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Optimized Sub-Ballast Structure for High-Speed Line with Asphalt Layer and Multiaxial Geogrid

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Abstract

Preparations for the future construction of high-speed railway lines across the territory of the Czech Republic have begun in the Czech Republic with the aim of connecting it to the European network. This article describes findings from a project focused on the optimization of the substructure of high-speed railway lines with an asphalt layer and the inclusion of a multi-axial geogrid. A number of full-scale laboratory experiments were carried out at the Czech Technical University in Prague. The result of laboratory tests, which included both static and dynamic load modes, is the design of an optimized sub-ballast structure for the use in high-speed railway lines.

Keywords: high-speed line, asphalt, multiaxial geogrid, sub-ballast, mechanically stabilized layer, cyclic loading.

1 Introduction

The Czech Republic is preparing for the systematic construction of high-speed railway lines (HSL) that will be connected to neighboring countries (Germany, Austria, Poland, Slovakia) and thus become an integral part of the European and global high-speed railway network.

The concept of the Czech Railway Administration is based on the technology of the construction of French high-speed railway lines of the LGV type [1]. This assumes the use of a classic construction with a track bed in combination with an asphalt layer of a specific composition, placed directly under the track bed [2]. Its application uses experience from road constructions and brings advantages to the environment of railway tracks, especially in the form of available construction technology, high load-bearing capacity, good drainage of water on the surface, enabling the movement of vehicles during the establishment of the track bed [3].

Similar constructions using an asphalt layer are also used in other European countries, e.g. Italy and Spain. Certain differences can be seen in the design parameters and composition of the structure, especially in the thicknesses of the individual structural layers, especially the asphalt layer and the equalizing granular layer placed below it, which is usually made of crushed stone mixture with a grain size of 0-32 mm (Fig. 1). In principle, it can be stated that as the thickness of the asphalt layer decreases, which normally varies between 12 and 14 cm, the thickness of the base layer of the 0-32 mm fraction increases and vice versa.

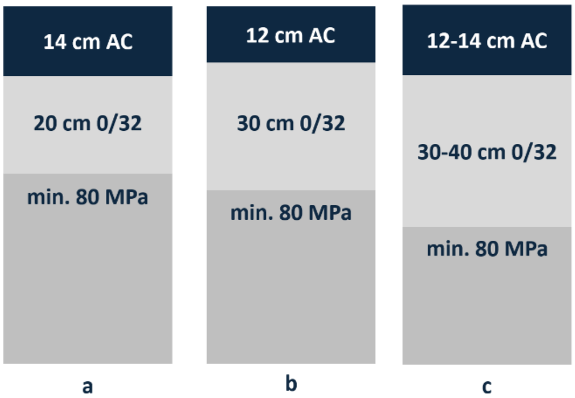


Figure 1: HSL substructure with AC layers: a) France, b) Italy, c) Spain [1].

As part of the CK02000293 project, a study focused on optimizing the composition of a high-speed track with asphalt in combination with the use of a multiaxial geogrid was prepared. The project was motivated by the fact that in the Czech Republic the availability of the necessary amount of high-quality natural aggregate for the planned construction of linear structures is not currently guaranteed. Any possible reduction in the thickness of granular layers, which will enable the saving of natural aggregates, is therefore very welcome.

2 Theoretical background

The alternative construction of the railway bed for the HSL assumes the use of rigid geogrids with the aim of reducing the thicknesses of the layers of aggregate and asphalt placed above. The solution is based on the interlocking mechanism of aggregate grains in the openings of rigid geogrids (Fig. 2). This mechanism causes the distribution of the vertical load over a larger area of the layer and thus a reduction in pressure per unit area. It is further assumed that this mechanism immobilize the grains and thus prevent their lateral movement. The layer of aggregates combined with a geogrid is adjusted to the form of a mechanically stabilized layer (MSL) through effective compaction.

It can be assumed that the use of MSL should have a positive effect on the reduction of horizontal stresses and thus lateral pressures, especially at the level and a certain vertical distance from the position of the geogrid. This mechanism, when properly configured, should lead to a reduction in horizontal deformations of the aggregate layer above the geogrid, or deformations on the lower surface of the asphalt layer, thereby limiting the amplitude of horizontal stresses in the lower part of the asphalt layer. The result is a reduction in the intensity of fatigue and an increase in the lifetime of the asphalt layer. At the same time, it is possible to consider reducing the thickness of the asphalt layer while fully preserving its function and effectiveness in the construction.

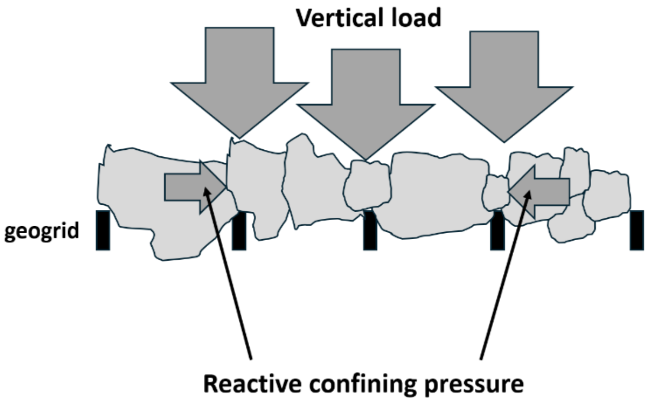


Figure 2: Mechanism of interlocking in mechanically stabilized layer.

The application of geosynthetic products for high-speed lines is documented, for example, in [4, 5].

3 Experimental works

Experimental work within the aforementioned project was divided into three separate stages, which are described separately below.

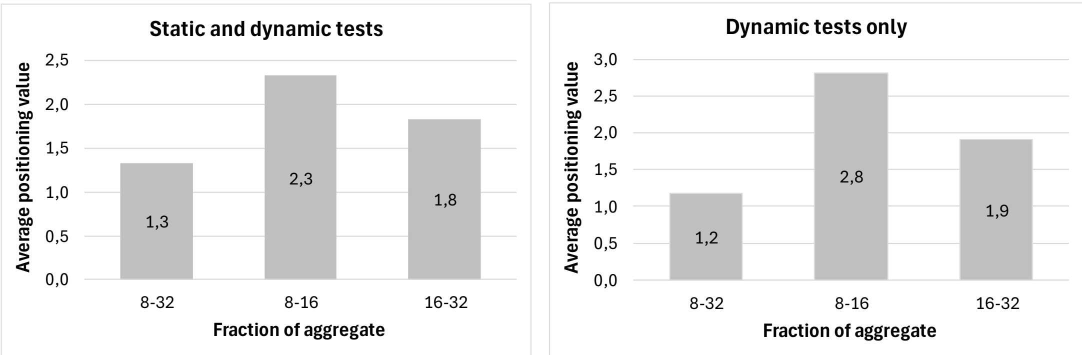
3a Granulometry of the mixture

In the first stage, a suitable aggregate granulometry was searched for the selected type of multiaxial geogrid. Multiaxial geogrids are a new type of geosynthetics for which the appropriate aggregate fraction in relation to the size of the holes in the geogrid has not yet been experimentally verified. The variable shapes and dimensions of the multiaxial geogrid, formed by an assembly of hexagons, trapezoids and triangles, must be taken into account. Due to the maximum size of the holes (hexagons), it was obvious that the maximum grain size should not exceed 32 mm, which is basically the upper limit of the standard grain class 0-32 mm. The aim of the experiments was to verify which aggregate fraction best fits the dimensions of the geogrid openings.

A box with dimensions of 800 x 400 x 300 mm was used to carry out the experiments in the laboratory. A 100 mm thick layer of extruded polystyrene (EPS) simulating softer soil was first placed in the box, followed by a geogrid and then two layers of crushed stone mixture of the same thickness. In the first layer, one of three grain sizes was chosen (8-32, 16-32, 8-16), the second layer was always fraction 8-32. Two thicknesses of aggregate were investigated - 75 mm and 100 mm after compaction with a manual vibrating plate.

Load tests were carried out using a steel plate with dimensions of 150 x 300 mm and penetration tests using a special penetration cone. Both tests were carried out in static and dynamic mode. Up to 18 different parameters were monitored for each fraction, and a ranking (1, 2, 3) was evaluated for each parameter depending on the results achieved, with the lowest value representing the best result. This was followed by the calculation of the ranking averages for the aggregate fraction. The results are presented in Fig. 3. The best result (lowest value) was achieved when using the 8-32 mm fraction, both in the combined evaluation of all tests (18 parameters) and in the separate evaluation of tests in dynamic mode (11 parameters). More information on this phase of the experiments is given in [6].

However, for the next phases of the experimental tests, it was decided to use the 0-32 mm fraction, mainly for practical reasons, as the 8-32 fraction is not commonly available from aggregate producers for linear constructions in the Czech Republic.



a) b)

Figure 3: Positioning of different fraction of aggregate in tests:
a) static and dynamic tests, b) dynamic tests only.

3b The influence of geogrid on the thickness of the MSL

The second stage was aimed at verifying the behavior of the multiaxial geogrid in combination with different aggregate thicknesses. For this purpose, an experimental box with dimensions of 1000 x 1000 x 800 mm was used, in which 4 structures of different composition were built (Fig. 4). The M-0 model is based on the original LGV design without a geogrid and is a reference model. Other models (M-I to M-III) contain a geogrid and different thicknesses of aggregate above it: 200, 150 and 100 mm.

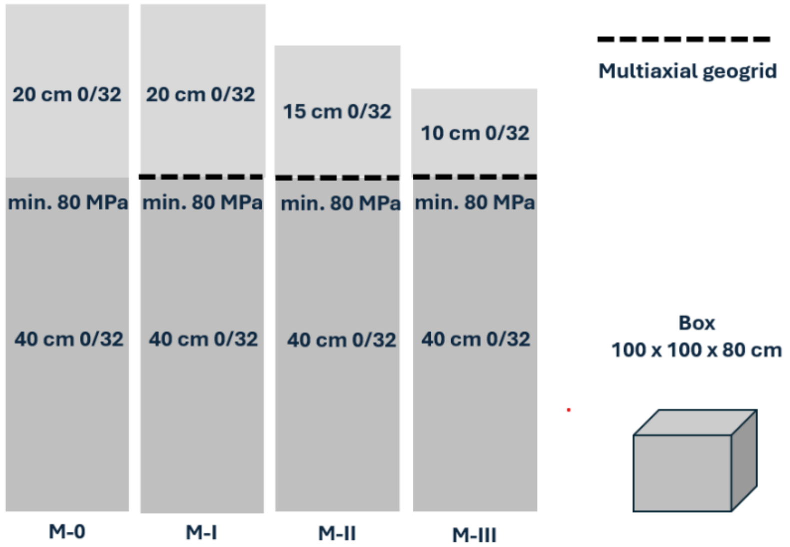


Figure 4: Profiles of various thicknesses of MSL tested in the experimental box.

The loading of the structure was carried out using a laboratory press through a part of a plastic sleeper measuring 880 x 250 x 150 mm adapted to the dimensions of the box. The load in the static mode took place in the range of 0-100 kN, which represented a maximum contact stress of 0.45 MPa [7]. Dynamic loading was performed with the following parameters: frequency 3 Hz, maximum contact stress 0.55 MPa, a total of 10,000 cycles.

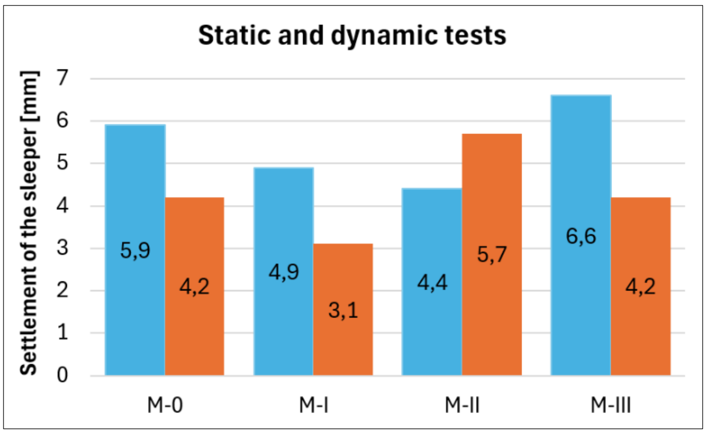


Figure 5: Settlement of the sleeper in static (left column) and dynamic (right column) regimes.

The permanent sleeper settlement was one of the important parameters when comparing the listed structures in relation to the reference structure without geogrid. In Fig. 5 the sleeper settlement values of individual models in both static and dynamic loading modes are compared. It can be seen from the results that the M-I model, i.e. the model with a geogrid and 20 cm of 0-32 mm aggregate, has the smallest overall values compared to the M-0 model. In the M-II, the lowest sleeper settlement was recorded in the static load mode. Based on this knowledge, a more detailed examination of the M-II model was carried out, which represents a saving in thickness and therefore also in the amount of aggregate.

3c Full structure testing

In the last stage, there were experiments aimed at testing the entire composition of structures, including the asphalt layer. Based on the results of the second stage, it was decided to test, in addition to the construction of the standard composition used on the LGV consisting of a 14 cm asphalt layer and 20 cm of 0-32 mm aggregate, also a construction with a 15 cm mechanically stabilized layer and asphalt with a reduced thickness of 7 cm (Fig. 6). The reason was the result of a numerical analysis, which assumed that this structure is even 19% stiffer than the reference structure without a geogrid and with the original layer thicknesses.

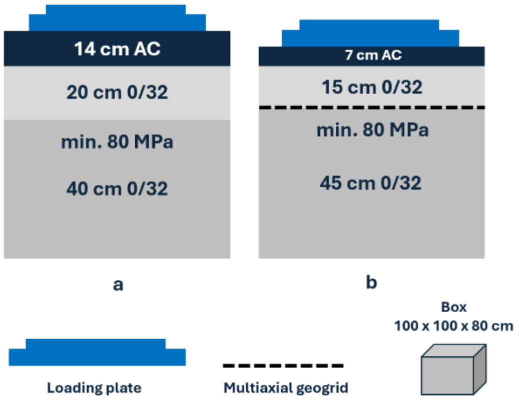


Figure 6: Profiles of the models including asphalt layers: a) without geogrid, b) with geogrid and reduced asphalt layer.

In both cases, the requirement of a bearing capacity of at least 80 MPa according to the Czech methodology of static plate load test was met. The models were assembled on a scale of 1:1 in the same experimental box as in the 2nd stage of the experiments. The loading was carried out with a laboratory hydraulic press through a concrete load plate with a diameter of 790 mm, on which a steel plate with a diameter of 400 mm was placed.

The loading took place in dynamic mode with a force of 3-125 kN with a frequency of 3 Hz until reaching 100 000 loading cycles. After reaching the specified number of cycles (100, 500, 1 000, 5 000, 10 000, 50 000 and 100 000), a static loading of the plate was performed, which resulted in contact stress under the concrete plate of 5, 40, 80, 120, 160 and 200 kPa.

The following parameters were monitored: settlement of the structure, lateral pressures on the box wall, horizontal deformation of the upper surface of the MSL in contact with the asphalt and horizontal deformation of the geogrid. The elongation of the geogrid at maximum load was 0.068 %, indicating considerable horizontal stiffness of the MSL. In the case of lateral pressures and horizontal deformations of the upper surface of the MSL in contact with the asphalt, no fundamental differences were observed between the monitored structures. More significant differences were noted for settlement, with the geogrid structure showing less settlement in all load cases. At the smallest contact stress of 5 kPa, the settlement of this structure was 16 % smaller, and in the case of the largest stress of 200 kPa, it was 20 % smaller than the reference model without mechanical stabilization by geogrids (Fig. 7).

Experimental work in phase 3 on 1:1 models showed that the structure with 7 cm of asphalt layer and 15 cm of mechanically stabilized layer has even better deformation behavior than the original structure with 14 cm of asphalt and 20 cm of 0-32 mm aggregate. This conclusion confirmed the theoretical assumption based on the findings from the previous phases of the project.

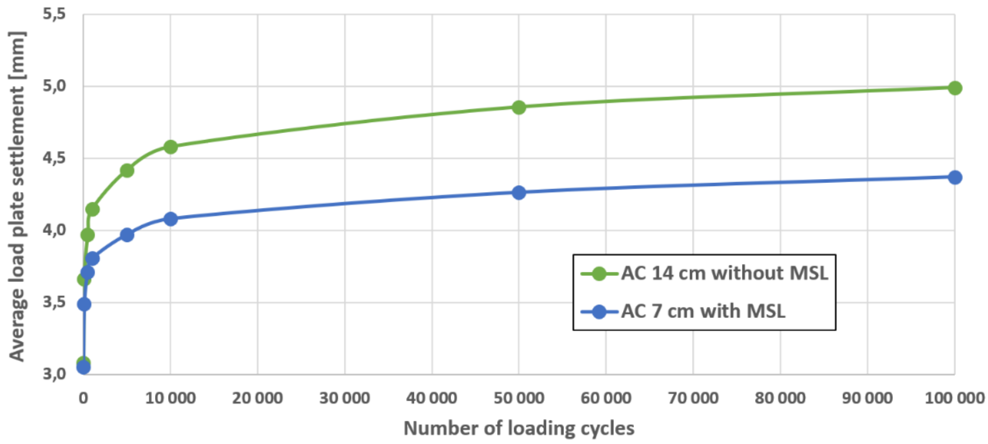


Figure 7: Comparison of settlements in both models under maximal load (125 kN).

4 Conclusions

Based on a series of laboratory tests, which were divided into three consecutive phases, the following findings were obtained:

- The best performance of multiaxial geogrid has been identified when aggregate of fraction 8-32 mm is applied. However, for practical reasons, it is preferable to use the 0-32 mm fraction, as it is a commonly available type of aggregate.
- Reducing the thickness of aggregate 0-32 from 20 cm to 15 cm in combination with the application of a geogrid resulted in a reduction of sleeper settlement by 25 % under static loading.
- The construction with a reduced asphalt layer (7 cm) and a 15 cm mechanically stabilized layer enables an even better performance from the point of view of the settlement of the structure than the original asphalt layer with a thickness of 14 cm and 20 cm of aggregate.

The newly designed structure (Fig. 8) was recommended to the managers of the railway infrastructure of the Czech Republic as suitable for the planned high-speed railway lines due to the possible savings of up to 50 % of the volume of asphalt and 25 % of aggregate in the underlying layer.

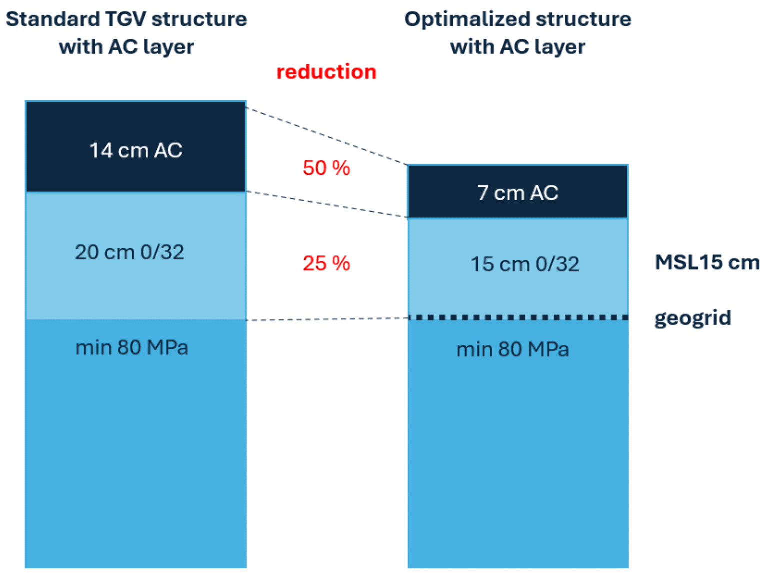


Figure 8: Optimized structure of HSL with reduced thicknesses of layers compared with reference structure without geogrid.

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