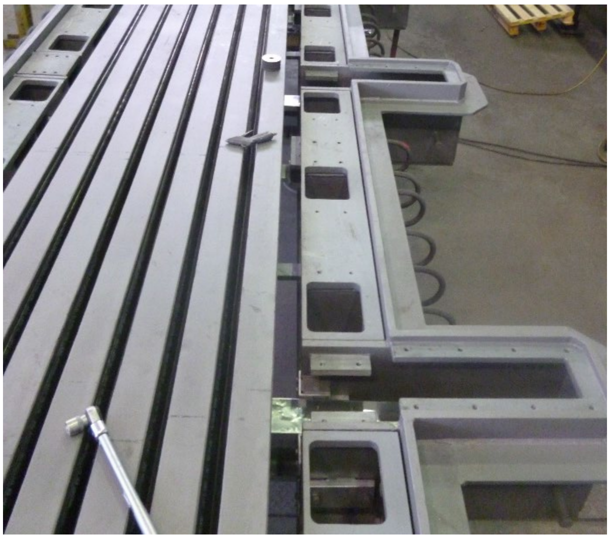

Figure 10. A Tensa-Modular "Quick-Ex" joint is designed to allow the mechanical part of the joint to be easily replaced without any cutting etc.

Figure 11. A Tensa-Modular "Quick-Ex" joint as installed, showing screws in surface which enable the steel plates at both sides to be easily removed and the joint's mechanical part to be replaced

3.2 Bearing and seismic isolator solutions

Replacement of bearings and seismic isolators can also impact on traffic, e.g. during deck lifting work or during periods when the superstructure is not properly supported, so it is important to recognise the value of component designs that simplify replacement work and minimise the associated impact on traffic – for example, as described below.

3.2.1 Use of anchor plates for easy replacement

Perhaps the most obvious example of how effort and traffic disruption during bearing/isolator replacement can be reduced is the option of equipping them with anchor plates (Figure 12). This can enable them to be replaced without any impact on the sub- or superstructure, with only minimal lifting of the superstructure required.

Figure 12. Once installed, a bearing with anchor plates can be unscrewed and removed with only minimal lifting of the superstructure required

3.2.2 Avoiding need to replace bearings by designing for changing needs/conditions

Where it is anticipated that a bridge's bearings will be subjected to changing conditions that would make an otherwise properly functioning bearing obsolete, ways of designing them with an appropriate adaptability should be explored. For example, where soil settlement or other ground movements might be expected to alter the clear height between a superstructure and its substructures at bearing locations, designing the bearings to be height-adjustable can avoid the need to replace the bearing when the clear height changes, avoiding any disruption to traffic [13].

3.2.3 Designing bearings for partial replacement

When a bearing deteriorates or fails, it is often just one part or aspect that does so while the rest of the bearing, and its connections to the main structure, remain in good condition. In many cases, for instance, the most susceptible part to damage of a sliding bearing is its sliding interface. In such cases, designing the bearing to enable its sliding material to be easily replaced – without replacing the entire bearing – can considerably reduce not only costs and effort but also the impact on traffic. This was demonstrated, for instance, in the bumper bearings used in the construction of the Ohio River Bridge (Downtown Crossing), a cable-stayed bridge connecting the US states of Kentucky and Indiana. Per the bridge engineer's initial estimate, the accumulated sliding path to which these bearings might be subjected is expected to be up to 1450 km over 50 years. This extraordinary amount of movement required the bearings to be designed with a special focus on replaceability, considering that PTFE, the most commonly used sliding material, suffers serious deterioration after a sliding distance of just 20 km. Even using a far superior alternative sliding material – a UHMWPE known as *Robo-Slide*, which has been tested to 50 km of accumulated sliding distance without any wear, and which offers twice the compressive strength of PTFE – it might be expected that the sliding material of any bearing may need to be replaced during its service life. This was made possible, without replacing the entire bearing, by the provision of an additional removable plate (with sliding material embedded in it), bolted to the bearing plate (see Figure 13). Once the need to replace the sliding material is established, the removable plate can be unbolted and temporarily removed from the bearing, enabling a new sheet of sliding material to be inserted into it. The removable plate of each bearing was also provided with lifting lugs, making the replacement process yet easier, considering the vertical orientation of the bumper bearings and the plates themselves.

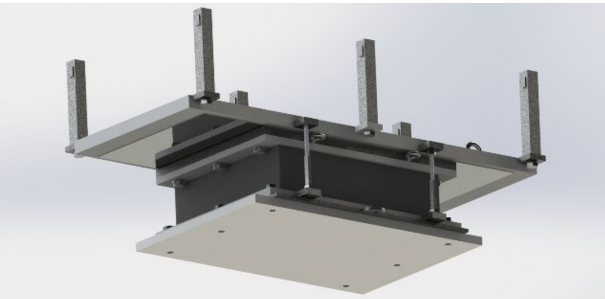

Figure 13. Design of elastomeric bumper bearings of the Ohio River Bridge (Downtown Crossing). The removable shim plate (with lifting eyes at side) enables the sliding material to be easily replaced

4. Conclusions

The use of the well selected, properly designed and fabricated key bridge components, such as bearings, expansion joints, dampers, STUs and seismic isolators can be very beneficial in minimising disruptions to bridge traffic from maintenance-related work. This is particularly true in relation to the quality and suitability for use of the components selected for use. It is also very true in relation to the use of components that are specifically designed to facilitate easy replacement with minimal impact on traffic.

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