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Assessment of Changes in Granulometry of Cyclically Loaded Aggregate with Geogrid

L. Hornicek[1], J. Kawalec[2] and P. Mazurowski[3]

[1]Faculty of Civil Engineering, Czech Technical University in Prague, Czech Republic
[2]Tensar International, s.r.o., Cesky Tesin, Czech Republic
[3]Tensar Polska sp. z o.o., Gdansk, Poland

Abstract

The effective connection of stabilizing geogrids and suitable granular material creates a mechanically stabilized layer. When using lower quality aggregate, it is damaged in the form of grain cracking and mutual abrasion of grains during long-term cyclic loading. A series of laboratory tests was carried out, in which limestone aggregate of fraction 0/45 mm was cyclically loaded with 1 million cycles. The test results showed that when using a stabilizing geogrid, there was a significant reduction in changes in the granulometry of the aggregate before and after the test. At the same time, significantly less settlement of the loading plate was recorded during loading when using a stabilizing geogrid.

Keywords: aggregate granulometry, geogrid, cyclic loading, grain size distribution, lower-resistance aggregate, loading plate.

1 Introduction

Changes in granulometry (grain size) due to crushing and abrasion of grains during loading are a key factor for the service life of transport structures. Therefore, it is necessary to use aggregates with parameters that correspond to the expected nature of the load and the expected service life of the application. However, in all situations it is not necessary to use natural aggregates of the highest quality, especially of volcanic origin, the production of which is energy-intensive and accompanied by negative environmental impacts – noise, vibration, and dust [1, 2].

Long-term repeated traffic loads cause the particle size distribution of aggregate grains to shift, often resulting in fewer coarse particles and more fine particles [3]. A higher concentration of fine particles in the aggregate layer reduces its water drainage capacity outside the transport structure [4]. In the extreme case, the layer becomes clogged, when the gaps between the aggregate grains are filled with the fine-grained component. This condition subsequently leads to a chain reaction, when in addition to the loss of permeability, mechanical stability disorders and deformations of the layer also occur [5].

With a suitable combination of the type and dimensions of the stabilizing geogrid and the granular material of adequate grain size, a mechanically stabilized layer is created. This significantly contributes to limiting the movement of aggregate grains, increasing the stiffness and overall resistance of the transport structure [6]. Another expected positive impact of using stabilizing geogrids is the reduction of aggregate degradation under long-term traffic loads. A series of comparative laboratory tests was conducted to verify this hypothesis.

2 Experimental works

Experimental work included the implementation of two comparable laboratory models with lower quality aggregate, one model without and the other with an inserted stabilizing geogrid.

The laboratory tests were performed in the experimental box with dimensions of 1.0 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. The timber walls were lined with galvanized plates to reduce friction between the track bed and the box walls.

2a Composition of the model structure

First, a model designated as M1 was implemented with the following composition of layers from the bottom: 10 cm of polystyrene (EPS), 2 layers of aggregate (limestone 8-45 mm), each 15 cm thick after compaction, totally 30 cm. Subsequently, a model designated as M2 was implemented, which differed in that an Tensar coextruded multi-shape stabilizing geogrid was placed over the entire area between the layers of aggregate. The polystyrene used was of the EPS 100 type with a thickness of 100 mm, surface dimensions of 1000 x 500 mm and compressive strength at 10% compression of 100 kPa. Compaction of granular layers was carried out by means of manual compaction plate for 20 minutes.

The aggregate used was limestone fraction 0-45 with a continuous granulometric curve, which is used as standard for cement production. This is an aggregate with lower compressive strength and lower abrasion resistance (LA 19) compared to the aggregate used in railway construction in the Czech Republic. After the aggregate was imported, the 0-8 mm fraction, which made up approximately a third of the total volume, was removed using an 8 mm sieve. The fine-grained component was removed from the aggregate to better assess changes in aggregate granulometry due to cyclic loading.

The process of building the models is shown in Figure 1.

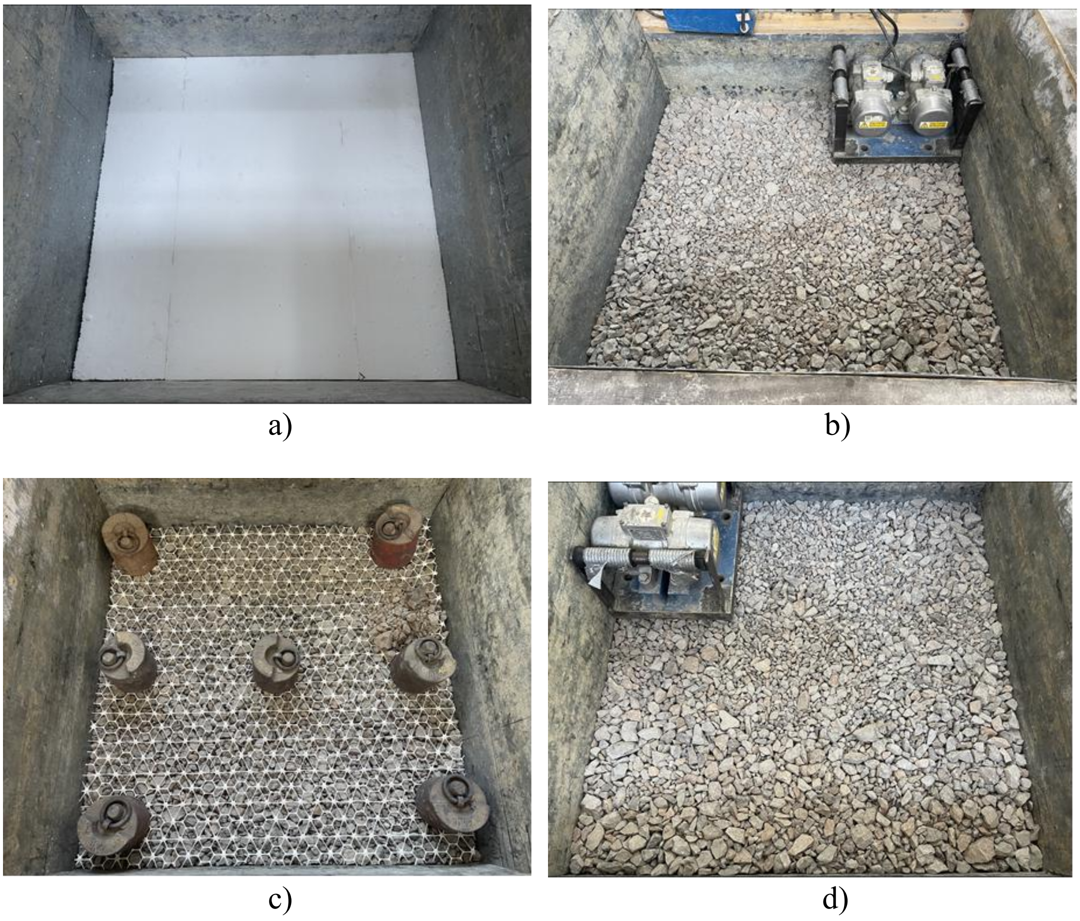


Figure 1: Building the models: a) EPS at the bottom, b) compaction of the 1st layer of aggregate, c) placing the geogrid, d) compaction of the 2nd layer of aggregate.

2b Loading

A circular aluminum plate with a diameter of 40 cm and a thickness of 15 mm was placed in the middle of the model, and a steel plate with a diameter of 30 cm was placed concentrically on it so that they were in an ideal horizontal position. Subsequently, a preload of the plate was applied to ensure primary consolidation and the desired plate settlement (8 kN for 10 seconds).

Subsequently, cyclic loading was carried out using a stable hydraulic cylinder in the range of 1 million cycles, divided into two steps:

Step 1: Apply 200 000 cycles of loading with a force of 1-25.1 kN (corresponding to a pressure under the plate of 0.20 MPa) at a frequency of 3 Hz.

Step 2: Apply additional 800 000 load cycles with a force of 1–20.1 kN (corresponding to a pressure under the plate of 0.16 MPa, which means a 20% reduction) at a frequency of 3 Hz.

The original assumption was to apply cyclic loading with gradually increasing loads, however, during the implementation of the M1 model, it turned out that the assumption was too ambitious and due to the rapid increase in plate settlement, the loading scheme had to be adjusted.

The process of loading the models is shown in Figure 2.

Figure 2: Loading the models.

3 Measured parameters

Loading of the structure was accompanied by continuous monitoring of the settlement of the loading plate and comparison of the state before and after loading in terms of EPS deformation, moisture content, bulk density and aggregate granulometry.

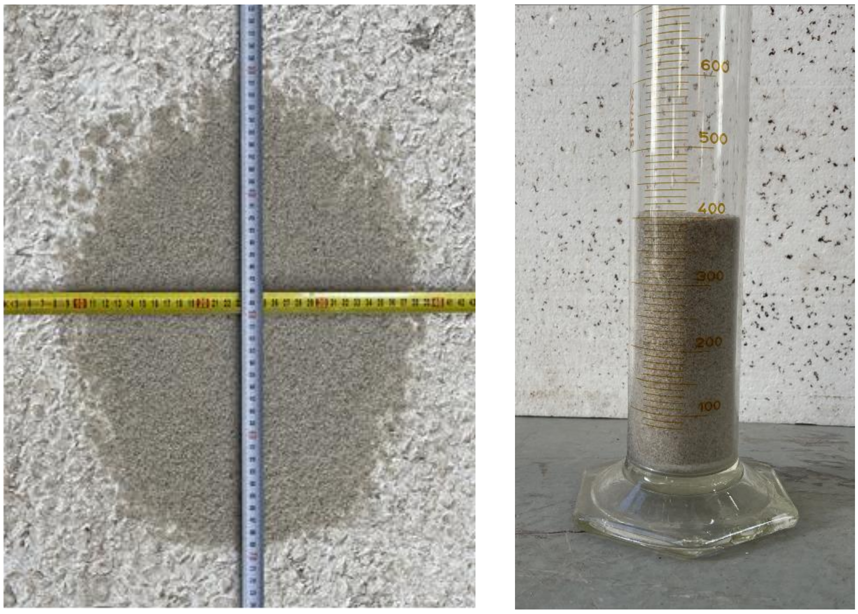
3a Settlement of loading plate

The settlement of the loading plate was monitored at 4 points evenly distributed on the plate corresponding to the position of the longitudinal and perpendicular axis of the experimental box. The settlements were measured using the Mitutoyo digital meters with a precision of 0.01 mm, which were fixed with stands onto a transverse steel construction. This, in turn, was firmly fixed to the testing room floor at a sufficient distance from the experimental box to avoid any effects on the exerted load.

The values were always read after reaching the specified number of loading cycles, in a situation where the plate was loaded with a force corresponding to the mean value of the cyclic loading range, i.e. 13.05 kN or 10.55 kN, respectively.

3b Deformation of EPS

After the loading was completed and the granular layers were removed, the deformation of the polystyrene (EPS) piece placed under the loading plate was documented in detail. The size of the deformed (compressed) part of the polystyrene was measured in the longitudinal and transverse directions (Fig. 3a). The dimensions of the deformed basin were measured, and its volume was determined using fine-grained sand. The volume of sand was determined in a graduated cylinder (Fig. 3b).



a) b)

Figure 3: Measurement of deformed basin: a) measurement of dimensions, b) volume determination.

3c Moisture content and bulk density of aggregate

During the establishment of the granular layers, an aggregate sample was taken from each layer to determine the moisture content (water content in the aggregate). The bulk density of the aggregate used was calculated from the known volume of granular layers and the determined weight of the aggregate using a crane scale.

3d Grain size distribution

When setting up the models, a sample of approximately 10 kg of aggregate was taken from each layer and subjected to a sieve test to determine the grain size. After the model was loaded, two samples were again taken from each layer, from the profile under the loading plate. Sieve tests were again performed on these samples.

4 Evaluation of results

Comparison of data record from both measurements of the load plate settlement during cyclic loading is shown in Fig. 4. Significantly lower plate settlement was recorded in the model with geogrid (M2). A different course is evident immediately after the start of the second stage of loading (> 200 000 cycles) due to a 20% reduction in loading force.

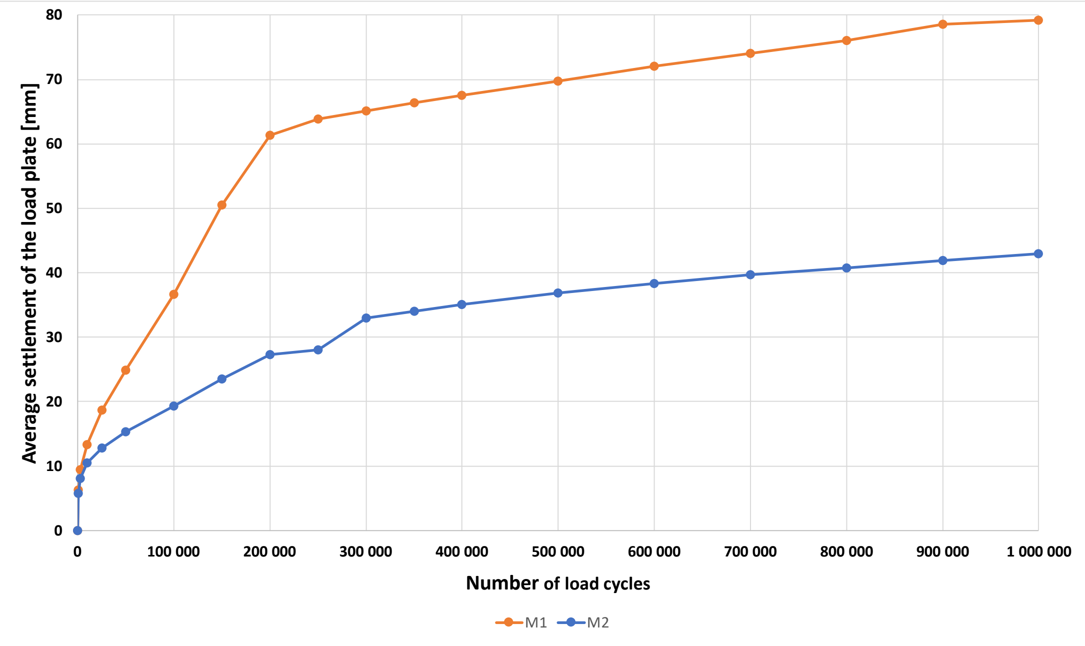
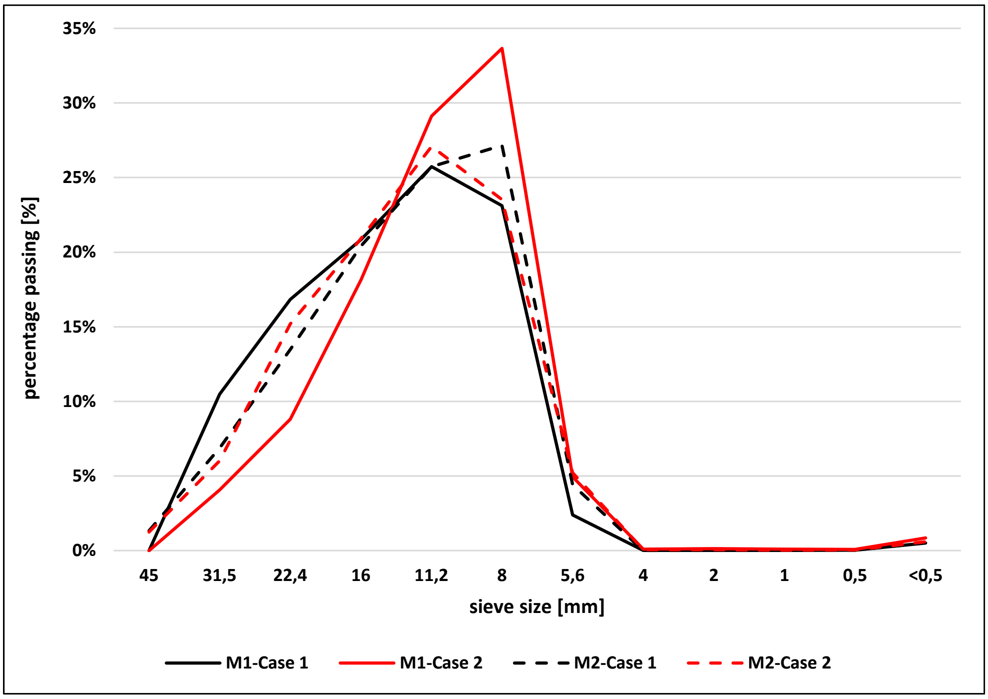


Figure 4: Settlement of loading plate during loading.

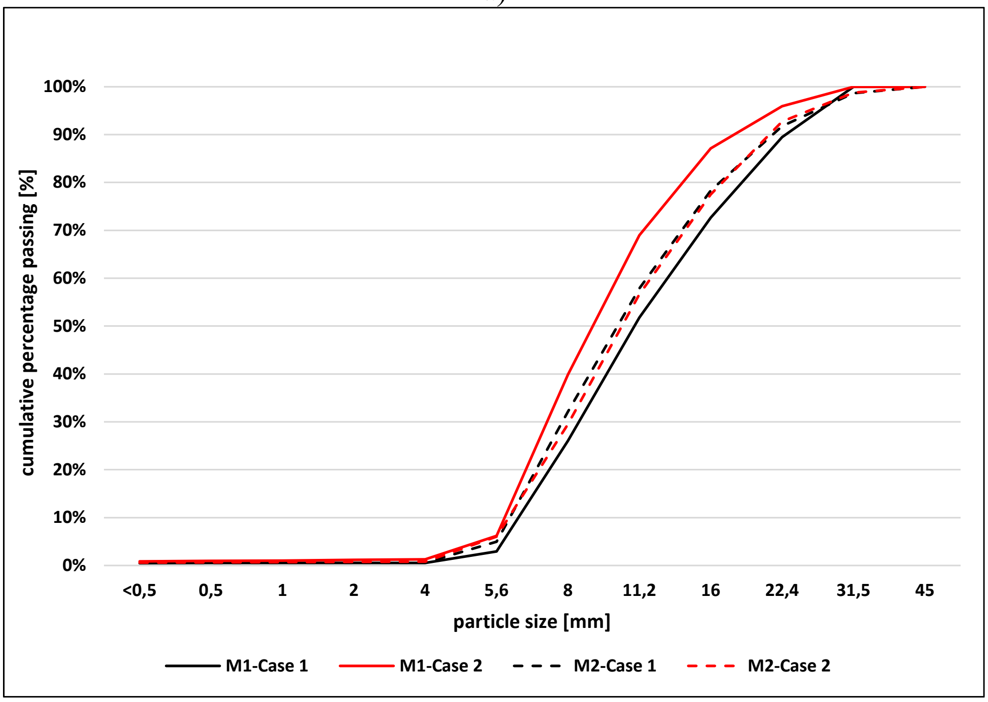
Sieve analysis and grain size distribution of both models are available in Fig. 5a and Fig. 5b. Case 1 (black colour) means evaluation of fresh aggregate, before measurement. Case 2 (red colour) means aggregate evaluated after loading from the profile situated below loading plate. A change in grain size between Case 1 and Case 2 is evident in the model without geogrid (M1), there was a percentage increase in the 4/11.2 mm fraction due to loading.

A comparison of aggregate moisture content, aggregate bulk density and EPS deformation after loading is shown in Tab. 1. The differences in the values of aggregate moisture and aggregate bulk density are very low, which ensured good mutual comparability of the models. Differences are noticeable in the deformation of

EPS – while depth of deformation is similar in two models (15.1 mm vs 16.3 mm), there is a significant difference in the volume of deformation (405 ml vs 650 ml). This suggests that geogrid helped to spread the load over larger area of subgrade, which is also confirmed by deformation longitudinal and transversal dimensions measurement.



a)



b)

Figure 5: a) sieve analysis, b) grain size distribution.

Table 1: Comparison of moisture, bulk density and EPS deformation results.

Parameter / Model	M1	M2
Average water content [%]	0.31	0.26
Aggregate average bulk density [kg/m^3]	1736	1693
EPS deformation - longitudinal [cm]	37	40
EPS deformation - transversal [cm]	29	35
EPS deformation - depth [mm]	15.1	16.3
EPS deformation - volume [ml]	405	650

5 Conclusions

Based on a set of two laboratory tests, the following findings were obtained:

- The expected number of 1 million loading cycles was achieved for both models. However, the loading parameters had to be reduced compared to the original assumption in relation to the response of the aggregate without fine-grained fraction. The course of the plate settlement during loading of the surface of the used limestone aggregate of fraction 8/45 mm was almost linear throughout the entire loading period. Such behaviour is specific to aggregate without a fine-grained component.
- While the model with geogrid did not show a significant change in the grain size curve in the profile under the load plate compared to the unloaded aggregate, a significant change was recorded in the model without geogrid. There was a percentage increase in the proportion of fraction 4/11.2, and a decrease in fraction 11.2/45.
- The M2 model with geogrid showed significantly less settlement of the load plate during cyclic loading compared to the M1 model without geogrid. Deviating settlement is particularly noticeable during the first 200 000 cycles. While the model without geogrid showed a settlement of the load plate of 61.3 mm after reaching 200,000 cycles at a force load of 13 kN, the model with geogrid showed only 27.3 mm (difference of 34 mm, proportion of 44.6%). After reaching 1 million cycles at a force load of 10.5 kN, the settlement of the plate was 79.2 mm for the model without geogrid and 42.9 mm for the model with geogrid (difference of 36.3 mm, proportion of 54.2%).
- The model with geogrid showed higher values for all monitored parameters of EPS deformation caused by cyclic loading. The load was spread over a larger area using a geogrid. In the case of the deformation basin volume, the difference is 60.5%.

In conclusion, it can be stated that the hypothesis was proven. When applying a stabilizing geogrid to a granular layer, a significantly smaller change in the granulometry of the aggregate used was found as a result of cyclic loading of 1 million cycles.

Acknowledgements

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