Geosynthetics, J. Kuwano & J. Koseki (eds)
© 2006 Millpress, Rotterdam, ISBN 90 5966 044 7

The use of geogrids in the construction of piled embankments on the new lines of the Italian high speed train

Marchi G.F.
D.I.S.T.A.R.T. – University of Bologna

Schiavo M. & Kempton G.
Consultants

Naughton P.
School of Engineering, Institute of Technology, Sligo, Ireland

Scotto M.
Officine Maccaferri Spa

Keywords: piles, embankments, geogrids

ABSTRACT: The new railway line running from Milano to Bologna crossed an area of compressible soils in the Parma area. In particular, the results of the site investigation at some locations suggested a more innovative solution from the classical approach was required to resolve potential settlement problems. At the instruction of the of the railway engineering company ITALFERR, the designer and the main contractor compared the classical deep and short pile foundations with concrete slab with a geosynthetic solution based on high tensile strength polyester based geogrids. A technical, construction and cost benefit analysis showed that the geosynthetic reinforced piled embankment designed in accordance with BS 8006 (1995) offered the best solution, with the final technical and design options left to the contractor. A full-scale site investigation program was carried out on the foundation soil. The first embankment was built in 2003 and the construction phase was fully monitored to verify the effectiveness of the design. Over the following two years many other railway embankments were built on the same line using this design with some small changes mainly related to the pile cap size.

1 INTRODUCTION

Piled embankments were used in the area of Parma during the construction of the new Italian high-speed railway line (Treno Alta Velocità) connecting the cities of Napoli and Milano. This construction technique offered superior technical and cost benefits over traditional consolidation based methods.

The choice of a non-traditional solution was driven by the need to solve potential localized differential settlements of the railway embankment, while stratifying the construction time requirements.

The traditional construction technique of consolidation could not guarantee that the rate of settlement of the railway embankment would be under the clients specified maximum value of 0.05 m/10 year.

The piled embankments discussed in this paper are located south of the city of Parma parallel to the A1 (Milano-Bologna) motorway. This area was well known for rising spring-water. Concern was expressed at the influence the springs could have on the rate of settlement and the subsequent performance of the railway embankment if traditional construction methods were employed.

To over come potential localized differential settlement and the influence of the springs the designers selected to pile the embankment foundation and to spread the load of the embankment onto the piles with high strength polyester based geogrids. Based on technical and cost benefit analysis this was preferred to a concrete slab construction and also consolidation based methods such as pre-loading and vertical drains.

With no relevant Italian national standard the railways authority specified that the Code of Practice for Strengthened/Reinforced Soils and other Fills (BS8006, 1995) should be used in designing the geogrid foundation layer to minimize the risk in the design of this innovative technique.

This paper provides information on the geotechnical background of the compressible soils and details the final solution.

2 GEOTECHNICAL INFORMATION AND EVALUATION OF THE EXPECTED SETTLEMENTS

2.1 *Geotechnical information*

A detailed site investigation involving both *in situ* and laboratory testing was preformed. The stratigraphic profile is presented in Figure 1. Table 1 summarizes the properties of the soils encountered in the area of the piled embankments.

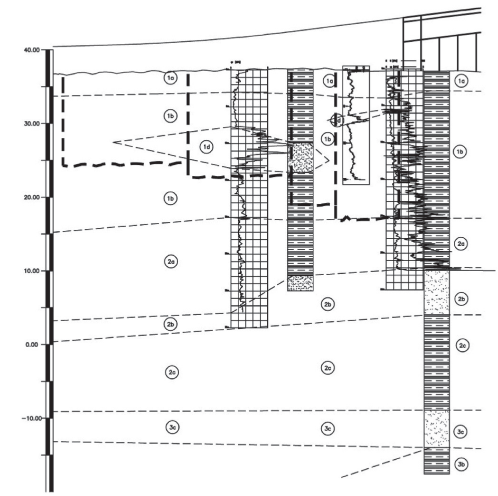

Figure 1. Stratigraphic profile of the piled embankment area.

Table 1. Soil characterization.

Units	Depth		γ	E	c_v
	From[m]	To[m]	[kN/m³]	[MPa]	[m²/s]
EMB	–	–	19.5	> 60	–
1a	0.0	4.0	19.0	7.0	1.5×10^{-7}
1b	4.0	20.0	18.0	5.3 + 0.4z	1.0×10^{-7}
2a	20.0	27.0	18.5	13.0	2.0×10^{-7}
2b	27.0	33.5	19.5	41.0	–
2c	33.5	46.5	19.0	22.5	1.5×10^{-7}
3a	46.5	–	19.5	55.0	–

2.2 *Settlement calculation*

Based on the soil parameters obtained from the site investigation the magnitude of settlement was estimated using elastic techniques.

The analysis indicated that the use of piles to support the embankment would reduce, by a third, the rate of settlement over a 10 year period (3-13 years), Table 2, resulting in rates of settlements well below the clients maximum rate of 0.05 m/10 year.

Table 2. Settlement analysis.

Height of embankment	Construction method	Magnitude of settlement, η		Rate of settlement Δη/Δt
		3 years	13 years	
[m]		[m]	[m]	[m/10 years]
7.0	No Piles	0.18	0.23	0.05
	Piles	0.05	0.07	0.02
6.0	No Piles	0.14	0.19	0.05
	Piles	0.04	0.06	0.02
5.0	No Piles	0.14	0.18	0.04
	Piles	0.05	0.06	0.01
4.0	No Piles	0.09	0.12	0.03
	Piles	0.04	0.05	0.01

3 DESCRIPTION OF THE DESIGNED SOLUTION

The final solution, designed in accordance with BS 8006 (1995), consisted of 0.5 m diameter continuous flight augured (CFA) piles installed at 2 m centres on a square grid. The length of the piles varied depending on the height of the embankment and the results of the settlement analysis. No pile caps where used and the high tensile polyester geogrid was installed with a thin layer of sand separating the geogrid and the pile top, Figure 2.

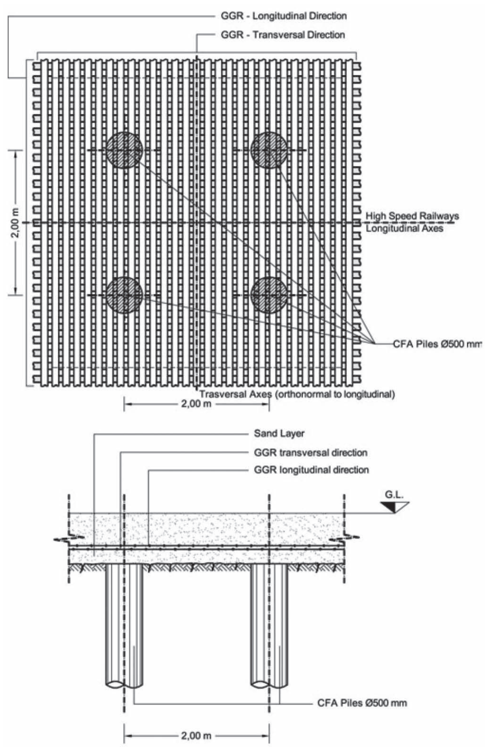

Figure 2. Details of the installation layout of the reinforcement geogrids.

A maximum short-term design strain of 4%, with a further 1% creep strain over the design life, was used in the calculation of the tension in the reinforcement. The strength of the reinforcement ranged from 900 to 1050 kN/m depending on the height of the embankment. Two layers of geogrid, one in the longitudinal and the second in the transverse direction were installed, Figure 3 and Figure 4. In the longitudinal direction the geogrid was layered resulting in no overlaps and a significant cost saving for the client.

In the transverse direction the geogrid was anchored using 0.5 m of gravel, around which the grid was

© 2006 Millpress, Rotterdam, ISBN 90 5966 044 7

Figure 3. Installation layout of the cross resistant geogrids.

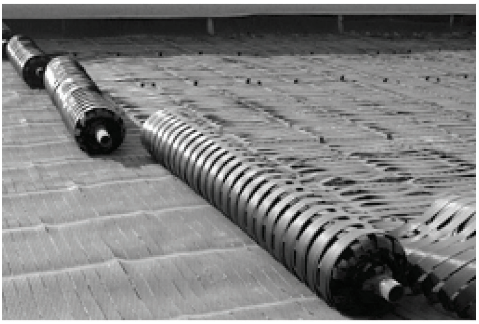

Figure 4. Installation layout of the longitudinal geogrids.

Figure 5. Both side anchorage of the cross resistant geogrid.

rapped, to achieve the required anchorage length specified by the design method (BS 8006, 1995), Figure 5.

4 DISCUSSION OF DESIGN TO BS 8006 (1995)

The design decision not to use pile caps had a significant influence on the required strength of the geogrid. The tensile strength of the geogrid reinforcement was calculated in accordance with BS8006 (1995). Figure 6 presents the variation of the tensile strength of the geogrid with pile cap size, for piles installed at 2.0 m centres and an end of design life strain of 5%, for different height embankments. It is clear that increasing the pile cap

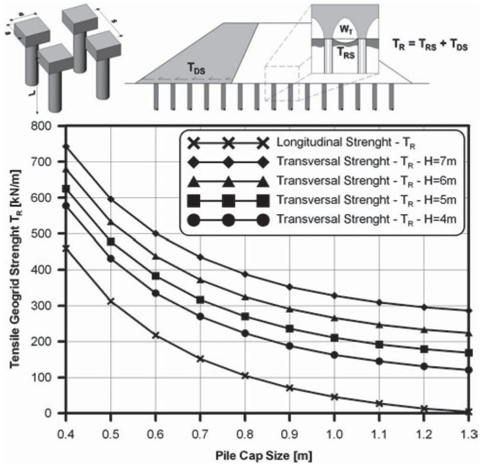

Figure 6. Tensile Strength of the geogrids Vs. Pile Cap Size.

size reduces the tensile strength in the reinforcement (the reduction in tensile strength is not however a linear function of the pile cap size).

It should be emphasized that the high geogrid tensions are a logical result of the BS8006 assumption of ignoring the positive contribution of the confined subsoil so that the embankment is fully sustained by the geogrid only (Kempton & Naughton, 2003).

This supposition can, as first impact, be considered too cautious, but the working difficulty in compacting the soil around the pile caps results in negligible contribution from the subsoil.

5 REINFORCEMENT MATERIAL

This project was the first large-scale use of piled embankment on high-speed railway applications in Italy. Railway embankments are considered a particular severe application due to the very restrictive tolerance on settlement.

The selected geogrid had not only to meet the strength requirements and have a maximum elongation over the design life of 5%; it also had to have its long-term properties certified by an independent competent testing and certification authority like the British Board of Agreement.

A strip based geogrid, Figure 7, that was widely used for similar application worldwide and certified by the BBA (BBA Agrément Certificate Nos 3338-1997 and 4065-2003) as basal reinforcement of embankments since the 1997, was selected for this application.

The selected geogrid consisted of high tenacity polyester encased in a polyethylene sheath. Details of the product are given in Naughton *et al*. (2005).

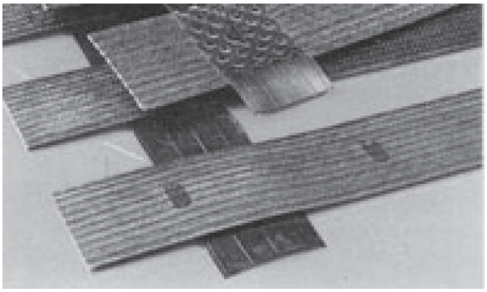

Figure 7. Strip type geogrid used to reinforce the embankments.

6 CONCLUSION

Many other Italian railway and highway embankments (RI83, RI84, RI87, RI89 and RI90, where "RI" is the Italian symbol for embankment) have used been constructed using the piled embankment technique described in this paper.

The interest in this embankment is still very high, as it was the first where the contractor and the designer decided to optimise the geosynthetics performance and remove the requirement for costly pile caps. It is still under discussion if it is the best solution from an economic point of view.

The most important conclusion was that the results are as, at the moment, estimated during the design phase.

Unfortunally we don't have a sufficient settlement data to pubblish on the paper due to the short time passing between the geogrids installation phase and the end of the construction phase. The settlement evolution during the construction phase give us a reasonable comparison between the predicted data and the observed data (the same order). We don't perform the same comparison in a long term behaviour because the embankments are too young to obtain an appreciate monitoring data. We postpone the discussion later when we hope to obtain a sufficient good data to publish.

Ultimately, otherwise, the design approach illustrated in this paper was the desired outcome of the Italian railway authority.

ACKNOWLEDGEMENTS

The authors wish to extend special thanks to: the Consorzio CEPAV UNO, the EUROVIE S.c.a.r.l., Dott. Eng. A. Boschi.

REFERENCES

BBA (1997). Terram Paralink geocomposite products. Agrément Certificate No 97/3338.

BBA (2003). Paralink geocomposite products. Agrément Certificate No 03/4065.

BS 8006 (1995). Code of practice for strengthened/reinforced soils and other fill. British Standards Institution, London.

Kempton and Naughton (2003). Piled embankments with basal reinforcement: development of design methods and stste of the art. L'Ingegnere e l'Architetto, Italy, Volume 1-12/2002, July.

Naughton, P.J., Balderson, T. and Loronzo, R. (2005). The properties of polyethylene encased high tensity linear elements. Geosynthetics and Geosynthetic-engineered soil structures: Contributions from the symposium honouring Professor Robert m. Koerner. Ed. Ling, H.I., Kaliakin, V.N. and Leshchinsky, D., pp 19-38.

Rehnman S.-E., Eriksonn U.B. and Jendeby L. (1999). Embankment on soft soil, interaction between embankment, reinforced and piles. Long term measurement at Urvalla, Sweden. Geothecnical engineering for transportation infrastructure, pp. 1867-1872.

© 2006 Millpress, Rotterdam, ISBN 90 5966 044 7