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The Creep-Strain Advantages of Polyester Geogrids

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Summary For most polymeric based materials creep becomes a significant consideration in assessing long-term load carrying capability. The long-term creep-strain being defined as the increase in the extension of a material under a constant applied load. Geosynthetic design for soil reinforcement applications typically requires an evaluation of creep-strain in the geogrid for the design life of the structure. A major advantage of high-tenacity polyester-based geogrids by comparison with other available polymers as a soil-reinforcement element is the low creep-strain that develops under load. The correlation between creep-strain of a given geogrid and the allowable design load is significant. This paper investigates polyester creep-strain characteristics and finally presents three case-studies detailing polyester geogrid usage where long-term strain is a major concern.

1. INTRODUCTION

Geogrids are commonly used in various soil reinforcement applications such as retaining walls, reinforced slopes, embankment support over soft foundations and soil veneer covers for landfills. The design life will generally be in the range three years to one hundred years for the structures being constructed. It is therefore critical for the designer to know the total strain of the reinforcement element to be used for the entire design life under consideration. The total strain is a combination of the initial short-term strain component and the long-term creep-strain. The designer can therefore limit total strain to acceptable serviceability levels by careful consideration of design loads to be carried by the geogrid reinforcement.

2. DETERMINATION OF GEOGRID DESIGN LOAD

The acceptable load limitations for a given design life when selecting geogrids is dependent on the following:

- Ultimate Tensile Load;
- Strain Limitation due to design life;
- Potential installation damage to the geogrid by the reinforced fill;
- Durability concerns;
- Temperature;
- Soil Interaction.

The polymer used in the manufacture of a geogrid will have a major bearing on all of the above properties.

Standards Australia Committee CE/32 (1996) is presently writing an Australian Standard *"Earth Retaining Structures (including Reinforced Soils)"* that address the various factors of safety to be considered for the above criteria in the case of different polymers for various design periods. This standard has taken consideration of existing British and American models in place.

2.1 Immediate Strain

Total strain in geogrids under a given load is usually limited to 10% and can be broken into two components:

a. An immediate strain that is developed when the load is applied, usually this occurs during the construction phase.
b. The creep-strain which begins after this period and extends for the entire design life of the structure.

The short-term load strain characteristics of a geogrid (ultimate or quality control load) is determined by a Wide-Width Tensile Test, such as ASTM D-4595. This test is carried out at a strain rate of approximately 10% per minute. As all geosynthetic reinforcement products, regardless of polymer, will rupture at a total strain of around 15%, the test will generally last only 1.5 minutes. This type of test is considered acceptable for quality control purposes, but the load at rupture is no more than a starting point in determining acceptable design loads, as this test does not consider creep-strain, installation damage or durability.

3. CREEP -STRAIN

A geogrid subjected to constant load will continue to creep with time. Tests, such as ASTM D-5262, are typically used to measure creep-strain. This test is usually performed at various load levels relative to the ultimate wide width tensile load (ASTM D-4595) of a geogrid.

As the geogrid is subjected to constant load, an initial elongation will develop and an ongoing strain, known as creep-strain, acts thereafter. The creep is therefore considered as the time-dependent strain developing under a constant load, after load application. The strain developed after initial strain, typically 0.01 hrs, is considered time-dependent or creep-strain (Koutsourais, 1995).

4. THE EFFECT OF POLYMER TYPE ON CREEP-STRAIN

Polymer composition has a direct relationship to creep (Greenwood and Myles, 1986). The creep of a reinforcement element is a function of polymer type (see Figures 1 and 2), manufacturing process, applied load-level, temperature and time (Den Hoedt, 1986). Greenwood et. al (1986) have shown that polyester will exhibit a relatively high elongation on loading and during the first hour, but that subsequently creep-strain is extremely low. An initial load of 60% of ultimate (ASTM D-4595) on polyester geogrids yields over 80% of total strain in the first ten thousand hours (Greenwood and Myles, 1986), attributed mainly to initial strain upon loading. The total strain which the polyester geogrid or geotextile develops is dominated by initial load-strain characteristics (Koutsurias, 1995).

Table 1. GlassTransitionTemperature.

Geotextile element	Glass transition temp, T_g (°C)	Melting point, T_m (°C)
Polyaramid fibres		370
Polyester fibres	90 to 110	260
Polypopylene tapes	-20	170 to 180
High density polyethylene (HDPE)	-120 to -90	130

At least ten thousand hour continuously tested creep-strain of geogrids has been a requirement in the United States (Geosynthetic Research Institute - GRI: GG3, 1990). Provided the creep gradient remains constant, extrapolation can be made for one or two logarithmic time spans (Greenwood and Myles [1986] and den Hoedt [1986]. The Draft Australian Standard has adopted a similar extrapolation procedure .

4.1 Polyester

Polyester geogrids are manufactured from high tenacity polyester filaments, classified as having a breaking tenacity in the range of 6.3 to 9.5 grams per denier, the weight in grams 9000 metres of filament. Molecular weights range from 26,000 to 32,000 g/mole and carboxyl end group contents between 17 and 29 (Koutsourais, 1995).

4.2 Glass Transition Tempurature

Changes to ambient temperature affect the creep of different polymers to varying degrees (see Table 1 - Exxon manual 1994). For polyester, normal ambient temperatures are below glass transition temperatures, and an increase in operating temperature will not increase the rate of creep to the same degree as it does HDPE (High Density Polyethylene) and Polypropylene geogrids, where normal ambient temperatures lie within their Visco-elastic range.

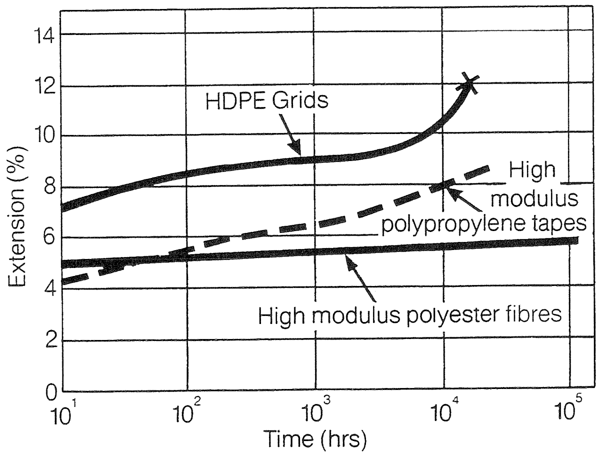

Figure 1. Creep at 40 % of ultimate load.

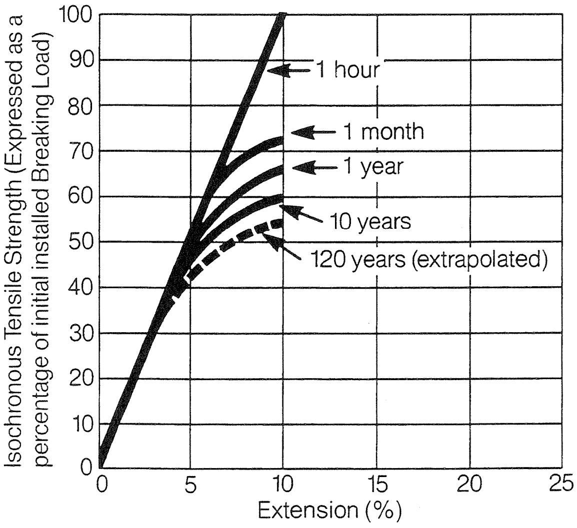

Figure 2. Tensile Strength vs extension over time.

4.3 Other Polymers - Creep-Strain

Creep data on HDPE geogrids presented by Bush (1990) shows that at loads as high as 16% of ultimate load (ASTM D4595), 67% of total 10,000 hrs. strain is attributable to creep and at 44% of ultimate load (ASTM D-4595), the creep component is 55% of 10,000 hr. strain. The total long-term strain of a HDPE geogrid is dominated by its tendency to creep (Koutsourais, 1995), rather than initial load-strain characteristics, such as polyester geogrids.

5. CASE STUDIES

Three separate soil reinforcement case studies in Australia where polyester based geogrids were specified due mainly to their long term creep-strain capacity, are presented below.

5.1 Case Study One - Interim Connection F3

The RTA of NSW is presently constructing an interim connection from the F3 Sydney-Newcastle Freeway to the New England Highway through an area west of Newcastle. This dual carriageway, most of which is being designed, built and supervised by the RTA staff, posed major geotechnical and environmental difficulties where the selected road corridor traversed the fringe of a low-lying region known as the Hexham Wetlands.

Until new product developments in the geosynthetic field became available, road pavement construction through wetland regions such as these would normally have employed piles to support low-level bridges, requiring high-cost piling and bridge infrastructure works.

It was decided that fill embankments using soil reinforcement techniques would be a cost-effective method of maintaining the vertical alignment of this proposed high-speed section of road. The aim is to improve the overall stability of the embankment, as consolidation of the underlying soil took place, with corresponding increases in soil shear strength.

The RTA, through the sophisticated use of geosynthetics, including wick drains, geotextiles and geogrids, believed it could accelerate the process of consolidation to a little over 3 years. It is estimated that using a conventional approach of pre-loading could have taken up to 300 years to achieve a similar result.

The most important embankment, in terms of the critical path program to meet the overall construction constraints, was Swamp 2. This region consisted of clay deposits up to 20 m in depth, with undrained shear strengths of approximately 20 kPa and a requirement to support an embankment over 6 m in height. The ensuing program was followed to shorten consolidation time, increase bearing capacity of the clay, and to protect against slip-circle failure. A separation layer of geotextile and bi-axial geogrid was placed and covered with 1 m of "Bottom Ash" to form a working platform/drainage layer. "Bottom Ash" is a previously useless by-product from a nearby coal power station. It has a high friction angle of around 40°, is free draining and very light compared to naturally occurring soils usually placed in theses applications.

Vertical wick drains were driven to provide a free drainage path for water to be expelled from the clay and dramatically accelerate the total expected settlement of 1.7 m. Approximately 5,000 drains totalling 90,000 lineal m were installed.

After an exhaustive tendering process Paralink 200M soil reinforcement was chosen, and laid transverse to the embankment to mobilise the geogrid in the most important direction to guard against slip-circle failure.

Paralink 200M is a polyester-based geogrid encased in a polyethylene sheath. The excellent long-term creep-strain properties of polyester were critical in the choice of product. Over 13,000 m^2 of Paralink 200M were installed.

The RTA is monitoring the performance of the Paralink 200M in relation to the original design estimates, using instrumentation to measure stresses and strains to compare actual field values against expected results.

The embankments are being built in "lift" stages, between periods of settlement of around 6 months, to allow for the increase in shear capacity of the clay below. Over 200,000 m^3 of "Bottom Ash" is used in the core regions of the embankments, with toe berms adding to the resistance against slip-circle failure.

The RTA has expressed satisfaction at the results thus far.

5.2 Case Study Two - Reinforced Slope

A precast concrete arch approximately 8 m high and 50 m long was constructed under the F3 Freeway at Minmi near Newcastle. The arch was a Design and Construct contract won by Cooper Contractors. Consultants were Connell-Wagner and Coffey Partners. The New South Wales Roads and Traffic Authority as client supervised the construction in late 1995 and early 1996.

Nearing completion of the construction it became apparent that a potential problem existed at the south-western entry way into the arch culvert. As the arch did not run directly perpendicular to the road, but rather at around a 30° angle, the south-ern face of the arch was being subjected to a considerable eccentric load that was not being placed on the northern face. The concrete arch was not designed to take such a load mismatch.

Cooper Contractors, in conjunction with Connell-Wagner and Maccaferri Pty. Ltd. proposed an innovative solution whereby polyester geogrid (Miragrid) was used to reinforce the soil rather than allow the arch to take a load for which it was not designed. The creep-strain of the geogrid needed to be kept to a minimum.

A reinforced slope was constructed in two stages, partly by Cooper Contractors and partly by the RTA using Miragrid 5T and Miragrid 7T geogrid at 500 mm elevations embedded up to 4 m into the fill over a lineal length of around 20 m. As the life-span of the arch is 100 years the geogrid selected needed to function effectively for that same period.

5.3 Case Study 3 - Reinforced Retaining Wall

A culvert with an invert over 9 m below road level needed to be constructed under Woodhill Rd. in Ferny Hills. The local council commissioned a design by Ove Arup which incorporated retaining walls at both inlet and outlet ends of the culvert.

Besser-Pioneer Contracting in association with Maccaferri Pty. Ltd. proposed through Ove Arup the use of geogrid reinforced modular block retaining walls. In some regions these walls were to be up to 8 m in height.

The culvert was designed for a 1 in 100 year flood and had to cater for a 2.4 m change in water level.

A Diamond Block wall at 1 in 5 face slope was selected as the facia, with Miragrid 5T and 7T geogrid being embedded into the embankment as soil reinforcement.

This system has the advantage of being both pinless and mortarless, with a frictional connection maintaining the bond between the Diamond blocks and the Miragrid geogrid.

As the design life for this structure was 100 years, the long-term creep-strain characteristics of the geogrid were very important. The selection of Miragrid, a polyester based geogrid, ensured minimal long-term strain with the result that movement at the face would be negligible. All relevant serviceability requirements were thus met, with the finished retaining wall being both cost-effective and aesthetically pleasing.

6. CONCLUSION

Polyester geogrids, when loaded up to 60% of ultimate tensile strength, will exhibit less than 2% creep-strain for a design life in excess of 100 years (Koutsourais, 1995). This generally will ensure long-term serviceability requirements in soil-reinforced structures if the correct grade of polyester geogrid is nominated. The designer should be aware of the advantages polyester based geogrids offer over alternative polymers especially in regard to creep-strain.

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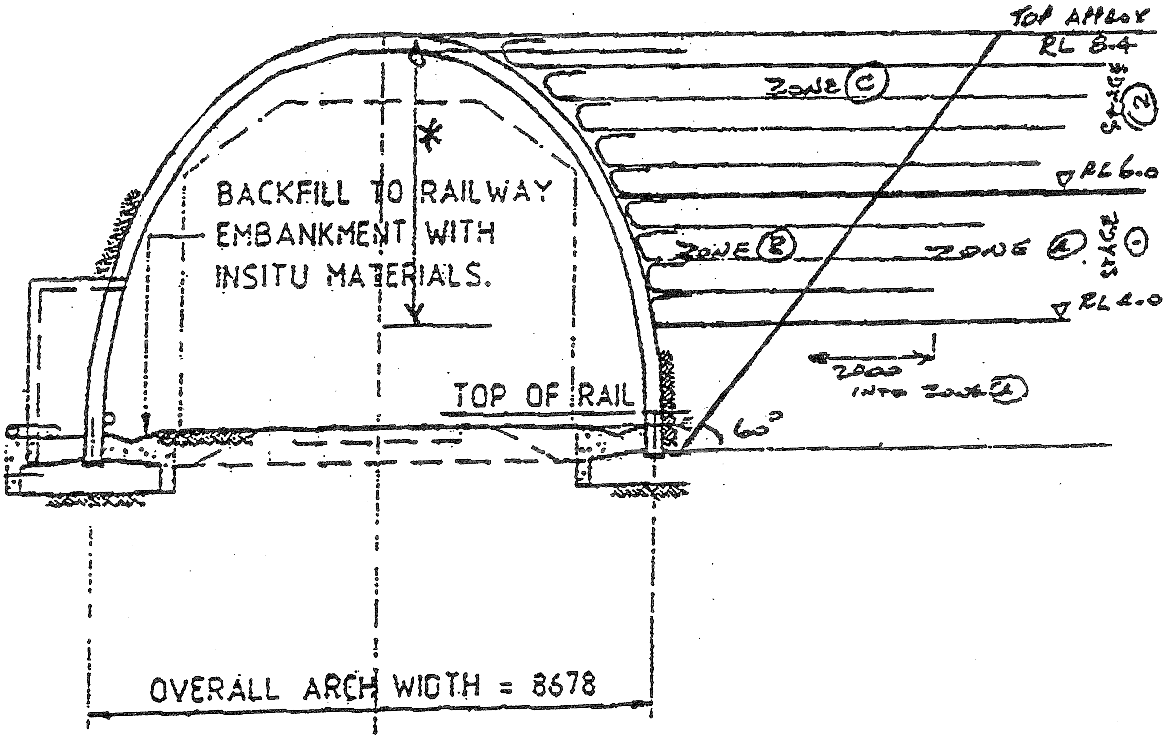

Figure 3. Railway Arch.

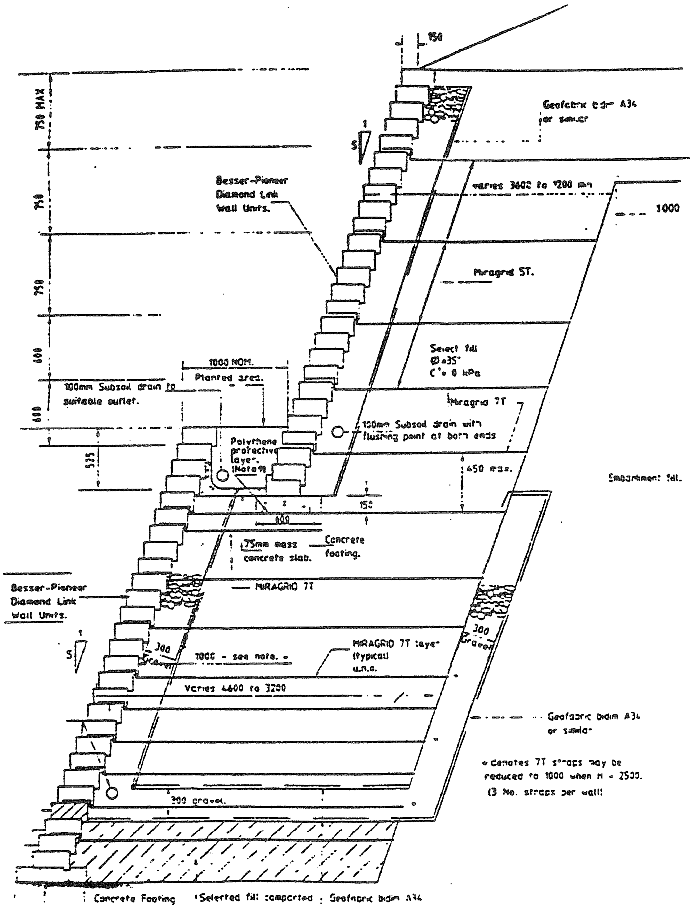

Figure 4. Diamond Block Wall.