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Geosynthetics

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GIROUD-HAN DESIGN METHOD
PART 2

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PART 2 | **Recommendations for the proper use of the method**

The Giroud-Han design method for geosynthetic-reinforced unpaved roads

By Jie Han and J.P. Giroud

Since its publication in 2004, the Giroud-Han design method for geosynthetic-reinforced unpaved roads has received considerable attention by the geosynthetics industry. This article is the second of two that provides practical information for the users of the method as well as for those who want to learn about the method.

Introduction

Since its publication, the Giroud-Han (G-H) method (Giroud and Han, 2004a, b) has been used to design many geosynthetic-reinforced unpaved roads, generally with success. However, sometimes the method has been a victim of its success. Some users have adopted the method without fully understanding the assumptions made during its development and often ignoring its limitations. As a result, unsatisfactory results have sometimes been obtained and some misleading conclusions have been drawn in practice and publications. In addition, some issues have arisen from the widespread use of the G-H method; therefore, it is necessary to discuss and address these issues. The objective of this article is to provide recommendations for the proper use of the method. Recommendations are made regarding subgrade strength, base strength and stiffness, filtration requirements, geogrid properties, reliability, and method of verification.

A companion article by Giroud and Han was published in the February/March 2012 issue of *Geosynthetics*, which summarizes the development and calibration of the G-H design method. All of the equations mentioned in this article are numbered according to the equations in Part 1 (i.e., 9, 7, 8, 2, 1) and all equations (1–9) can be found in that February/March companion article.

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Subgrade strength

Subgrade condition

The G-H method assumes that the subgrade consists of saturated fine-grained soil (silt and clay) and that it fails under an undrained condition. In some cases, the subgrade is unsaturated and not necessarily a fine-grained soil. This fact must be taken into consideration prior to use of the G-H method. The strength of unsaturated subgrade may drop significantly after soaking. The strength of a soaked subgrade should be used as a design input if an unpaved road is likely to become soaked during its design life.

Variability

Soil properties vary from one point to another. The variability of subgrade strength has a great effect on the performance of unpaved roads, especially when the subgrade CBR

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value is low. Using **Figure 1** as an example, the required compacted base thickness of the geogrid-reinforced section for 1000 axle passes as a function of the subgrade CBR at a rut depth of 75 mm is 48 cm for CBR = 0.5%, 28 cm for CBR = 1%, and 18 cm for CBR = 1.5%. This shows that the increase in the required base thickness is 71% for a 0.5% reduction in the subgrade CBR from 1% to 0.5%, and 56% for a 0.5% reduction in the subgrade CBR from 1.5% to 1%. Therefore, **Equation 9** for specific biaxial geogrids* in the companion article is more sensitive for subgrade CBR values below 1% (and so are probably the generic **Equations 7** and **8**). As a result, when subgrade CBR values fall below 1%, designers should pay closer attention to how they assign soil properties to be used in the design.

Proper construction practices and procedures are required when dealing with very soft ground because construction techniques can heavily influence the performance. Additionally, subgrade strength variability introduces significant complexities for full-scale experimental studies. Care should be taken when analyzing and interpreting results of full-scale studies involving geosynthetics on soft ground. Variability of ground conditions, and/or discrepancies between real-life construction practices and those used in experiments can easily govern results of studies. In their full-scale field study, Cuelho and Perkins (2009) showed that the subgrade had a significant variability in vane shear strengths and CBR values. For example, the WeG-2 test section had CBR values ranging from 1.3% to 2.2% for Layer 4 **(Figure 2).** Such a large variation in the subgrade strength should be avoided in any full-scale experimental study because it may result in misleading conclusions.

Subgrade CBR is often estimated from a field-obtained dynamic cone penetrometer (DCP) value. A commonly used correlation between CBR and DCP was proposed by Webster et al. (1994) and adopted within the ASTM D6951 / D6951M – 09 DCP standard (ASTM International, 2009). **Figure 3** clearly shows that this correlation also has a large variability. The variability becomes even more significant when the CBR value is less than 10%, which is generally the case when reinforcement is needed in unpaved roads.

Sensitivity

Many soils are sensitive—i.e., their strength decreases when the soil is disturbed. As demonstrated by Fannin and Sigurdsson (1996), the average undrained shear strength of the subgrade in their study decreased from

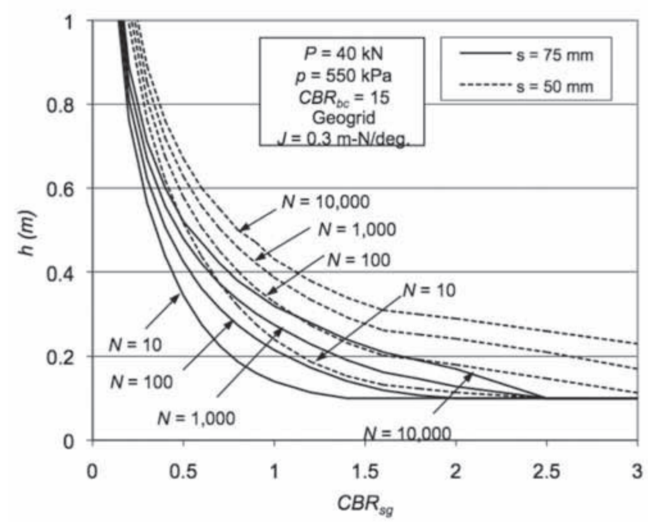

FIGURE 1 Design chart for geogrid-reinforced unpaved roads (Giroud and Han, 2004b)

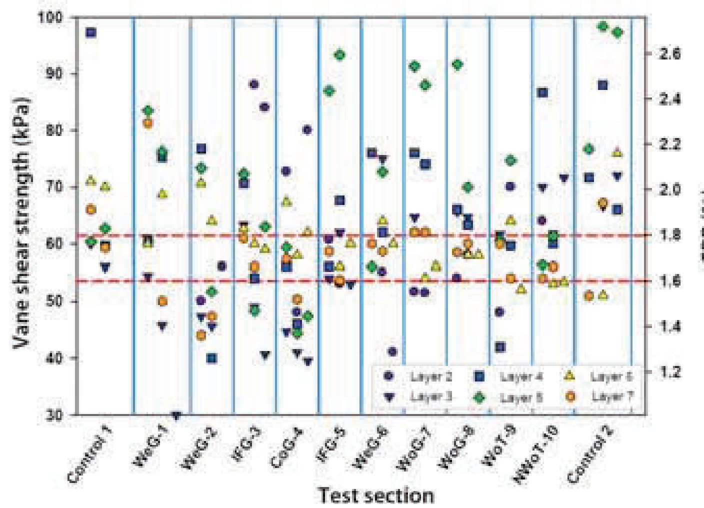

FIGURE 2 Variation of vane shear strengths of subgrade (Cuelho and Perkins, 2009)

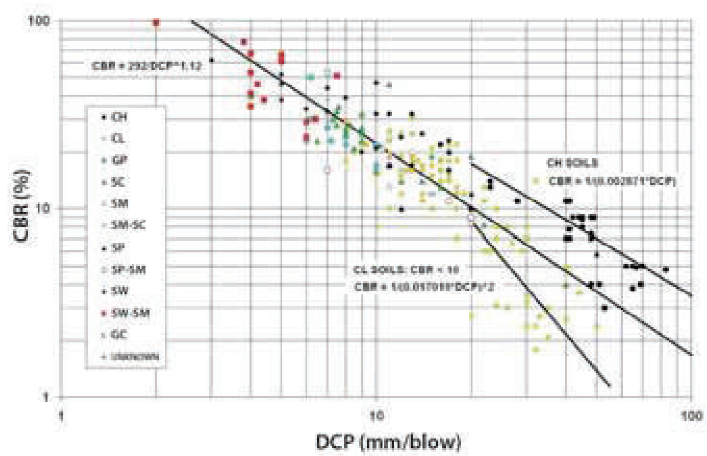

FIGURE 3 Correlation between CBR and DCP (Webster et al., 1994)

*Tensar biaxial geogrids, BX1100 and BX1200

40.0 kPa (measured on an undisturbed sample) to 5.7 kPa (measured on a remolded sample). One may expect to see similar strength reduction after trafficking disturbance. This strength reduction affected the performance of the unpaved road as Giroud and Han (2004b) showed from the back-calculated undrained shear strengths. To be conservative, the undrained shear strength of the disturbed subgrade should be used in the design.

Soil sensitivity affects not only design, as discussed above, but also field test interpretation. **Figure 4** shows the reduction of the undrained shear strength of the subgrade due to traffic in the Cuelho and Perkins (2009) study. No doubt this strength reduction affected the performance of all the test sections. Because the degrees of strength reduction in different test sections were different, the influence of strength reduction on the performance of each section is different. As a result, actual performance comparison among test sections with different geosynthetics is difficult.

EQUATIONS 1-2, 7-9

Equations written with c_u for the shear strength of the subgrade

$$h = \frac{1 + k \log N}{\tan\alpha_0 \left[1 + 0.204\left(R_E - 1\right)\right]} \left[\sqrt{\frac{\dfrac{P}{\pi r^2}}{\left(\dfrac{s}{f_s}\right)\left[1 - \xi \exp\left(-\omega \left(\dfrac{r}{h}\right)^n\right)\right] N_c\, c_u}} - 1 \right] r \qquad (1)$$

$$h = \frac{1.26\left(1 + k \log N\right)}{1 + 0.204\left(R_E - 1\right)} \left[\sqrt{\frac{\dfrac{P}{\pi r^2}}{\left(\dfrac{s}{f_s}\right)\left[1 - 0.9 \exp\left(-\left(\dfrac{r}{h}\right)^2\right)\right] N_c\, c_u}} - 1 \right] r \qquad (2)$$

Equations written with CBR_{sg} for the shear strength of the subgrade

$$h = \frac{1 + k \log N}{\tan\alpha_0 \left[1 + 0.204\left(R_E - 1\right)\right]} \left[\sqrt{\frac{\dfrac{P}{\pi r^2}}{\left(\dfrac{s}{f_s}\right)\left[1 - \xi \exp\left(-\omega \left(\dfrac{r}{h}\right)^n\right)\right] N_c\, f_c CBR_{sg}}} - 1 \right] r \qquad (7)$$

$$h = \frac{1.26\left(1 + k \log N\right)}{1 + 0.204\left(R_E - 1\right)} \left[\sqrt{\frac{\dfrac{P}{\pi r^2}}{\left(\dfrac{s}{f_s}\right)\left[1 - 0.9 \exp\left(-\left(\dfrac{r}{h}\right)^2\right)\right] N_c\, f_c CBR_{sg}}} - 1 \right] r \qquad (8)$$

$$h = \frac{0.868 + \left(0.661 - 1.006 J^2\right)\left(\dfrac{r}{h}\right)^{1.5} \log N}{1 + 0.204\left[R_E - 1\right]} \left[\sqrt{\frac{\dfrac{P}{\pi r^2}}{\left(\dfrac{s}{f_s}\right)\left[1 - 0.9 \exp\left(-\left(\dfrac{r}{h}\right)^2\right)\right] N_c\, f_c CBR_{sg}}} - 1 \right] r \qquad (9)$$

Base thickness, strength, stiffness, and filtration

Base thickness

As pointed out in the companion article (Giroud and Han, 2012), the base thickness determined by the G-H method is a compacted base thickness rather than an initial, uncompacted base thickness. Therefore, to properly use the G-H method, the base thickness considered in design and in calculations done to compare different solutions should always be the compacted base thickness.

Base strength and stiffness requirement

The G-H method assumes that the base has enough strength and stiffness to support traffic loads before the subgrade fails. In reality, however, if a low quality base is used, the base may fail or experience excessive deformation within the base layer itself, resulting in surface rutting. The design chart proposed by Hammitt (1970) for aircrafts on unsurfaced soils, shown in **Figure 5**, may be used for trucks on unpaved roads. This chart makes it possible to verify the quality of the base material. If the quality of the base is not sufficient, it should be replaced with a better-quality base or improved by use of a layer of geogrid within the base. Proper field installation and compaction of bases are also important to ensure sufficient base strength and stiffness. In some full-scale field studies, special installation and construction procedures (including fewer passes of compaction) were utilized to minimize disturbances to the soil layers, instrumentation, and geosynthetics, which resulted in lower base strength and stiffness and were not representative of procedures used in real projects.

Filtration requirement

The base aggregate should have an appropriate gradation to meet filtration requirements to minimize the migration of fine particles from the subgrade into the base. The intermixing of base and subgrade would reduce the strength and stiffness of the base and result in additional rutting due to the deteriorated base. Christopher and Holtz (1989) suggested that, without any geosynthetic, additional base thickness is required to compensate for the loss of good aggregate into the subgrade, as illustrated in **Figure 6**, which presents an empirical graph based on field observations. According to this figure, the additional base thickness required to compensate for the loss of aggregate could be as much as 20% when the subgrade CBR is equal to 3%. This ultimately leads to reduced road life and poor performance. As illustrated in **Figure 6**, a lower CBR subgrade results in more loss of the base aggregate into the subgrade. The technical guidance laid out by Anderson (2006) may be used to verify whether the base meets the filtration requirement. In some cases, the solution adopted consists in using a lift of subbase aggregate or a geotextile, which meets filtration requirements, followed by a geogrid and a final lift of base aggregate.

Geogrid properties

Tensile properties

Giroud and Han (2006) stated that tensile strength has not been found to be an accurate predictor of performance for geosynthetics in unpaved road applications. **Figure 7** plots the traffic benefit ratio (TBR) as a function of the tensile strength at 5% strain of the geogrids used in unpaved road full-scale trafficking tests by Watts et al. (2004). The TBR is a performance indicator and is defined as the ratio of the number of passes necessary to reach a given rut depth for a section containing a

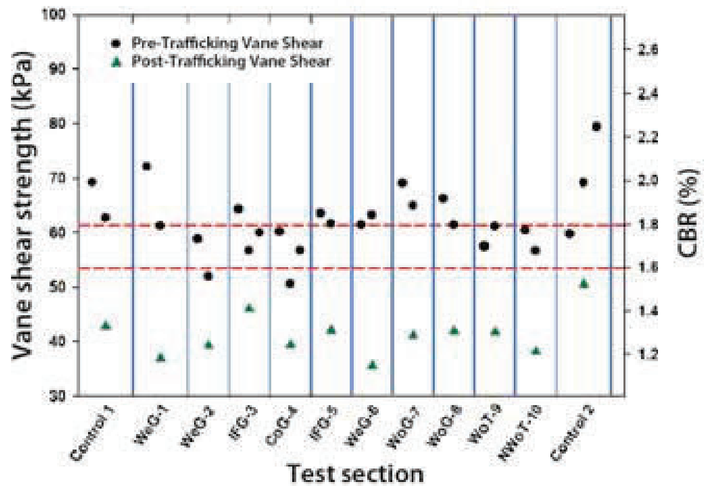

FIGURE 4 Reduction of subgrade shear strength after trafficking (Cuelho and Perkins, 2009)

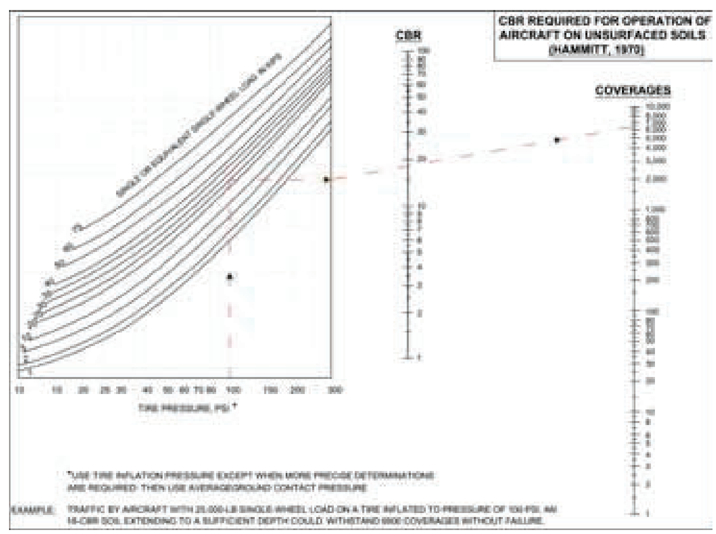

FIGURE 5 Required CBR value for the base (Hammitt, 1970)

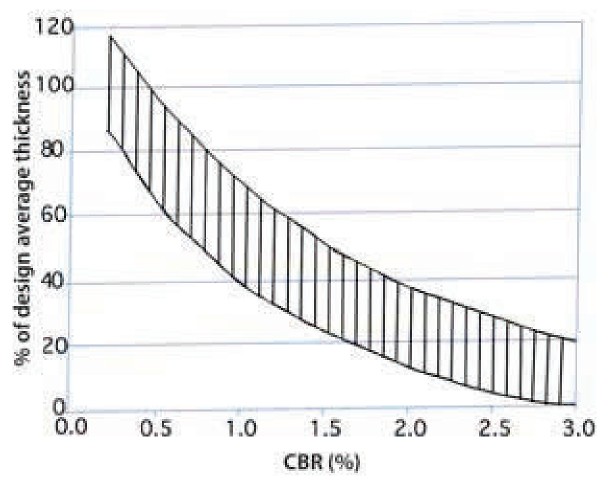

FIGURE 6 Additional base thickness required due to aggregate loss into weak subgrades (Christopher and Holtz, 1989)

geosynthetic to the number of passes necessary to reach the same rut depth for an unreinforced section with the same base thickness and subgrade properties. Inspection of **Figure 7** shows that there is no correlation between the tensile strength at 5% strain and the performance of the tested unpaved road sections. Also, Giroud and Han (2006) calculated the geogrid tensile strain in the unpaved road trafficking tests by Watts et al. (2004) using profiles provided by Watts (personal communication, 2005). These profiles correspond to maximum rut depths (i.e., at the end of testing) for Section B of the Watts et al. (2004) tests. They found that the average geogrid strains under the dual wheels ranged between 0.1% and 1.2%, which are significantly less than 5%. Although not demonstrated in these tests, it may be possible that a correlation between tensile strength and performance exists for geosynthetics not included in this study. However, such a relationship must be established through the use of full-scale testing.

Many early theories for unpaved roads relied on the tensioned membrane effect. While this may still be the dominant mechanism and a valid theoretical approach for some types of geosynthetics, the benefit of high tensile strength through the tensioned membrane effect comes only with significant surface and subgrade deformations that are typically in excess of what is allowed for most unpaved roads to remain in service, as shown by Giroud et al. (1985).

Aperture shape and geometry effects

Geogrid properties considered to be important for lateral restraint of the aggregate are rib shape, rib thickness, aperture size, initial tensile modulus, in-plane flexural stiffness of the ribs, and junction efficiency (Webster, 1992). Some newly-introduced geogrids into the paved and unpaved road markets have triangular apertures and new directions of strength. These new geogrids have significantly different physical and mechanical properties from biaxial or uniaxial geogrids. The new aperture shape and new range of physical and mechanical properties have been shown to provide improved performance (Watts and Jenner, 2008; Dong et al., 2010; White et al., 2011). Also, Dong et al. (2011) showed that geogrids with triangular apertures have more uniform radial tensile stiffness than those with rectangular or square apertures. Giroud (2009) has stated:

"The effectiveness of geogrid-aggregate interaction depends on the relative geometry of the geogrid and aggregate. Square or rectangular apertures can be expected to promote a cubic arrangement of aggregate, which is a loose arrangement. This would limit the benefit of interlocking. In contrast, triangular apertures would promote a hexagonal arrangement of aggregate, which is a dense arrangement. Therefore, triangular apertures may lead to maximum stiffness of the reinforced aggregate, i.e., maximum interlocking."

Reliability and method of verification

Reliability vs. probability of failure

Due to the variability of pavement structures (subgrade, subbase, base, and surface layers), traffic loading, and design methodologies, pavements have been designed based on reliability as discussed in the AASHTO Design Guide (AASHTO, 1993). Reliability is the probability for the actual road performance (or serviceability) to exceed or equal the design road performance. As schematically shown in **Figure 8,** the dots represent the actual individual performance with a statistical distribution, while the performance curve represents the average performance of the road. The road performance decreases from the initial serviceability (p_0) toward the terminal serviceability (p_t), at which point major rehabilitation or reconstruction is required. If the design curve matches the average performance curve, there is an equal chance of failure or success in terms of design vs. actual performance. A design with a higher reliability (i.e., higher standard normal deviate, Z_R, at a certain overall standard deviation, s_0) requires a more expensive pavement structure (e.g., thicker and/or using more geosynthetics), which has less chance of failure in terms of design vs. actual performance. AASHTO (1993) suggested 50% to 80% reliability for local road design. Unpaved roads are mostly local roads, farm roads, or temporary haul roads; therefore, it is reasonable for these roads to be designed at a reliability of 50%. The equation of the G-H method (i.e., **Equation 2** and subsequent equations in the companion article) for unreinforced bases was calibrated against the average performance of unreinforced unpaved roads tested by Hammitt (1970); therefore, the design reliability is 50%. A design method with a higher reliability can be

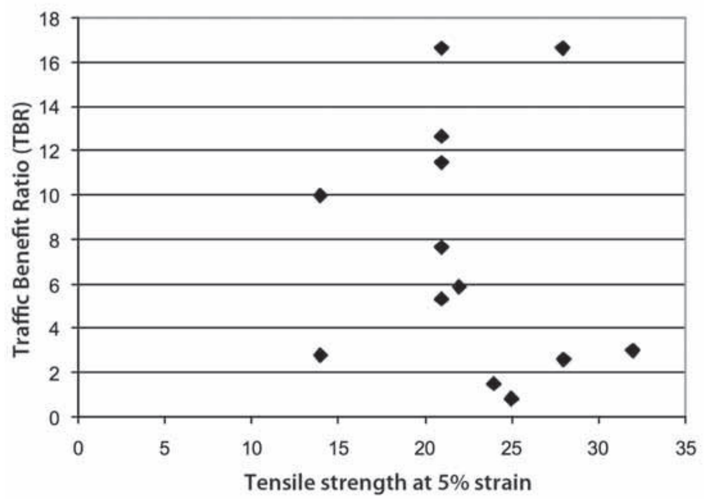

FIGURE 7 Relationship between traffic benefit ratio and geogrid tensile strength at 5% strain

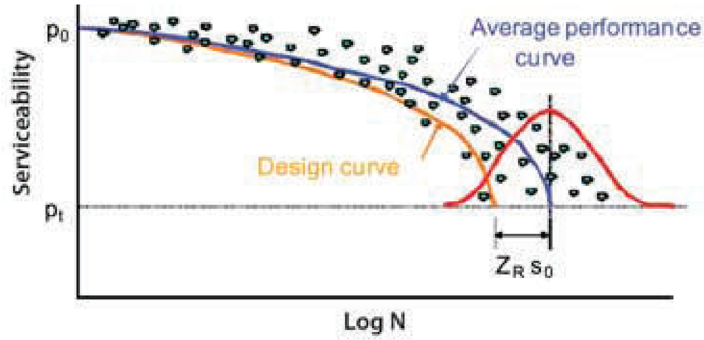

FIGURE 8 Schematic representation of design vs. performance (modified from AASHTO, 1993)

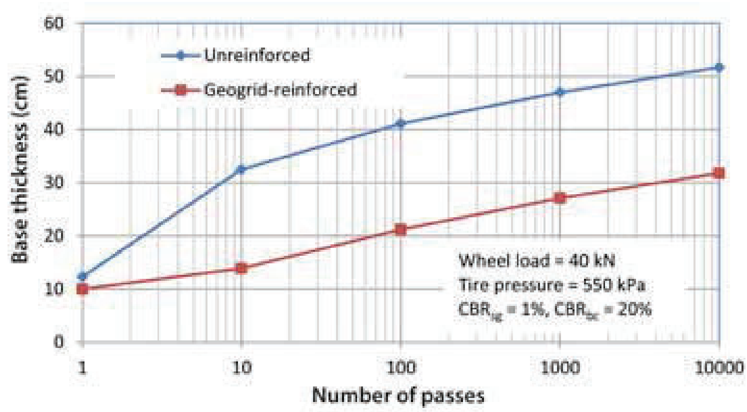

FIGURE 9 Base thickness vs. number of passes obtained using the G-H method

developed, but it will result in a more expensive design. Any evaluation of field performance of unpaved roads against the G-H design method should consider this fact.

Number of passes vs. thickness for verifying the design method

As shown in **Equation 1** and subsequent equations in the companion article (Giroud and Han, 2012), the required base thickness, *h*, is a function of log *N* (*N* is the number of passes) as shown in **Figure 9**, where the points were calculated using the G-H method. For example, a 40-cm thick unreinforced base is predicted to withstand 70 passes of a 40 kN wheel load. If there is a 10% increase in the base thickness (i.e., 44 cm), which is considered a tolerable deviation in current construction practice, the number of passes increases to 300, which is approximately 330% greater than the number of passes for the 40-cm thick unreinforced base. For a specific biaxial geogrid-reinforced base, a 20-cm thick reinforced base is predicted to withstand 70 passes while a 22-cm thick reinforced base (10% increase from the 20-cm thick reinforced base) is predicted to withstand 140 passes, which is 100% greater than the number of passes for the 20-cm thick reinforced base. In other words, a base with 10% variation in the thickness can result in 100% to 330% difference in its pavement life. This exercise demonstrates that results predicted using the G-H method (for both unreinforced and reinforced unpaved roads) appear to be far more sensitive when they are expressed in terms of service life than when they are expressed in terms of base thickness. Therefore, results expressed in terms of service life are prone to larger errors than results expressed in terms of base thickness. For this reason, it is more reasonable and objective to compare unpaved road field test results with predicted ones in terms of base thickness.

Another aspect related to base thickness is the accuracy of construction. In the Cuelho and Perkins (2009) study, the variation of the base thicknesses measured after compaction for the nominal base thickness of 20 cm reached 4 cm (i.e., 20% error), which is excessive. The correct way to evaluate how a design method predicts the performance of a road section involves the use of the actual and carefully measured base thickness beneath the wheel load or at the point of instrumentation measurement.

Conclusions

This article highlights the issues raised from the widespread use of the design method for geosynthetic-reinforced unpaved roads published by Giroud and Han in 2004 and offers recommendations for dealing with these issues including subgrade strength, base strength and stiffness, filtration requirements, geogrid properties, reliability, and method of verification.

As demonstrated in the article, base and subgrade variability, which may be high, can have a great influence on the performance of an unpaved road. Subgrade strength may decrease after soaking and/or disturbance, especially for sensitive soils. For these cases the remolded shear strength and/or soaked CBR strength of the subgrade soils should be used in design. The aggregate used for the base should be properly selected in terms of quality and gradation to meet filtration requirements, and should be compacted to ensure that it exhibits sufficient strength and stiffness to sustain traffic loading. Higher tensile strength geosynthetics at 5% strain do not necessarily lead to better performing products in unpaved road applications. Geogrid aperture shape and geometry affect the effectiveness and efficiency of geogrid-aggregate interlocking.

The Giroud-Han design method was calibrated based on 50% reliability. The verification of the design method against field test data should consider this reliability and use the actual compacted base thickness measured at the point of data collection.

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