DISCUSSIONS AND CLOSURES

Discussion of "Development of Downdrag on Piles and Pile Groups in Consolidating Soil" by C. J. Lee and Charles W. W. Ng

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Frank M. Clemente Jr., M.ASCE[1]

[1]Technical Director, Geotechnical Engineering, Earth Tech, OneWorld Financial Center, New York, 10281. E-mail: frank.clemente@earthtech.com

This noteworthy paper prompts the following comments in response to two statements by the authors.

The authors state the following:

> "Although the study of dragload on piles has been investigated and well documented in the literature, the investigation of downdrag has received less attention. There are only few reported settlement measurements from field monitoring (Bjerrum et al. 1969; Endo et al. 1969; Lambe et al. 1974; Okabe 1977), ..."

The discusser produced a paper (Clemente 1979), which may be of interest to the authors. It included profiles of ground settlement versus time, profiles of settlement versus depth, and profiles of measured downdrag or dragload in prestressed concrete piles in a deep, 43 meter (140 f) thick deposit of soft clay consolidating under a 3.7 meter (12 f) embankment.

The authors state the following:

> "... the inner piles are shielded (or protected) by the outer piles. This suggests that sacrificial piles can be designed and built to protect pile groups in consolidating soils."

The quantity of sacrificial outer piles that may be required to shield the inner piles is likely to be significant and costly. An example of a similar concept (Okabe 1977) employed 14 cased outer piles to shield 24 inner piles.

Where costly sacrificial piles are contemplated, consideration can also be given to coating the piles with bitumen. If anticipated large downdrag and dragloads may lead to unacceptable pile settlement values or to potential structural damage of piles, bitu-

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Discussion of "Design Method for Geogrid-Reinforced Unpaved Roads. I: Development of Design Method" by J. P. Giroud and Jie Han

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Michael R. Simac[1]; David J. Elton[2]; and Stephan M. Gale[3]

[1]Principal Engineer, Earth Improvement Technologies, P. O. Box 397, Cramerton, NC 28032. E-mail: simac.eit@earthlink.net
[2]Associate Professor, Dept. of Civil Engineering, Auburn Univ., Auburn, AL. E-mail: elton@eng.auburn.edu
[3]Principal Engineer, Gale-Tec Engineering, Inc., Wayzata, MN. E-mail: smg@gale-tec.com

We commend Giroud and Han on their paper, which adds significantly to the body of knowledge for engineering analysis of unpaved roads. The development of the truncated cone stress distribution represents a technical advancement and simplifies the calculations for this application. The proposed design method also incorporates the modulus of the aggregate base course and subgrade soil as a ratio, permitting quantification of geosynthetic improvement on that ratio, known as the stress distribution angle. The manner in which the geogrid improvement on that modulus ratio or stress distribution angle is formulated and presented in the design method is the focus of this discussion.

Selection of Aperture Stability Modulus for Geogrid Performance

Giroud and Han selected aperture stability modulus (ASM) of geogrid reinforcement as the only performance property upon which to calibrate this new design method for unpaved roads. The basis for this selection are two studies on geogrid reinforcement for paved roads (p. 779) that have far different performance (failure) criteria than the limiting rut depths (50–100 mm) stated as a limitation of the design method (p. 781). The two previous

Table 1. Comparison of Aggregate Thickness for Unpaved Road Design Methods

	100 cycles of 80 kN axle load, rut 75 mm, CBR=1.0		
Method	Unreinforced	Geogrid	Geotextile
Giroud and Han with B11	**0.41 m**	**0.21 m**	**0.26 m**
Giroud and Noiray with B11	0.38 m	0.25 m	0.25 m
Barenberg with B11	0.43 m	0.26 m	0.26 m
Giroud and Han with B12	**0.41 m**	**0.13 m**	**0.26 m**
Giroud and Noiray with B12	0.38 m	0.25 m	0.25 m
Barenberg with B12	0.43 m	0.24 m	0.24 m

studies appear to be based on the testing of a proprietary polypropylene geogrid with formed ribs and junctions.

Aperture stability modulus (ASM, symbol "J") is an index test conceived to measure the in-plane stiffness of a geogrid reinforcement, by measuring the torsional load required to twist the geogrid through a particular in-plane angular distortion. The procedure attempts to quantify the combined effects of tensile modulus and junction strength. Several researchers, Webster (1992) and Kinney (2000), referenced by the authors, and GRI (2004) have attempted to define the test procedure. However, there is no consensus standardized test method for ASM (J) at this time, unlike the ASTM procedure for CBR, the design parameter for soil and aggregate course base strength.

There are no provisions in the design method to account for installation damage and other environmental factors known to affect synthetic polymer products used in soil reinforcement. This is unique to, and particularly important for, the Giroud-Han method since it attributes a significant amount of the aggregate savings to the ASM (J) of the geogrid reinforcement. Other unpaved road design methods do not rely as much on geosynthetic strength being present throughout the service life, but rather on the mere presence of the geosynthetic improving bearing capacity performance of the subgrade.

Use of ASM is a departure from the well-known standard practice of geosynthetic tensile strength established in Giroud and Noiray (1981), Bender and Barenberg (1978), and the long-standing work by the U.S. Forest Service (see Steward et al. 1977). Additionally, Berg et al. (2000, pp. 63–64) previously reviewed those same paved road studies and concluded that "there was not clear, quantifiable values for these properties (ASM) specifically related to performance." Instead, Berg et al. recommended generic base stabilization performance be based on "empirical evidence," starting with "tensile strength at specific strains."

We suggest that the proposed geogrid-reinforced unpaved road design method would be significantly more generic and applicable were it calibrated to average tensile strength at 2% to 5% strain in two directions, versus ASM. The numerical difference, for say 5%, is illustrated below:

B11	ASM=0.32	avg$T$=11.0 kN/m = (8.5+13.4)/2
B12	ASM=0.65	avg$T$=15.8 kN/m = (11.8+19.8)/2

This change in the ratio between the performance properties of B11 and B12 from 2.03 for ASM to 1.44 for average tensile strength should lead to better correlation with observed performance in the lab and field studies, as shown in Giroud and Han's Figs. 5 and 6.

Typical Aggregate Base Course Thickness for Design Method

The authors' Figs. 5 and 6 clearly show the decreased influence of the proprietary geogrid performance properties with increasing aggregate base course thickness. Therefore, it appears to be more appropriate to base the design method on the performance of the 0.25 m section, which is more representative of typical unpaved road aggregate base thickness, which range from 0.2 to 0.6 m. This would also produce a conservative approximation of geogrid reinforcement effects on aggregate base course thickness less than 0.25 m, a more desirable approach than a potentially unconservative aggregate base course thickness over 0.15 m, as currently proposed by the authors. It is important to maintain a degree of conservatism when attempting to aggressively advance design procedures relative to established design practices that have performed well. This is especially the case when the lab and field research data used to establish the Giroud and Han design method rarely went over 1,000 load cycles and most tests or observations endured less than 500 cycles.

Comparison of Unpaved Road Design Methods

To quantify the aggregate base course reduction proposed in the Giroud and Han design method using ASM, calculations were

Table 2. Comparison of Aggregate Thickness for Unpaved Road Design Methods

	1,000 cycles of 80 kN axle load, rut 100 mm, CBR=1.0		
Method	Unreinforced	Geogrid	Geotextile
Giroud and Han with B11	**0.38 m**	**0.20 m**	**0.25 m**
Giroud and Noiray with B11	0.53 m	0.40 m	0.40 m
Barenberg with B11	0.56 m	0.30 m	0.30 m
Giroud and Han with B12	**0.38 m**	**0.11 m**	**0.25 m**
Giroud and Noiray with B12	0.53 m	0.40 m	0.40 m
Barenberg with B12	0.56 m	0.28 m	0.28 m

performed using comparable, current-practice design methods for typical stabilization applications. Those results are presented in Tables 1 and 2. For this comparison, the average tensile strength at 5% strain for B11 & B12 was used in both the Giroud and Noiray (1981) and Bender and Barenberg (1978) methods as the geosynthetic performance property. Since those methods do not distinguish between product type, geogrid, or geotextile, identical aggregate thickness result. Contrast this with the Giroud and Han method, which utilizes a lower bearing capacity factor for geotextiles of similar strength as a geogrid, and eliminates any benefit of the tension membrane effect for geotextiles.

Table 1 shows that both the unreinforced and reinforced aggregate thickness calculated by the three methods are similar, except for the Giroud-Han design using B12 geogrid, (high J, ASM). However, when significant load cycles are considered, like in Table 2, the unreinforced aggregate thicknesses are quite different. Although geotextile aggregate thickness compare favorably in Table 2, the unreinforced and geogrid aggregate thickness for Giroud-Han are significantly less than current practice would utilize.

The approximate 70% reduction in aggregate thickness due to incorporation of the B12 geogrid seems particularly aggressive when compared with the 48% reduction for B11 geogrid and the roughly 35% reduction due to geotextile reinforcement calculated by the new Giroud-Han method. These large differences in aggregate thickness seem particularly unusual when considering the relatively small difference in performance characteristics between the three geosynthetics compared.

Summary

These comments and comparative analyses are provided so that more consideration can be given to secant moduli (i.e., average tensile strength at 2% or 5% strain) versus ASM, as the geogrid performance property. It is also suggested that the design method be reformulated based on a typical aggregate thickness of 0.25 versus 0.15 m.

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Closure to "Design Method for Geogrid-Reinforced Unpaved Roads. I: Development of Design Method" by J. P. Giroud and Jie Han

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J. P. Giroud[1] and Jie Han[2]

[1]Consulting Engineer, JP GIROUD, Inc., 5837 North Ocean Blvd., Ocean Ridge, FL 33435.

[2]Associate Professor, Civil, Environmental, and Architectural Engineering Dept., Univ. of Kansas, 1530 W. 15th St., Lawrence, KS 66045-7609.

The writers of the paper are grateful to the discussers for their interest in the research work presented. All the points made in the discussion are addressed below.

Generic Nature of Design Method Presented in the Paper

The discussers suggest that the design method for unpaved roads presented in the paper would be more generic and applicable if it were calibrated using the tensile strength at 5% strain rather than the aperture stability modulus. In fact, the design method presented in the paper is generic. Eq. (11) and the two equations derived from it before the calibration of the method [i.e., Eqs. (14) and (32)] can be used for unreinforced and reinforced unpaved roads; and, in the case of reinforced unpaved roads, these equations can be used for both geotextile reinforcement and geogrid reinforcement. Since Eq. (32) is generic, it can be calibrated using any appropriate characteristic of the geosynthetic through the constant *k*. Therefore the design method presented in the paper [as expressed by Eq. (32)] does not have to be used with the aperture stability modulus if another relevant parameter can be identified.

Calibration of the Design Method

In the paper, the calibration of the method using the aperture stability modulus starts after Eq. (32). Eq. (41), which is derived from Eq. (32), uses the aperture stability modulus because the writers consider it an appropriate way to characterize with a single parameter the properties that allow a geogrid to reinforce an unpaved road, i.e., mostly the in-plane stiffness of the geogrid and its ability to interlock with aggregate. Using only the tensile modulus (expressed by the tensile strength at 5% strain), as suggested by the discussers, does not account for the geogrid properties that ensure interlocking between the geogrid and aggregate. The irrelevance of the geogrid tensile strength at 5% strain for the design of geogrid-reinforced unpaved roads can be illustrated using the results of full-scale tests carried out by Watts et al. (2004). Fig. 1 gives the traffic benefit ratio (TBR) as a function of the tensile strength at 5% strain of the geogrids tested by Watts et al. (2004). The TBR is defined as the ratio of the number of passes necessary to reach a given rut depth for a section containing reinforcement and 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 Fig. 1