No seam stress

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In contemporary practice, continuously reinforced concrete pavements (CRCP) are terminated and anchored at each bridge abutment.

Approach slabs, with transverse joints at each end, then provide the CRCP-to-bridge abutment link (Figure 1a). The resulting transition is often not smooth, as the provision of transverse joints can lead to discontinuities in the carriageway profile, particularly if there is significant settlement of the approach embankment. The seamless pavement, which was adopted for the construction of the majority of motorway underbridges on the Westlink M7 (WM7) Motorway in Sydney in 2004, is an enhancement that eliminates transverse expansion joints at bridge structures and provides a reinforced concrete connection between the CRCP and the bridge deck (Figure 1b). This results in improved ride quality for highway users, reduced maintenance costs and increased service life for the bridges. Additionally, it eliminates the need for pavement anchors behind each abutment, thereby reducing the pavement cost and minimizing construction activities in an area that is generally on the critical path.

The seamless connection between the CRCP and bridge deck must accommodate the stresses induced by shrinkage, creep, thermal strain, embankment settlement and traffic loads. Numerical models developed to analyze these parameters have been shown to compare well to the results of post-construction monitoring.

The seamless-pavement concept also has recently been considered for use on bridges with jointed plain concrete pavement (JPCP) approaches and retrofitting existing bridges.

Better without

The seamless pavement has a number of advantages over the conventional bridge approach slab system, advantages that result from the elimination of joints:

- Joints in pavements are a continual source of maintenance, so elimination will reduce maintenance costs;
- Deck joints are locations where water and other contaminants can concentrate, thereby increasing durability concerns. The removal of joints will thus enhance the service life;
- The removal of joints allows the wearing course to be installed in a continuous process, minimizing carriageway roughness. The seamless pavement also assists in minimizing the bump that is common at the bridge abutments, as it provides a continuous structural element, which provides a much more effective transition at the bridge abutment;
- The noise of vehicle wheels striking pavement and bridge joints is a cause of considerable community protest in urban areas, and the elimination of the joints overcomes this problem;

Australia's bridges holding up well without joints

- Bridge substructures are normally designed for the effects of horizontal loads, primarily arising from vehicle braking and other impact loads. These loads are transferred away from the bridge with the seamless-pavement connection with possible savings in substructure costs;
- Drainage systems are often provided to minimize the quantity of water flowing across deck joints. The elimination of deck joints obviates the need for drainage systems; and
- Construction is a relatively simple procedure, involving the installation of the sub-base, the tieing of reinforcement and concreting.

A seamless continuum

CRCP has been used for many years and the behavior is well understood. As the concrete initially shrinks, small transverse cracks develop at regular spacing throughout the length of the pavement. Where the seamless pavement anchors the CRCP into the bridge deck, the section of transition pavement must be designed for both the longitudinal effects associated with shortening (and lengthening) of the pavement and bridge, as well as out-of-plane effects caused by differential embankment settlements near the bridge abutments and the applied traffic loads.

This elegant yet simple concept requires the bridge and pavement to be assessed as a seamless continuum. The bridge, which is stiff compared with the pavement, drags the pavement toward the bridge as it shortens, transferring loads to the pavement subgrade in friction. The total movement is taken up in multiple cracks in the CRCP transition zone. The length over which these loads are transferred varies, depending upon the imposed strains and the relative stiffness of the bridge and pavement elements. Additional longitudinal reinforcement is provided in this region to ensure that concrete crack widths and reinforcement stresses remain within the code requirements.

The performance of the seamless pavement under serviceability conditions is the most critical design case, since there is significant overload reserve in the continuous-pavement system. The performance of the pavement in the post-elastic state clearly demonstrates that the potential risks in the overloaded condition are very small.

By region

The pavement can be considered as having three distinct regions. Region 1 is the normal fully restrained region of the CRCP away from any end effects. Region 2 is that part of the pavement in which the forced movement imposed by the bridge is accommodated. Friction forces between the pavement and the sub-base are generated in the transition zone. No friction forces are assumed to be developed in the approach

Figure 1a. Conventional CRCP/bridge interface.

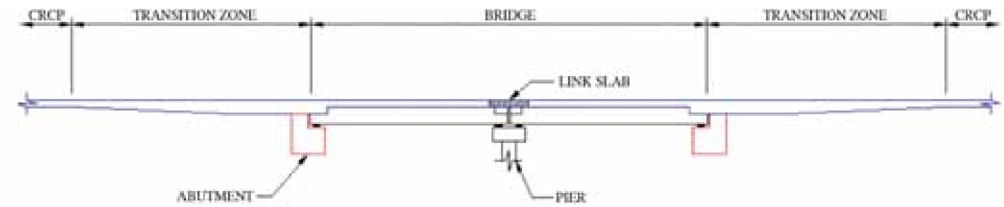
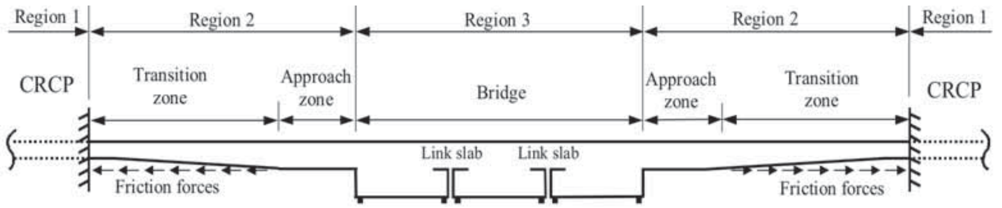


Figure 1b. The seamless pavement concept.



zone, as the embankment is deemed to have settled, creating a void under the zone. Region 3 is the bridge deck, which is assumed to be unrestrained. The longitudinal in-plane forces are determined from a structural flexibility approach.

A linear elastic-beam-on-elastic-foundation model was used to assess the behavior of the transition pavement when subjected to out-of-plane loads.

Reinforcement is provided in the transition zone to resist the applied loads and control crack widths, and the level of reinforcement is transitioned over the affected length to match the magnitude of induced forces. The amount of reinforcement in the transition slab reduces (smaller bars or wider spacing) farther away from the bridge to the normal CRCP reinforcement at a distance of about 300 ft from the abutment. This is necessary in order to control the level of cracking and ensure the flexibility of the transition slab. If too much reinforcement is placed into the transition slab then the transition slab would become too stiff and the longitudinal movements from the bridge would simply be transferred further down the pavement slab.

Short and simple

Construction of the conventional triple-lug pavement anchor system is a labor-intensive process that interrupts the effective operation of the paving equipment. It also isolates the area adjacent to the bridge abutment, thereby affecting construction-vehicle access and the timely completion of followup construction activities. The seamless pavement eliminates the pavement anchors, the approach slab subgrade beam and associated subsoil drainage system. It requires only a short, simple connection to the bridge deck such that mechanical equipment can pave to within approximately 60 ft of the bridge, reducing the amount of hand-placed concrete.

Normally the single layer of reinforcement in the CRCP is placed with a mechanized jig. Two layers are, however, required in the transition zone, which can extend up to 300 ft in length. A cost-effective method for placing this steel was developed involving the use of the mechanized jig for the placement of the bottom layer, with the upper layer placed by hand.

The connection of the pavement-bridge system is made with a closure pour of a small gap at 60 ft from the abutment. With no restraint prior to the closure pour, the free ends of both the pavement and bridge at the gap are constantly moving with time. If the closure pour is made when the gap is closing, compression will arise, which will not be able to be carried by the fresh concrete. If the closure pour is made when the gap is opening, tension will arise, which can cause cracking of the fresh concrete. A closure-pour sequence, which relies on the closure-gap reinforcement resisting compressive forces as well as tensile forces, was therefore developed to manage these possible variations in environmental conditions.

Sturdy 7

The main carriageways of the WM7 are generally CRCP, with a relatively short length of flexible pavement near the southern interchange with the M5 Motorway. The CRCP has an asphaltic concrete wearing surface, primarily for noise attenuation in the urban environment.

Pavement-condition assessments are carried out annually to ensure that the pavement network is maintained below the pavement-performance measures and to assist in predicting what maintenance is likely to be required in future years. This data collected includes a visual condition assessment, roughness, rutting and texture surveys, and skid-resistance assessment. The overall condition of the motorway pavements after eight years of operation is very good.

The longitudinal movement of the WM7 bridges was managed by one of the following methods:

- No joints (seamless pavements): As described in this article, this technique was adopted for all mainline nonsegmental bridges less than 400 ft in overall length;
- Small-movement joints ("buried"): Used at the abutments of bridges where calculated bridge movements were less than 0.8 in. The joint was composed of a sealant at deck level with an asphalt overlay;
- Strip-seal joints: Used at bridge-movement joints where calculated bridge movements were greater than 0.8 in. and less than 2 in.; and
- Finger joints: Used at segmental bridge-movement joints where calculated bridge movements were greater than 2 in.

All of the deck joints have performed well. Maintenance has been required to a number of the finger joints generally associated with loose hold-down bolts. There also has been some unexpected movement at abutments with high approach embankments, which has resulted in some minor modifications to the joint to ensure satisfactory long-term performance. There have been no reported problems with the strip seal joints, other than the general requirement for removal of debris from the road surface.

A survey of all the small-movement ("buried") bridge-deck joints was carried out in 2009. This survey photographed the condition of the asphalt at the abutments of all bridges where a strip-seal or finger-plate joint was not installed and identified that the asphalt covering the small-movement joints had cracked and was deteriorating. In a number of locations the deterioration had been sufficient to warrant the replacement of the asphalt with a "thermojoint" (asphaltic plug joint).

The survey also demonstrated that there was no sign of any distress in the asphalt at any of the seamless-pavement bridges. In fact it was not possible to identify any difference in the asphalt overlay over the entire length of the bridge and the adjacent CRCP approaches. The Rooty Hill Railway Bridge is approximately 30 ft above the existing surface and one of the bridges where there were obvious signs of approach embankment settlement, yet there have been no impacts on the pavement performance.

In addition to the annual pavement inspections, regular inspection of the bridges is carried out. These inspections have confirmed that the bridges are generally in very good condition. In all cases, bridges connected seamlessly to the CRCP are behaving as expected with regards to resistance of longitudinal loads. No cracks were visible in link slabs, the members with least capacity.

A closure-pour sequence, which relies on the closure-gap reinforcement resisting compressive forces as well as tensile forces, was developed in Australia.

Ready to expand?

Consideration also has recently been given to extending the use of seamless pavements to bridges with JPCP approaches. A length of CRCP constructed adjoining the bridge, which is anchored using traditional anchors at a suitable distance away from the embankment, would eliminate the expansion joints normally provided and provide a smooth pavement transition across the abutment region.

This technique has been successfully used on a bridge with a very large skew over a railway near Katoomba, to the west of Sydney, where by continuing the reinforced pavement past the end of the bridge a long and difficult joint was completely eliminated.

The Transportation Research Board (SHRP 2 Renewal Project R19A) "Design Guide for Bridges for Service Life," includes the concept of the seamless pavement within the chapter on jointless bridges. This guide also includes in an appendix a possible design of an anchorage system for the transition slab adjoining a JPCP using a number of short steel piles anchored to a buried secondary slab. The authors consider that a traditional CRCP anchorage with concrete anchor beams would be more economical, since the length of the transition zone is governed by the ability to absorb the changes of length arising from the bridge shortening.

For existing bridges exhibiting serious joint problems and pavement settlement adjacent to the abutments, it should be technically and economically feasible to retrofit the bridges with a seamless connection. The bridges must be able to resist the forces arising from the bridge-pavement interaction, and the length of reinforced transition zone must be sufficient to allow the longitudinal movements at the bridge abutments. For bridges that have been constructed for some time, future bridge shortening associated with concrete shrinkage and creep would be minimal, which would considerably reduce the length of the approach pavement required and the forces developed.

Loads of potential

Bridges incorporating seamless-pavement connection were first completed nine years ago on the WM7 Motorway in Sydney. Site inspections have demonstrated that the bridge structures are performing as predicted, with excellent rideability. The seamless pavements are showing no signs of distress arising from the increased longitudinal loads for which they have been designed.

Bridges of up to 400 ft in length have been designed and constructed using the seamless-pavement technique. Further refinement of the design parameters is possible, which would lead to the use of seamless pavements on longer bridges. **R&B**

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