The Significance of Geosynthetics with Special Reference to Unpaved Roads

Abstract

The study presented in this paper is devoted to the use of geotextile in unpaved roads. Therefore geotextiles and unpaved roads (such as trafficked areas) will only be discussed in this papers. The design method developed in this paper can be used for unpaved roads reinforced with geotextiles by neglecting the effects of aggregate interlock and geosynthetic in-plane stiffness. The design method can also be used for unreinforced unpaved structures by neglecting the effect of reinforcement on subgrade bearing capacity. The use of the method for trafficked areas requires some judgment on the part of the design engineer because the number of vehicle passes is difficult to estimate when the traffic is not channelized.

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Introduction

The technique of ground improvement using geotextile is extensively used in the construction of unpaved roads, fabrication yards, parking spaces, etc. When the underlying soil is soft, having poor consistency and high compressibility, a geotextile layer can be placed over the subgrade followed by a compacted granular fill layer. Tingle and Jersey (2007) categorically pointed out the problems associated with maintaining low-volume unpaved roads with minimum funding and identified geotextile reinforcement as a possible means to deal with this condition. Use of geotextile as soil reinforcement has been reported to increase the overall stiffness and bearing capacity of the geotextile-soil composite. Geotextiles are also found helpful in reducing settlement and rutting depth. For a given design condition, these improvements lead to a reduced amount of aggregate material and time required for construction and extending of the service life. Geotextile mainly provides separation between base course and subgrade. An analytical approach to the design of geotextile-reinforced unpaved roads was first introduced by Giroud and Noiray (1981). The bearing capacity of the soft subgrade is considered to increase from πc_u to $(\pi + 2) c_u$ with the inclusion of a geotextile; where c_u is the undrained shear strength of the cohesive subgrade. Additional improvement due to membrane action is considered to be a function of the geotextile tensile strength and allowable rut depth.

Reinforcement Mechanisms

For roadway applications, geotextiles have been mostly used for separation, drainage, and filtration and woven geotextiles are sometimes used for reinforcement as a tensioned membrane. Lateral confinement, increased bearing capacity, and the tensioned membrane effect have been identified as the major geosynthetic reinforcement mechanisms (Giroud and Han, 2004). The stabilization of unpaved roads on soft ground with a geotextile is primarily attributed to the basic functions of separation of the base course layer from the subgrade soil, and a reinforcement of the composite system. Although field trafficking studies have consistently shown that the geotextile reduces rutting, there does not seem to be a consistent relationship between improved trafficability and tensile strength of the geotextile. The relationship appears to be good in some trials and poor in others. Analytical models have been proposed for the improved bearing capacity of a geotextile reinforced system that account for contributions from (1) a greater load distribution in the stabilized base course layer; (2) a larger bearing capacity factor due to confinement of the subgrade leading to a plastic, rather than elastic, yield; and (3) a tensioned-membrane effect in the deformed geotextile at large ruts. Although the basic functions of the geotextile are reasonably well understood, there are few data from field trials involving traffic loading that allow the relative improvement in performance of a road section with a geotextile to be quantified. This field test describes the performance of an unpaved- road trafficking trial at Vancouver, British Columbia (B.C.). The response to traffic loading of four test sections, each stabilized with a different geotextile, is compared with that of an unreinforced test section. Interpretation of the data addresses the development of ruts, subgrade deformations, strain in the geotextile, and the implications of the field observations for current design methods.

Functions of Geotextile in Unpaved Roads and Areas

Geotextile have been used for sub grade stabilization and base course reinforcement for construction of unpaved structures (roads and areas) since the 1970s. Placed between the subgrade and base course, or within the base course, the geotextile improves the performance of unpaved roads carrying channelized traffic and unpaved areas subjected to random traffic. Improved performance consists of increases to the volume of traffic that can be carried by a given thickness of base course, decreases to the base course thickness required to carry a given volume of traffic, or combinations of both increased traffic and thickness reduction. Use of lower quality base course material is another potential benefit provided by geotextile. Geotextile can provide separation between base and subgrade materials and reinforcement of the base course and subgrade. Separation prevents the mixing of subgrade soil and granular base materials and the resulting deterioration of the base course. Reinforcement increases the bearing capacity of the subgrade, stiffens the base layer thereby reducing normal stresses and changing the magnitude and orientation of shear stresses on the subgrade in the loaded area, restricts lateral movement of the base course material and the subgrade soil, and can provide tensioned membrane support where deep rutting occurs. Two types of geosynthetics are typically used in unpaved structures: geotextiles and geogrids. From the viewpoint of unpaved structure reinforcement, there is a significant difference between geogrids and geotextiles. Due to their large apertures, geogrids may interlock with base course aggregate if there is an appropriate relationship between geogrid aperture size and aggregate particle size. While the degree of interlocking depends on the relationship between geogrid aperture size and aggregate particle size, the effectiveness of interlocking depends on the in-plane stiffness of the geogrid and the stability of the geogrid ribs and junctions. As a result of interlocking, the mechanisms of unpaved structure reinforcement are different for geotextiles and geogrids.

Theory

The empirical design of geosynthetic-reinforced unpaved roads began with the incorporation of geotextiles at the base–subgrade interface for separation, filtration, and reinforcement. The first notable design procedure for geotextile-reinforced unpaved roads was proposed by Barenberg et al. on the basis of the limit equilibrium bearing capacity theory. The limit equilibrium bearing capacity theory is based on selecting an aggregate base thickness such that the vertical stress applied to the subgrade is below the theoretical limits for subgrade shear failure. This design procedure is based on the bearing capacity theory of a footing under static load, a granular fill, and a soft cohesive subgrade. An additional assumption is that the failure mode of the unreinforced system is characterized by local shear, while the failure mode of a geotextile-reinforced system is characterized by a general shear failure due to additional distribution of the load. Barenberg et al. proposed bearing capacity factors of 3.3 and 6.0 for unreinforced and reinforced systems, respectively. These factors were suggested for roads designed for very low traffic volumes and large deformations. The limit equilibrium bearing capacity theory was modified by Steward et al. by proposing lower bearing capacity factors to account for increased traffic requirements. Steward et al. suggested an unreinforced bearing capacity factor of 2.8 and a geotextile reinforced bearing capacity factor of 5.0 for unpaved roads designed for 1,000 equivalent single-axle loads (ESALs) and 2-in. of rutting. Steward et al. used a Boussinesq solution for calculating the vertical stress beneath a uniform circularly loaded area and the modified bearing capacity factors to construct design curves for single, dual, and dual tandem axle loadings.

An alternative approach in the design of geosynthetic-reinforced unpaved roads was based on the widespread acceptance of the tensioned membrane effect as the primary reinforcement mechanism responsible for changing shear failure modes from localized shear for unreinforced systems to generalized shear for geotextile-reinforced systems. New design procedures were developed on the basis of the use of large-deformation membrane analysis equations. The most popular design procedure was produced by Giroud and Noiray and was also based on limit equilibrium bearing capacity theory with modifications to include benefits of the tensioned membrane effect.

More recently Giroud and Han modified the Giroud and Noiray method to consider the stress distribution, base course strength properties, geosynthetic–base interlock, and geosynthetic in-plane stiffness. These additions are combined with previously considered factors: traffic volume, wheel load, tire pressure, subgrade strength, rut depth, and influence of the type of geosynthetic on the failure mode of the system.

Giroud and Han's design method is based on determining the stresses at the base–subgrade interface and determining the rut depth as a function of those stresses and the subgrade bearing capacity. The influence of the number of vehicle passes and the properties of the geogrid are accounted for through modificationsof the stress distribution angle of the aggregate base.

Three critical assumptions regarding the subgrade bearing capacity factors are made by Giroud and Han. First, they select a bearing capacity factor of 3.14 for unreinforced unpaved roads, which is the elastic limit for a saturated undrained subgrade (zero shear strength, a conservative assumption). Second, a bearing capacity factor of 5.14 is selected for the case of a geotextile-reinforced unpaved road on the basis of the assumption that the geotextile provides a separation function resulting in a condition of zero shear strength at the base–subgrade interface. Finally, a bearing capacity factor of 5.71 (theoretical ultimate bearing capacity factor with maximum inward stress on the subgrade) is used for the geogrid-reinforced unpavedroads because of the expectation of maximum inward shear stress at the base–subgrade interface resulting from geogrid–aggregate interlock.

The restrained horizontal movement of the base material dueto the geogrid is expected to result in zero outward shear stress being applied to the subgrade surface. Interesting adaptations include the use of a mobilization coefficient to account for the fact that only a fraction of the maximum bearing capacity of the subgrade is mobilized during loading.

In summary, the common empirical design methods of reinforced unpaved roads are based on the limit equilibrium bearing capacitytheory. These design methods range from the original work of Barenberg et al. to the most recent adaptation by Giroud and Han.

Table : Shows the Critical Assumptions for the Three Design

Engineering Technical Letter 1110-1-189	Failure in subgrade Fine-grained subgrade soils with undrained loading conditions 2-in. rut failure criterion 1,000-pass failure criterion with linear extrapolations to higher traffic levels Geotextile primary function: separation rather than reinforcement Minimum aggregate thickness of 6 in. (0.15 m)
Giroud and Han (2004)	Uniform base course thickness Channelized traffic for nontraffic areas Minimum base course thickness of 4 in. (0.1 m) for constructability and anchorage purposes Fine-grained subgrade soils with undrained loading conditions Reinforcement allowing loads in the elastic zone while acting as though the subgrade is in the plastic zone Reorientation of shear stress at the subgrade interface Resilient moduli of base course and subgrade used Upper bound of base to subgrade modulus ratio: 5 Limited to less than 10,000 vehicle passes Minimum aggregate thickness of 4 in. (0.10 m)
Giroud and Noiray (1981)	Fine-grained subgrade soils with undrained loading conditions Limited to less than 10,000 vehicle passes Elliptical contact area from wheel replaced with rectangular area associated with dual tire Geotextile roughness preventing failure of the aggregate layer by sliding along the geotextile Pyramidal distribution of load in aggregate layer Assumed angle of load distribution pyramid Reinforcement allowing loads in the elastic zone while acting as though the subgrade is in the plastic zone Induced settlement under load assumed to be parabolic No minimum aggregate depth

Experimental Study

Laboratory model footing tests were performed to study the improvement in behaviour of a geotextile-reinforced soil layer as a function of footing settlement. Tests were carried out in a steel tank having a diameter of 700 mm, a height of 700 mm, and a 150 mm diameter rigid circular footing (Figure 1). The model subgrade was prepared by placing commercial-grade kaolinite, from a slurry, in the test tank and artificially consolidating the kaolinite. The liquid limit and plastic limit of the kaolinite were 45 and 25%, respectively, having silt and clay fractions of 71 and 29%, respectively. The final thickness of the subgrade after consolidation was maintained at 450 mm. The water content of the consolidated kaolinite layer was measured as 32 to 33%.

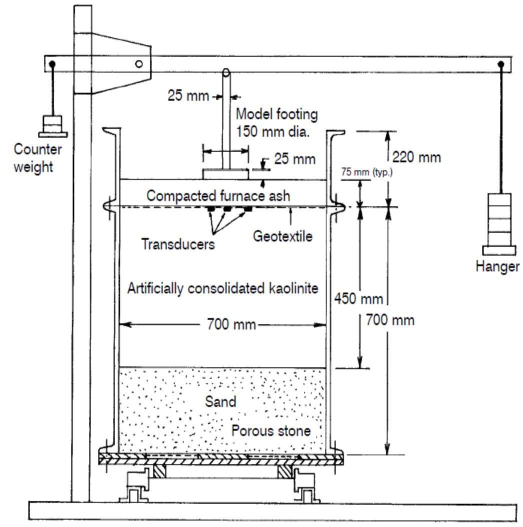

Figure-1: Test Set-up for the Laboratory Model Footing Test.

The engineering properties of the material are given in Table 3. Furnace ash layer thicknesses of 40, 75, 110, and 150 mm were used. The furnace ash was compacted at optimum water content in layers of 35 to 40 mm using a 20 kN rigid circular plate. The unit weight of the compacted furnace ash was 11.6 kN/m3, corresponding to 80% of the maximum dry density. The 1st tests consisted of model footings placed on the compacted furnace ash overlying the consolidated kaolinite layer without a geotextile at the interface. In the 2nd tests, a 700mm diameter geotextile specimen was placed at the interface of the kaolinite and furnace ash layers. Before laying the geotextile, pressure transducers were placed at three positions (centre, edge, and 50 mm from the centre of the footing) on the kaolinite layer in order to measure the kaolinite-geotextile interface stresses with increases in footing pressure. Polypropylene, needle-punched nonwoven and multifilament woven geotextiles were used.

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After preparing the soil layer, the footing was placed on top and in the centre. A load was applied to the footing in increments using a lever system (Figure 1). For each load increment the settlement was recorded with time. The next load increment was applied when the settlement stabilised. The process was continued until a large soil layer deformation was measured.

Table-3

Engineering properties of the furnace bottom ash.

Physical property	Value
Specific gravity	2.10
Particle size distribution	
Gravel	2%
Coarse sand	7%
Medium sand	55%
Fine sand	33%
Silt	3%
Uniformity coefficient	2.10
Optimum moisture content	29%
Maximum dry unit weight	11.6 kN/m^3
Internal friction angle	45°

Table-4

Engineering properties of the nonwoven and woven geotextiles.

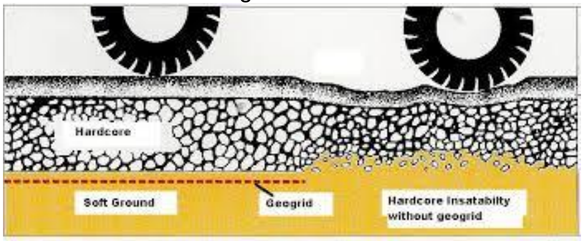
Physical property		Nonwoven geotextile	Woven geotextile
Mass per unit area (g/m^2)		204	204
Thickness under a 2 kN/m^2 load (mm)		3.40	0.65
Peak wide-width tensile load (kN/m)	MD	31.0	40.8
	CD	13.4	22.3
Elongation at maximum load (%)	MD	60.6	17.6
	CD	75.0	17.8
Secant modulus at 10% elongation (kN/m)	MD	39.2	314.9
	CD	39.2	157.5
Elongation at 50% peak strength (%)	MD	29.0	5.6
	CD	41.0	6.4
Geotextile-kaolinite interface friction angle (°)		22	25

Note: MD = machine direction; CD = cross-machine direction.

Discussion of Test Result

Load-Settlement Performance

Average footing pressure versus settlement curves for fill thicknesses of 75 and 110 mm are presented. It is seen that for footing deformations less than 10 mm there is practically no change in the load-settlement behaviour with the inclusion of a geotextile at fill-subgrade interface.But,for unreinforced layer it is much higher in comparison with the reinforced layer beyond 10 mm of settlement. Further, the load-settlement behaviour is found to be similar for both woven and nonwoven geotextile.



Load Capacity Ratio (LCR)

Improvement in the load-carrying capacity of a reinforced soil layer with the inclusion of a geotextile is typically expressed as the ratio of the ultimate load on the reinforced soil to that of the unreinforced soil. The improvement parameter is denoted by the load capacity ratio, LCR, and is defined as:

$$LCR = \frac{\text{Footing pressure for reinforced soil bed at a specified settlement}}{\text{Footing pressure for unreinforced soil bed at the same settlement}}$$

Table-5

Bearing capacity factors and improvement ratio.

Reference	Unreinforced	Reinforced	Improvement ratio
Giroud and Noiray (1981)	3.14	5.14	1.64
Milligan et al. (1989)	2.57	5.14	2.00
Houlsby and Jewell (1990)	3.07	5.69	1.85

Analysis

Efficiency Calculation

The efficiency of the geosynthetic as a reinforcement in a road can be quantified by the Traffic Benefit Ratio, defined as:

$$\text{TBR} = \frac{N_r}{N_u}$$

where TBR is the traffic benefit ratio, Nr is the number of load cycles on the reinforced road for a given rut depth and Nu in the number of load cycles on the unreinforced road for the same rut depth. Koerner (1994) reports values of TBR varying between 2 and 16, depending on the soil and geosynthetic characteristics.

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Conclusions

All three design methods show significant benefits in terms of reduced aggregate thickness for geotextile- and geogrid-reinforced unpaved roads.Inclusion of a geotextile layer at the fill-soft subgrade interface improves the load-carrying capacity of the soil layer at a greater footing settlement.

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