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Unpaved road reinforced with geosynthetics

Lidia Sarah Calvarano[a,]*, Rocco Palamara[a], Giovanni Leonardi[a], Nicola Moraci[a]

[a]"Mediterranea" University of Reggio Calabria, Feo di Vito, Reggio Calabria 89122, Italy

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Abstract

Geosynthetics are commonly used in mechanically stabilization of unpaved roads with a low volume of traffic. The practical use of geosynthetics above a weak subgrade or within a base course has demonstrated the benefit of reducing rut depths and prolonging pavement life. The purpose of this paper is to provide design criteria currently available for reinforced unpaved roads. This paper deals with the results of a parametric analysis varying soil and geosynthetic mechanical properties, allowable depth rut and traffic conditions. The focus of the present study is to compare these different design procedures aimed at estimating the base thickness required for reinforced unpaved roads, providing their improvements and limits. Design procedures are also compared with data obtained from field tests.

Keywords: Geosynthetics; reinforced unpaved road; improvement; design procedures

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1. Introduction

The technique of soil-improvement using geosynthetics is extensively used in the construction of unpaved roads. Unpaved roads are usually used for temporary roads. They remain in service for only short periods (often less than 1 year), and are subjected to low volume of traffic (less than 10000 load applications). Unpaved roads typically consist of an aggregate layer resting on the subgrade. The aggregate base distributes the load. The subgrade carries the vehicular load. When the subgrade is weak, due to its poor consistency and high compressibility, generally, a

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* Corresponding author. Tel.: +39-0965 1692306; fax: +390965 1692201.
E-mail address: lidia.calvarano@unirc.it

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geosynthetic reinforcement is placed at the base/subgrade interface to improve the road performance. This technique is particularly effective because the performances of reinforced unpaved roads are enhanced by reducing permanent rut deformations for a given number of axle loads. Therefore, the goals of geosynthetic reinforcements are an increase of the road service life; a decrease of the construction cost by decreasing the base layer thickness (if the cost of the geosynthetic reinforcement is less than the cost of the saved base material); a decrease of the time required for the construction and of the periodic maintenance interventions [1,2]. This paper deals with the results of a parametric analysis varying soil and geosynthetic mechanical properties, allowable rut depth and traffic conditions, in order to compare Giroud and Han [3,4] and Leng and Gabr [5] design procedures aimed at estimating the base thickness required for unpaved roads reinforced with different geosynthetics.

2. Unpaved road improvement by geosynthetics: functions and mechanisms

Geosynthetics used in unpaved road are essentially geotextiles and geogrids. Geocells are also used, but to a limited extent. In this paper, the attention is focused on the use of geogrids as reinforcement. The interaction due to the geogrid interlocking with aggregate minimizes lateral movement of aggregate particles and increases the modulus of the base course, which leads to a wider vertical stress distribution over the subgrade and consequently a reduction of vertical subgrade deformations. The degree of interlocking depends on the relationship between geogrid aperture size and aggregate particle size, on the shape and thickness of ribs [6-14]. The effectiveness of interlocking, instead, depends on the in-plane stiffness (more than strength) of the geogrid and on the stability of the geogrid ribs and junctions [15]. Two are the main reinforcement mechanisms: the lateral confinement effect and the tension membrane effect. They require different depth values of rutting in order to be mobilized. At small permanent deformation magnitudes, the lateral restraint mechanism is developed by the ability of the base aggregate to interlock with the geogrid. As increasing of permanent deformations (which are often acceptable in unpaved roads) the tension membrane mechanism [16,17] develops. If the geosynthetic has a sufficiently high tensile modulus, tensile stresses will be mobilized in the reinforcement, and a vertical component of this tensile membrane resistance will help to support the applied wheel loads.

3. Unpaved design methods review and objectives of this study

Over the years, various design methods aimed at estimating the aggregate base thickness required for reinforced unpaved roads, have been developed. The earliest design techniques for geosynthetic reinforced unpaved road, with a low volume of traffic, were proposed by Barenberg et al. [16] and by Giroud and Noiray [17] and both include the membrane effect assuming that significant rutting occurs. A comparison between the above procedures was carried out by Calvarano et al. [18]. Giroud and Han [3,4] who modified the Giroud and Noiray method [17] did further headway. Their approach is based on determining the base aggregate thickness as a function of the stresses at the base-subgrade interface and of the subgrade bearing capacity. The authors take into account: the effects of degradation in base course strength; the number and size of load cycles (axle passes); the mechanical geogrid properties; how the load distribution angle, within the base course, decreases with time; and the calibration and validation of the theoretical results with empirical data from laboratory full-scale test sections and monitored unpaved roads.

On the basis of above considerations, the following equation, to solve iteratively, was derived to predict the required thickness of aggregate base providing the prescribed serviceability, in term of allowable rut, for given loading conditions and soil subgrade support [4]:

$$h = \frac{(0.868 + (0.661 - 1.006 \cdot J_{ASM}^{2})) \cdot \left(\frac{r}{h}\right)^{1.5} \cdot \log \mathrm{N}}{1 - 0.204 \cdot (R_E - 1)} \cdot \left(\sqrt{\frac{\frac{P}{\pi r^2}}{\left(\frac{s}{f_s}\right) \cdot \left(1 - 0.9\, exp\left(-\left(\frac{r}{h}\right)^2\right)\right) \cdot \mathrm{N_c c_u}}} - 1 \right) \cdot r \qquad (1)$$

where: h is the required base course thickness (m); J_{ASM} is a geogrid aperture stability modulus (m-N/degree); N is the number of axle passes; P is the wheel load (kN); r is the radius of the equivalent tire contact area (m); E_1 and E_2 are moduli of base course and subgrade soil, respectively; R_E is a limited modulus ratio of base course to subgrade soil [3]; s is an allowable rut depth (mm); fs is a factor equal to 0.075 m; N_c is a bearing capacity factor (equal to 3.14 for unreinforced unpaved roads and 5.71 for geogrid-reinforced unpaved roads).

Leng and Gabr [5] proposed a further development in geosynthetic-reinforced unpaved roads design. Their model in addition to considering the base course property, the mobilization of subgrade bearing capacity with rutting, the contribution of geogrid reinforcement, takes into account, also, the degradation of base course with cyclic loading. The degradation of unpaved road was expressed considering how both the base course-subgrade elastic modulus ratio (E_1/E_2) and the load distribution angle degrade with increasing of number of wheel load repetitions. Definitely, the highlight of the Leng and Gabr design procedure is to consider an unpaved road section as a two-layer system, where a stiffer soil layer (aggregate base course) rests on a softer layer (subgrade). For a given loading condition, the base with a high modulus reduces drastically the stress on the subgrade, under the wheel loading, in comparison with the case of elastic, isotropic and homogeneous semi-infinite half space. Therefore, for the two-layer unpaved road section, the authors replace the base course layer of thickness h, having elastic parameters E_1 and μ_1, by an equivalent layer thickness h_e with the same modulus and Poisson's ratio of the underlying subgrade (E_2 and μ_2, respectively). Therefore, the required base course thickness can be determined by the following equation [5]:

$$h = \frac{a \cdot (1 + K_2 \cdot \log \mathrm{N})}{\tan \alpha_1} \cdot \left(\sqrt{\frac{\mathrm{p_c}}{\mathrm{m_c} \cdot \mathrm{N_c} \cdot \mathrm{c_u}}} - 1 \right) \tag{2}$$

where: h is the required base course thickness (m); a is the radius of the equivalent tire contact area (m); K_2 is the degradation constant of the stress distribution angle (that is correlated to an average geogrid tensile strength (J_t) at 2% of strain); N is the number of axle passes; α_1 is an initial stress distribution angle (which is in function of the degradation of the elastic modulus ratio (E_1/E_2) and of the average geogrid tensile strength (J_t) at 2% of strain); p_c is the tire contact pressure (kN/m^2); m_c is a mobilized bearing capacity ratio; N_c is a bearing capacity factor (equal to 3.8 for the unreinforced sections and 6.0 for the geogrid-reinforced sections); c_u is the subgrade undrained shear strength (assumed by AASHTO design guidelines [19] equal to 30 times the subgrade CBR, kN/m^2).

4. Design parameters

Design parameters relating to geosynthetic mechanical properties, allowable depth ruts, subgrade mechanical characteristics, traffic conditions are given below. The study presented in this paper is focused on the use of geogrid in unpaved roads. Three bi-oriented geogrids with different mechanical properties, were selected (Table 1).

Table 1. Mechanical properties of the geogrids, commercially available, used in design procedures.

Geogrid	Direction	Tensile Strength at 2% of Strain (kN/m)	Average Tensile Strength at 2% of Strain (kN/m)	Tensile Strength at 5% of Strain (kN/m)	Geogrid Stiffness, $J_{2\%}$ (kN/m)	Geogrid Stiffness, $J_{5\%}$ (kN/m)	Aperture Stability Modulus (m-N/deg)
GG1	MD	4.1	5.35	8.5	205	170	0,32
	TD	6.6		13.4	330	268	0,32
GG2	MD	6	6.70	11.7	300	234	0.48
	TD	7.4		14.6	370	292	0.48
GG3	MD	6	7.00	11.8	300	236	0.65
	TD	9		19.6	450	392	0.65

A serviceability criteria offered by AASHTO design guidelines [19] consider allowable rut depths from 13 to 75 mm. In the case of unpaved access roads, allowable rut depths greater than 75 mm are sometimes used, such as 100 mm. So, three allowable rutting values equal to 0.050 m, 0.075 m and 0.100 m were chosen.

Also, for unpaved roads, geosynthetics with reinforcement function are required only for weak subgrade [19] characterized by California Bearing Ratio (CBR) less than 3 (or undrained shear strength, c_u, less than 90÷120 kPa). In this analysis, subgrade CBR values varying from 0.5 to 3 were used.

About traffic assumptions, being vehicular traffic channelized, it is characterized by the number of passes (N_{cycles}) of a given axle during the road design life. About the axles and loads design parameters, the wheel load (P) is the load applied by one of the wheels, in the case of single-wheel axle, or the load applied by a set of two wheels, in the case of dual-wheel axles and it is considered to be half of the axle load (P_{Axle}). In this analysis P_{Axle} =80 kN, so P=40 kN and a tire contact pressure (p_c) equal to 556 kPa, were assumed.

5. Results of analysis

Figure 1a shows, for fixed design conditions (i.e., subgrade CBR and allowable rut depth), an increase in the unreinforced and reinforced base aggregate thickness ($h_{B,unrenif}$ and $h_{B,reinf}$) with increasing number of vehicular load cycles and with decreasing geogrid mechanical properties (respectively in term of geogrid tensile stiffness, by Leng and Gabr method, and of the aperture stability modulus, by Giroud and Han one).

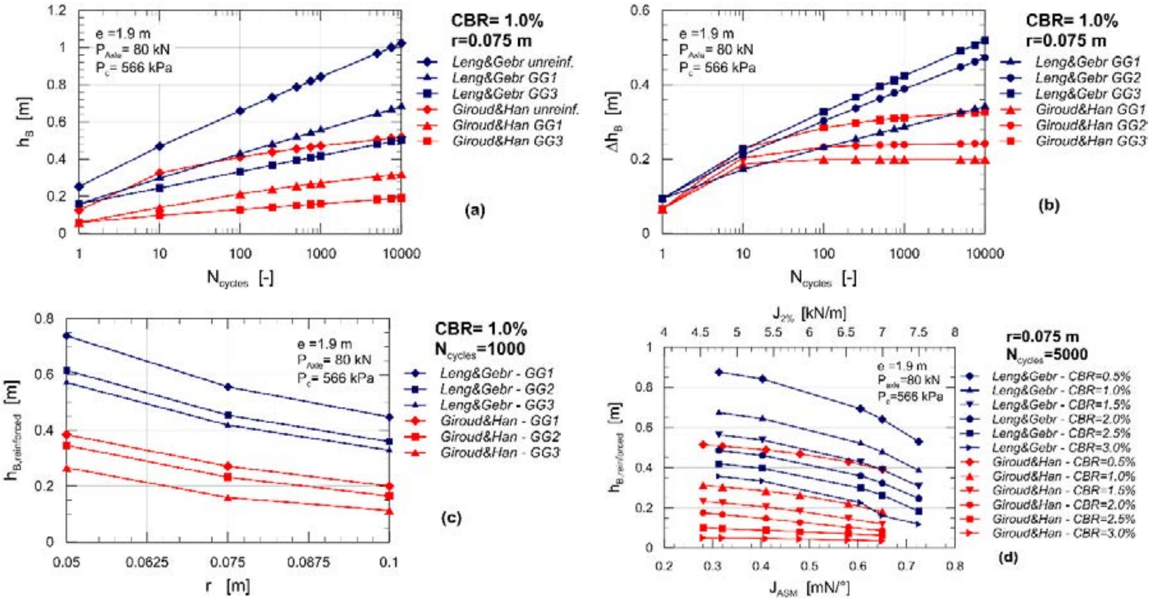

Fig. 1. (a) Unreinforced and reinforced base aggregate thickness versus number of wheel passes for each geogrids chosen; (b) Reduction of the reinforced base layer thickness versus vehicular cyclic load for each geogrids; (c) Reinforced base aggregate thickness versus depth rutting for each type of reinforcement; (d) Reinforced base aggregate thickness varying geogrids' mechanical properties for each subgrade CBR chosen.

Figure 1b, shows that the higher improvement offered by the reinforcement, in terms of reduction of the reinforced base layer thickness, is offered by Leng and Gabr. The results, also, confirm that there is higher efficiency when the reinforcement, placed at based-substrate interface, has higher mechanical proprieties. Consequently, benefits are in term of saving of aggregate material needed for the base layer construction.

For both proposed design methods the aggregate base thickness increases with the increase of rutting, and all depth values of rutting chosen (r = 0.050 m ÷ 0.100 m) are large enough to let the geosynthetic layer work providing a reinforcement support proportionally to own mechanical characteristic (Fig. 1c). This suggests that better reinforced base performance is mainly due to the lateral restraint of the base soil which develops for more reduced rut depth and it is, therefore, always the first mechanism to be active. Then, by increasing rut depth, the membrane mechanism, that requires higher values of geosynthetic deformation to be achieved, could take over. Figure 1d confirms that, at equivalent traffic capacity and serviceability conditions, geogrid benefits increase with decreasing subgrade mechanical proprieties and with the use of stiffer geogrids. For all combinations of design parameters (i.e., traffic conditions, CBR subgrade, geogrid mechanical characteristics and allowable rutting, Fig.1a-d) is evident that the Leng and Gabr design procedure is more conservative in comparison with the Giroud and Han one. The reason is probably due because the Leng and Gabr design procedure in addition to considering the degradation of stress distribution angle with number of cycles (as Giroud and Han method done) takes into account also the effect of wheel load repetitions on degradation of elastic modulus ratio (E_1/E_2). This ratio is very important because it governs how vertical stresses are distributed on subgrade and consequently the amount of vertical subgrade deformations developed. Therefore, the amount of improvement due to the reinforcement effect has been related to a Performance Index (PI) which is defined as follows:

$$PI=\left\{1-\left[\left(h_{B,unre\inf.}-h_{B,re\inf.}\right)/h_{B,unre\inf.}\right]\right\} \tag{3}$$

Figure 2a reports PI versus subgrade CBR, at the same design conditions in term of equivalent traffic capacity, allowable rutting and geosynthetic reinforcement used. In the range of subgrade strength chosen, the results confirm that the Leng and Gabr design procedure shows higher PI than Giroud and Hann method, where, generally, the average differences are about 40%. At the end, in Figure 2b, the above two aggregate base thickness design procedures are compared with field data offered by Fannin and Sigurdsson [20]. These field tests were performed using the geogrid GG1 placed on a subgrade characterized by a CBR of about 1.3%. It is noteworthy that, both in the case of unreinforced and reinforced base layers, the aggregate base thickness by Leng and Gabr design procedure and by Giroud and Han one represent, respectively, the upper and lower bound limits of the experimental field data.

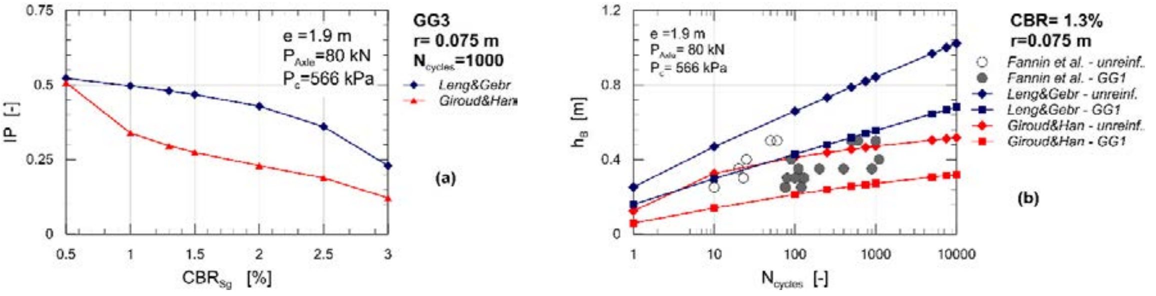

Fig. 2. Comparison between theoretical data by Giroud and Hann and Leng and Gabr design procedures: (a) Performance Index (PI) versus subgrade CBR; (b) Comparison between theoretical results obtained by above procedures and experimental field data obtained by Fannin [20].

6. Conclusions

Based on the parametrical analysis carried out on Leng and Gabr and Giroud and Han unpaved roads design procedures, the following conclusions could be drawn.

Because both design methods consider the benefits offered by reinforcement action, the dependency of the required aggregate layer on rut depth and reinforcement mechanical proprieties (in term of geogrid tensile stiffness or aperture stability modulus) are reflected on the results. Particularly, reinforcement benefits generally increase with increasing allowable rut depth and with the use of stiffer geogrids. Anyway, as subgrade mechanical characteristics increase, so the design base thickness and the benefits offered by reinforcements decrease.

For all combinations of design parameters (i.e., traffic conditions, CBR subgrade, geogrid mechanical characteristics and allowable rutting), it is evident that the design base thickness by Leng and Gabr is less than the design base thickness by Giroud and Han. The reason is probably due because the Leng and Gabr design procedure in addition to considering the degradation of stress distribution angle with number of cycles (as Giroud and Han method done) takes into account also the effect of wheel load repetitions on degradation of elastic modulus ratio

(E1/E2). This assumption makes the method more realistic because E_1/E_2 ratio governs how vertical stresses are distributed on subgrade and consequently the amount of vertical subgrade deformation developed.

The amount of improvement introduced by the reinforcement has been related to a Performance Index (PI). In the range of subgrade CBR chosen, the Leng and Gabr design procedure shows higher PI than Giroud and Hann method, where generally the average differences are about 40%. At the end, comparing the above two base thickness design methods with experimental field data, it is noteworthy that, both in the case of unreinforced and reinforced base layers, the base thickness by Leng and Gabr design procedure and by Giroud and Han method represent, respectively, the upper and lower bound limits of the experimental field data.

But, both these design models have a limitation that their calibration were carried out exclusively using just two geogrids' types (GG1 and GG3). Therefore, it would be necessary a more wide experimental investigation on different types of geogrids to obtain a wide database that allows to make the design method more general and applicable to any type of reinforcement geogrid. In addition, since interlocking likely plays a key role in the behavior of unpaved roads, can be said that the shape and mainly the scale effect likely play a key role in the behavior of unpaved roads, too. Therefore, a more complete calibration should be developed taking into account, in addition to the geogrid mechanical properties, the average size of the base particles (D_{50}) in according to the size of the geogrid openings and to the rib thickness and profile, too. These could be another potential research subjects.

References

[1] G. Leonardi, M. Buonsanti, FEM analysis of airport flexible pavements reinforced with geogrids, Adv. Sci. Let. 13 (2012) 392-395.

[2] G. Leonardi, M. Buonsanti, F. Scopelliti, Theoretical and computational analysis of airport flexible pavements reinforced with geogrids, in 7th RILEM International Conference on Cracking in Pavements, RILEM Bookseries 4 (2012) 1219-1227.

[3] J. P. Giroud, J. Han, Design method for geogrid-reinforced unpaved roads. I. Development of design method, J. Geotech. Geoenviron. Eng. 130 (8) (2004) 775-786.

[4] J. P. Giroud, J. Han, Design method for geogrid-reinforced unpaved roads. II. Calibration and applications, J. Geotech. Geoenviron. Eng. 130 (8) (2004) 787-797.

[5] J. Leng, M.A. Gabr, Deformation-resistance model for geogrid-reinforced unpaved road, Transportation Research Record Journal of the Transportation Research Board 1975 (1) (2006) 146-154.

[6] D. Cazzuffi, L.S. Calvarano, G. Cardile, N. Moraci, P. Recalcati, European experience in pullout tests: The influence of geogrid's geometry and structure on interface behaviour, Geosynthetics 29(5) (2011) 42-51.

[7] D. Cazzuffi, N. Moraci, L.S. Calvarano, G. Cardile, D. Gioffrè, P. Recalcati, The influence of vertical effective stress and of geogrid length on interface behaviour under pullout conditions, Geosynthetics 32(2) (2014) 40-50.

[8] N. Moraci, G. Cardile, D. Gioffrè, M.C. Mandaglio, L.S. Calvarano, L. Carbone, Soil geosynthetic interaction: design parameters from experimental and theoretical analysis, Transportation Infrastructure Geotechnology 1(2) (2014) 165-227.

[9] N. Moraci, D. Cazzuffi, L.S. Calvarano, G. Cardile, D. Gioffrè, P. Recalcati, The influence of soil type on interface behavior under pullout conditions, Geosynthetics 32(3) (2014) 42-50.

[10] L.S. Calvarano, D. Gioffrè, G. Cardile, N. Moraci, A stress transfer model to predict the pullout resistance of extruded geogrids embedded in compacted granular soils, In proceeding of 10th International Conference on Geosynthetics ICG 2014, Berlin, Germany.

[11] G. Cardile, L.S. Calvarano, D. Gioffrè, N. Moraci, Experimental evaluation of the pullout active length of different geogrids, in proceeding of 10th International Conference on Geosynthetics ICG 2014, Berlin, Germany.

[12] G. Cardile, N. Moraci, L.S. Calvarano, Geogrid pullout behaviour according to the experimental evaluation of the active length, Geosynthetics International 23(3) (2016) 194-205.

[13] N. Moraci, G. Cardile, Pullout behaviour of different geosynthetics embedded in granular soils, in Proc.4th Asia Reg. Conf. (2008) 146-150.

[14] N. Moraci, M.C. Mandaglio, D. Gioffrè, G. Cardile, D. Cazzuffi, P. Recalcati, C. Starrantino, Temperature monitoring of a geosynthetic-reinforced embankment in a seismic area, in Proc. 17th ICSMGE 2 (2009) 1666-1669.

[15] S.L. Webster, Geogrid reinforced base course for flexible pavements for light aircraft: Test section construction, behavior under traffic, laboratory test, and design criteria, Technical Report DOT/FAA/RD-92/25, U.S., 1993.

[16] E. J. Barenberg, J. Dowland, J. Hales, Evaluation of Soil Aggregate Systems with Mirafi Fabric, Civil Engineering Studies, Department of Civil Engineering, University of Illinois, Report No UILU-ENG-75- 2020, 1975.

[17] J. P. Giroud, L. Noiray, Geotextile-reinforced unpaved road design, J. Geotech. Geoenviron. Eng. 107(9) (1981) 1233-1254.

[18] L.S. Calvarano, R. Palamara, G. Leonardi, N. Moraci, Reinforced unpaved roads: parametrical analysis of design procedures, in 6th European Geosynthetics Congress EUROGEO6 (2016) accepted for printing.

[19] AASHTO Guide for the design of pavement structures, American Association of State Highway and Transportation Officials, 1993.

[20] R. J. Fannin, O. Sigurdsson, Field observations on stabilization of unpaved roads with geosynthetics, Journal of Geotechnical Engineering 122(1966) 544-553.