GEOGRID REINFORCED RAILWAYS EMBANKMENTS: DESIGN CONCEPTS AND EXPERIMENTAL TEST RESULTS

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ABSTRACT

Over the past years, considerable advances have been made into the understanding of the behaviour of using geosynthetics to improve the performance of shallow embankments. Detailed investigations have been performed using small scale and large scale models to evaluate their performance and to develop rational methods for design. This document provides a guide to geotechnical engineers who wish to analyse the performances of geogrid reinforcements when installed in different locations of the track structure.

Keywords: railways; embankments; geosynthetics; reinforcement; geogrid; improvement; settlement; strain gauge; f.e.m.; empirical results

1. Introduction

Railways embankments on soft soil require proper ground improvement and good soil compaction. A railway line shall be considered as a multi-layer composite system comprising of natural ground, fill soil, reinforcement layers, rail track system and wheel train loads. 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 including short and long term settlements due to static and dynamic loadings. Geosynthetics have been proved to be suitable as reinforcement for both the embankment bottom and fill at the subgrade and sub-ballast level.

The geogrid reinforcements perform the following functions:

1. create a stiff platform where horizontal shear strains and vertical settlements are controlled and minimised;
2. increase the bearing capacity and the load distribution by enlarging the foundation slip failure line, thus reducing vertical stresses;
3. increase the fill soil stiffness by enhancing the soil compaction, providing inner tensile strength and an apparent long term cohesion of the fill soil even under high dynamic loads approaching the critical speed;
4. increase the dumping efficiency of the embankment fill thus allowing higher railways speed;
5. reinforce, filter and separate the soil components.

Therefore geogrid reinforcements are frequently used for the rehabilitation of existing railway embankments and for design of new lines as discussed below.

2 Rehabilitation of existing railway: two instrumented cases

In recent years, due to the exceptional increase of traffic, speed and train axle load, 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 passages. 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 installing a thick sub-ballast under running traffic is extremely difficult and expensive and sometimes impractical. The reinforcement of the sub-ballast by means of a geogrid allows the reduction of the depth of the excavated soil and at the same time assures higher long-term performances.

Hereby is presented the design for the rehabilitation of the Foligno-Terontola railway line, founded on a very old embankment (second half of the XIX century) subject to continuous and differential settlements. The design solution was determined 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, as shown in figure below.

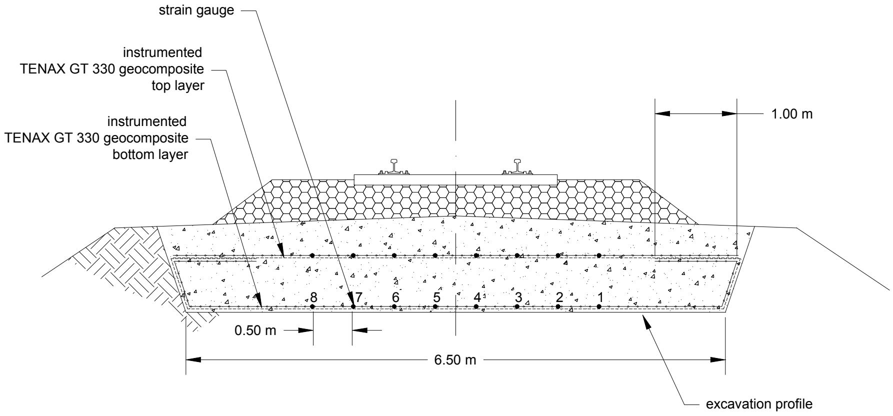


Fig. 1 Spello railways cross section

The geogrid-geotextile TENAX GT 330 geocomposite is composed by an integral biaxial polypropylene geogrid TENAX LBO 330 SAMP heat-bonded to a non-woven whose properties are reported in table 1. This geosynthetic has exceptional confining and reinforcing properties due to its high tensile modulus and junction strength. The non-woven 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	LBO 330 SAMP	LBO 401 SAMP
Tensile Strength	30 x 30 kN/m	30 x 30 kN/m	30 x 40 kN/m
Strain at Peak	11 x 11%	11 x 11%	11 x 11%
Strength at 2% Strain	10.5 x 10.5 kN/m	10.5 x 10.5 kN/m	10.5 x 12.0 kN/m
Strength at 5% Strain	21.0 x 21.0 kN/m	21.0 x 21.0 kN/m	21.0 x 24.0 kN/m
Unit Weight	560 g/m^2	420 g/m^2	600 g/m^2
Residual Strength after Installation	100%	100%	100%
Geogrid Mesh Size	40 × 27 mm	40 × 27 mm	34 × 27 mm
Geotextile Pore Size	0.08 – 0.13 mm	None	None

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 clean granular material, and the ballast and railway tracks rebuilt without delays to the train traffic. Figures below show the reconstructed Spello railway line and the construction phase of geocomposites soil covering during the night work.

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 layers have been instrumented (figure 1).

Fig. 2 Reconstructed railway line and geocomposite fill covering during the night

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 and in the order of 0.03%.

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.

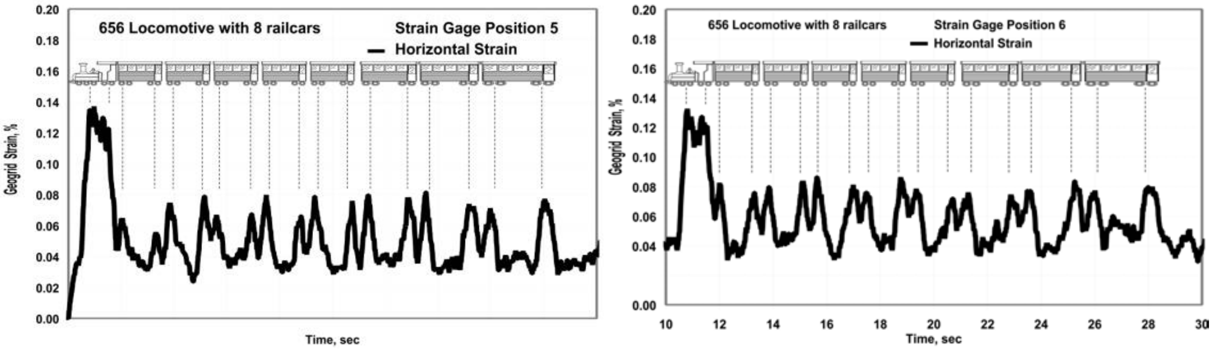


Fig. 3 Railway base monitoring by means of strain gages installed on the upper geogrid layer at position 5 and 6 (figure 1) during train passage

Additional field tests and measurement experiments have been performed on the rehabilitation of an existing embankment at Celje – Slovenia (1996) on the Trieste – Wien line. The subsoil was a silty clay having a modulus E<10 MPa and the track was repaired with a single layer of Tenax TENAX LBO 401 SAMP geogrid and one layer of filter geotextile. Figure 4 and 5 show the two track lines where the construction was performed with excavation of one line and traffic on the other single track and vice versa.

Strain gauges have been installed along the geogrid sections and the recoded strain at a location 0.60 m far from the vertical of the beams, were very small (0.02%) as shown in figure 6. These strains are in agreement with previous empirical trials and with the ones indicated by Selig and Waters (1994) [1] ranging between 0.7% and 0.01% for subgrade and sub-ballast section for track sections.

This very low strain is a good demonstration of the efficiency of the geogrids used in providing confinement to the material.

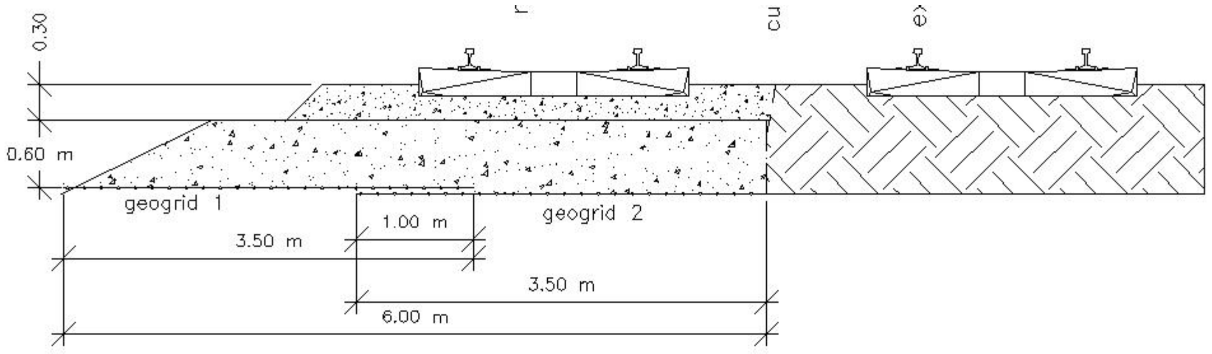


Fig. 4 Celje – Slovenia railways cross-section with single layer geogrid and geotextile

Fig. 5 Excavation, of the existing embankment, installation of the geotextile and geogrid layers, filling and compaction of the new embankment

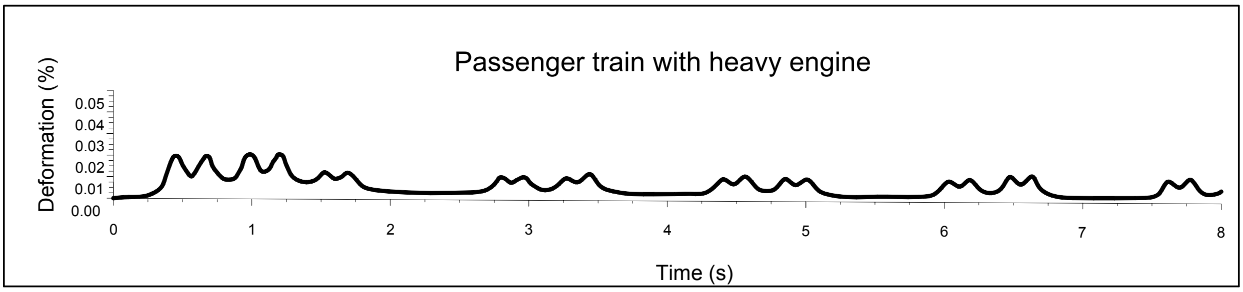


Fig. 6 Celje – Slovenia Railway base monitoring by means of strain gage during train passage

3. Design of new railway lines: Full scale test results

Similirar problems are encountered while designing high-speed railways lines where the allowable settlements at the track level is in the order of few millimetres. Due to the complexity of the problem and to the different mechanisms involved, it is extremely difficult if not impossible to define a design method based upon a closed form solution. Therefore very often design is performed using numerical analysis or a simplified approach such as the elastic beam based upon the Winkler foundation method whose input coefficients are determined by empirical full scale tests.

“V. J. Jain and K. Kesheav” (1999) [2] have performed a series of empirical full scale tests to show that geogrid reinforcement layers installed at the base and within the embankment allow the reduction of vertical stresses and therefore reduction in settlements. The test apparatus and cross section is shown in figure 7 and the tests have been performed using Tenax bioriented geogrid LBO 330 SAMP placed at and within the sub-ballast level. The test section had a track length of 13.0 m, a full width of 3.75 m, was loaded with several axle loads ranging from 20.32 to 30 t applied at a frequency: 2-5 Hz. The soil test stratigraphy was: poorly compacted sand, 0.60 m sub-ballast (unreinforced, reinforced with 1 or 2 layers TENAX LBO 330 SAMP (30 x 30 kN/m) and 0.30 m ballast.

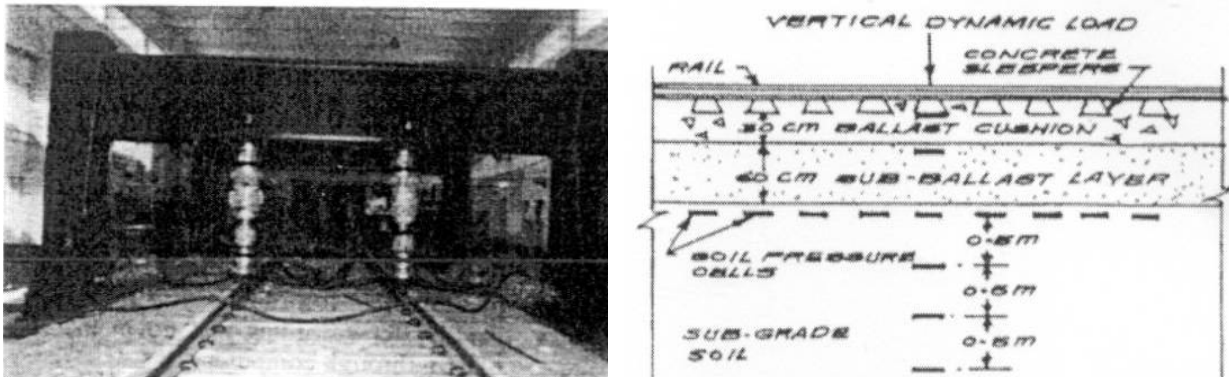


Fig. 7 Picture of the full scale test section apparatus and typical cross section of the testing area

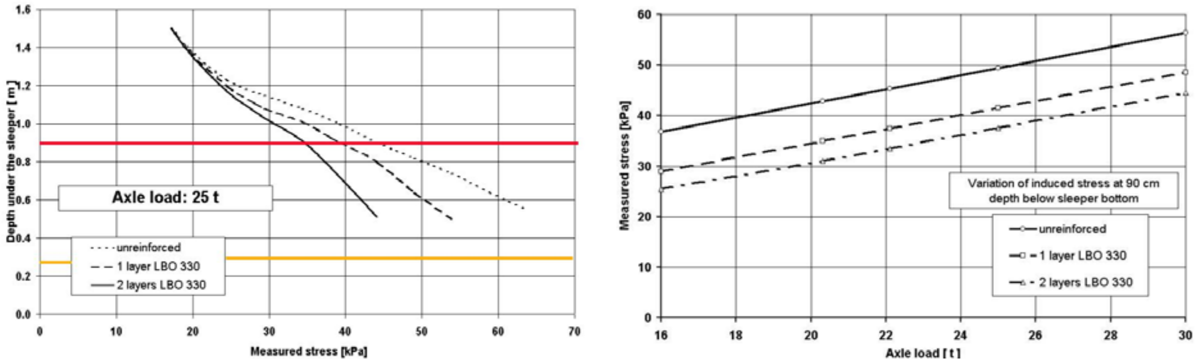


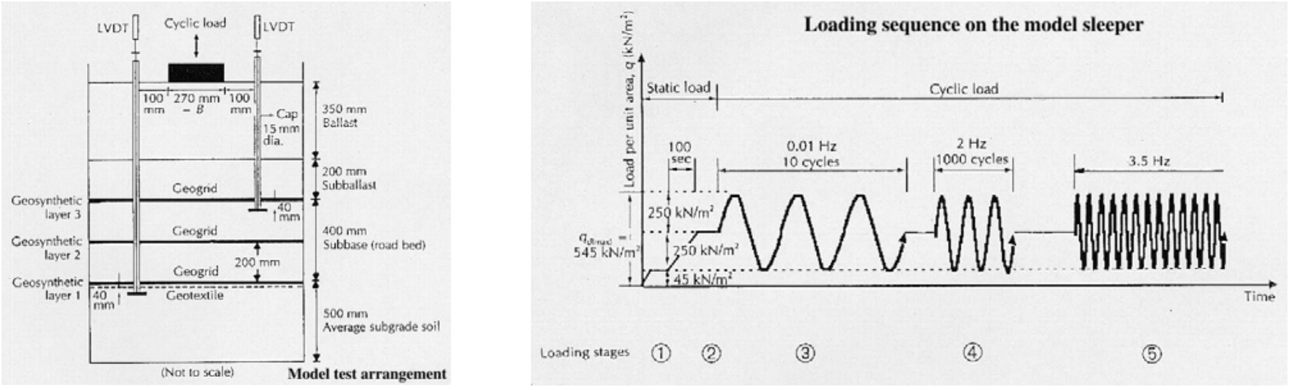
Fig. 8 Experimental results showing: a) measured vertical stress for different cross sections under 25t axle load and b) measured stresses for the different cross sections and axle loads at 0.90 m below the sleepers

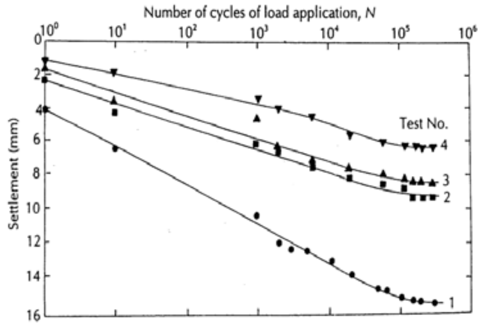
The measured stress reduction at the sub-ballast base is about 8 kPa for 1 geogrid layer and 13 kPa for 2 geogrid layers (figure 8). This reduction is almost constant whichever is the axle load. When analysing figure 8 b, it is possible to highlight the dynamic load by deducting the static load of 18 kPa corresponding to 0.90 m of ballast and sub ballast. Table 2 shows how the presence of one geogrid layer reduces the dynamic loads between 40 to 20% while two geogrid layers reduce the dynamic loads between 60 to 30% at a depth of 0.90 m.

Similar behaviour has been shown by other authors (Shin, Kim and Das) [3] while studying geogrid reinforced railways sections by means of true scale tests measurements. Below are presented the settlements recoded during the trials that are significant since they refer to half a million cyclic loading having frequency as per actual high speed train (Figure 9).

Table 2: Influence of the reinforcement layers on the reduction of the dynamic loads as function of the axle load

	Without Geogrid Reinforcement		**Single Layer Geogrid**		**Double Layer Geogrid**	
Axle Load [t]	Dynamic Stress [kPa]	Ratio	Dynamic Stress [kPa]	Ratio	Dynamic Stress [kPa]	Ratio
16.00	18.79	100%	10.94	58%	7.51	40%
20.32	24.84	100%	16.99	68%	13.07	53%
22.10	27.34	100%	19.49	71%	15.56	57%
25.00	31.40	100%	23.55	75%	19.63	63%
30.00	38.41	100%	30.56	80%	26.64	69%





		Settlement			Reduction			Stiffness		
Test n°	Reinforced/Unreinforced	d_t	d_d	d_s	R_t	R_d	R_s	S_t	S_d	S_s
		mm	mm	mm	%	%	%	%	%	%
1	Unreinforced	15.2	6.8	8.4	0	0	0	100	100	100
2	1 geotextile, 1 geogrid	9.3	3.6	5.7	39	47	32	163	147	189
3	1 geotextile, 2 geogrids	8.5	3.0	5.6	44	57	34	179	151	231
4	1 geotextile, 3 geogrids	6.4	1.4	5.0	58	79	40	238	168	486

d_t, R_t, S_t = Total Settlement, Reduction and Stiffness of the subgrade soil and subbase course

d_d, R_d, S_d = Settlement, Reduction and Stiffness measured of the subgrade soil

d_s, R_s, S_s = Settlement, Reduction and Stiffness measured of the subbase soil

Fig. 9 Experimental results showing: a) testing apparatus, b) applied cyclic loadings, c) measured total vertical settlements for different cross sections and d) total sub-ballast and subbase settlements and corresponding reductions

The loading cycles are aimed to enhance the fact that the irregularity of the rail level under the train passage becomes rapidly worst with additional passages. 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. 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. The use of a proper geosynthetic reinforcement material offers the possibility to solve, or drastically reduce the problems.

The test box was 1.4 m x 1.0 m x 2.0 m in dimension and the applied loads were 500.000 cycles of 545 kPa (equivalent to 23.4 kN axle load) at a frequency of 0.1 Hz – 2 Hz – 3.5 Hz. The section stratigraphy was from top to bottom: 0.35 m ballast, 0.20 m sub-ballast gravel, (21.2 kN/m³), 0.40 m foundation and 0.50 m of poorly compacted sand (15 kN/m³). Test No. 1 was unreinforced, No.2, 3 and 4 were respectively with 1, 2 or 3 extruded geogrids type LBO 401 SAMP and a filter geotextile layer.

4. Conclusion

The use of geosynthetics to improve the bearing capacity and settlement performance of railways shallow embankments has proven to be a cost-effective solution. In marginal ground conditions, geosynthetics enhance the ability to use shallow foundation rafts in lieu of more expensive consolidation systems or deep foundations. A reinforced soil raft consists of one or more layers of a geosynthetic reinforcement and controlled fill placed below a conventional track system to create a composite material with improved performance. Reinforced soil rafts may be used to construct shallow embankments on loose granular soils, soft fine-grained soils, or soft organic soils. The fill placed between layers of reinforcement is usually a compacted clean coarse aggregate, but may also consist of compacted sand. There are a number of factors that may influence the performance of a geogrid reinforced soil structure, including: 1) type of reinforcement; 2) number of reinforcing layers; 3) depth below the ballast of the first reinforcement layer; 4) spacing between reinforcing layers; 5) dimensions of the reinforcement; and 6) type and placement of the fill.

Field measurements have demonstrated that the use of extruded integral geogrids guarantees a complete confinement to the aggregate; the effectiveness of this confinement effect is demonstrated by the strains measured on the geogrids, lower than 0.03%.

True scale tests have been performed to verify the effect of geogrid insertion. The main conclusions from these tests are that the insertion of geogrid layers guarantees an important reduction in the stress on the subgrade, and then in the vertical deformations with up to 39, 44, and 58% reduction respectively for 1, 2 or 3 layers geogrids. The corresponding increases in total soil stiffness are 163, 179 and 238%.

The results, from field experience and laboratory tests, seem to show the possibility to define a design method, based on the demonstrated improvement in the modulus of the railway foundation due to the geogrid insertion. By using very simple plate bearing tests on the existing ground and by knowing the required plate modulus at the top of the foundation layer, it could be possible to estimate the required thickness both in the reinforced and unreinforced cases. This could lead to an increased lifetime of the structure (keeping the same thickness) or a reduction of the required thickness. This system could be easily used for both rehabilitation of existing lines or design of new lines.

5. References

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