DESIGN AND CONSTRUCTION OF HIGH-REINFORCED MOTORWAY EMBANKMENTS IN GREECE: EXPERIENCES AND LESSONS LEARNED

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Abstract: Experiences and lessons learned from the design and construction of five high-reinforced motorway embankments in Greece are presented. More specifically, the paper focuses on four reinforced embankments of the Egnatia highway, near Metsovo town, up to 30m high having slope inclination up to 55 degrees and on a 13m high reinforced embankment with 65 degrees slope inclination located at the highway connecting Arta and Trikala, which is currently under construction.

The necessity for constructing high-reinforced embankments was due either to restrictions on the available space, geomorphological peculiarities, the presence of a river nearby the alignment, or to the presence of active landslides.

Extended use was made of both uniaxial and biaxial geogrids as reinforcement. The design procedure is summarised following current Greek practice, for obtaining the optimum reinforcement spacing, extent and strength, and also presenting specific construction details.

Contractors' difficulties are presented in applying the specifications on site, as well as for selecting reinforcement from those types available in the market, combining both performance and price.

Keywords: Reinforced embankment, geotechnical design, case study.

INTRODUCTION

Over the last fifteen years major infrastructure technical works have been constructed in Greece, including a network of modern motorways designed and constructed according to the latest international standards. Following worldwide trends where the inclusion of geosynthetic reinforcements within embankment themselves gained a surprisingly growth, the reinforced embankment technique proved a very efficient, economic and in many cases unique technical solution along such motorways. Moreover, it should be mentioned that many of the already constructed reinforced embankments are classified, by considering both their geometry (i.e. mainly their height) as well as their geotechnical particularities, in a high grade of importance, worldwide.

Although reinforced embankments gained an acceptance as technical solutions both from the clients of the projects as well as from the civil engineers involved, the available design procedures are still numerous, and in some cases conflicting concerning basic assumptions. The paper summaries the basic issues of the current design procedures in Greece, mentions the main apparently incompatible assumptions of the most often used codes, present case studies from Greece and reports construction difficulties and issues that are considered of primary importance.

REINFORCED EMBANKMENTS AS CONSTRUCTION SOLUTIONS

The concept of reinforced embankment construction and particularly the advantages they are offering by providing a relative steep external slope has increasingly been used along highways. In mountainous regions, for instance, there were cases where due to the steep ground morphology, solutions using reinforced embankments were proved to be uniquely viable (Figure 1) in comparison to conventional embankment with relative mild slopes (i.e. of the order of 2:3 – vertical : horizontal). Similar cases include highway alignments near rivers where a reduced occupation of space is demanded (Figure 2), or highway alignments adjacent to already defined land expropriation limits, nearby structures or even expensive land.

The construction of reinforced embankments also proved to be a design solution for cases where highway alignments cross unstable slopes. Having defined the geometry and the mechanisms of unstable masses, reinforced embankments over which highways pass have been used as a stabilization measure by providing a solution as toe weights (see Figures 6a - 6c). Alternatively, reinforced embankments have also been designed to separate the highway

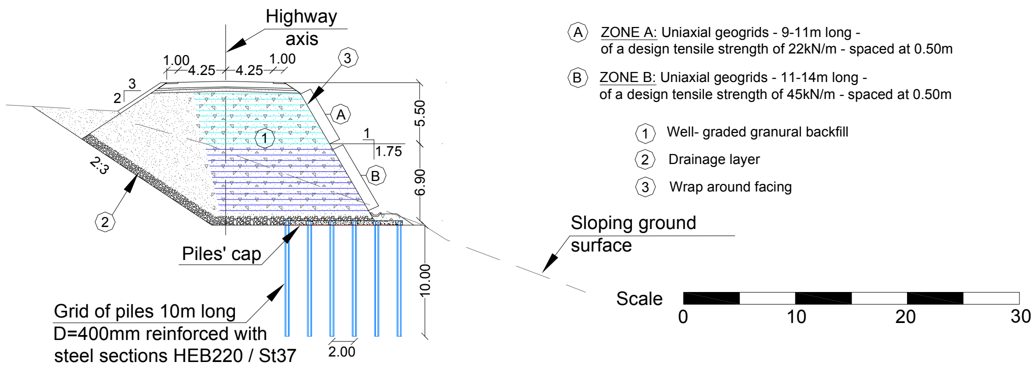


Figure 1. Typical cross section of a 13.0m high reinforced embankment, founded on a steep sloping ground at a 60m long part of the Arta – Trikala highway in Greece.

embankment itself from active landslides, after slope surface re-profiling at the higher parts of the unstable mass and providing that the embankment foundation rests on stable ground (see Figure 3).

Apart from the benefits that reinforced embankments could offer due to their more or less flexible geometry, potential benefits have also been gained by the inclusion of geosynthetics within embankments constructed from mainly unsuitable material according to the Greek specifications for highway constructions. The latter can further contribute to the reduction of the cost of the structure that would be otherwise built with expensive cohesionless fill, to the improvement of the performance of clayey embankments that would otherwise be constructed without reinforcement, to the use of on-site material that would otherwise require disposal and to reduce transportation costs for transferring specified granular backfills. By considering all the above-mentioned arguments, it could be stated that reinforced embankments provide in many cases more economical solutions whilst also providing environmental benefits.

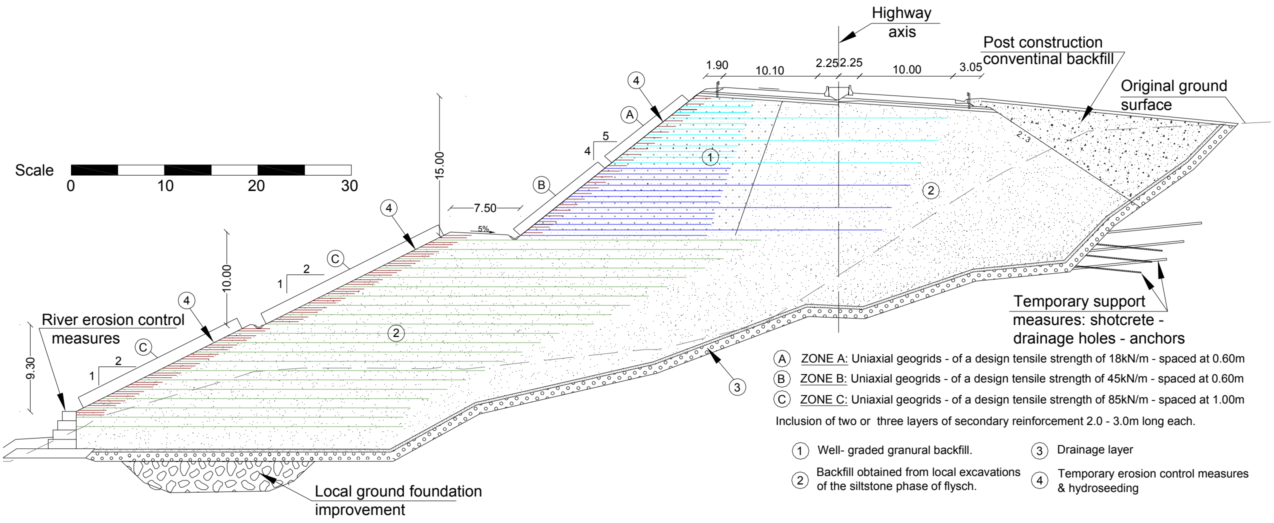


Figure 2. Typical cross section of a 35m high reinforced embankment along 250m long part of the Egnatia highway in Greece, founded on flysch formation adjacent to a river.

DESIGN APPROACH

Methods of analysis

Various specifications or design guides for reinforced embankments are available worldwide (i.e. BS 8006 1995, NF P94-220 1998, Rogbeck 2005 etc) with many common assumptions as well as many diversifications. Eurocode 7 does not yet deal with the concept of reinforced soil and the second part of EN 14475 (2006) concerning the design of reinforced embankments is still under preparation.

Both limit equilibrium methods - i.e. slip circle methods or two part wedge failure mechanisms (e.g. Leshchinsky and Volk 1985, Schmertmann et al. 1987, Jewell 1991) - and limit state approaches (i.e. BS 8006 method) are currently used in Greece for the design of geosynthetic-reinforced embankments. The most often used specifications in current practice are the British and French design guides. Failure mechanisms including external, internal and compound failures, for both static and seismic conditions are generally considered. As far as earthquake loading is concerned the provisions of the Greek Seismic Resistance Design Code are mandatory and used by incorporating within each analysis a horizontal and a vertical component of the maximum most likely expected ground seismic acceleration.

In order to cope with the various design guide inconsistencies, the Association of Scientists of Egnatia Odos S.A. (Egnatia Odos 2007) which is the responsible company by law for the design - construction and maintenance of the Egnatia highway, prepared a very useful design guide matching in a single report preferred design procedures, successive design steps and required safety factors.

Geotechnical parameter selection

Various design guidelines for geosynthetic-reinforced soil structures disagree over the shear strength parameters that should be selected to characterize the backfill material. Due to the extensible nature of geosynthetic reinforcements several recommendations, including HA 68/94, propose the adoption of the constant volume angle of shearing resistance φ_{cv} for the design of reinforced soil structures (e.g., McGown et al. 1989, Jewell 1991). The rationale for this recommendation has been that the soil strength is expected to reach its peak before the reinforcements achieve their ultimate strength.

In contrast, US practice has been toward the use of peak shear strength for the design of geosynthetic-reinforced structures. This is also reflected in the US Federal Highway Administration (FHWA) design guidelines (Elias et al. 2001). Zornberg J.G. (2002) has also presented additional claims for the selection of the peak angle of shearing resistance in the internal stability design of geosynthetic-reinforced soil structures. As far as cohesion design value is concerned a range of 0 - 5kPa is usually adopted.

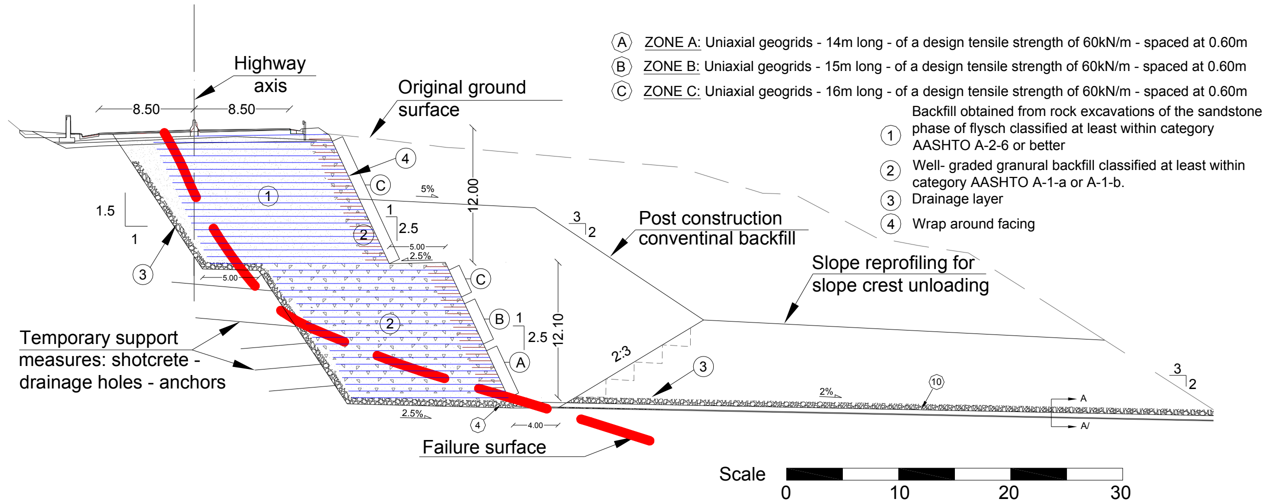


Figure 3. Typical cross section of a 24.0m high reinforced embankment, designed to separate the highway from an active landslide at a 200m long part of the Tripolis – Kalamata highway in Greece.

Reinforcement selection – design values

Although in the mid 90's the first reinforced embankments in Greece were constructed by enhancing their shear strength with geotextiles, recent trends led towards the use of geogrids. That is mainly due to the better interlocking that they can supply, by means of their apertures, to soil particles.

Design values of the geosynthetics are usually chosen by using the relevant testing certificates of each product. Generally, the existence of a certificate is considered necessary for the use of a product. Long term tensile design strength values after 120 years life are mandatory for the stability calculations.

Load cases – Failure mechanisms

All construction stages and loading conditions are taken into account including those factors, and particularly geosynthetics strength, which show time-dependant behaviour.

Current regulations specify three load cases to be considered i.e. i) self-weight (static) loading by considering undrained foundation behaviour as well as maximum annual pore water pressures, ii) self-weight (static) loading by considering the maximum expected pore water pressures within a 50 years return period and iii) self-weight loading by considering both earthquake effect and the maximum annual expected pore water pressures. The vertical live highway surcharge is mainly taken equal to 20kPa.

For each load case failure mechanisms including external, internal and compound failure mechanisms are generally considered. Serviceability calculations are not regularly considered for reinforced embankments with slope inclination less than 70^o (BS 8006), unless the embankment has to be specially designed for maximum tolerances i.e. used as a bridge abutment foundation.

Facings – slope vegetation

Various alternatives have been chosen for the facing of the reinforced embankments (Jones 2005, Christopher et. al. 2005). Although for the cases where the external slope gradient is less than 70^o mainly flexible facing solutions have been chosen i.e. wrap around technique in combination with vegetation, gabions units etc. As a guide for the minimum external slope gradient over which special measures have to be taken for the protection of the outer parts of the embankment BS8006 and Elias (2001) proposals have been adopted, i.e. requirement for a special provision for the slope facing over 45^o. However, provision of at least a temporary erosion control geosynthetic has to be made to facilitate vegetation. The most common planting procedure involves hydroseeding.

CASE STUDIES

Reinforced embankments along the Egnatia Highway

The Egnatia highway is a Greek road axis orientated from west to east, starting at Igoumenitsa harbour and ending at the Kipos bridge on the Greek-Turkish border. The Egnatia highway, which will soon be completed, aside from being one of the most important national traffic arteries, will also be the main artery linking trade and commerce from Europe to the middle East.

Numerous reinforced embankments have been constructed along the Egnatia highway, many of which are at its western part which is considered as the most difficult for its construction. This is due to the high altitude, the steep mountain slopes and the flysch, which is the dominating geological formation in the area causing in some cases large scale landslides. Flysch represents a typical structurally complex geological formation including different lithological units as clay, shale, marl, siltstones, sandstones and conglomerates and it is closely related to the Alpine orogenesis. In many cases alternations of two or more lithological units are observed while rarely only one unit predominates. Flysch

a

b

Figure 4. Photographs taken during reinforced embankment construction along the Egnatia highway (see also Figure 2). a) Foundation excavations for the embankment anchoring - b) placement of geogrids and backfilling process.

Figure 5. View of the final geometry of the reinforced embankment (see also Figure 2). Commencement of vegetation growth.

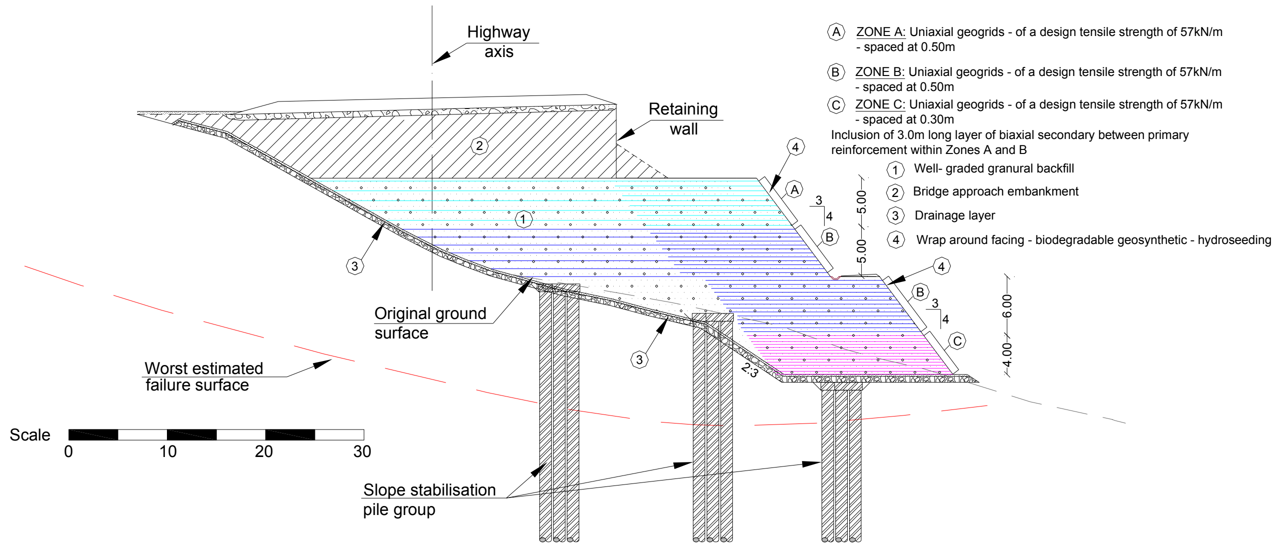
of the Epirus region has also suffered intense past tectonic movements and has been folded and faulted. The shallowest zones of the flysch (weathered mantle), mainly appear in clayey phase and deeper a transition zone often exists before reaching the unweathered flysch. The transition zone is characterised by intense fracturing, the degree of which is gradually reduced with depth. Such complex lithology and structure in connection with the unfavourable geomorphological and climatic conditions of these areas cause serious landslide phenomena. Instability phenomena are mainly developed due to the thick mantle of weathering, and road construction on these unstable or marginally stable geological features is very problematic and in any case challenging.

One of the highest reinforced embankments is located near Metsovo town, where the alignment passes along generally marginal stable areas consisting of the siltstone phase of flysch. In order to cope with a relative high and long embankment adjacent to Metsovitikos river, a solution for the construction of a reinforced embankment was adopted (Figures 2, 4, 5). The 35m high embankment was designed and constructed having, at the higher parts, 4:5 (vertical : horizontal) slope inclination whereas at the lower parts 1:2 (vert:horiz) slope inclination. Between the slopes with different inclinations, a 7.5m wide berm was foreseen. A narrower berm was also foreseen in the middle of the height of the lower 1:2 inclined slope. The embankment was founded on the insitu flysch. A base drainage layer, approximately 1.00m thick, was foreseen. A granular backfill was used for the upper, steeper part of the reinforced embankment, whereas locally available materials were used for the lower part of the embankment, mainly from the siltstone phase of flysch. An increased compaction effort was specified for the lower part of the embankment (dry density of the order of 95% of the Modified Proctor). The shear strength of such unsuitable, in any other case construction materials, was enhanced by the insertion of geosynthetic reinforcements i.e. geogrids.

Extended application of uniaxial high density polyethylene geogrids was carried out, having long term design strength, depending on the placement elevation, varied from 18kN/m, 45kN/m to 85kN/m. Short lengths of lighter biaxial orientated geogrids were also placed between the primary reinforcements in order to minimize face bulge and local soil particle collapses.

No provision for special facing units was made, apart from the placement on the external slope of a temporary – biodegradable geosynthetic, which helped vegetation growth after hydroseeding.

A few kilometers after the previously described reinforced embankment, the alignment of Egnatia highway passes through ancient large-scale landslides. Due to such geotechnical particularity as well as space limitations, solutions with a series of reinforced embankments were designed in order to cope both with the geometry of the alignment and with slope stabilization (Figure 6a - 6c). The reinforced embankments themselves provide, in



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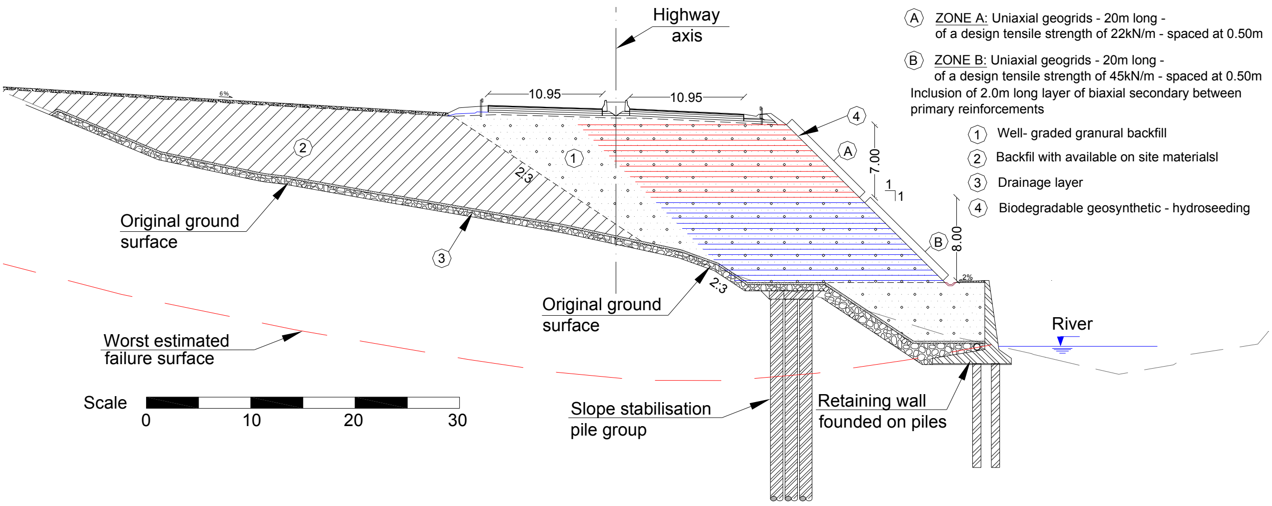

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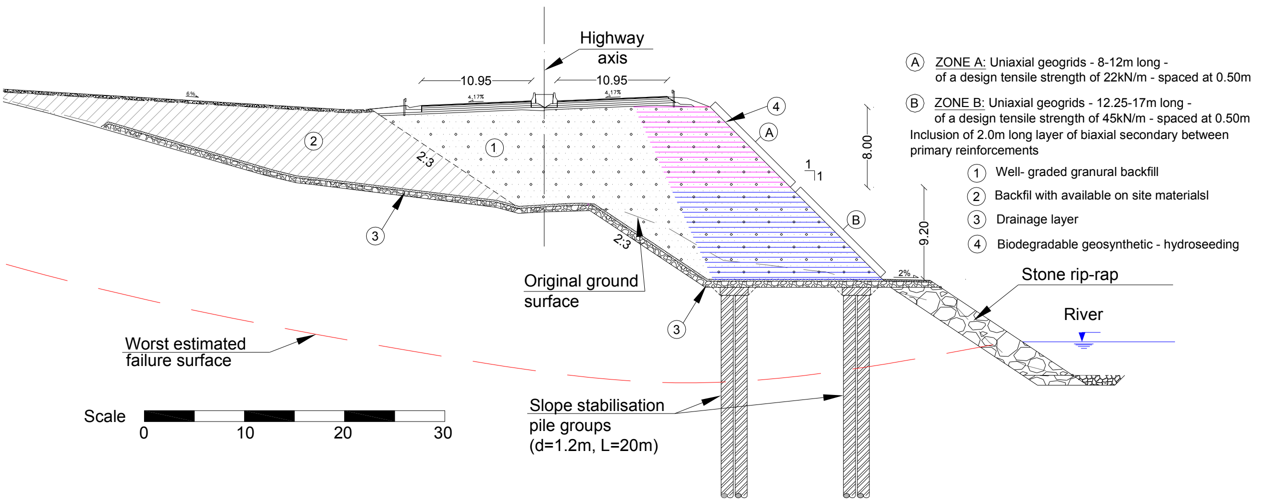

c

Figure 6 (a, b and c). Typical cross sections of reinforced highway embankments along the Egnatia highway designed also as slope stabilization measures by providing a downslope toe weighting.

collaboration with other drainage measures (i.e. a grid of vertical drainage shafts from surface down to a buried gravelly river bed) a means of stabilization measure working as downslope toe weights. Typical cross sections of the geometries of the reinforced embankments are presented in Figures 6a – 6c. Uniaxial high density polyethylene geogrids were used as reinforcements. A wrap around facing solution was adopted for those embankment sections having external slope gradient over 45^{o}. Following the completion of the embankments post hydroseeding has been specified which will also be enhanced with biodegradable geosynthetics.

Reinforced embankment along the Arta – Trikala Highway

Along a 60m long part of a recently constructed section of the Arta – Trikala highway, just before the entrance of Agia Kiriaki tunnel, the local steep surface geomorphology determined the necessity for the construction of a reinforced embankment (Figures 1 and 7). The use of a steep faced embankment with a 1.75:1 (vert:horiz) side slope was chosen to reduce the occupied space at its base. Uniaxial geogrids were used as primary reinforcements and a standard wrap-around grid face detail was adopted. The long term design strength values of the reinforcements were specified from 22kN/m for the higher levels of the embankment to 45kN/m for its lower levels. A light, temporary scaffold with widely spaced boards was erected during construction to define the geometry of the embankment. The uniaxial primary grid reinforcement layers were cut to the design length and laid horizontally onto compacted fill with their long axis running at right angles to the face.

External slope stability calculations indicated the need for the improvement of the foundation, since unsatisfactory safety factors were estimated. For that reason the half external part of the reinforced embankment foundation was improved by a grid of 10m long concrete micropiles, reinforced with steel section HEB220/St37 that were arranged in a 2.0x2.0m grid. A drainage layer approximately 0.8m thick was specified along the base in order to avoid high pore pressures within the embankment itself. An even grain size distribution was specified for the granular material of the drainage layer having a range of particle sizes between 5 – 150mm with maximum percentage of fines (d<0.076 mm) less than 10%. Additional for avoiding future clogging of such drainage layer a filter over it was specified with an also even grain size distribution having a range of particle sizes between 0 – 50mm with maximum percentage of fines (d<0.076 mm) less than 10%.

Finally, in order to cope with the environmental issues a planting solution by using the hydroseeding method was specified after the laying of a biodegradable geosynthetic.

Figure 7. View of the final geometry of the reinforced embankment along a section of the Arta – Trikala highway (see also Figure 1).

CONSTRUCTION ISSUES

The construction of a reinforced embankment, even in those cases where a fully completed and detailed design has been supplied by the clients' consultant to a constructor, needs a degree of refinement during construction. This is due to the fact that the final design of a reinforced embankment specifies an arrangement of the geosynthetic materials (i.e. spacing, lengths of reinforcements etc) as well as a proposal for the required long term tensile strength of the geosynthetic reinforcements. Although in the majority of cases the design has been based on specific available products on the market, the latter are not usually the ones preferred by the constructor due to their probable high price. In that case, the selection of a different geosynthetic reinforcement, which will often have a different long term tensile strength is not useable in the available design. Hence, it is not unusual that an updated final design has to be carried out during construction. The possibility has also been noted on the recently published design guides of Egnatia Odos (Egnatia Odos 2007).

The geosynthetic reinforcement shall be placed wrinkle free, pulled taut, aligned, and secured before backfill placement to prevent displacement during placement and compaction of fill. The geosynthetic reinforcement material shall be placed with the direction of maximum strength perpendicular to the slope alignment. Each layer of geosynthetic reinforcement shall be placed onto the embankment material to form a continuous mat. Adjacent strips of geosynthetic reinforcement placed in this manner need not be overlapped. During spreading and compacting of the backfill, a minimum fill thickness of 0.15m is required prior to operation of vehicles over the reinforcement. Sudden braking and sharp turning shall be avoided. Construction equipment shall not be operated or driven directly on the reinforcement. Reinforced fill shall be placed from the slope face back toward the fill area to ensure that the reinforcement remains taut. The maximum loose thickness of each lift of embankment material shall not exceed 0.3 meters and shall be compacted to specification by the design relative compaction. At locations where compaction is accomplished with hand-operated equipment, fill shall be placed in horizontal layers not more than 0.15 m in uncompacted thickness. Only hand-operated equipment shall be allowed within 1 m of the front limit of geosynthetic reinforcement. Control of moisture in the fill shall be maintained to provide acceptable compaction. Discing and ploughing must not be allowed in the reinforced zone.

Finally, concerning delivery, handling and storage of geosynthetic reinforcement it should be stated that an appropriate protective cover against ultraviolet radiation and against abrasion during shipping and handling are considered necessary. Geosynthetic reinforcement shall be handled and stored in accordance with the manufacturer's recommendations in order to prevent degradation of their physical properties. The same also applies, not only for their storage, but for the external part of geosynthetics when i.e. a wrap around facing is constructed. Therefore, an immediate surface protection measure should be, as soon as possible, applied if needed.

SUMMARY

The paper briefly reviewed the currently design procedures that are applied for the design of reinforced embankment in Greece. It is clear that while there are many similarities between the available design methods / guides, several important differences exist on basic assumptions leading in many cases to significant variations in the amount of reinforcements required. A unique design approach is still missing for Europe. The first steps toward the enactment of a single design approach for the Greek practice carried out by Egnatia Odos S.A is strongly advocated.

Numerous highway-reinforced embankments have been constructed in Greece, and particularly along mountainous region with unfavourable geomorphological and geotechnical conditions. Reinforced embankment not only served as solutions for the passage of the highway alignments but also as a means, in combination with other measures, for slope stabilisation.

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