Geosynthetic reinforcement for unpaved roads – recent experience

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ABSTRACT: Modern geosynthetic materials, including geotextiles and geogrids, are often used to generate savings in materials and time on construction projects. Geosynthetics are used, as reinforcement and separation membranes for unpaved roads that are supported by low strength or unsuitable subgrades. When geotextiles are used, unsuitable subgrades can be left in place and can also facilitate the reduction of the road base thickness. This paper reviews the design methods currently used to build geosynthetic reinforced unpaved roads. It also helps validate the design approaches used and presents the results of physical modelling carried out to characterize the response of geogrids to wheel loadings in such structures. A number of recent case histories of projects in the UK and Ireland are outlined, showing the use of geotextiles and geogrids to reinforce unpaved roads founded on peat, alluvial soils, and low strength glacial tills. The cost savings achievable are commented upon and the results of performance monitoring over time are presented. The overall aim of the paper is to show how geosynthetic reinforcements can be efficiently utilized in unpaved access roads over unsuitable subgrades, leading to savings in materials, time, and reduced environmental impacts.

KEY WORDS: Geosynthetics; Reinforced soil; Unpaved roads; Temporary works; Geotechnical engineering.

1 INTRODUCTION

Geosynthetic materials, including geotextiles and geogrids, have been in common use on construction sites since the 1970s and their use often results in savings in materials and time. One area where extensive use is made of geosynthetics is the reinforcement of unpaved roads, often for temporary access purposes, over low strength or otherwise unsuitable subgrades. By allowing the unsuitable subgrade to remain in place and allowing for reduced road thicknesses, the appropriate use of geosynthetics can lead to substantial reductions in the cost and environmental impact of such unpaved roads. Other benefits include the reduction of rutting and increased road service life.

Unpaved roads are generally constructed by placing one or more layers of high quality granular fill material, either natural gravel, crushed rock, or crushed construction and demolition waste, over a natural subgrade. The natural subgrade may have been stripped of topsoil or not. When specified, one or more layers of geotextile or geogrid are placed between the subgrade and the granular fill. These geosynthetics can act as separators and reinforcements. A typical reinforced unpaved road cross section is shown in Figure 1.

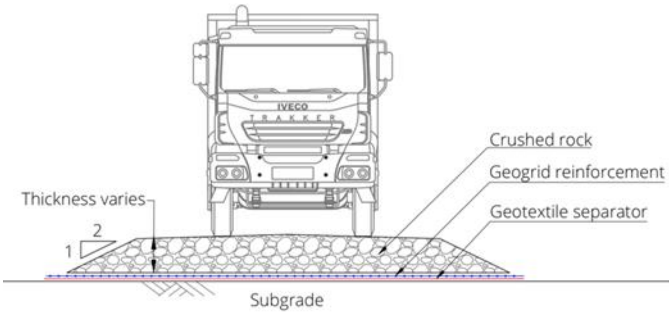

Figure 1. Typical unpaved road cross section.

2 DESIGN OF UNPAVED ROADS

2.1 Introduction to design methods

Many design methods have been proposed for unreinforced and reinforced unpaved roads over the years. A significant body of field test data, where unreinforced unpaved roads and airfields were tested under known loadings, was published in 1970 (Hammitt), and various authors have developed design methods based on these and other data (Giroud and Noiray, Milligan a,b , Jewell, Giroud and Han.

Loading imposed on the subgrade includes a vertical component, caused by the traffic loading P applied to the road and spread at an angle β through the thickness D of the granular fill and the self-weight of the granular fill, and a horizontal component, caused by lateral earth pressure developed in the granular fill, P_{fill}. The typical situation of loading over a width 2B, along with a likely failure mechanism, is illustrated in Figure 2.

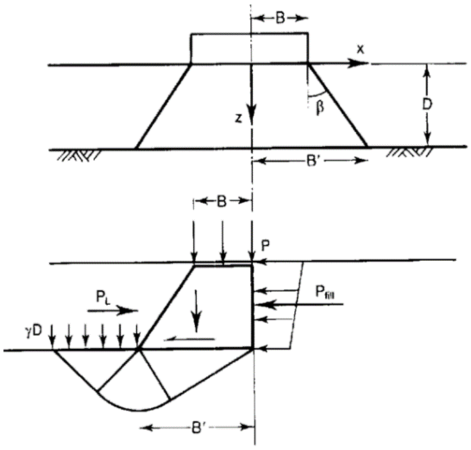

Figure 2. Combined loading on subgrade (no reinforcement) [5].

The horizontal thrust generated in the fill, P_{fill}, is normally only partially resisted by the available passive resistance P_L, in the unloaded adjacent fill, and consequently the excess lateral thrust is transmitted to the subgrade as an outward shear stress. This outward shear stress may reduce the bearing capacity of the subgrade by up to 50% [CIRIA SP123]. The bearing capacity of the subgrade is related to the undrained strength, c_u, by a variable bearing capacity factor, N_c, which can vary between 2.8 and 3.33 for unreinforced roads ([Milligan et al, 1 and 2] and between 5.14 and 5.71 for reinforced roads where the reinforcement is in a position to carry all the outward shear stress [Giroud and Han 1 and 2].

2.2 *Design objectives and processes*

The design of unpaved roads focusses on the specification of a thickness (D or h) of high quality fill and a suitable geosynthetic arrangement. The design is often controlled by a serviceability limit state of excessive rutting rather than an ultimate limit state of overall failure or local failure in the granular fill. It is generally assumed that a potential failure is confined to the subgrade, which is the natural ground or the existing fill at the site. The limit state of overall failure or local failure in the granular fill is checked by inspection or by calculation where necessary. A serviceability limit state may typically be defined as rutting of 75mm or more, measured from the highest point each side of a channelised track. Clearly this value will vary from project to project depending on the vehicles accessing the unpaved road.

2.3 *Separation*

Geotextile separators, usually consisting of non-woven products, are commonly used between the subgrade soil and the granular fill. They serve to separate the weak fine-grained subgrade from the expensive imported fill. The separator layer is placed below the geogrid as shown in Figure 1. Through this separation function they preserve the strength of the granular road construction. Two mechanisms which can lead to the degradation of the road are the “pumping” of fines from the subgrade into the granular fill, reducing the elasticity and shear strength of the granular fill, and the loss of granular fill into the soft subgrade, reducing the effective thickness of the granular fill.

Geotextile separator layers are required to be sufficiently durable to maintain their integrity during installation and in service, and to permit the easy passage of water out of the reinforced fill. Non-woven geotextile separator fabrics with tensile strengths in the range of 8 to 10 kN/m and water flow rates of over 100 $l/m^2.s$, such as Thrace PB1000/S8NW, have proven satisfactory.

2.4 *Reinforcement*

The reinforcement function can be provided by a separator geotextile or, more commonly, by a dedicated geogrid reinforcement product. In addition to resisting the outward shear stresses shown in Figure 2, which is often referred to as the “tensioned membrane” effect, a further benefit of the inclusion of a geogrid reinforcement at the interface between the insitu soil and the unpaved road is the confinement and lateral restraint of the granular particles which interlock with the ribs of the geogrid [Giroud, 2009], as illustrated in Figure 3.

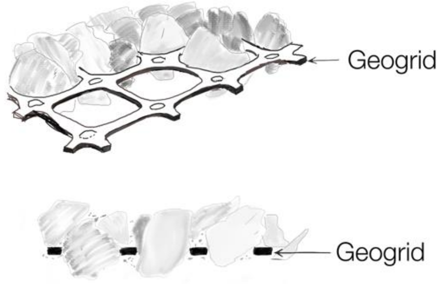

Figure 3. Interlocking of granular particles with geogrid ribs.

The efficiency of this interlock will vary depending on the nature and properties of the geogrid; the microscale study of this effect is an area where further research is needed.

Several types of geogrid are available on the market: woven and coated, welded junction, and extruded punched-and-stretched geogrids. These are made with various polymers including polypropylene, polyethylene, and polyester. This paper focuses on the use and performance of punched-and-stretched geogrids, also known as extruded geogrids, which are manufactured by pre-straining the polymer; woven and welded junction geogrids are not pre-strained and may present lower initial stiffness. While geogrids are manufactured in different manners, certain standardised tests can be used to compare their index properties. Two of these index properties shall be considered in this paper, namely tensile strength and aperture stability modulus.

2.5 *Giroud-Han design method*

The Giroud-Han design method [Giroud and Han 1,2] has been used by the authors for the design of at least 20 unpaved roads in Ireland and the UK and it is considered to have been successfully applied. Design using the Giroud-Han (G-H) method involves iteratively solving for the thickness of granular fill (h) corresponding to a given reinforcement condition (none, geotextile, or geogrid). It is usual in the authors’ experience to apply a safety factor of 1.2 to this thickness, although in cases where sufficient comparable experience exists this safety factor may be reduced.

It is important to note that it is recommended that the G-H method is used within the following boundaries (Giroud and Han, 2004b, Feb/March 2012):

- Surface rut depths are between 40 and 100mm,
- A minimum granular fill thickness of 100mm is used,
- The CBR of the subgrade soil is less than 5%,
- The subgrade soil is saturated, incompressible, and frictionless. This excludes the use of the design method in peat.
- Aperture stability modulus of geogrids should be less than 0.8 mN/deg.

It is recommended that, for the case of geogrid reinforcement, the generic G-H design equations are calibrated for the proposed product. This was carried out for two extruded biaxial geogrids by the original authors ([GH 2004b] but has very rarely been carried out aside from this. By way of explanation, it has been noted that hundreds of unpaved roads and areas in the United States, Canada and Latin America have been designed in a consistent manner using the generic, uncalibrated, design equations without known performance problems

[Giroud 2009]. This paper shall go on to document several other examples.

A feature of the G-H design method is that the contribution of the tensioned membrane effect is completely neglected, as it is considered that the tensioned membrane effect is only applicable once rutting has exceeded 100mm and exceeded the serviceability limit state. In this way, the tensioned membrane effect provides an additional level of safety in reserve to guard against an ultimate limit state failure once the serviceability limit state has been exceeded.

The generic uncalibrated G-H equation is (Giroud & Han 2004a):

$$h = \frac{1.26 + (0.96 - 1.46J^2)\left(\frac{r}{h}\right)^{1.5} \log N}{[1 + 0.204(R_E - 1)]} \times \left[\sqrt{\frac{P}{\pi r^2 \left(\frac{s}{f_s}\right)\left\{1 - \xi\left[-\omega\left(\frac{r}{h}\right)^n\right]\right\} N_c c_u}} - 1 \right] r \qquad \textbf{(1)}$$

Where h = thickness of the granular fill (appears on both sides of equation); R_E = limited modulus ratio (less than 5); J = aperture stability modulus of the geogrid (0 for unreinforced or geotextile reinforced); r = radius of the equivalent tire contact area (m); P = wheel load (kN); N = number of axles passes; s = allowable rut depth; f_s = factor equal to 75mm; N_c = bearing capacity factor; and c_u = undrained shear strength. The Greek symbols ξ and ω and the symbol n are unknown constants which were determined through calibration with unreinforced unpaved road test data [Hammit, 1970]. Bearing capacity factors have been proposed as follows:

- N_c = 3.14 for unreinforced unpaved roads (allowing for a reduction due to outward shear stresses),
- N_c = 5.14 for geotextile-reinforced unpaved roads (allowing for the full bearing capacity of the clay), and
- N_c = 5.71 for geogrid-reinforced unpaved roads (allowing for a benefit from maximum inward shear stresses being generated between the fill and the subgrade).

As stated previously, the resulting equation is generic for the unreinforced and geotextile-reinforced cases but further calibration is required for use with geogrids. The original authors selected the aperture stability modulus (J) as the most applicable parameter for two extruded biaxual geogrids that they calibrated the equation for, and suggested that other parameters may be more relevant for other geogrids. Calibration to a specific geogrid may consist of large scale cyclical plate loading tests or full scale load tests. When calibration was carried out using two reference geogrids (denoted B11 and B12 in the original text), an equation as follows was obtained:

$$h = \frac{0.868 + (0.661 - 1.006J^2)\left(\frac{r}{h}\right)^{1.5} \log N}{f_E} \left[\sqrt{\frac{P}{\pi r^2 m N_c c_u}} - 1 \right] r \qquad \textbf{(2)}$$

In Equation 2, m is the bearing capacity mobilisation coefficient which is proportional to allowable rut depth s, and f_E is the modulus ratio factor. Strictly, Equation 2 applies only to two specific geogrid reinforcements, but in practice it has been widely applied [Giroud 2009].

3 SOIL PROPERTIES

3.1 Subgrade

The subgrade is typically the insitu natural soil immediately below the proposed road, and in the case of peat, may encompass a partially-decomposed "crust" of dry organic material at the surface.

Ground investigations must be carried out in advance of design and should be sufficient to characterise the nature, depth, and strength of the various soil strata underlying the site.

Typically, reinforcement is most needed with soils behaving in a fine-grained manner, such as fine-grained glacial till, soft silts, soft clays, and peat, which exhibit an undrained shear strength, and this paper will limit its scope to these soils.

3.1.1 Undrained shear strength

Undrained shear strength (c_u) is the resistance to internal shear deformation of the soil per unit area when the soil is loaded sufficiently quickly that movements of pore water cannot take place. As traffic loadings are typically dynamic and quickly applied and removed, this is the appropriate strength to consider. However, undrained shear strength is not an intrinsic parameter of a soil but rather varies with many factors including anisotropy, test type, effective stress, stress history, rate of loading, and temperature effects (Long, 2018). Further, the bearing capacity-type failure that causes rutting and overall failure imposes several types of loading on the soil along the failure surface – compression, simple shear, and extension.

For design, it is essential that a representative value of undrained shear strength is chosen as that parameter is the critical geotechnical parameter controlling the design.

As ground investigations for unpaved roads are often cursory and conducted with limited budget, the information available from which to derive undrained shear strength is often lacking; typically, in-situ tests consisting of plate loading tests, field vane tests, or standard penetration tests at intervals along the road alignment have been carried out. Sometimes, samples retrieved from the field may have been subjected to unconsolidated undrained triaxial tests. It is a challenge to derive a representative value of c_u to use in design and experience of local conditions is invaluable in this regard.

California Bearing Ratio (CBR) values derived from plate loading tests can be correlated with c_u. A range of correlations between CBR and c_u have been presented by various authors (Black and Lister, Jenkins and Kerr, Tingle and Webster); these range from $c_u = 23 \cdot \text{CBR}$ to $30 \cdot \text{CBR}$. The Authors consider the correlation $c_u = 30 \cdot \text{CBR}$ to be appropriate for design in Irish conditions.

3.1.2 Particular precautions for peat landscapes

Special precautions are required in areas of peat, especially upland areas where the contact between the upper peat and the underlying strata may be sloping. Such designs are not considered in this paper.

3.2 Granular fill

A crushed rock fill complying with Class 6F2 of the TII Specification for Road Works is the preferred material for reinforced unpaved road construction. The grading envelope of this material is shown in Figure 4. Recycled crushed concrete has also proven satisfactory, whereas recycled fill from other construction and demolition waste streams has proven less than satisfactory. The key requirements for the fill are durability, a high peak effective angle of shearing resistance, and a coarse grading. A crushed rock material commonly sold as *3" inch down* by quarries typically has a grading falling within the allowable grading envelope for Class 6F as shown in Figure 4 may be suitable. Fines passing the 0.063mm sieve should make up less than 10% of the material by mass.

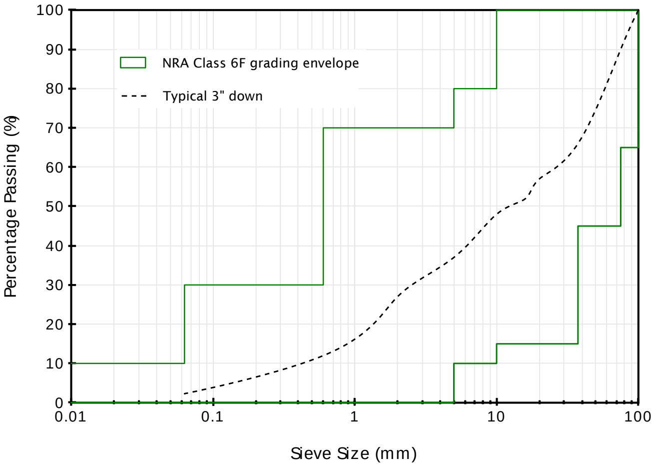

Figure 4. Grading curve for preferred fill materials.

4 WHEEL LOADING

The primary loadings applied to reinforced unpaved roads are vehicle wheel loads, typically taken from quoted or specified axle loads. The axle load for a conventional road-going four-axle rigid truck (for example a gravel truck or fully laden concrete truck) is 80 kN, however the axle load for cranes can be much higher. Off-road earthmoving vehicles impose axle loads higher than this. For example, a fully loaded Volvo A25 articulated dump truck can exert 160 kN and the larger A40 may exert 240 kN on each rear axle (Volvo CE).

It is assumed in design that loads are moving along the road and hence are treated as dynamic loads; if it is likely that vehicles may stop and park overnight, then a separate static loading analysis would be appropriate.

5 CASE HISTORIES

A number of case histories are presented, which show the application of the calibrated G-H equation (Equation 2) to geotextile- and geogrid-reinforced unpaved roads. The locations of these case history sites are shown in Figure 5.

5.1 East Anglia One, Ipswich.

This project comprised of 37km of access haul roads with a width of 5.50m and 9 site compounds along the access route. The route was from the coast north of Felixstowe and passed north of Ipswich, terminating to the east of the town, as shown in Figure 6. The access roads facilitated the installation of 110kV power cables from the offshore wind turbines to the transfer power station. The access roads were designed to support 500,000 cycles of construction traffic and a special cable laying rig with axle loads of 100kN.

Figure 5. Locations of case history projects.

The access roads were constructed on farm lands with glacial till sub-grades which had CBR values > 1%. The undrained shear strength of the sub-grade was assumed to be 25kPa.

The road's foundation was initially constructed from a 550mm thick granular recycled construction waste backfill. However, the construction waste backfills became unstable and broke down as vehicles tracked over sections of the access roads. The construction waste material was deemed unsuitable and was replaced with competent Class 6F2 capping materials.

The granular capping base was reinforced with one layer of Thrace TG3030S biaxial geogrid. A Thrace PB1000/S8NW non-woven geotextile acted as a separator membrane between the granular base and the subgrade.

Figure 6. East Anglia One onshore access road route map.

The access road performed very well, with rutting less than 40mm. This design saved the importation of significant volumes of imported Class 6F2. The original design proposal without geotextile membranes and reinforcing grid specified a base thickness of 770mm. This equates to a backfill material saving of approximately 29%. On this project, the total volume of backfill saving equated to 44,770m². At an average of 10m² per full transport lorry, this equates to a saving of 4470 loads of Class 6F2 capping material.

5.2 *Lidl, Birr*

As part of an upgrade of the Lidl store in Birr, Co. Offaly, a new piled supermarket structure was provided and the existing car park was improved and extended. The entire site was underlain by significant peat and lacustrine deposits. The measured undrained shear strength (c_u) of the lacustrine deposits was 15kPa and of the soft dark brown plastic pseudo-fibrous peat was 25kPa. The peat extended to 3.0m below ground level. An access road was constructed on top of the soft peat to facilitate construction traffic such as tipper trucks, excavators, and the piling rig. The access road was designed to support an axle load of 80kN and a wheel load of 40kN with 5,000 axle loadings over the construction period. A rut depth of 50mm was assumed with a 500kPa tyre pressure.

The design assessment determined that a 450mm thick Class 6F2 capping was required to support the construction traffic. The granular base was reinforced with one layer of PB1000/S8NW separator membrane which was installed on top of the soft subgrade and one layer of Thrace TG4040S PP biaxial geogrid which was placed directly on top of the separator membrane. The 450mm thick layer of Class 6F2 granular fill was installed and compacted on top of the geogrid.

The access road performed very well with rutting less than 40mm observed in service. This design saved the importation of significant volumes of Class 6F2 granular fill. The original design proposal without geotextile membranes and reinforcing grid specified a base thickness of 715mm This equates to a material backfill saving of approximately 37%.

The project shows the satisfactory use of the G-H method for a road over peat, subject to very careful geotechnical investigation and evaluation of overall stability.

5.3 *Center Parcs*

The site of the proposed Center Parcs Longford Forest location is located at Newcastle Wood, in Co. Longford approximately 3km to the east of Ballymahon. The subgrade soils comprised of very soft to soft organic rich silt/clay. Glacial Till underlies the Peat or Topsoil across the entire site, to depths of approximately 2.50m to 9.50m below natural ground level. The Glacial Till is made up of laterally and vertically variable, interbedded clay, silt and gravel soils.

Twenty-four plate bearing tests using a 450mm diameter steel plate were carried out along the main entrance road and future car parking area. The lowest CBR value was 1.0% and the average CBR was 2.3%. An undrained shear strength of 25kPa for the glacial till was assumed. The design of new access roads and parking areas was carried out in accordance with the Forest Road Manual 26 and the G-H method.

- The design brief specified a minimum target value of 15% CBR on top of the 6F2 capping layer.
- The access haul roads and parking areas were designed to support 750,000 vehicle cycles from Volvo A40 articulated haulers with a 250kN axle load during the construction phase.
- The 6F2 base thickness equated to 900mm with two layers of Thrace TG4040S PP biaxial geogrid. The first layer was place on top of a Thrace PB1000/S8NW separator membrane and the second grid layer was placed in the middle of the capping base layer.

At the end of the construction phase, plate loading tests were carried out to determine if the design criteria were achieved. The results were very impressive with rut depths of approximately 20mm being observed in practice. The lowest CBR result on top of the capping layer equated to 28.8% and the highest to 168.40%. The average measured CBR at subformation level was 40%.

5.4 *Grange Castle South, Co. Dublin*

The project was located in the IDA Grange Castle South Business Park where an unpaved road was required to allow the delivery of a large transformer to the site. The subgrade comprised of soft glacial tills. A series of plate bearing tests were carried out using a 450mm diameter steel bearing plate. The lowest test result equated to 0.5% CBR with 1% CBR as a lower average value. Two design proposals were considered for each of the subgrades. The access road was designed to support a 16 Axle Small Girder Frame Transport Vehicle with a trailer gross weight 2429 kN and an axle load of 151.80kN.

Figure 7. Transformer arriving at Grange Castle South site.

The first design considered a sub-grade with a CBR of 0.5%. A granular 6F2 capping 900mm thick was required to support the imposed vehicle load. The granular base was reinforced with one layer of PB1000/S8NW separator membrane and two layers of Thrace TG4040S PP biaxial geogrid. The first geogrid layer was placed directly on top of the separator membrane and the second layer placed 450mm above the first geogrid layer midway in the granular base as a secondary reinforcement.

The second design considered a subgrade with a CBR of 1.0%. A granular 6F2 granular base 350mm thick was required to support the imposed vehicle load. The granular base was reinforced with one layer of PB1000/S8NW separator membrane which was installed on top of the soft subgrade and one layer of Thrace TG4040S PP biaxial geogrid which was place directly on top of the separator membrane. The 350mm thick 6F2 capping was installed and compacted on top of the geogrid.

The access road performed very well with rutting less than 30mm observed. This design saved the importation of significant volumes of imported 6F2. The original design proposal without geotextile membranes and reinforcing grid specified a base thickness of 1300mm in areas where the CBR of 0.5% was encountered and 650mm in areas where a CBR of 1% was encountered. This equated to a material backfill saving of approximately 38%.

5.5 Páirc Uí Chaoimh GAA Stadium

As part of the redevelopment of the Páirc Uí Chaoimh GAA stadium in Cork, a granular base was required to support a stormwater attenuation system and eventually an artificial turf training pitch. This design demonstrated the use of the G-H method outside of its intended application and for a situation where traffic was not strictly channelized. Engineering judgement was used to identify a suitable value for wheel loading P and axle passes N to represent the future use of the site. The granular base was to have a final CBR of 2%. A comprehensive site investigation was carried out prior to carrying out the design, and the ground conditions encountered during the investigation are summarised below:

- Made Ground up to 2.0m BGL.
- Soft Cohesive Alluvial/Estuarine Deposits were comprised of very soft and soft-to-firm grey and brown laminated (slightly) sandy clayey Silt with shell fragments present to depths of between 3.5m and 4.8m BGL.

The design called for removal of all Made Ground. A ground improvement base was to be constructed on-top of the Soft Silty Clay with an assumed CBR of 1%. The design led to the specification of one layer of Thrace PB1000/S8NW separation membrane, one layer of Thrace TG4040S PP biaxial geogrid, and a 300mm thick layer of 6F2 capping.

The final acceptance test result on top of the 6F2 capping indicated a CBR of 8.4% using a 300mm diameter steel plate and rutting of up to 40mm was visible due to site traffic. The design was found to be satisfactory.

5.6 Dubber Cross

A project at Dubber Cross, Finglas, Dublin 11, involved providing an economical design for a 1km long temporary site access road over agricultural lands. The design was based on an interpreted characteristic undrained shear strength of 50 kPa for the firm to stiff brown glacial till (Dublin Boulder Clay) just below the topsoil. 250mm of crushed rock meeting the main requirements of Class 6F2 was specified over one layer of Thrace PB1000 geotextile. The crushed rock was compacted by tracking in. Design allowed for a rut depth of 75mm after 1500 passes of an 80kN axle. The performance was satisfactory, with rut depths typically 60 to 70mm but up to 100mm observed during the life of the road. The road was installed during very wet weather and this may have reduced the CBR of the subgrade, contributing to the more severe than anticipated rutting observed. It is noted that the rutting did not cause any serious issues for plant and vehicles accessing the site.

A design achieving a similar degree of serviceability but without the addition of reinforcement would have required a base thickness of 400mm of crushed rock rather than the 250mm used. Hence the use of reinforcement resulted in a saving of around 600m^3 of crushed rock and an overall saving of 33% in material costs, with a marginal increase in labour costs.

6 CONCLUSION

This paper has documented six case histories where the Giroud Han (G-H) method has been used to design reinforced unpaved roads in Ireland and the UK. The main conclusions are as follows:

1. The G-H design method has been found to satisfactorily predict the performance of unpaved access roads in Ireland and the UK.
2. For the projects where geogrid was used, the G-H design equation was not specifically calibrated for the proposed geogrid material yet satisfactory performance was achieved.
3. Calibration of the G-H design method specifically for the products discussed may yield further savings and it is a task being considered for further development.
4. Overall, considerable material savings of between 29 and 38% were achieved through the use of reinforcement. In addition to time and cost savings, this represents a significant reduction in transport movements and greenhouse gas emissions.
5. The project at Dubber Cross shows that weather may have an impact on the performance of unpaved roads and that a reassessment of the design may be needed during extended periods of wet weather.
6. While it is arguable that geosynthetics introduce extra complexity into projects and increase labour costs, the authors have observed that there is generally an extra level of engineering care and attention put into the construction of unpaved roads when geosynthetics are specified. This must be beneficial to the outcome of the project.

ACKNOWLEDGMENTS

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