The study of the interlock of ballast in triaxial geogrids

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Abstract. Rail transport is the most efficient way of transport from an energetic and environmental point of view. The integration of geosynthetics in the rehabilitation solutions has grown substantially in the last decade, such as the application of different geogrids for reinforcement and/or stabilization of ballast layer. It appears to be consensual that the effectiveness of the geogrid depends on the degree of interlock between the geogrid and the granular material. The main purpose of this study is to analyse the relation between the geogrid aperture size and the ballast size that maximizes the interlock. The influence of the geogrid location in the ballast layer and the ballast grading are also addressed. The results suggested that, in order to obtain a higher interlock percentage, a selected ballast layer, with a reduced maximum dimension, should be used in contact with the geogrid and the geogrid should be placed in the ballast layer, above the interface ballast/substructure. The results suggested that the relation between the geogrid aperture size and the maximum dimension of the aggregate should be around 1.22 in order to improve the interlock.

1 Introduction

The modernization and rehabilitation of railways is one of the priorities of the Investment Plan of the National Railway Network, which aim is to increase its efficiency and the quality of the service. It identifies as a weakness of the Portuguese railways its degradation, which leads to a limitation of capacity and speed reduction [1].

Due to the current economic constraint, solutions that include the application of geogrids represent alternatives that improve the track behaviour. They can be used as reinforcement and/ or stabilization and consequently provide the improvement of track behaviour. However, for the reinforcement function, it seems that the tensile properties are a key parameter, while for the stabilization function it is essential that there is a good ratio between the opening size of the geogrid (A) and the size of the aggregate (D), and consequently, a good interlock.

Several authors have been studying the influence of the application of the geogrid in the ballast layer not only with laboratory tests, but also with *in situ* tests. A common conclusion of the studies performed is that the interlock of the ballast particles inside the geogrid openings must exist in order to improve the track behaviour. This is defined through the

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A/D ratio, nevertheless this relation is not consensual among the authors, and therefore mode studies are required.

The aim of this work is to study the interlock of the ballast particles inside the openings of a triaxial geogrid, addressing the influence of the ballast grading and the geogrid position. Based on the results, suggest an A/D ratio that maximizes the interlock. The geogrid was placed at the interface between the ballast and subballast and 45mm above this interface.

2 State of the art

Several studies were performed, regarding the influence of geogrids application, addressing topics such as the ballast layer settlement [2-9], displacement [5-7], breakage [5, 6, 8, 9], the ballast layer stiffness [2, 8], the track deformability [10], the ballast movement [2], the lateral track resistance [12], the rail deflection [13, 10], the track geometric parameters [10] and the relation between the geogrid aperture size and the ballast size [5, 14, 15]. In these studies, both laboratory and *in situ* tests were carried out.

Concerning the application of geogrids in railway ballast, the main results obtained in the literature related to the shape of the geogrid are presented in Table 1.

Table 1. Improvement of the railway track behaviour when geogrids are used in ballast layer.

Topics	**Improvement (%)**		**Improvement in terms of geogrid shape (%)**			**Improvement of the most common geogrids used in railways (%)**	
	Laboratory	***In situ***	▯	□	△	□ 65x65mm	△ 55x55x55mm[1]
Ballast layer settlement	10 to 65 (33)	5 to 35 (20)	5 to 61 (30)	15 to 57 (33)	17 to 65 (36)	15 to 57 (34)	21 to 65 (42)
Ballast lateral displacement	18 to 88 (57)	14 to 51 (32)	13 to 88 (55)	41 to 71 (56)	#	53 to 71 (62)	*
Lateral track resistance	8 to 40 (36)	34 to 42 (38)	*	8 to 42 (31)	*	*	*
Ballast breakage	0,7 to 53 (25)	*	0,7 to 53 (34)	2 to 51 (19)	#	2 to 51 (18)	*
Rail deflection	*	43	46	30	64	*	64

*: not studied by the authors; #: not representative; ( ): average; [1]: hexagon pitch equals to 120mm

Comparing the improvements obtained when geogrids are used in the railway ballast, the most efficient seems to be the triaxial geogrid [4].

The influence of the geogrid location in the ballast layer is presented in Table 2, in terms of ballast layer settlement, breakage, lateral track resistance and lateral displacement.

Table 2. Influence of the geogrid location in the ballast layer.

Location[1] (mm)	Improvement				References
	Ballast layer settlement (%)	Ballast breakage (%)	Lateral track resistance (%)	Lateral displacement (%)	
0	5 to 65 (30)	0,7 to 50 (26)	*	13 to 65 (38)	[3-7, 9-11, 13]
65 (1,23D_{max})	48 to 61 (55)	39 to 54 (48)	*	65 to 88 (75)	[5]
100 (1,59D_{max})	15 to 52 (33)	4 to 8 (6)	8	*	[8, 12]
200/ 3,17$D_{máx}$	20	2	31 to 34 (33)	*	[8, 12]
100+200	20	#	40 to 42 (41)	*	[8, 12]

*: not studied by the authors; #: not representative; ( ): average; D_{max}: maximum size of the ballast; [1]: measured from the interface ballast /subballast.

As shown in Table 2, the application of a geogrid at 65mm from the interface brings the best improvement, when compared with the placement at the interface. The use of two geogrids simultaneously, placed at 100mm and 200mm, improves the lateral track resistance significantly.

From the literature, it was observed that the main influence of the geogrid effect is given by the interaction between geogrid and ballast.

Based on the results obtained by the authors, the optimum location of the geogrid in the ballast layer, that maximizes the interaction between the ballast and the geogrid, is 1.23 to 1.59D_{max}. As regards the relation A/D_{50}, for biaxial geogrids it seems to be between 1.15 and 1.71 and for triaxial geogrids between 1.08 and 1.43.

It is consensual among the authors that a good interlock, between the ballast particles and the geogrid openings, contributes significantly to the improvement of the railway track behaviour. However, the optimum relation A/D is still an issue, because it depends on the ballast grading, the geogrid and the type of test used by each author to analyse the application of geogrids in the ballast layer. Furthermore, more research is needed to analyse the relation A/D for triaxial geogrids in the Portuguese context and the A/D that maximizes the interlock.

3 Case study

3.1 Setup

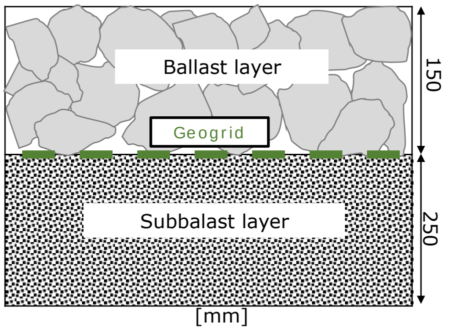
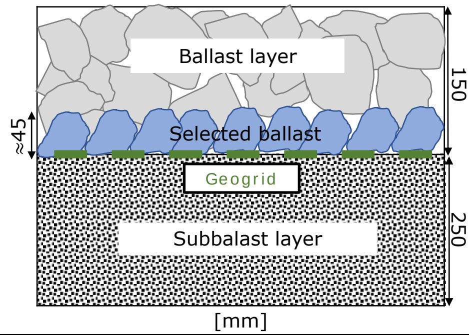
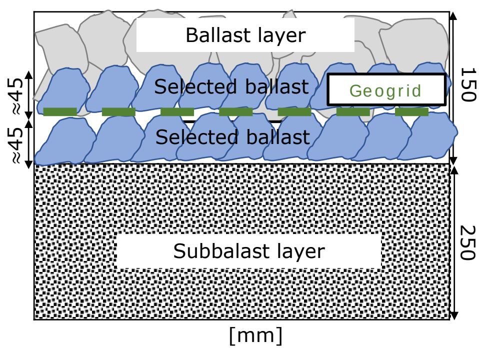
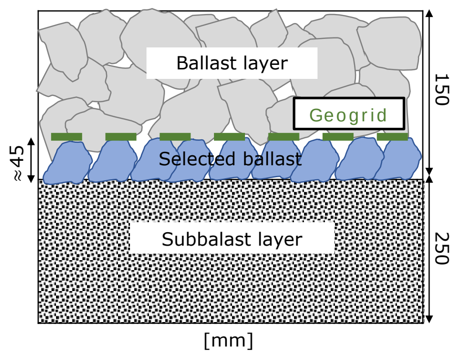
A triaxial, polypropylene, extruded geogrid and with a 120mm hexagon pitch was used. The ribs length is approximately 55mm. According to the manufacturer, the radial secant stiffness at 0.5% strain is 540kN/m [16].

The ballast grading used in the current study is presented in Fig 1. It is in accordance with the standard NP EN 13450 [17].

The maximum size, the average size and the minimum size of the particles of the subballast used in the current study is 31.5mm, 8mm and 0.063mm, respectively.

Table 3 presents the four physical models studied. For each model, the total openings and the openings with a particle interlocked were counted and the percentage of interlock calculated.

Table 3. Physical models analysed.

G/0	#G/0
	
#G/45.1	**#G/45.2**
	

Based on the first model (G/0), the maximum size of the particles that were interlocked was around 50mm. Therefore, the ballast selected for a better interlocking had a maximum size of 45mm. This ballast was selected from the standardized one, using a 45mm sieve.

The main objective was to study the improvement of the interlock by addressing:

- The location of the geogrid;
- The ballast size (selected ballast).

Fig.1 shows the particle size distribution for the ballast used in the current study and the selected ballast.

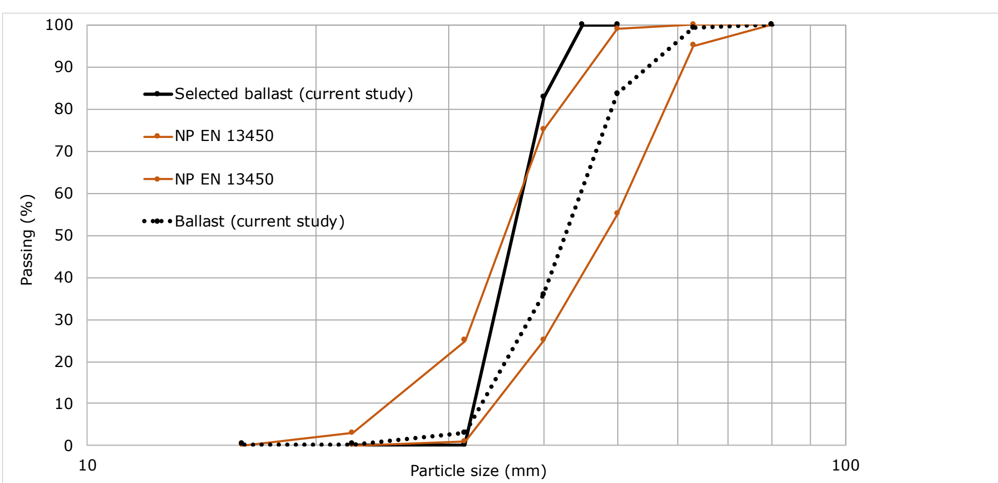


Figure 1. Particle size distribution of the ballast used in the current study and of the selected ballast.

3.2 Results analysis

The percentage of interlocked particles and the A/D relation in each physical model are presented in Table 4.

Several authors suggested values for the relation A/D, in order to achieve a good interlock. Different D have been used considered: D_{50} [5, 14], D_{max} and D_{min} [15]. Han et al. [3] questioned the suitability of the use of D_{50}, because the percentage of too coarse or too fine particles affect the D_{50} and do not contribute to the interlock.

Table 4. Interlock analysis.

Model	**G/0**	**#G/0**	**#G/45.1**	**#G/45.2**
D_{max}[1] (mm)	63	45	45	45
D_{50}[2] (mm)	43	36.64	36.64	36.64
A[3] (mm)	55	55	55	55
A/D_{max}	0.87	1.22	1.22	1.22
A/D_{50}	1.30	1.50	1.50	1.50
Interlock (%)	49	88	92	65

[1]: ballast maximum size; [2]: ballast average size; [3]: geogrid aperture size (length of the rib)

When the geogrid is placed in the ballast, the interlock increases as follows:

- when placed at the interface, from 49% (G/0) to 88% (#G/0);
- when placed at 45mm above the interface, from 49% (G/0) to 65% (#G/45.2), for selected ballast placed bellow the geogrid, and from 65% (#G/45.2) to 92% (#G/45.1), for selected ballast placed below and above the geogrid.

These results are consistent with the results presented by Indraratna et al. [6].

As presented in Table 4, the results suggest the A/D_{max} should be 1.22 and that the placement of the geogrid 45mm above the interface improved the interlock.

Fig. 2 shows some examples of interlocked particles in the geogrids apertures.

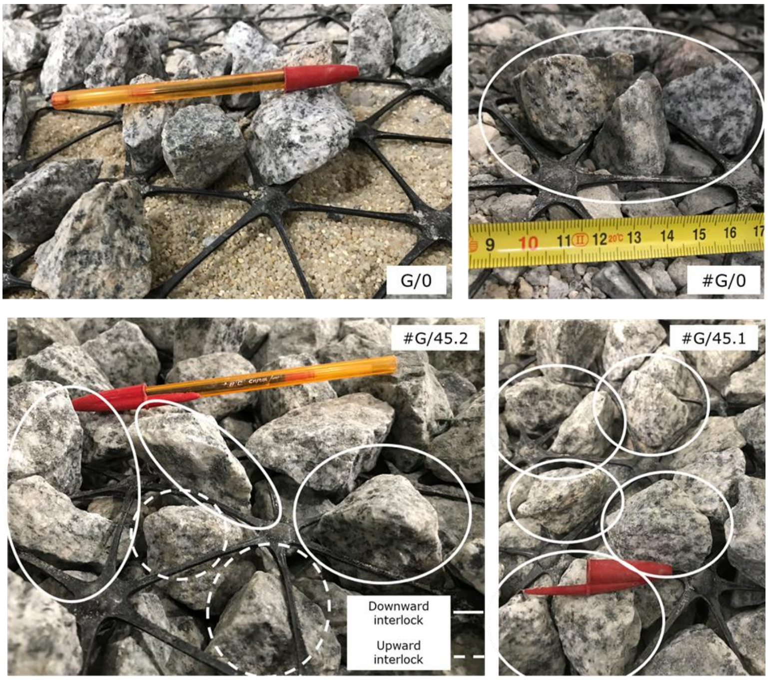


Figure 2. Interlocked particles in the geogrid openings in each physical model: G/0, #G/0, #G/45.1, G/45.2

4 Conclusions

The main purpose of this work was to study the A/D that maximize the interlock, where A is the geogrid aperture size and D the ballast size, addressing the influence of the geogrid location in the ballast layer and the influence of having a selected ballast layer close to the geogrid.

The size of interlocked particles in the geogrid was analysed and, in order to increase the interlock percentage, a selected ballast layer was used with ballast maximum size (D_{max}) of 45mm.

The results showed that to obtain a higher interlock percentage, a selected ballast layer, placed in contact with the geogrid, should be used. When placing the geogrid at 45mm above the interface, the interlock is improved, even more.

The use of D_{max} of the ballast seems to be more practical for the calculation of the relation A/D, as it can be easily implemented during track rehabilitation. The results suggested that to improve the interlock, the A/D_{max} should be around 1.22 and the geogrid should be placed 45mm above the interface.

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