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Toward an optimized trackbed design using geogrids

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ABSTRACT: The French National Rail Network (RFN), particularly its conventional lines, was initially built between the mid-19th and the early 20th centuries. Historically, maintenance efforts primarily focused on track renewal (rails, sleepers, and ballast), often neglecting the underlying layers. In recent years, increasing rail traffic and train speeds have imposed higher and more frequent cyclical loads, under which the trackbed can suffer for irreversible mechanical damage. This issue is exacerbated in certain areas where there is a lack of drainage network maintenance. In this case, substantial work is required to restore the track to nominal condition; this includes the excavation of part of railway structure and the construction of a new good quality trackbed. These typically involve deep excavations and the reconstruction of high-quality trackbed, leading to considerable costs and limited operational efficiency. To address these challenges and align with goals of cost reduction, improved yield, and environmental sustainability, innovative approaches to reducing excavation depth are critical. SNCF Reseau's preliminary research suggest that geogrids offer a promising solution. Geogrids are geosynthetics constituted by a network of tensile elements with openings of sufficient size to allow interlocking with the subballast layers granular materials. Such kinds of products are widely used in roads and other rail-networks, to reduce the thickness of built trackbed structure without compromising performance. This study focuses on identifying suitable geogrids characteristics or use on the RFN considering operational objectives, then define an optimized trackbed design including geogrids. The second step is particularly challenging because the mechanical behaviors of trackbed soils are heterogeneous, poorly characterized and trackbed design depends on the target bearing capacities given numerous uncontrolled variables under current SNCF Réseau standards. Once various designs have been validated, they will be verified to identify the most optimized considering operating conditions, environmental impact, cost, and yield.

KEYWORDS: Railway improvement, Trackbed design, Geogrid

1 INTRODUCTION

Track exploitation efficiency is linked to the quality of the entire railway system. The standard railway track is composed of several components that must perform specific functions satisfactorily in response to traffic loads and environmental factors (Selig and Waters, 1994).

Ballasted tracks, representative of the French network, are constituted of two main components:

- the superstructure that consists of rails, fastening systems and sleepers,
- the substructure that contains ballast, subballast, capping layers and subgrade (Selig & Waters, 1994). In the specific case of the French railways, conventional lines are made of an interlayer, placed between the ballast layer and the subgrade, and built up over the years by the penetration of ballast grains in the subgrade. The trackbed consists of all the layers constituting the substructure excluding the ballast. The Figure 1 shows typical Franch railway substructure for new (new railway structure) and conventional (old non renewed railway structure) lines.

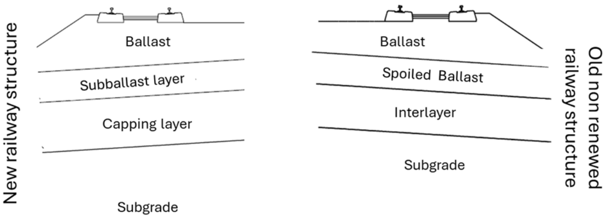


Figure 1. Typical French railway substructures

The trackbed is considered as anchors that carry the superstructure. When mechanical failures appear in the trackbed, renewals are needed. However, these works are sometimes poorly considerate because of their cost and their performance. In this sense, innovative solutions are needed to ensure the perfect productivity of a considered line.

Stabilisation is defined in the NF EN ISO 10318-1 to improve the mechanical behaviour of unbound grained material, by including one or more layers of geosynthetics so that deformation under applied loads is reduced, minimizing movements of the unbound grained material. This kind of methodology used in the trackbed allow a reduction of the railway material thickness and ensure the good quality of the structure. This study focusses on the use of stabilisation geogrids under the subballast layer to increase the bearing capacity of the trackbed.

Geogrids are defined as any geosynthetics planar structure formed by a regular network of tensile elements with apertures of sufficient size to allow interlocking with surrounding soil, rock, earth, or any other geotechnical material to perform the functions of reinforcement and/or segregation (Carroll, 1988).

Such kind of geosynthetics is already used in other rail-networks, as the Network Rail (UK) or the Deutch Bahn (German), to reduce the thickness of the trackbed. One of the aims of the project is to define optimized trackbed dimensioning including geogrids as presented in Figure 2.

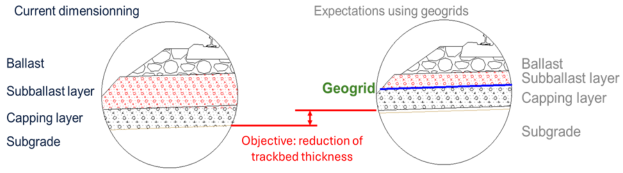


Figure 2. Expectations of using geogrids for trackbed reinforcement

Using geogrids in the French network is challenging and some questions are rising, as:

- What kind of geogrid can be used considering the railway environment, the objectives of performance, etc.?
- What is the most appropriate or optimized dimensioning for trackbed including geogrids, on conventional lines?

- What are the consequences in terms of cost and efficiency of the renewal and in terms of environmental impacts?

2 THE CHOICE OF THE GEOGRID

As previously mentioned, this study focusses on the use of geogrid placed under the subballast layer to improve the mechanical properties of the trackbed.

Tensile strength of the geogrid is one of the important parameters to consider. It provides confinement to resist granular extension strain hence reinforcing the trackbed (Milligan and Love, 1984; Selig and Waters, 1994).
Perkins (1999), describes four mechanisms:

1. reduction of the amount of lateral spreading,
2. increase in the lateral stress within the aggregate layer, thereby increasing its stiffness,
3. improved vertical stress distribution onto the underlying subgrade,
4. reduction in shear stress within the subgrade.

The literature highlights important geogrid parameters to be considered ensuring their proper functioning:

- Tensile strength is a parameter to be considered, especially when there is a risk of localized settlement.
- Secant Stiffness, and more precisely the secant stiffness at 2% strain. According to some field tests, this value must be higher than 350kN/m.
- Geogrid mesh opening which must be 1.4 times larger than the grain size of the "bearing" layer (*i.e.*, above the geogrid) to ensure optimal particle confinement. Considering the size grain of the material used at SNCF Réseau, the mesh opening must be between 20 and 50 mm.
- Type of material constituting the geogrid (PP, PET, etc.) is also important. Indeed, it is necessary to consider a potential degradation of the geogrid due to basic environment, presence of fuel, etc. The type of used geogrid will depend on the electrification of the rail line.
- Shape of the geogrid (triaxial, biaxial, uniaxial, see Figure 3) also has a non-negligible importance on the isotropic nature of its functioning. Considering the objectives, only biaxial and triaxial geogrids will be considered.
- Manufacturing techniques is also important. Geogrids can be knitted, welded or even punched and drawn, see Figure 3. The punched and drawn geogrids are supposed to be less flexible, the meshes are less deformable and provide better grain containment. On the contrary, knitted geogrids are more flexible but the set of filaments constituting the meshes allow a locking of the grain material within the meshes (at "large scale") but also within the filaments (at "small scale"). The welded geogrids are supposed to have an intermediate behaviour.
- Geogrid's lifespan must be in line with the service life of the works to be carried out. In our cases, the service life must be between 50 and 100 years but may be reduced in some cases.

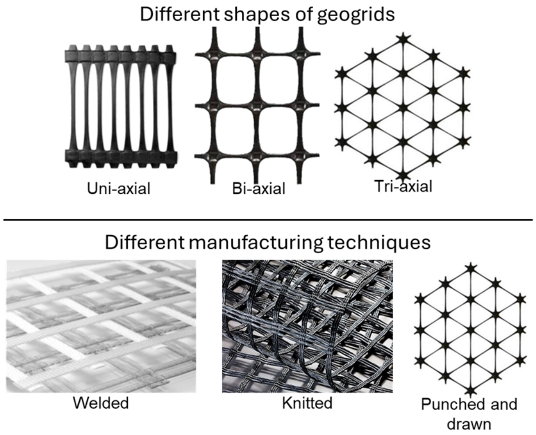


Figure 3. Example of different shapes of geogrids (on the right side) and manufacturing techniques (on the left side).

Considering the objectives of mechanical quality of the trackbed, the trackbed materials allowed in SNCF Réseau network, the on-field feedback, range of values for the different geogrid parameters are proposed. Table 1 indicates some geogrids and associated characteristics that are accepted on SNCF Réseau network.

Table 1. Example of parameters for different geogrids (GGR) used for trackbed reinforcement.

	GGR1	GGR2	GGR3
Tensile strength (kN/m)	> 40	> 40	> 40
Mesh opening (mm x mm)	25 x 25	-	38 x 38
Ultimate resistance deformation (%)	≤ 10	< 7	13
Material	PET	PP	PP
Shape	Biaxial	Biaxial	Biaxial
Manufacturing technique	Knitted	Welded	Punched and drawn

The position of the geogrid within the trackbed is also important. Most of the examples provided in the literature propose the installation of geogrids between the layer of poor mechanical quality and a layer of reported materials of good mechanical quality. Other examples propose the installation of a collection of geogrids within the layer of good mechanical properties to spread its effect over the entire thickness of the layer.

Considering all the characteristics of the geogrids and providers feedback, a list of accepted products is proposed for future works on the French railway network.

3 DEFINITION OF THE OPTIMIZED TRACKBED DIMENSIONING

According to geogrid manufacturers, for trackbed dimensioning using geogrids, it is necessary to provide a bearing capacity (NF P 94-117-1 standard) value to be reached at the top of the trackbed structure *i.e.*, at the top of the subballast layer.

However, according to SNCF Réseau's standards, the acceptance of trackbed works consists of load-bearing tests on top of the placed subgrade and of the capping layer and the checking of the compaction level of the subballast layer using a gamma-densimeter. Hence, the subballast layer bearing capacity remains unknown.

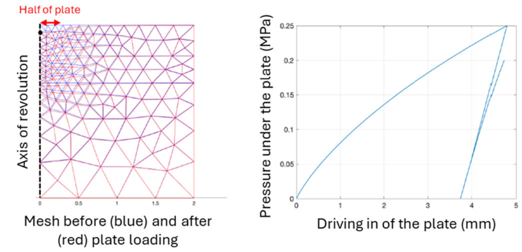
To fill this lack of information, a numerical modelling approach is proposed. The aim is to provide EV2 values at the top of the subballast layer (by simulating a plate loading test) for each trackbed configurations proposed in SNCF Réseau's standards (*i.e.*, considering capping layer bearing capacity and thickness and, subballast layer thickness). The numerical modelling does not include geogrids in the trackbed. Indeed, the behaviour of the trackbed with geogrid is complex. The obtained EV2 values will be used as a reference to be obtained with a equivalent structure including geogrid.

Two numerical models are proposed for EV2 estimation:

- ANA code was developed by Prunier (2020) and using finite elements. This work is described by Prunier (2023).
- A model based on a 2D-axisymmetric numerical model using the software FLAC2D v9. The first results are presented by Jenck et al. (2024).

The Figure 4 shows examples of results obtained numerical models developed by (A) Prunier (2023) et (B) Jenck *et al.* (2024).

A) After Prunier (2023)



B) After Jenck et al (2024)

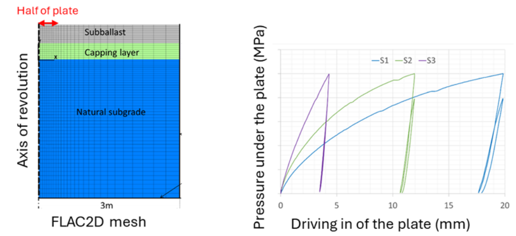


Figure 4. Examples of results obtained with the numerical models of (A) Prunier (2023) and (B) Jenck *et al.* (2024). On the left side: mesh of the numerical model. On the right side: numerical results of the plate-loading test simulation.

Numerical models highlight that EV2 modulus values vary according to the mechanical properties and the thicknesses of each trackbed layers and the mechanical properties of the subgrade. Numerical models also show the non-negligible influence of the model parameters (intrinsic characteristics of materials as the Young's modulus, cohesion, ultimate friction angle, …). As a first approach, Prunier (2023) et Jenck *et al.* (2024) defined intrinsic characteristics of the trackbed material from the literature. However, as the influence of these values is non-negligible, it would be helpful to perform triaxial tests to appreciate the mechanical properties of the different layers. Tests are currently performed on capping layer and subballast layer materials, and results will be included in the numerical models to improve them.

4 MONITORING OF TRACKBED IMPROVED USING GEOGRIDS

Geogrids are currently used at the national scale to improve the railway trackbed, even if the associate dimensioning is not optimized, see Figure 5.

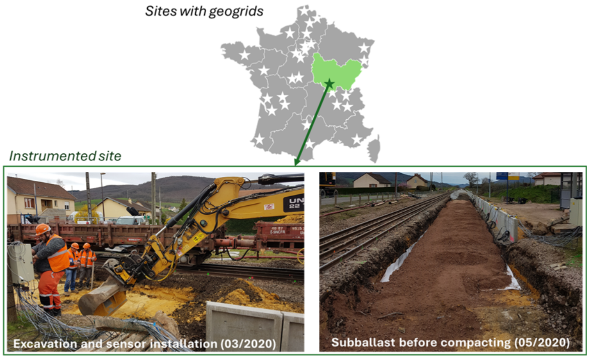
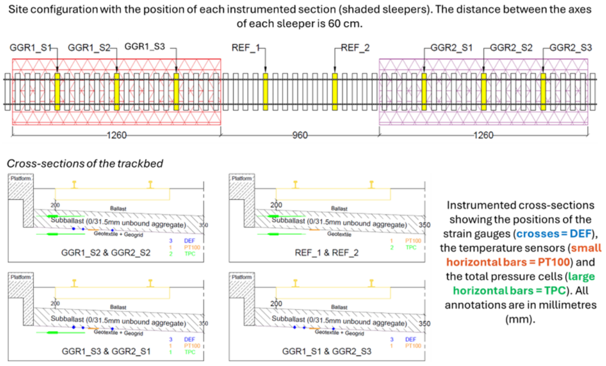


Figure 5. Site locations with geogrids in the French railway network (stars). The green star locates the site monitored with specific sensors.

One specific site in Bourgogne-Franche-Comté (France, green star in Figure 5) is monitored with different sensors since December 2020, Yaba *et al.* (2021, 2024).

In this site, the subgrade consists of silty sands with pockets of alluvial gravels (rolled gravel). *In-situ* tests on the exposed subgrade confirmed its poor mechanical properties. The renewed trackbed consists of a geotextile at the top of the subgrade underlaying a geogrid and 25 cm of subballast. Two types of geogrids were installed to compare their behaviours through time, see Figure 6. These geogrids were selected to observe the effect of geogrid's stiffness on its performance (the stiffness of GGR1 is higher than GGR2's).
The zones at each extremity of the site are equipped with geogrids (named GGR1 and GGR2), while the zone in the middle is left without geogrid and is considered as a reference (REF). Eight sections are equipped with sensors: three sections for each zone with geogrid and two section for the reference zone. Monitoring is performed using strain gauges, temperature sensors, total pressure cells (see cross-sections in Figure 6). More details are available in Yaba *et al.* (2021, 2024).


Site configuration with the position of each instrumented section (shaded sleepers). The distance between the axes of each sleeper is 60 cm.

Instrumented cross-sections showing the positions of the strain gauges (**crosses = DEF**), the temperature sensors (**small horizontal bars = PT100**) and the total pressure cells (**large horizontal bars = TPC**). All annotations are in millimetres (mm).

Figure 6. Monitored site configurations.

After three years of monitoring, Yaba *et al.* (2024) shows that geogrids improve load distribution and reduce dynamic stress amplification in the tracked. These improvements are developed during the first couple of years of service and then plateau once the geogrid has fully been mobilised. However, GGR1 provided fastest and more significant improvements than GGR2. The monitoring shows that the geogrid's stiffness is crucial when selecting a geogrid.

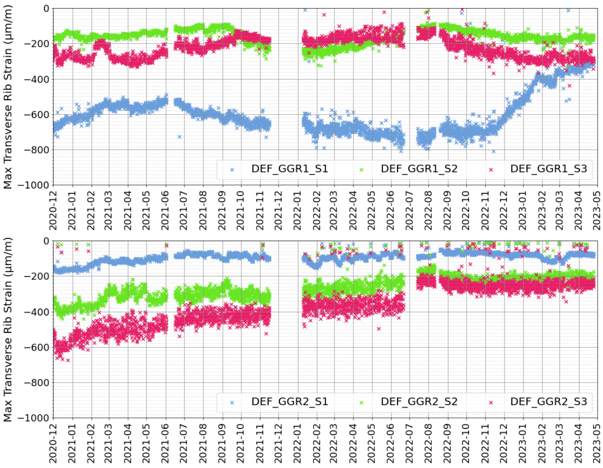


Figure 7. The transverse Rib strain evolution on GGR1 and GGR2 between 2020 and 2023.

These monitoring results will be analysed during several years to appreciate the performance of the geogrid in the trackbed through time and train circulations and will help to develop the use of geogrid at the national scale.

Other sites equipped with geogrids are monitored by analysing the track geometry variations through time.

5 CONCLUSIONS AND PERSPECTIVES

The presented project aims to evaluate the impact of geogrid stabilization in trackbed structures and propose an optimized design using this methodology.

Facing the multitude of existing products and their associated properties, one of the objectives of the project is to determine crucial geogrid parameters to be considered.

The second step is to determine the mechanical objectives to reach at the top of the trackbed to design an optimized trackbed structure using geogrids.

In parallel, geogrid stabilisations are used in test sites to evaluate their ability to improve railway trackbeds and their fatigue through train circulations.

To go further, other research projects are ongoing.

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Future SNCF Réseau research project aims to analysed SNCF Réseau's standards and to challenge and optimize existing trackbed designs.

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