PRELIMINARY RESULTS FROM AN INSTRUMENTED RAILWAYS EMBANKMENT REINFORCED WITH A GEOGRID-GEOTEXTILE GEOCOMPOSITE

A. Buonanno[1], F. Montanelli[2], and P. Rimoldi[3]

ABSTRACT

A railroad track is continuously subject to large dynamic loadings (load-unload cycles) so that frequent and expensive repair operations are required to maintain the ballast characteristics. Often the difficulties to find out good quality fill soil and the difficulties of transporting it further increase construction and maintenance costs. The use of a proper geosynthetics reinforcement material offers the possibility to solve, or drastically reduce the problems.

In central Italy, a railway line with very a old embankment (second half of the XIX century) was subject to continuous settlements, due both to the poor quality of the soil forming the embankment (mainly silt) and to the bad characteristics of the sub-grade (lacustrine clays). After removing the ballast and part of the embankment body, a geogrid-geotextile geocomposite was laid. The embankment has been reconstructed using better fill material. In some sections of the embankment the geogrid ribs were instrumented with strain gages, in order to verify the effect of the reinforcement in the short and long term and to determine the magnitude of the stresses that are transmitted to the geogrid due to the passage of different types of trains.

This paper contains a description of the F.E.M. analysis that has brought to the choice of such solution, of the construction method, of the instrumentation program and an analysis and discussion of the results of such monitoring.

EXISTING CONDITION AND DESIGN SOLUTION

In recent years due to the exceptional increase of traffic, speed, axle load of trains, several existing railways lines are showing signs of distress, instability and settlements. The solution of improving the top layer of the railway track by providing suitable designed sub-ballast layer is essential to withstand higher stresses. However laying of thick sub-ballast under running traffic is extremely difficult and expensive. The reinforcement of the sub-ballast by means of a geogrid-geotextile geocomposite allows the reduction of the depth of the excavated soil and at the same time assures higher long-term performances.

It is well known that the irregularity of the rail level under the train passage becomes rapidly worst with additional passage. This phenomenon is called “track deterioration”. The track deterioration is different from global failure of structures like landslides because is an accumulation of plastic deformations either in the ballast layer or in the sub-grade layers. This phenomenon has serious influence on the safety and efficiency (speed restriction) of train operation.

The purpose of the track components is to convert the wheel load to relatively uniform stresses on the sub-grade. The track sub-structure layers (ballast, sub-ballast and sub-grade) have significant influence on the railways performance: all the stresses and thus settlements occur in these layers and may be due to several different causes.

In central Italy, the Foligno-Terontola railway line had very old embankment (second half of the XIX century) and it was subject to continuous and differential settlements, due both to the poor quality of the soil forming the embankment (mainly silt) and to the bad characteristics of the sub-grade (lacustrine clays).

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[1] F.F.S.S., Ferrovie dello Stato Italiano, Roma, Italy
[2] Tenax SpA, Viganò, Italy
[3] Tenax SpA, Viganò, Italy

The existing Terontola-Foligno railways embankments, in the Spello vicinity, can be modelled having an embankment height of 1.5 m within station 7+500 and 9+000 and 0.5 m within station 10+300 and 10+800. Above both embankments, a ballast thickness of 0.5 m was present. The embankment sections were composed of silty material and they were resting above about 10 m of normally consolidated clays. The maximum train axle load was 25 t/axle and for static analysis this load was taken equivalent to 20 kPa, due to geometrical and simplification analysis.

The settlements in the embankment were due to both train load and reload axle cycles and to seasonal water content changes within the embankment body: in fact the silty sub-ballast was subject to cycles of swelling and desiccation during the wet and dry seasons.

This seasonal behaviour was modelled using a F.E.M. analysis, on three different embankment cross-sections: SP-3: existing condition; SP-2: double geogrid-geotextile geocomposite layers (TENAX GT 330) with 0.70 m sub-ballast substitution with free-drainage granular material (Figure 1); SP-1: as SP-2 but with 1.5 m soil replacement.

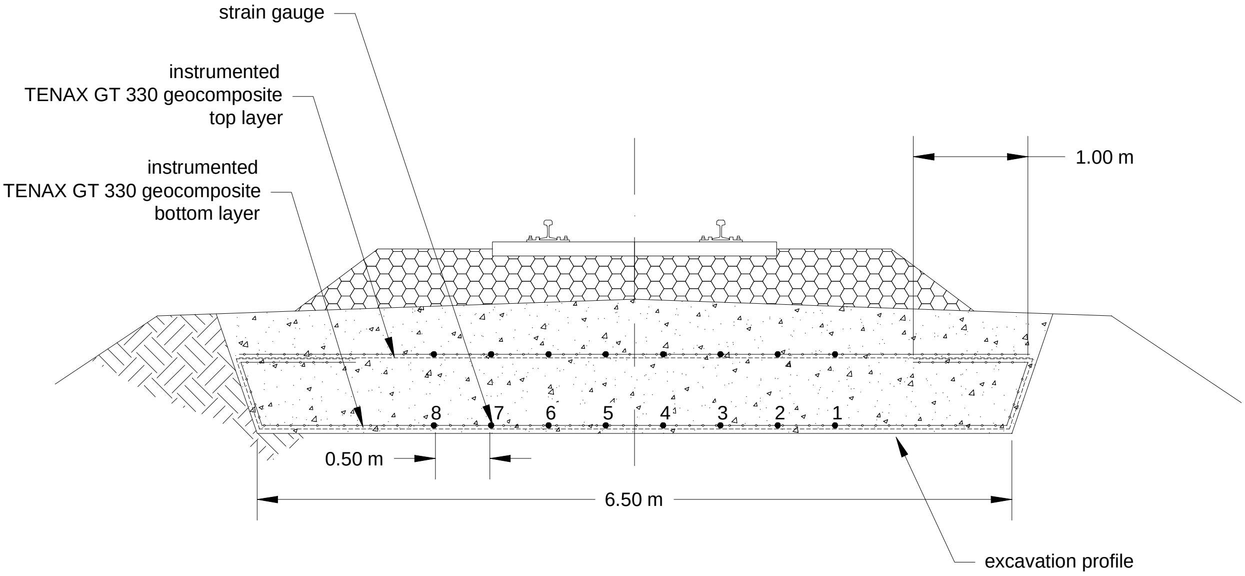

Figure 1: SP-2 cross-section showing within the railroad embankment: the wrapped around geocomposites layers, the strain gage instrumentation layout, the ballast and sub-ballast structure.

The railway cross section was modeled under plane strain conditions using PLAXIS F.E.M. program. The three noded isoparametric soil elements were modeled as elastic perfectly plastic elements using the Mohr-Coulomb criterion. Geogrid reinforcements were represented by means of two noded fully elastic truss elements with axial stiffness and specific interface parameters. The Young modulus for the geogrid was selected at 2 % of axial strain determined by wide width tensile test.

The calculated F.E.M. settlement results, under the railroad centerline, are shown in figure 2. The determined seasonal settlements for the existing condition (SP-1) are in the order of 13 mm. The combined use of free-drainage granular soil and geocomposites layers reduces the existing seasonal settlements between 20% (SP-2) and 40% (SP-3). In fact the grain size of the granular sub-ballast reduces the water formation within the embankments and thus the swelling and desiccation cycles. Moreover the stiff base reinforced with the geocomposites allows a better stress distribution across the full section.

Several authors have demonstrated the effective use of geogrid reinforced ballast sections; in particular we refer to V. J. Jain and K. Kesheav (1999). These authors have demonstrated the use of a double layer of geogrids substantially reduces the vertical stress level under the railways section.

Empirical tests conducted on full-scale railways sections show a reduction of 30% of unload-reload cycle induced stresses when measured at 0.90 m below the sleepers. Moreover they suggest that the sub-grade soil in the top one meter of railway formation truly govern its axle load capacity. Therefore, to strengthen an existing railroad formation, the excavation shall be limited to replacement of the upper one meter.

Based upon these suggestions and the performed F.E.M. analysis, for the design of the Terontola-Foligno railways embankments the SP-2 solution has been chosen as being the most economical and with the best performances since it was reducing by 20% the settlements due to seasonal settlements and the ones due to cyclic loadings. Thus the ballast was removed together with 0.70 mm of silty embankment and replaced with new ballast and granular fill soil reinforced with a double layer geocomposite (Fig. 1).

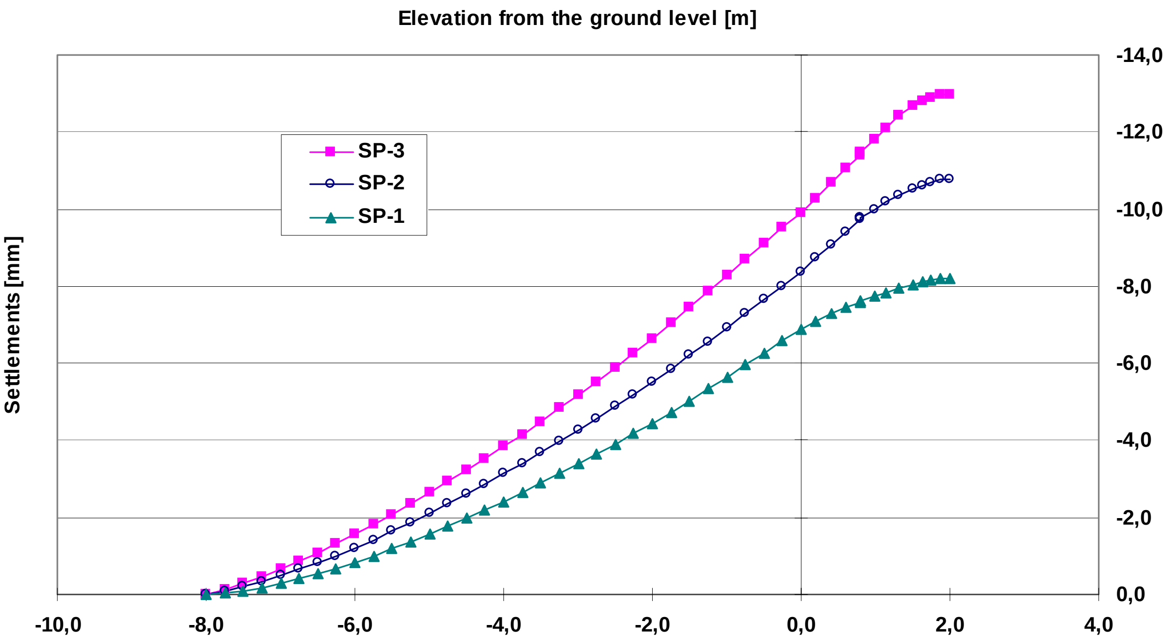

Figure 2: Vertical settlements due to seasonal water content variations along the railway centre line for cross sections SP-1, SP-2 and SP-3.

The geogrid-geotextile geocomposites properties are reported in table 1 and in figure 3 a photo of the geocomposite is shown. This geosynthetics has exceptional confining and reinforcing properties due to its high tensile modulus and junction strength. A nonwoven geotextile is heat-bonded on the lower side of the geogrid layer to assure a filtration function.

Table 1. Geogrids nominal properties.

Product Name	GT 330
Structure	Integral Biaxial PP Geogrid heat-bonded to a Nonwoven Geotextile
Polymer Type	Polypropylene, (PP)
Wide Width Nominal Tensile Strength, MD x TD	30 x 30 kN/m
Wide Width Strain at Peak, MD x TD	11 x 11%
Wide Width Tensile Strength at 2% Strain, MD x TD	10.5 x 10.5 kN/m
Wide Width Tensile Strength at 5% Strain, MD x TD	21.0 x 21.0 kN/m
Unit Weight	560 g/m^2
Residual Strength after Installation	100%
Geogrid Mesh Size	40 × 27 mm
Geotextile Pore Size	0.08 – 0.13 mm

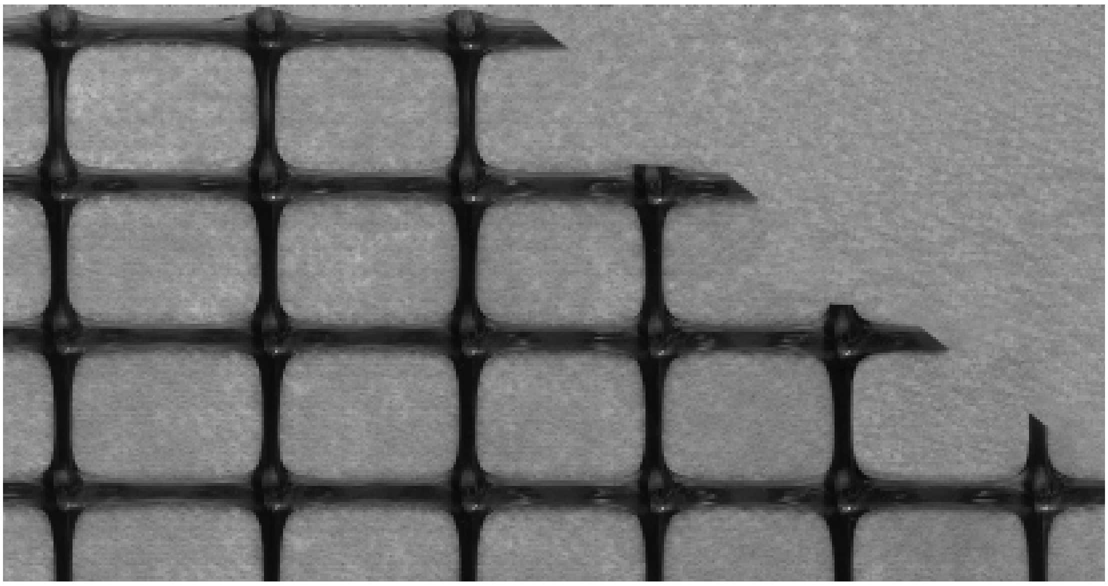

Figure 3: Photo of the GT330 geogrid-geotextile geocomposite.

The reconstruction of the railway took place during the night to avoid train traffic interruption. Every night, within 6 hours, 30 m of railroad section were fully dismantle, excavated, reinforced with the geocomposite, filled and compacted with granular material, and the ballast and railway tracks rebuilt without delays to the train traffic. Figure 4 shows the reconstructed Spello railway line and the construction phase of geocomposites soil covering during the night work.

Figure 4: Reconstructed railway line and geocomposites fill covering during the night.

INTRUMENTATION AND MONITORING

The geogrid ribs were instrumented with self-temperature compensated strain gauges having a nominal gauge length of 5 mm, a maximum strain limit of 3 % and a measurement accuracy of 0.5 %. Eight strain gauges were installed on each reinforcement layer at a spacing of about 0.50 m and all the instrumentation was connected to an automatic acquisition system capable of acquiring data up to frequency of 1 kHz. Both upper and lower geogrid layer have been instrumented (figure 1).

Geogrids laboratory specimens were instrumented with strain gauges and tested in the laboratory to obtain a correlation gage factor between the in-situ strain gages measurements and actual overall geogrid strain. The correction gage factor was taken equal to one after test results analysis.

The geogrid strain data have been collected during the passage of several type of train. In particular, in figures 6 and 7, the data are shown for strain gages 5 and 6 (under the railway beam) for a 656 locomotive with 8 railcars.

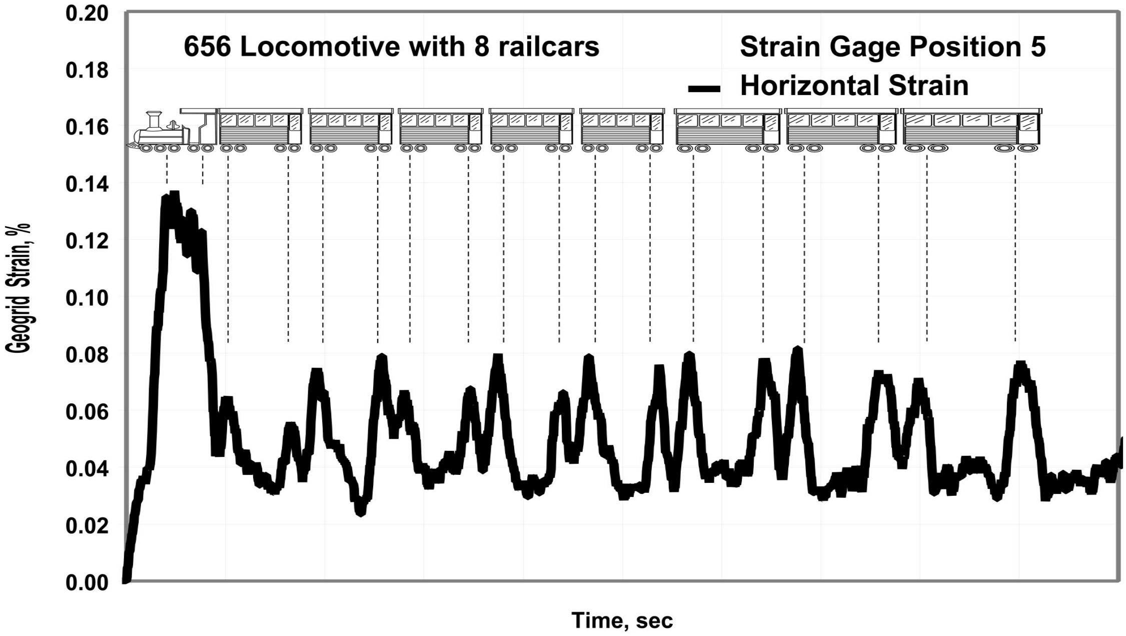

Figure 6: Railway base monitoring by means of strain gage installed on the upper geogrid layer at position 5 (figure 1) during train passage.

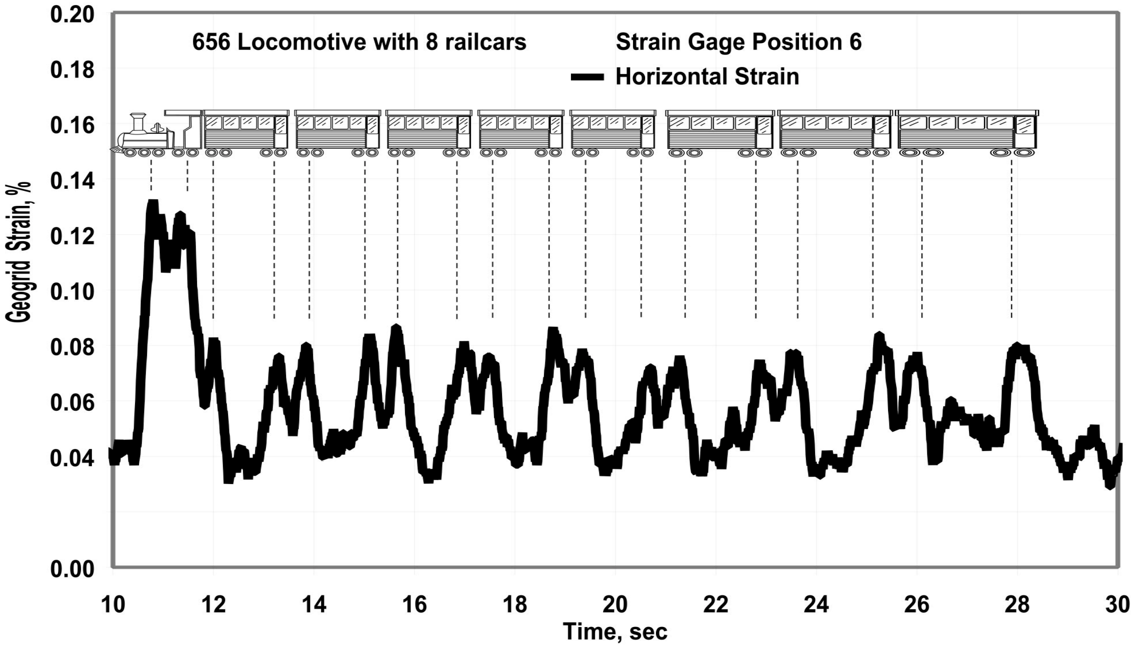

Figure 7: Railway base monitoring by means of strain gage installed on the upper geogrid layer at position 6 (figure 1) during train passage.

The data shown are for the strain gages located on the upper geocomposites layer at a depth of 0.30 m under the ballast. The measurements show very low peak strain of 0.14% under the locomotive axle weight and 0.08% under the railcars axle load. It is interesting to evaluate that the shape of the strain curve is very well fitting the actual cyclic load condition imposed by the axle loads. Thus the railways beams, the sleepers, the ballast and the sub-ballast soil do not fully distribute the train axle loads along and across the embankment, but the axle loads can be easily detected by the instrumentation on the geogrid at a depth of about 0.80 m from the sleepers. For the strain gages located far (1 m) from the vertical of the beams, the measured strains were very small thus confirming what has been indicated previously.

"V. J. Jain and K. Kesheav" (1999) estimate, from empirical tests conducted in very similar condition, a peak vertical stress of about 40 kPa at a depth of 0.80 m with double geogrid reinforcing layers. An analysis conducted considering the membrane effect of the geocomposites, the measured strain and the applied vertical stress, has shown the absence of significant elastic deformation within the sub-ballast embankment at 0.80 m depth. The Authors have already planned to verify the long-term behaviour of the overall structure.

CONCLUSIONS

In recent years due to the exceptional increase of traffic, speed, axle load of trains, several existing railways lines are showing signs of distress, instability and settlements. These phenomena have serious influence on the safety and efficiency (speed restriction) of train operation. The irregularity of the rail level under the train passage becomes rapidly worst with additional passage.

The Foligno-Terontola railway line had very old embankment (second half of the XIX century) and it was subject to continuous and differential settlements. The design solution was determined either by F.E.M. analysis and comparing empirical results obtained by other Authors. The solution required the reinforcement of the sub-ballast by means of a double geogrid-geotextile geocomposite layer and the excavation and replacement of the first 0.70 m of sub-ballast with free-drainage granular fill soil to avoid swelling and desiccation within the silty embankment.

The empirical data collected show that under the vertical of the railway beam, the axle loads are easily transferred and redistributed by the geogrid layer and the fill soil. The magnitude of the strain is quite low (max 0.14% strain) thus indicating low elastic vertical settlements. The long-term behaviour of the railway embankment shall be monitored to verify its efficiency under seasonal cycles and fatigue stresses.

The installation of a sub-ballast thickness of 0.70 m in existing structure has proved difficult and costly. Thus the use of stiff integral biaxial geogrids or geocomposite is essential in assuring vertical stress reduction on the sub-grade soil and thus reducing the depth of sub-ballast layer required. The influence of a high quality geosynthetics on the overall construction cost has been minimal and very well paid back by the performances obtained.

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