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

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Part 1 | Method development and calibration

By J.P. Giroud and Jie Han

Since its publication in 2004, the Giroud-Han design method for geosynthetic-reinforced unpaved roads has received considerable attention from the geosynthetics industry. This article is the first of two that provides practical information for the users of the method as well as for those who want to learn about the method. Click here to read part 2.

Introduction

The Giroud-Han (G-H) design method provides a design tool to determine the thicknesses of unreinforced and geosynthetic-reinforced aggregate bases for unpaved roads over soft subgrade. The method was published in two parts (Giroud and Han, 2004a, b) in the *ASCE Journal of Geotechnical and Geoenvironmental Engineering*.

The G-H method replaces the widely used method published by Giroud and Noiray (1981) and has been included in the updated “Geosynthetic Design and Construction Guidelines” manual by the Federal Highway Administration (FHWA, 2008).

Development of the G-H method was a long and complex effort in the late 1990s and early 2000s. The length and complexity were justified by the authors’ desire to openly provide all details and calculations pertaining to the development of the method. However, the need for a summary of the method has been expressed. This article presents a summary of the method’s features.

Even though the G-H design method has been adopted by consultants and geosynthetic manufacturers, a number of issues have arisen, which are clarified in this article. In particular, this article clearly indicates the equations that are generic—and can be used with any geosynthetic with appropriate calibration—and the equations that were calibrated for specific geosynthetics. This distinction between generic and calibrated equations is crucial because it was not clear to some readers of the original publications of the G-H method.

Also, the calibration steps were not easy to follow due to the length and complexity of the original papers. In this article, they are presented in a concise manner.

Definitions pertinent to unpaved roads

Unpaved roads typically consist of an aggregate layer (often called “base course” or simply “base”) resting on the subgrade. When a geosynthetic is used in an unpaved road, it is generally placed at the base/subgrade interface. The use of geosynthetics in unpaved roads is a mechanical stabilization technique that is different from chemical stabilization. In mechanical stabilization, the base is improved via the inclusion of a geosynthetic layer (or layers) and the aggregate remains unbound. Chemical stabilization involves inclusion of chemicals (e.g., lime, cement, binders) to bind aggregate materials or the subgrade soils.

It is important to distinguish between aggregate that is bound (as a result of chemical stabilization) and aggregate that is unbound. In this article, only unpaved roads constructed with unbound aggregate are considered. These roads can be either unreinforced or reinforced using geosynthetics. The term *reinforced* is equivalent to *mechanically stabilized* throughout this article.

The use of the terms *reinforced* and *reinforcement* in the context of unpaved roads does not imply that the geosynthetic simply adds force (i.e., simply adds its strength) to the unpaved road structure. As shown in the original publication (Giroud and Han, 2004a), a geosynthetic improves an unpaved road through complex mechanisms that mostly do not involve the strength of the geosynthetic per se. Therefore, in the context of unpaved roads, *reinforced* and *reinforcement* should be regarded only as convenient terms established by tradition.

Development of the generic equation of the Giroud-Han method

The G-H method can be used for the design of both unreinforced and geosynthetic-reinforced unpaved roads constructed with unbound aggregate.

In the development of the G-H method, the stresses at the interface between the base

and subgrade are estimated using a stress distribution angle (Figure 1). The effect of base stiffness on the stress distribution angle is quantified using an approximate relationship between the stress distribution angle and the base to subgrade modulus ratio based on the classical Burmister’s two-layer elastic solution (Burmister, 1958).

In the field, the stress distribution angle decreases progressively because of the progressive deterioration of the base due to cyclic loading resulting from trafficking. Laboratory tests by Gabr (2001) on unreinforced bases and on bases reinforced with biaxial geogrids, have led to a linear relationship involving the stress distribution angle and log*N*, where *N* is the number of load applications (i.e., the number of axle passes in the field). This relationship has recently been verified by Qian et al. (2011) for geogrids with triangular apertures.

The G-H method takes into account the progressive decrease of the stress distribution angle with a term *k* log*N*, where *k* is a dimensionless parameter that depends on the radius of tire contact area (which is assumed to be circular), the base thickness, and the geosynthetic. Indeed, the inclusion of the geosynthetic at the base/subgrade interface reduces the deterioration rate of the base; as a result, the rate of decrease of the stress distribution angle is reduced.

As the stress distribution angle decreases, the maximum vertical stress at the base/subgrade interface increases. Bearing capacity failure of the subgrade occurs when the stress distribution angle decreases to a point where the stress at the interface exceeds the mobilized bearing capacity of the subgrade. The mobilized bearing capacity of the subgrade depends on the undrained shear strength of the subgrade, the surface deformation or rut depth, the tire contact area, and the base thickness.

The presence of a properly selected geosynthetic at the base/subgrade interface results in a stabilization effect, which decreases subgrade deformation and allows for a higher bearing capacity factor than if there was no geosynthetic. Giroud and Noiray (1981) suggested bearing capacity factors of 3.14 and 5.14 in the case of unreinforced and geotextile-reinforced unpaved roads, respectively. These bearing capacity factors have been adopted in the G-H method. In the case of a geogrid-reinforced base, the lateral restraint due to geogrid-aggregate interlock results in an inward shear stress on the subgrade, which increases the bearing capacity factor from 5.14 to 5.71, as shown by Giroud and Han (2004a).

Based on all of the above considerations, Equation 1 (Table 1) for estimating the required base thickness was developed by Giroud and Han (2004a). The notations are in Table 2. The base thickness determined by the G-H method is a compacted base thickness rather than an initial, uncompacted base thickness.

It is important to note that Equation 1 is generic, because it has been developed without assuming the use of any specific geosynthetic. As a result, it can be used for unreinforced, unpaved roads and for unpaved roads reinforced with any type of geosynthetic. The selection of the values of the parameters α_0, ξ, ω, *n*, and *k* is discussed below.

Selection of some parameter values

The values of four of the five parameters mentioned above, α_0, ξ, ω, and *n*, can be selected without making any assumption on the type of geosynthetic. The selection of the values of these parameters is discussed below. The selection of the value of the fifth parameter, *k*, which depends on the geosynthetic, will be discussed in the following section.

Giroud and Han (2004a) interpreted the results of cyclic plate loading tests on unreinforced, unpaved roads and geogrid-reinforced unpaved roads performed by Gabr (2001) and concluded that α_0 can be considered constant for all unpaved roads constructed with unbound aggregate, unreinforced or reinforced, and that the value of 1/1.26 could be used for tan α_0 in all cases.

The three unknown parameters, ξ, ω, and *n*, were determined by Giroud and Han (2004b) using field data for unpaved roads constructed with unreinforced, unbound aggregate published by Hammitt (1970). The following values of these three parameters were found to provide the highest correlation between the measured base thickness values and the values calculated using Equation 1: $\xi = 0.9$, $\omega = 1.0$, and $n = 2.0$.

Using the above numerical values for tan α_0, ξ, ω, and *n*, Equation 1 becomes Equation 2 (Table 1). It should be noted that the above numerical values for tan α_0, ξ, ω, and *n*, are not necessarily set forever. It is possible that new test data will lead to different values for some or all of these four parameters. However, the authors of the G-H method believe that Equation 2 can be safely used in the meantime. Therefore, Equation 2 was used in the original papers (Giroud and Han, 2004a, b) for the next step, which is the calibration of *k*.

As with Equation 1, Equation 2 is generic because the four parameters (α_0, ξ, ω, and *n*) were calibrated independently of any reinforcement material. So Equation 2 is applicable to all cases: unreinforced unpaved roads, geotextile-reinforced unpaved roads, and geogrid-reinforced unpaved roads (all constructed with unbound aggregate). The only parameter that needs calibration before Equation 2 is used to design a reinforced unpaved road is the dimensionless parameter *k*, which depends on radius of tire contact area, base thickness, and reinforcement. Calibration of the G-H method through the dimensionless parameter *k* is discussed in the following section.

Calibration and validation of the Giroud-Han method

Because Equation 2 contains an unknown parameter, *k*, it must be calibrated. Since *k* represents the effect of the rate of deterioration, calibration should be done using tests that model the behavior of the unpaved road base under repeated loads. Furthermore, calibration should be done using relevant properties. Therefore, calibration should be done using a property (or a set of properties) of the geosynthetic shown to correlate with the performance of an unpaved road reinforced with that specific geosynthetic.

Giroud and Han (2004a) found that, for a geogrid-reinforced unpaved road, the deterioration rate correlated with the aperture stability moduli of the specific geogrids considered in their study*. They established the following relationship based on an interpretation of laboratory cyclic plate loading tests on geogrid-reinforced unpaved

roads by Gabr (2001): where *J* = aperture stability modulus of geogrid (with *J* = 0 for unreinforced and geotextile-reinforced unpaved roads). Measurement of the aperture stability modulus is presented in a draft test method by Kinney (2000).

Equation 3 is applicable only to two specific biaxial geogrids*.

Combining Equations 2 and 3 gives Equation 4 (Table 1). Since Equation 4 results from calibration done using laboratory tests, Giroud and Han (2004a, b) found it necessary to validate this equation using field data. Values of the base thickness h calculated with Equation 4 were then compared to values of the base thickness obtained in the field by Hammitt (1970) for the same number of axle passes for unreinforced unpaved roads. An average ratio of 0.689 was found between base thickness values observed in the field and calculated, hence Equation 5 (Table 1) is obtained by multiplying Equation 4 by 0.689.

Equation 5 is applicable only to the two biaxial geogrids used for this calibration*. However, an equation such as Equation 5 can be obtained for any type of geosynthetic by calibrating and validating Equation 2 for the considered geosynthetic.

*Tensar biaxial geogrids, BX1100 and BX1200

The process includes four steps:

1. selecting a relevant property (or several relevant properties) of the considered geosynthetic—i.e., one or several properties (not necessarily *J*) likely to give good correlation with the performance of an unpaved road incorporating that geosynthetic.
2. obtaining an expression for *k* similar to Equation 3, but where *J* is replaced by the selected property (or properties).
3. obtaining an equation similar to Equation 4, by combining Equation 2 with the expression obtained for *k* in the preceding step.
4. deriving an equation similar to Equation 5 by validating Equation 4 using field tests.

It is possible, however, to conceive a one-step calibration/validation process where the parameter *k*in Equation 2 would be calibrated using field tests that would simultaneously provide validation, which would lead directly to an equation similar to Equation 5.

Discussion of the calibration and validation

Equation 4 incorporates only the aperture stability modulus to model the effect of two specific biaxial geogrids* on aggregate thickness reduction, because this parameter had been shown in the original publication (Giroud and Han, 2004a) to correlate by itself with the performance of unpaved roads reinforced with these biaxial geogrids.

This was shown using geosynthetic-specific performance testing, which led to Equation 3—i.e., a relationship between the aperture stability modulus, *J*, of these geogrids and the performance of reinforced aggregate bases. Other commonly referenced properties of these geogrids, in particular ultimate tensile strength, have not been shown to correlate with road performance and, therefore, are not appropriate properties to calibrate the G-H method for two specific biaxial geogrids*.

Furthermore, other studies have also shown good correlation between road performance and the aperture stability moduli of these two specific geogrids* and a few other geogrids that were available at the time of the studies. For example, Webster (1992) and Collin et al. (1996) found that the aperture stability moduli of the geogrids included in their studies gave good correlation with the measured performance of paved roads incorporating these geogrids.

The above discussion shows that there are good reasons to use the aperture stability modulus to calibrate the G-H method for the two specific biaxial geogrids*. However, this does not mean that J is the only meaningful property of the specific biaxial geogrids evaluated, but it is a measurable property for which a mathematical relationship to performance can be established. In reality, it is likely that all of the properties (aperture size, rib geometry, tensile properties) work together and combine to deliver the observed performance. A sensitivity study may be conducted to investigate the importance and influence of each property; however, such a study may be extensive, time-consuming, and costly.

While the aperture stability modulus has been shown to be an appropriate property to calibrate the G-H method for specific types of geogrids*, it should not be considered a universal indicator of performance for all forms of geogrid. Therefore, the G-H design method does not have to be used with the aperture stability modulus if another relevant property can be identified for a particular geosynthetic. In other words, the aperture stability modulus may not be an appropriate property to correlate with the performance of unpaved roads incorporating geogrids other than the two biaxial geogrids* that were used as an example in the original papers by Giroud and Han (2004a, b).

*Tensar biaxial geogrids, BX1100 and BX1200

Based on the above discussions, the G-H method must be calibrated for each specific geosynthetic, and the calibration should be complemented by validation using full-scale tests.

Tests used for calibration must be as representative as possible of actual field conditions. Calibration of the method for a specific geosynthetic should be done using full-scale moving wheel tests or large-scale cyclic plate-loading tests.

Small-scale tests may be used to study how variations of properties within a given geosynthetic "family" influence performance of that family, but they cannot and should not be used for validation. Validation should be done only with full-scale experiments or test installations. Documented case histories can provide valuable information that complements the data from full-scale tests, thereby contributing to the validation of the method for a specific geosynthetic.

Calibration and validation of the design method for newly introduced geogrids with triangular apertures followed this procedure (i.e., the data from full-scale moving wheel tests and large-scale cyclic plate-loading tests were used). This procedure should be followed for every geosynthetic intended to be used in unpaved road applications. Even if a new geosynthetic has index properties similar to those of a geosynthetic for which the G-H method has been calibrated and validated through full-scale tests, it is important to implement the calibration and validation procedures for this new geosynthetic.

Expression of the G-H method as a function of the CBR

The undrained shear strength of the subgrade, c_u plays a key role in Equations 1, 2, 4, and 5 (Table 1). In practice, the undrained shear strength of the subgrade is often expressed in terms of California Bearing Ratio (CBR). If CBR is used, it is important to establish a relationship between undrained shear strength and CBR. The following relationship has been suggested to estimate the undrained shear strength of the subgrade as a function of the subgrade CBR (Giroud and Noiray, 1981; Giroud and

Han, 2004a): where: c_u = undrained shear strength (cohesion) of the subgrade soil (kPa); CBRsg = CBR of the subgrade soil; and *fc* = factor (kPa).

The value *fc* = 30 kPa proposed by Giroud and Noiray (1981) for fine-grained soils (silt and clay) has been adopted by Giroud and Han (2004a). The *fc* value may be different if the soil is not saturated and/or is not a fine-grained soil. Qian (2009) reported an *fc* value of 20.5 for a clayey sand. However, Gregory and Cross (2007) suggested an *fc* value of 11.1 for a cohesive soil, which is significantly lower than values suggested by others. The relationship between c_u and CBRsg should be verified or established if CBRsg is used in design.

In Equations 1, 2, 4, and 5, c_u can be replaced by its expression given by Equation 6. Combining Equations 1 and 6 gives Equation 7 (Table 3), which is generic as is

Equation 1.

Combining Equations 2 and 6 gives Equation 8 (Table 3), which is identical to Equation 7, but where the parameters α_0, ξ, ω, and n have been replaced by their best numerical value currently available.

Combining Equations 5 and 6 gives Equation 9 (Table 3) for the design of unpaved roads incorporating specific biaxial geogrids*.

*Tensar biaxial geogrids, BX1100 and BX1200

Applicability and limitations

Giroud and Han (2004a, b) stated that the G-H design method is applicable and limited to the following conditions:

1) The subgrade soil is assumed to be saturated and to have a low permeability (silt, clay). Therefore, under traffic loading, the subgrade soil behaves in an undrained manner. Practically, this means that the subgrade soil is incompressible and frictionless. For example, this requirement excludes unpaved roads built on peat.

2) The G-H method as initially published had been verified for rut depth between 50 and 100 mm. However, through extensive use of the method, it has been determined that the method is applicable to rut depths as small as 40 mm. Therefore, the validity of the method is currently limited to rut depths ranging between 40 and 100 mm. More calibration work, based on more field data, would be required to extend the validity of the method to a broader range of rut depths. These rut depths, essentially due to the deformation of the subgrade, are measured at the surface of the aggregate base. These are different from surface ruts, which may form during the construction process due to surficial disturbances of the base materials and not because of subgrade deformation. These surface ruts should be filled, rather than graded, prior to proof rolling to maintain the required base or subbase thickness above the geosynthetic.

3) The minimum required thickness of the base is 100 mm because the base thicknesses used in the calibration were no less than 100 mm and because such thickness is necessary for constructability. The base thickness determined by the G-H method is a compacted base thickness rather than an initial, uncompacted base thickness. 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.

The above limitations are related to the generic aspects of the G-H method. Also, Equations 4, 5, and 9 are applicable to only two specific biaxial geogrids* and should not be used for any other geosynthetic. For other geosynthetics, calibration and validation of Equation 2 should be done as described above.

*Tensar biaxial geogrids, BX1100 and BX1200

All of the above equations that give the required base thickness, h, must be solved by iterations because the term h is on both sides of the equation.

Conclusions

The basic equation developed by Giroud and Han (2004a, b) for the required thickness of unreinforced and/or geosynthetic-reinforced bases is generic. Therefore, this equation can be used for unpaved roads reinforced with any type of geosynthetic, provided it is calibrated for the specific type of geosynthetic considered.

This article has discussed the calibration of the Giroud-Han (G-H) method in detail. In particular, it has been indicated that the aperture stability modulus, which is an appropriate property to calibrate the G-H method for some specific biaxial geogrids*, may not be appropriate for other types of geogrids.

*Tensar biaxial geogrids, BX1100 and BX1200

Geosynthetic index tests of physical or mechanical properties are not universal indicators of the performance of unpaved roads, and higher-strength geosynthetics do not necessarily perform better in unpaved road applications. Physical or mechanical properties that are important for one form, type, or family of geosynthetics may not apply to other forms, types, or families of geosynthetics. If several geosynthetics appear to be similar, the method must be calibrated for each one. Furthermore, the applicability of the method for each of these geosynthetics must be validated using full-scale tests.

Calibration based only on small-scale tests and the index properties of the geosynthetic could lead to a false sense of security that the unpaved road design will meet performance expectations. Based on the limitations of the G-H method, as presented in this article, the designer should always verify that geosynthetic-specific full-scale testing along with case histories, for which a calibrated and validated G-H equation was utilized, resulted in satisfactory performance of the constructed unpaved road.

Issues have arisen as a result of the widespread use of the method. Issues related to the development of the G-H method were addressed in this article. Issues related to the use of the method are addressed in Part 2 in the April/May 2012 issue of *Geosynthetics*.

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

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Part 2 | Recommendations for the proper use of the method

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 from 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. Click here to read part 1.

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.

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 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 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.

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 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 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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