Is sustainable rehabilitation possible with Ultra-Thin Continuously Reinforced Concrete Pavement (UTCRCP) overlays?

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Abstract. Ultra-Thin Continuously Reinforced Concrete Pavement (UTCRCP) overlays consist of a 50mm thick steel fibre reinforced concrete layer, reinforced with about 6mm thick steel bars spaced at 50mm centres, both lengthwise and breadthwise. The thin reinforced concrete layer is placed on top of layer works to extend the life of existing pavements damaged by overloaded heavy vehicles. The maintenance cost of this thin overlay is limited by the reduction in the movement joints. A number of UTCRCP trial sections have been constructed in South Africa, with varying levels of success. In this paper the behaviour of the heavily reinforced thin concrete layers under both environmental and rolling axle loads are discussed, based on experimental test results. It is concluded that UTCRCP overlays can only be used for sustainable rehabilitation of pavements if the behaviour of the thin concrete layer under both environmental and rolling axle loads are understood and taken into account when deciding on joint spacing, steel reinforcing, casting conditions and materials used in the concrete.

1 Background

Ultra-Thin Continuously Reinforced Concrete Pavement (UTCRCP) overlays consist of a 50 mm thick fibre reinforced concrete surface layer, reinforced with about 6 mm thick reinforcing bars spaced at 50 mm centres, both lengthwise and breadthwise. The thin reinforced concrete layer is placed over pavement layers damaged by heavy vehicle axle loads. The long term maintenance cost of these thin concrete overlays should be limited due to the significant reduction in movement joints requiring regular routine maintenance [1]. Although a number of UTCRCP trial sections have been built, the question whether UTCRCP overlays can be used for sustainable pavement rehabilitation remains. In this presentation two major issues that threaten the sustainability of UTCRCP overlays are addressed. The first issue deals with the load spreading and failure mechanism design assumptions made during the design of UTCRCP overlays, while the second issue deals with the environmental load that the thin concrete overlay, with limited movement joints, is exposed to.

Rigid concrete pavements are normally about 250 mm thick concrete slabs with closely spaced movement joints. The slab thickness is determined based on the flexural strength of the unreinforced concrete and the concrete surface layer is deemed to behave according to the "beam on elastic support" principles as proposed by Westergaard in 1926 [2]. UTCRCP overlays are not only highly reinforced, resulting in ductile behaviour, but the thin concrete layer is also not rigid and differential movement across the width of the pavement, makes the design assumptions for rigid pavements not applicable for modelling the behaviour of UTCRCP overlays. Flexible pavements typically consist of a thin asphalt or bituminous layer and the failure mechanism of these pavements is typically rutting in the wheel path. The possibility that UTCRCP overlays act as flexible pavements when exposed to rolling axle loads should be investigated.

Rigid concrete pavements are prone to curling and warping as a result of temperature and humidity changes throughout the depth of the concrete layer. The UTCRCP concrete layer may be thin enough to limit the curling and warping effects, but the lack of thickness could result in increased length changes caused by daily and seasonal temperature and humidity variations. The magnitude of the effect of concrete thickness should be studied to ensure that designers can make appropriate assumptions in terms of spacing of movement joints and reinforcing bars.

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2 Experimental setup

Here two aspects of UTCRCP behaviour are considered, with not only the effect of rolling axle loads, but also the effect of environmental loads are taken into account. In the first experiment reinforced concrete slabs with thicknesses of 50 mm, 75 mm and 100 mm were instrumented with temperature sensors and strain gauges to determine not only thermal gradients, but also strains that develop in free moving slabs. These measured strains, can give an indication of the stresses that would develop in UTCRCP, where movement is constrained. In the second experiment, a 1:10 scale UTCRCP model was built and tested at 10 G centrifugal acceleration in a Geotechnical centrifuge to qualitatively study the complex soil structure interaction behaviour of the thin, ductile and flexible concrete layer placed on compacted soil layers and exposed to a rolling axle load equivalent to that of a typical 8 ton axle load (E80) [3,4]. Figure 1 gives an indication of a cross section through the scale model.

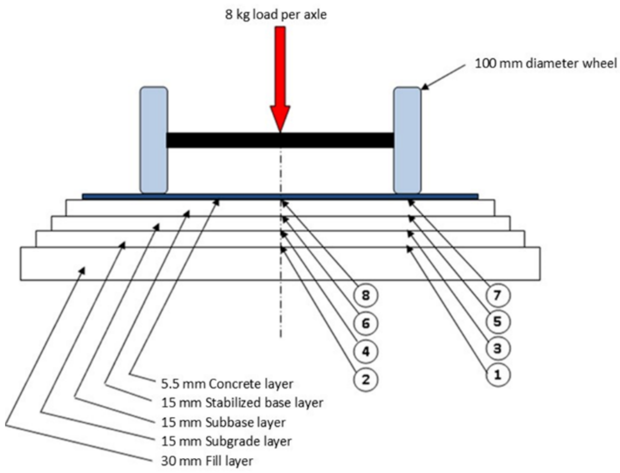

Figure 1: Centrifuge model of UTCRCP

By instrumenting each pavement layer in the wheel path and between wheel paths, the vertical displacements caused by the passing of a rolling axle load was measured. The shape of the deflection bowls of the pavement layers was used to develop a conceptual model of the load spreading and soil structure interaction under a UTCRCP overlay.

3 Results

The test results from the thin concrete slabs clearly indicated that the effect of daily and seasonal temperature changes results in significant concrete deformation. The advantage of a 50mm thick concrete slab is however the lack of thermal gradient, which explains the lack of curling and warping caused by temperature changes. The thermal expansion of the thin slabs will however be more than that of thicker slabs and contractors may have to cast some parts of the UTCRCP overlay when the temperature is high to ensure that length reduction takes place, thus preventing longitudinal buckling of the thin overlay. Sufficient steel reinforcing in the length of the pavement can prevent wide cracks from opening up as a result of drying shrinkage and thermal contraction during cold winter nights. Rainfall has a significant effect on the behaviour of the thin concrete slabs as moisture absorbed on the surface results in a significant length change. UTCRCP pavements should be constructed using concrete that will not absorb water during rain storms. This would be possible by using a combination of fine fillers and pore blockers, reducing the water/cement ratio and water content of the concrete and sealing the running surface of the pavement. The scale model test results indicate that the flexible thin concrete overlay spans across the rut that forms in the layer works after the first load cycle. The permanent damage that the supporting layer works experience is not visible from the surface as the ductile concrete layer rebounds when the wheel load moves away. As long as the highly reinforced concrete layer is ductile and strong enough to withstand repeated load cycles, the thin ductile UTCRCP overlay will protect the layer works, maintaining a useable riding surface.

Test results indicate that steel reinforcing is required in the breadth of the pavement to resist the sagging moments that develop under the wheels of heavy vehicles. However, the UTCRCP overlay not only has to bridge rutting of supporting layers caused by heavily loaded vehicles, but also has to resist the hogging moments caused in the centre of the axles when the downward force of the vertical wheel loads is resisted by an equal and opposite upward reaction between the wheel paths. By limiting the thickness of the concrete to as little as 50 mm it is possible to place only one layer of steel in the concrete to handle both sagging and hogging moments. By placing this reinforcing at mid-depth, there is sufficient concrete cover to protect the steel from the negative environment effects if a suitable concrete mix composition is used. The longitudinal reinforcing in the UTCRCP is required to prevent cracks from opening up as a result of both drying shrinkage and length reduction caused by decreasing concrete temperatures. The lack of thickness of the concrete layer means that the stresses caused by the volume changes is significantly higher than what design engineers normally calculate. The spacing of movement joints has to be balanced with the volume of steel required. Buckling of UTCRCP can be prevented through not only careful selection of materials used in concrete, but also specifying permissible temperature ranges for casting concrete.

4 Conclusion

UTCRCP overlays can be a sustainable solution to rehabilitation of pavements damaged by overloaded heavy vehicles. Design engineers and contractors will however have to take not only the actual soil structure interaction behaviour under rolling axle loads into account, but also the significant negative environmental effects that determine the allowable distance between movement joints, as well as the volume of longitudinal reinforcing required in the thin concrete layer.

References

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