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Cost Effective Alternative Solution for the Renovation of Concrete Pavements

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Abstract. The renovation of concrete pavements (typically motorways) is commonly done by deep replacement of the existing damaged concrete layers including underlying basal layers with newly installed layers with a new surfacing. This technology is rather expensive and time consuming. New alternative solution based on including of intermediate mechanically stabilised layer into road structure is presented. Full scale laboratory model of this structure has been realised. Results and observations are presented. Main contribution of new approach is possibility to remain old concrete layers on place and cover them by new pavement. Standard road structures where concrete layers are overlaid by new pavement in combination with long-term intensive dynamic loading and temperature changes are prone to reflective cracking. Proposed technology avoids that problem and enables cost effective reconstruction of damaged road.

1. Introduction

The renovation of concrete pavements in numerous countries is done using the method which requires complete demolition and removal of the original, worn-out and uneven concrete road surface, including the base course. This method is time-consuming and costly due to necessary large volumes of new materials and their transport, which is not very ecologically friendly. An interesting alternative to the above method seems to be using the road surface fragmentation in combination with surface milling [1]. The fragmentation consists in breaking up the existing concrete pavement slab into blocks, about one metre in size, followed by overlaying them directly with rather thick layer of new asphalt instead of extracting them. The advantage of this method is saving of substantial volumes of high-quality material in the construction and shorter construction times. Also means less volumes for transporting therefore less negative impact on the environment. The disadvantage of that method is that the problem of reflective cracking appears. Usually the method expects using of very thick top asphalt layers to delay reflective cracking appearance in time. New approach based on incorporation of mechanically stabilized intermediate granular layers in pavement structures is presented in this paper including full scale laboratory testing and its potential implementation in concrete paved roads reconstruction.

2. Reflective cracking

Rigid concrete slab type of the pavement requires leaving of joints between them due to horizontal deformations as the result of their expansion and shrinkage caused by daily and seasonal temperature fluctuations, figure 1. Another factor is long-term intensive cyclic dynamic loading caused by trafficking. Overlaying asphalt or asphalt concreter wearing course is prone to reflective cracking. Similar situation happens when concrete slabs are fragmented and network of cracks is formed before installation of wearing course, figure 1 [3]. When cracked concrete is overlaid by new wearing course, figure 2, conditions for development of reflecting cracking are fulfilled, figures 2 and 3. A top of the crack is the place where enormous concentration of tensile stresses occurs. The edges of the crack function like arms (levers), which when widening, are forcing the crack development upwards to upper layers, figure 3.

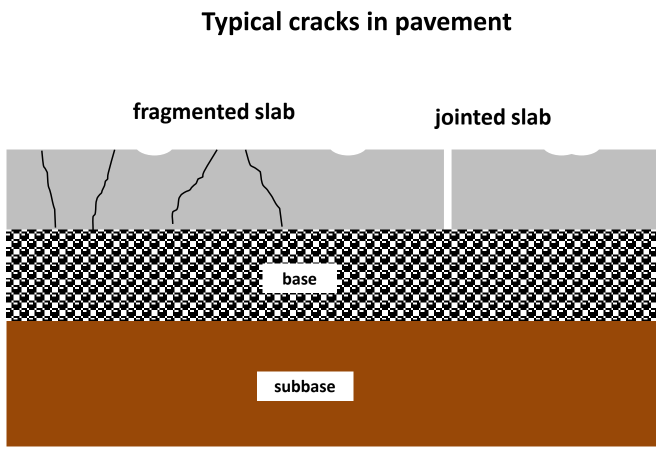


Figure 1. Typical cracks and surface damage of concrete pavement layer

Every cycle of the load delivers the energy to the system and speeds up the process. The longer the crack the higher concentration of the load at the pick of the crack. Typically, thicker asphalt layers is installed but this means just the delay of appearing the crack on the surface.

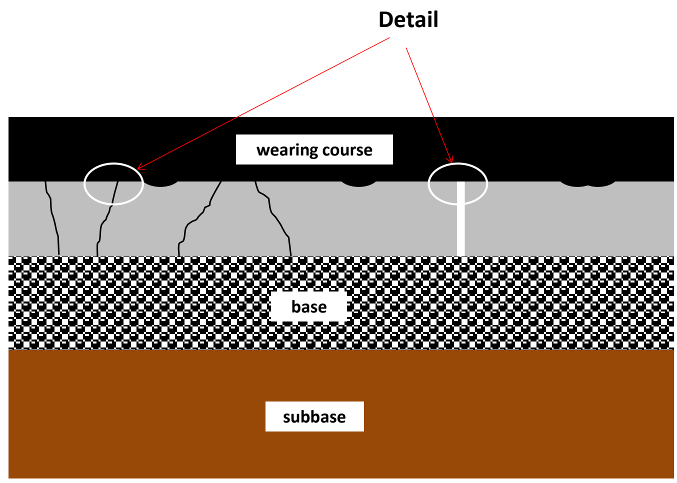


Figure 2. The situation when top asphalt layer is installed over cracked concrete (detail on figure 3).

In case when subsoil under the concrete slab is unstable with uneven properties, so called keyboard performance can happen. In such a case blocks of concrete being loaded are moving vertically individually forming conditions for the propagation of shear type cracking through asphalt layer.

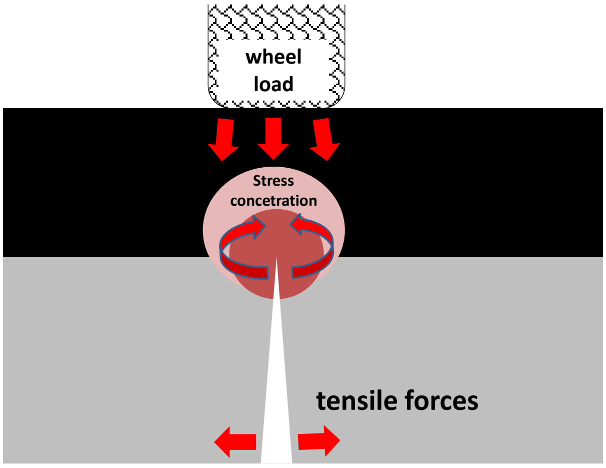


Figure 3. Detail indicated on figure 2

3. Mechanically stabilized granular layer (MSL)

Key mechanism involved in the stabilisation is interlock of aggregate provided by a stiff geogrid [15] structure, figure 4. During the placement and compaction of a granular layer over a geogrid, the aggregate particles partially penetrate into the apertures and abut against the ribs of the geogrid. This results in interaction of the geogrid and the aggregate under applied load by locking of the aggregate grain in the aperture. In this way the effect of interlock is defined as the inhibition of the movement of the particles of granular layer under applied load [13]. The scheme on figure 5 shows situation when the stone grain is properly locked in the aperture and loaded abutting forces are becoming active. Shear displacements between grains are restricted almost to zero. The system is stiff and performs closely as „quasi rock“ (immobilized grains form a kind of small piece of massive rock). Important features of geogrids are described in [14]: grain/aperture size ratio, geogrid rib shape and stiffness, aperture shape and stiffness.

Figure 4. Stiff geogrid with interlocked stones

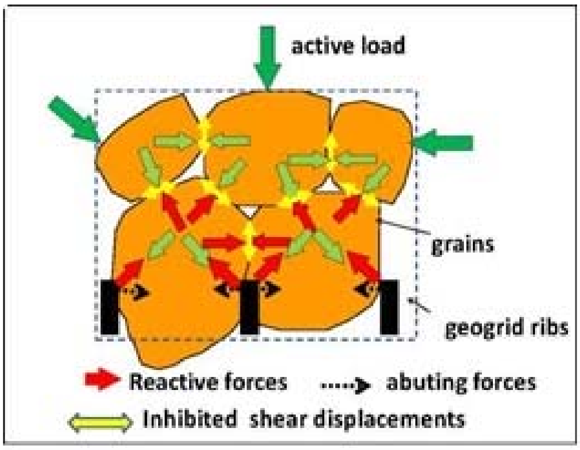


Figure 5. Interlocking mechanism and confinement of grains in geogrid

Important feature is that it is not any more discrete granular material and geogrid as separate element but a kind of composite with new quality performing like stiff continuum, figure 6. It means that macro deformations, typical for granular material under load, are replaced by micro deformations similar like in case of rock. Another important feature is observed within increasing external load when locking forces are also greater and mechanically stabilized layer becomes strong.

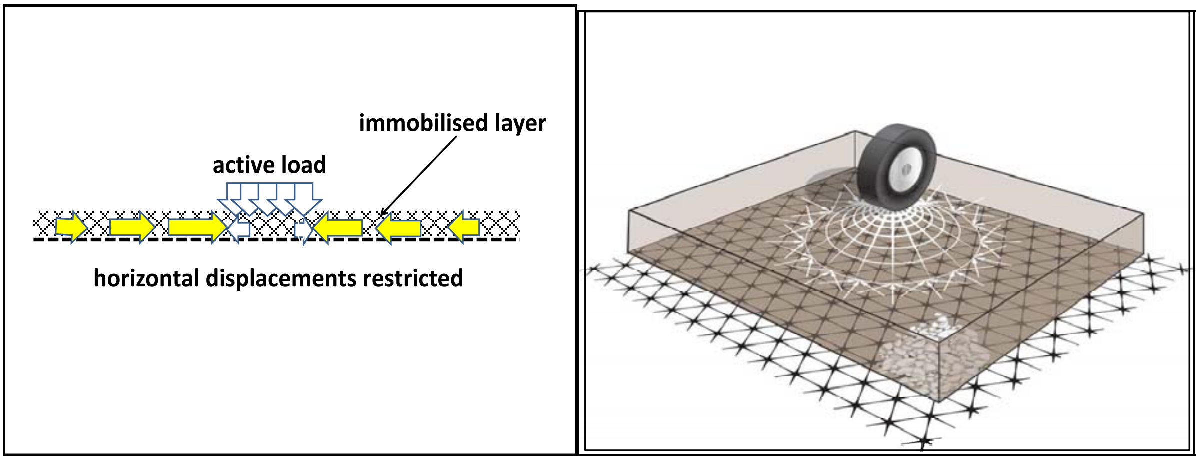


Figure 6 a (left). Mechanically stabilised layer as a continuum composite, the higher active load the greater immobilisation forces; **6 b** (right) load distribution from wheel immobilises forces in multi directions.

The performance of properly immobilized continuum layer means that the resistance against particle movement (immobilization) is mobilized in rather wide area of the layer, figure 6b. [16-21].

4. Laboratory model

The laboratory study [22] was based on the assumption that two concrete slabs divided by a narrow gap representing the expansion gap or another crack in the road pavement concrete layer would be overlaid with a layer of asphaltic concrete in combination with mechanically stabilized layer, figure 7, which will be exposed to long-term cyclic loading and the development of a reflective crack in the asphalt layer would be monitored. The objective was to verify whether the application of mechanically stabilized layer had a favorable effect on delaying the cracking and, further on, to optimize the composition of layers so that the construction would be able to resist the cracking as much as possible.

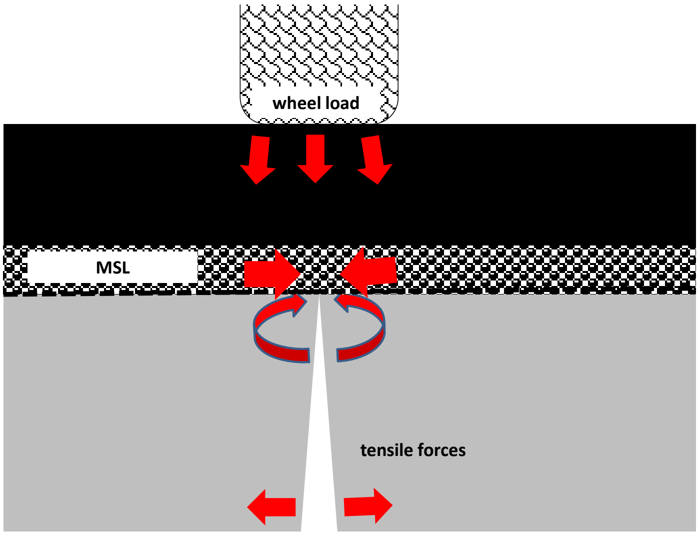
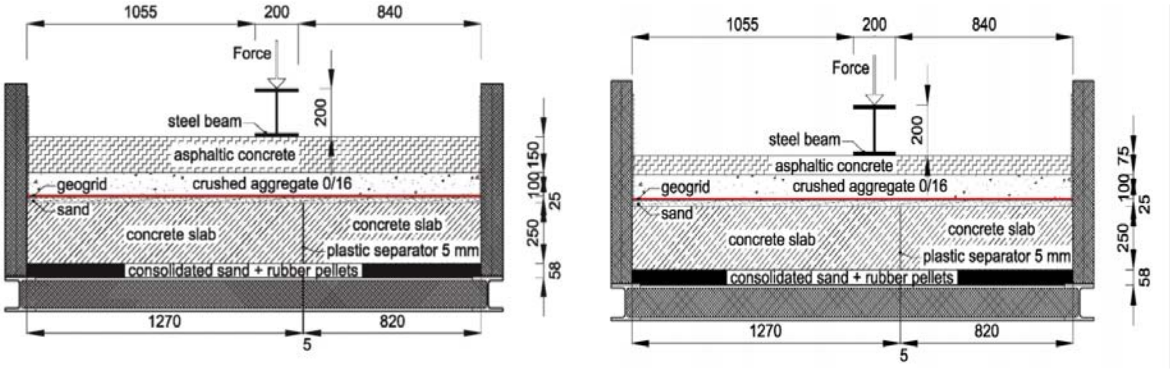


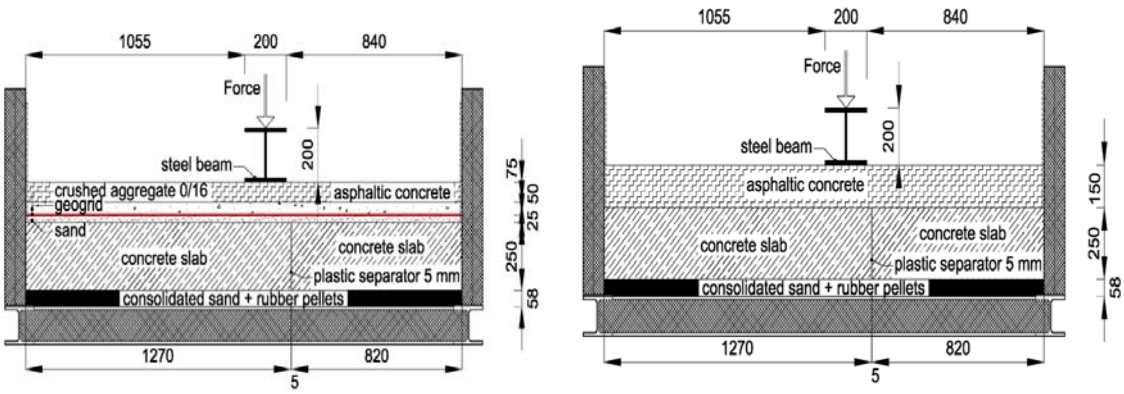
Figure 7. Inclusion of intermediate mechanically stabilised granular layer

Laboratory tests were performed at Czech Technical University in Prague, Faculty of Civil Engineering using the experimental box with dimensions of 2.0 x 1.0 x 0.8 m, which consists of welded steel sections with removable walls of timber baulk with a cross-section of 100 x 150 mm. One wall was equipped with a "window" enabling an access to perform direct measurements of the mutual settlement of concrete slabs during the loading process, figure 8.

Figure 8. Testing box assembled



Model 1 (left) and 2 (right)



Model 3 (left) and 4 (right)

Figure 9. Arrangements of laboratory full scale models 1-4

The arrangement of the models is seen on figure 9. Models 1, 2 and 3 differ with thicknesses of mechanically stabilized layer (50-100 mm) and asphalt layer (75-150 mm). Model 4 was built without mechanically stabilized layer as the control one with 150 mm asphalt layer installed directly on concrete slabs. There was 5 mm gap (joint) between slabs in all models with 5 mm plastic to ensure smooth vertical moving of them. A steel H-beam, 85 cm in length, 20 cm in width and 20 cm in height, was installed on the finished surface of asphaltic concrete so that its longitudinal edge was parallel to the joint between the concrete slabs and at a distance of 15 mm. This arrangement ensured that the steel beam was only located over one, the loaded concrete slab, but as close to the joint between the slabs as possible. All models were exposed to long-term cyclic loading with a frequency of 3 Hz. The force was applied in the central position onto the upper surface of the steel section by means of hydraulic actuator. A force of 70 kN was applied in the first 1000 loading cycles (initial consolidation), followed by a force of 94 kN up to 600 ths. cycles (corresponding to a contact stress under the steel section of 0.55 MPa), and finally a force of 122 kN (30 % increase) applied up to 1 mil. cycles in Models 1-2, or up to 2 mil. cycles in Models 3 and 4. The minimum force applied during the loading was 3 kN. The results of main monitored parameters are in table 1.

Table 1. The results of monitored parameters

Monitored parameter	Model 1	Model 2	Model 3	Model 4
Target number of loading cycles	1 million	1 million	2 millions	2 millions
Completed number of loading cycles	1 million	1 million	1.23 million	2 millions
Number of cycles at the first crack	700 000	620 000	697 000	535 000
Crack characteristics after loading completion	only surface fatigue cracks	only surface fatigue cracks	reflected crack through	reflected crack through
Settlement depth of the beam centre into asphalt at 1 mil. loading cycles in mm	5.9	6.3	7.5	6.2
Average value of elastic settlement of the asphalt surface at 94 kN in mm	1.17	1.55	1.79	2.00
Average value of elastic settlement of the asphalt surface at 122 kN in mm	1.56	1.85	2.10	2.43

General conclusion from the laboratory experiments is that inclusion of relative thin mechanically stabilized layer effectively prevents any generation of reflecting cracking. The best results were achieved when using a combination 100 mm mechanically stabilized layer and a 150 mm layer of asphalt. Even after the exposition of this construction to 2 million loading cycles with a contact pressure of up to 0.55 MPa, only little fatigue cracks on the asphalt layer surface were detected. It is caused by the action of lateral confinement in mechanically stabilized layer which does not allow to generate tensile forces for the origin of reflecting cracking. Further, it was shown that decreasing of the thickness of the layers of asphalt and mechanically stabilized granular layer leads to the appearance of reflecting cracks and also greater settlements of the asphalt surface.

5. Potential application of the results

The experiments executed in the laboratory provided good evidences of proper function of the proposed solution. The next step should be field testing section where the complete technology would be tested. Having on mind all the experience gathered so far, e.g. [1-11], the construction as shown on figure 10 appears to be efficient. A slurry of 2-3 cm is to be installed directly on the surface of concrete slabs. The role of the slurry lays in levelling of potentially uneven surface of the slabs, providing the space for the penetration of grains through geogrid aperture and binding the layer together. Then the geogrid is to be installed and filled by adequate crushed aggregate and properly compacted to form mechanically stabilized layer. Before placing of asphalt layer some bitumen spraying of the top of aggregate is recommended to achieve proper binging between layers.

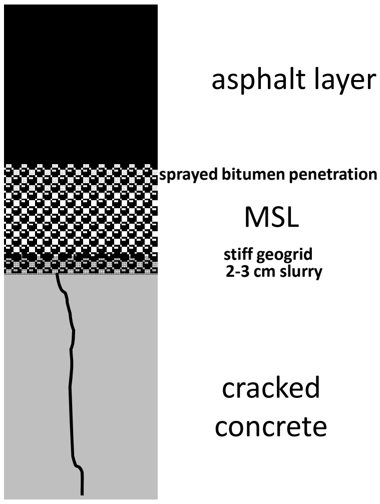


Figure 10. The profile of proposed structure resistant against reflective cracking development

6. Conclusions

Successful experimental works have been executed which brought good evidence about efficient preventing of the origin of reflective cracking by application of mechanically stabilized granular layer as the intermediate structural element of pavement structure. To verify long-term behaviour of road construction with mechanically stabilized granular layer under realistic conditions, it is recommended to implement the test road section.

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