# Stability of reinforced unpaved structures with geogrids reinforcements

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This study presents the contribution of geogrid reinforcements on the stability of unpaved structures. Reinforced and unreinforced unpaved structures are studied. Effects of different structure geometry such as: base layer thickness and number of geogrids layers are considered. As well as, different dual wheel trucks and different cohesion of subgrade soil are conducted. Finite element modeling is used to investigate the improvements of the load-carrying capacity of the unpaved structure due to the presence of geogrids. The results were verified with the results obtained in previous study for unreinforced structures. An extensive parametric study is conducted to examine the behavior of the unpaved structures with and without reinforcement. A design equation for obtaining the base layer thickness, including all the pertaining parameters is proposed.

يتعلق هذا البحث بدراسة اتزان وتصميم المنشآت الترابية الغير مسفلتة والتي يتم إنشائها فوق تربة ضعيفة قليلة النفاذية "تربة طينية أو طفليه" وذلك بتسليح تلك المنشآت بألواح البوليمر المعالج كيماويا(Geogrids) مع عمل مقارنة بين المنشآت المسلحة والغير مسلحة واستنتاج معادلات التصميم لكلتا الحالتين. من الدراسات والأبحاث السابقة والتي أمكن الحصول عليها تبين أن معظم الباحثين في هذا المجال ركزوا علي استخدام(Geotextile) في تسليح التربة والقليل منهم استخدم طبقة واحدة من (Geogrids) توضع بين طبقة الأساس والتربة الأساسية وقد وجد أن استخدام طبقة واحدة من التسليح لا يساعد علي تقوية المنشأ واتزانه بطريقة كافية. لذلك يتركز هذا البحث علي دراسة المنشآت الترابية الغير مسفلتة بتسليحها بطبقات من (Geogrids) توضع علي مسافات متساوية من بعضها داخل طبقة الأساس بحيث توضع أول طبقة عند السطح الفاصل بين طبقة الأساس والتربة الأساسية. وباستخدام هذه الطريقة تقل كثيرا سمك طبقة الأساس اللازمة للمنشأ تحت تأثير الأحمال العالية للعربات واللوريات عنها في حالة عدم استخدام الـ (Geogrids) لتسليح تلك الطبقة. وقد تم الأخذ في الاعتبار عند إيجاد معادلات التصميم أن تشتمل علي جميع المتغيرات التي تؤثر علي المنشأ مثل قوة تحمل التربة التي يتم عليها الإنشاء وقيمة الأحمال التي يمكن أن يتعرض لها المنشأ وعدد الطبقات المستخدمة في التسليح وكذلك تأثير الأحمال المتكررة علي اتزان المنشأ سواء كان مسلحا أو غير مسلح.

**Keywords:** Geogrids, Reinforced soil, Reinforcements, Unpaved structure, Base layer

## 1. Introduction

Since geogrid is a high strength, oriented polymer, its uses rapidly increase to improve the behavior of geotechnical structures. Unpaved roads are one of these structures that use geogrids reinforcement, especially when the base soil has insufficient bearing capacity to carry the traffic load. Unpaved roads can be reinforced by geogrids placed at various levels within the base layer and/or, more often, at base layer/subgrade interface.

Such reinforcement improves the performance of roads under heavy loads: for a given base layer thickness and a given allowable rut depth, the traffic can be increased in comparison with the allowable traffic on the same thickness of unreinforced base layer; or, for a given base layer thickness and a given traffic, the rut depth is smaller than with an unreinforced base layer. Alternatively, for the same traffic and allowable rut depth, the use of geogrid reinforcement allows a reduction in base layer thickness in comparison with the thickness required when the base layer is unreinforced; or construction of a base layer with low bearing capacity than usually required.

Most investigators working on the field of reinforced earth soil have concentrated on the use of geotextile as a reinforcing material [1-4]. Whereas some of them used geogrid as a reinforcing material [5-6] however they used one geogrid layer at base layer/subgrade interface.

Therefore, the present work focuses on the analysis and design of multi-layered reinforced unpaved structures. An extensive parametric study was carried out to investigate the influence of several parameters on the load response of reinforced unpaved structures. Finite element method adopted in the parametric study is verified and substantiated by the experimental results obtained by [5] for unreinforced structures. The parameters used include: base layer thickness, number of reinforcing layers, cohesion of subgrade soil, traffic loads and numbers of axle passages.

## 2. Theoretical background

### 2.1. Behavior and performance of unpaved roads

Generally, roads are constructed by placing a layer of aggregate, base layer, between the traffic load and the subgrade soil. The use of this layer helps to make a good distribution of traffic loads within the subgrade soil, especially, when the subgrade soil has insufficient bearing capacity. In addition, it helps to make the stress on the subgrade soil due to the traffic loads become less than the subgrade soil bearing capacity. To achieve its load distribution function, the base layer should have a sufficient thickness and adequate mechanical properties of its materials. The base layer, also, should be competent to maintain its load distribution function under repeated loads. So that, the base layer must be intact to prevent lateral or vertical displacements at the base layer/subgrade interface and the mechanical properties of its materials should be sufficient to prevent any degradation or shearing by traffic loads.

The performance of any road is considered satisfactory until its surface deformations, rut depth, are in unacceptable such that conditions for traffic. These unacceptable deformations may occur when the axle load exceeds the bearing capacity of the subgrade soil. In addition, these deformations can occur due to accumulation of small permanent deformations because of progressive use of the road and/or large deformation associated with shear failure of the subgrade soil. The damage of roads results from the progressive damage of subgrades and base layers. Progressive damage of the subgrade results from the decrease of shear strength of the subgrade soil due to fatigue generated by repeated loading. Progressive damage of the base layer results from; lateral displacement of base layer material caused by tensile and shear strains related to bending; and low confining stresses at the bottom of the base layer; migration of subsoil fine particles into the base layer aggregate; penetration of the base layer aggregate into subsoil; and, breakdown of base layer aggregate due to repeated loading and abrasion.

### 2.2. Behavior and performance of reinforced unpaved roads

As mentioned above, the behavior of unreinforced unpaved road showed that failure occurs from the base layer soil failure and/or subgrade soil failure. So that, to improve the performance of the roads, these failures must be prevented or delayed. Geogrid can improve the performance of the unreinforced road. It also, can prevent or delay the road failure by placing a layer of reinforcement at the base layer-subgrade interface or at various levels within the base layer. Geogrid can improve the behavior and performance of both the base layer and subgrade.

### 2.3. Influence of geogrids on the base layer behavior

Geogrids can improve the performance of the base layer because of its effect on the interlocking between geogrid and the base layer aggregates. This interlocking provides reinforcement to the structure, which can prevent shear failure and reduce permanent deformations of the base layer. Moreover, the interlocking influence is to: a) prevent or delay progressive failure of the base layer, b) reduce extent lateral displacements which accumulate with increasing numbers of load repetitions and thus preserving the effective thickness of the base layer, c) prevent lateral movements of aggregate, (thus preventing development of openings at the bottom of the base layer and limiting the rapidity and extent of penetration of fine subgrade soil into the aggregate), d) prevent aggregate stone from sinking into the subgrade soil, and; e) decrease the amount of aggregate breakdown, especially when weak aggregate is used.

### *2.4. Influence of geogrids on the subgrade soil behavior*

The improvement of the performance and behavior of the subgrade soil due to the use of geogrids is totally different than the improvement in the base layer due to the use of geogrids. Geogrids improve the subgrade soil performance through changes in the boundary conditions, i.e., applied stresses and deformations. This improvement occurs through three mechanisms:

*(i) Confinements,* geogrids provide confinement to the base layer through its small openings and thus deformations resulting from local shear failure.

*(ii) Load distribution,* as previously explained, due to the contribution of geogrids to improve the base layer behavior, geogrids increase the stiffness of the base layer, reduce lateral displacements and prevent aggregate separation and sinking. The result is a stiffer base layer and therefore an ability to provide a better load distribution than that possible with unreinforced base layer, and;

*(iii) Tension membrane effect,* If the subgrade soil is incompressible; such as saturated clay, deformation of the subgrade soil under the wheels causes heave between and beyond the wheels. Therefore, the geogrid exhibits a wavy shape; consequently, it is stretched. When a stretched flexible material has a curved shape, normal stress against its concave face is higher than normal stress against its convex face. This is known as the "tensioned membrane effect". Therefore, between the wheels and to a lesser extent beyond the wheels, the normal stress applied by the geogrid on the subgrade is higher than the normal stress applied by the base layer on the geogrid. Where under the wheels, the normal stress applied by the geogrid on the subgrade is smaller than the normal stress applied by the wheels plus the base layer on the geogrid. This action provides two beneficial effects, confinement of the subgrade soil between and beyond the wheels, and reduction of the stress applied by the wheels on the subgrade. The stress reduction resulting from the tensioned membrane effect is effective if traffic loads are repeated at exactly the same location (i.e., if the traffic is channelized), and if the tensile stress in the reinforcement does not decrease with time (i.e., if the reinforcement has low creep susceptibility at working loads).

Geogrid can reduce subgrade soil deterioration by reducing the magnitude of repeated deformation of the structure, thereby reducing disturbance of the subgrade soil and, consequently, fatigue occurs, resulting in a progressive decrease in shear strength of the subgrade soil.

## 3. Modeling parameters

Fig. 1 depicts the geometry of unpaved structure used in the analysis.

The base layer materials consist of sharp shaped aggregates, which have adequate properties to ensure a good distribution of the applied load over the subgrade soil. In practice, the California Bearing Ratio (CBR) of the aggregate should be greater than 80.

The mechanical properties of the geogrids used in this work are defined by the average tensile stiffness, k, for longitudinal and transverse directions of the geogrid layer. The geogrid layers are arranged within the base layer in even space. The first geogrid layer is placed at the base layer/subgrade interface.

The subgrade soil used in this study is a soft to stiff clay or silt, which have low permeability and saturated. The subgrade soil, also, assumed to be homogenous, at least over a thickness, D, sufficient to allow development of subgrade soil failure. The thickness, D, can be estimated using bearing capacity analysis which shows that D is usually less than 1.50 m [5, 6] The properties of subgrade soil are defined by its cohesion, $c_u$.

Dual wheel trucks are the common vehicles used in unpaved structures. Therefore, the dual wheels are adopted in this work. The traffic is considered to be channelized, which can be characterized by the number of

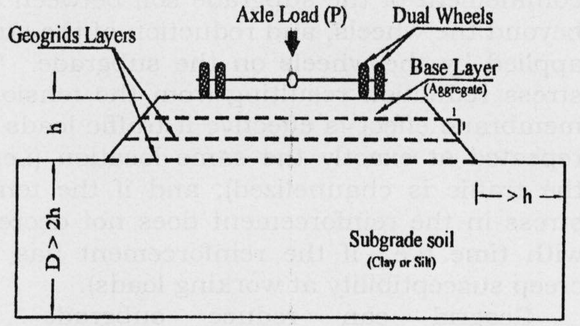

Fig. 1. Geometry of unpaved structure.

passages, N, for a given axle load, P, during the lifetime of the structure.

## 4. Theoretical study

Finite element technique was adopted throughout this analysis. Plane-strain six-node bilinear elements were used to model both subgrade and base layers soil elements. Geogrids elements were modeled by using three node truss elements. Using a three node per side interface elements treated the connection between geogrid elements and soil elements. Introducing a friction coefficient and a shear limit simulating the friction between the surfaces of geogrid and soil elements.

The boundary conditions imposed were:

i) The base nodes were restrained in the horizontal and vertical directions; and,

ii) The left-hand and right-hand side nodes were prevented to move in the horizontal direction. Multi-point constraints were used to join the soil elements to the geogrid elements along the geogrid layers.

The program was controlled by a maximum vertical displacement, rut depth, of 75 mms, and a minimum thickness of base layer ($h_o$) of four inches.

## 5. Results

Fig. 2 shows the relation between the base layer thickness ratio, R (where: R= $h/h_o$, h is the base layer thickness, and $h_o$ is the minimum thickness of base layer which equal four inches) and the subgrade soil cohesion, $c_u$ for reinforced and unreinforced base layer. The results of reinforced and unreinforced unpaved structures showed that the subgrade soil cohesion have a significant effect on the base layer thickness ratio, R for low strength subgrade soil and moderate effect for high strength subgrade soil as shown in fig. 2. For instance, the reduction in R for unreinforced structure was 35% (from 12.07 to 7.8 for $A_p$= 1 and N = 1000) when $c_u$ increased from 10 to 20 kN/m$^2$ while it was 6% when $c_u$ increased from 90 to 100 kN/m$^2$ (from 3.02 to 2.83) under the same conditions. Also, the results showed a significant reduction in R due to the presence of reinforcement under many cases of axle load passages, N. Fig. 3 illustrates the relation between the number of axle load passages, N and the base layer thickness ratio, R. Comparing with unreinforced structure, the base layer thickness ratio, R reduced by about 17% (from 12.07 to 10.05 for $A_P$= 1, N = 1000, and $c_u$ = 10 kN/m$^2$) when one geogrid placed at base layer/subgrade interface and by 39% (from 12.07 to 7.31), 52% (from 12.07 to 5.71) and 60% (from 12.07 to 4.85) when the base layer reinforced by two, three and four geogrids layers, respectively under the same conditions. This reduction occurred due to the contribution of reinforcement to increase the horizontal stiffness of the structure, which developed confining stresses within the soil mass and thus, reduced the required base layer thickness. Furthermore, reinforcing the base layer has a great effect on reducing the ratio R under different axle loads as shown in fig. 4.

## 6. Parametric study

The parametric study conducted in this work includes the following design parameters: the subgrade soil cohesion strength, $c_u$; number of axle passages, N; axle load, P, in terms of $A_p$ (where: $A_p$ = $P/P_s$ and $P_s$ is the standard axle load which equals 80 kN) and the number of geogrid layers, n.

## 7. Design formula for the base layer thickness

All the parameters included in this work showed a great effect on the base layer thickness.

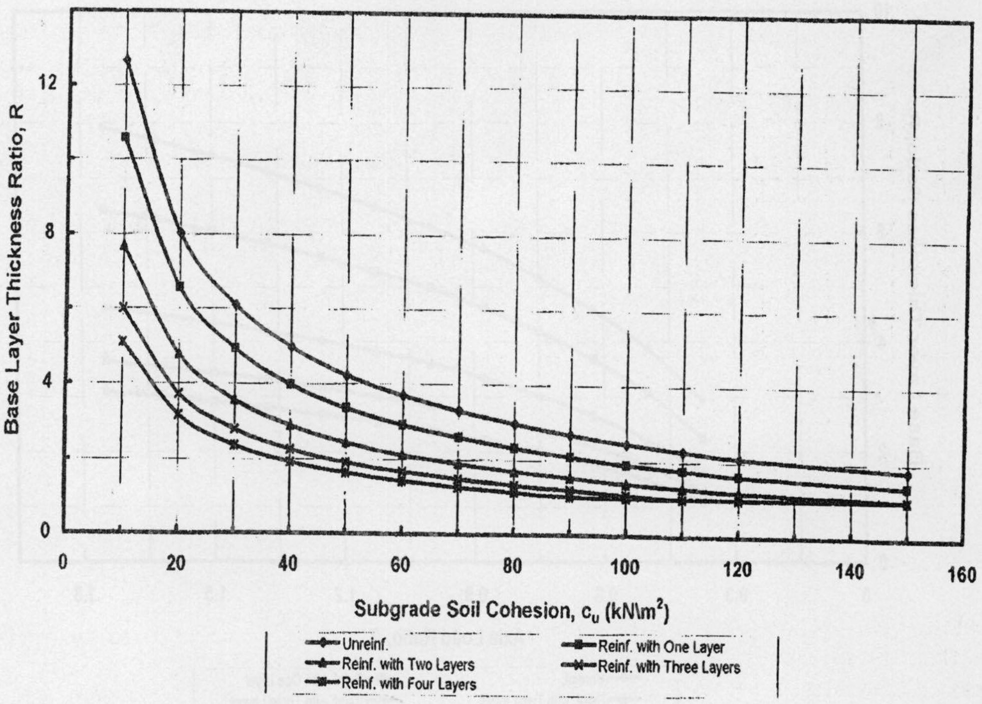

Fig. 2. Relation between base layer ratio, R and subgrade soil cohesion, $c_u$.

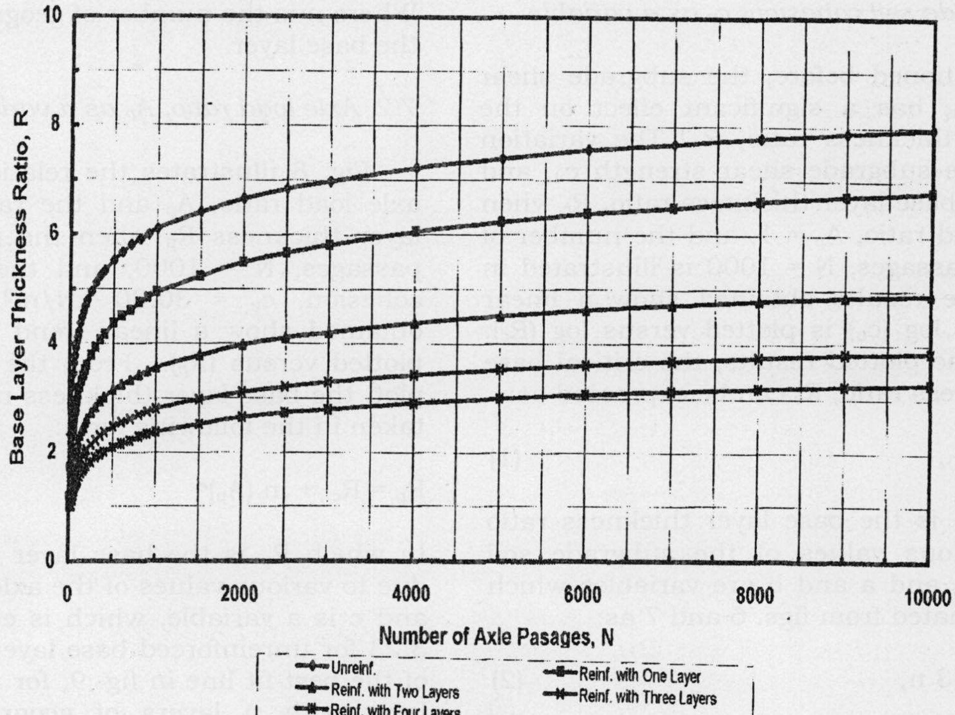

Fig. 3. Relation between base layer ratio, R and number of axle passages, N ($c_u$=30.00 kN\m$^2$ and $A_p$=1).

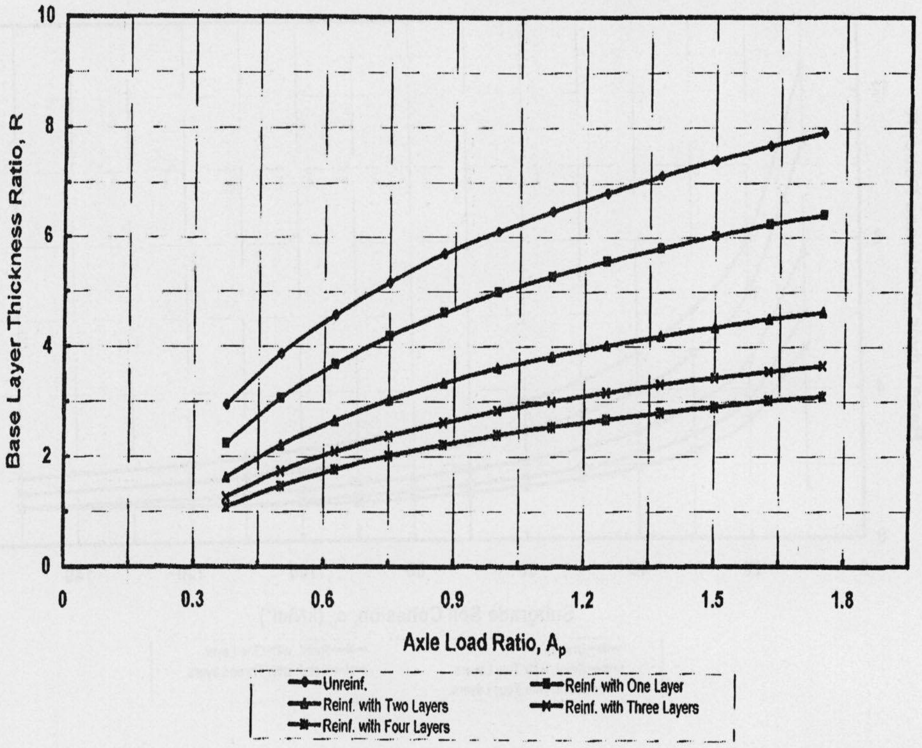

Fig. 4. Relation between base layer thickness ratio, R and axle ratio $A_p$ ($c_u$=30.00 kN\m² and N=1000).

### 7.1. *Subgrade soil cohesion, $c_u$ as a variable*

As mentioned before, the subgrade shear strength $c_u$, has a significant effect on the base layer thickness ratio, R. The variation between the subgrade shear strength $c_u$, and the critical base layer thickness ratio, $R_c$ when the axle load ratio, $A_p$ = 1, and the number of axle load passages, N = 1000 is illustrated in fig. 5. The results obtained show a linear trend when log ($c_u$) is plotted versus log ($R_c$). Based on the plotted results, the critical base layer thickness ratio, $R_c$ can be expressed as:

$$R_c = e^a/(c_u)^b . \quad (1)$$

In which $R_c$ is the base layer thickness ratio due to various values of the subgrade soil cohesion, $c_u$ and a and b are variables which can be estimated from figs. 6 and 7 as:

$$a = 4.35 - 0.3\ n, \quad (2)$$

$$b = 0.75 - n/59. \quad (3)$$

Where n is the number of geogrids used within the base layer.

### 7.2. *Axle load ratio, $A_p$ as a variable*

Fig. 8 illustrates the relation between the axle load ratio, $A_p$ and the ratio of the base layer thickness $R_p$ when the number of axle passages, N = 1000, and the subgrade soil cohesion, $c_u$ = 30.00 kN/m². The results obtained show a linear trend when log($A_p$) is plotted versus ($R_p$). From the best fit of this plot, the base layer thickness ratio, $R_p$ may be taken in the following form:

$$R_p = R_c + \ln (A_p)^c. \quad (4)$$

In which $R_p$ is the base layer thickness ratio due to various values of the axle load ratio, $A_p$, and c is a variable, which is estimated to be: 3.23 for unreinforced base layer and the slope of the best-fit line in fig. 9, for reinforced base layer with n layers of geogrids which are estimated as:

$$c = \ln \{14.73 * (n^{-1.02})\}. \quad (5)$$

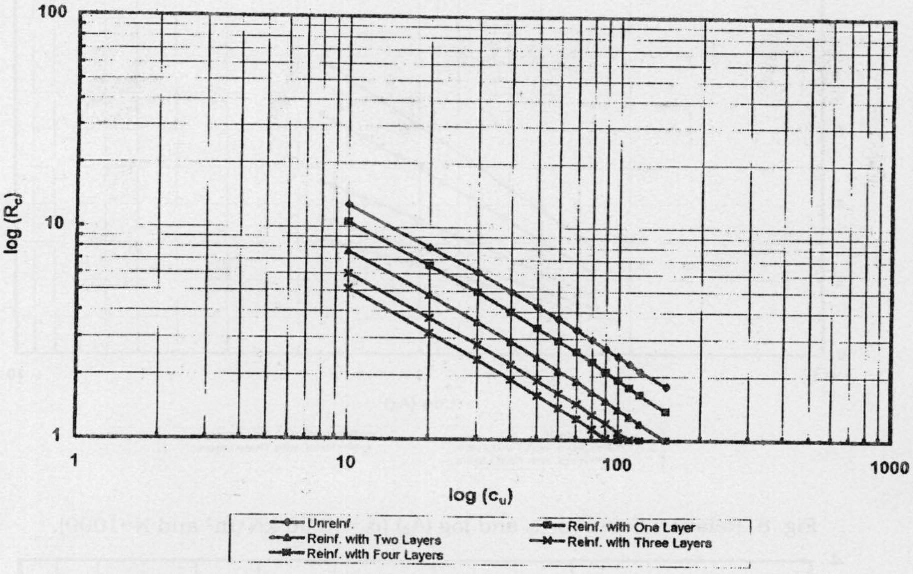

Fig. 5. Relation between long ($R_c$) and ($c_u$) ($A_p$=1 and N=1000).

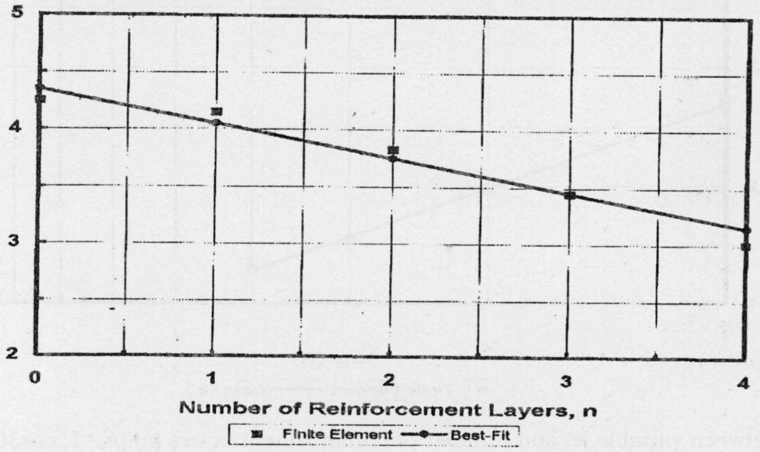

Fig. 6. Relation between variable (a) and number of reinforcement layers (n) ($A_p$=1, $c_u$=30 kN\m² and N=1000).

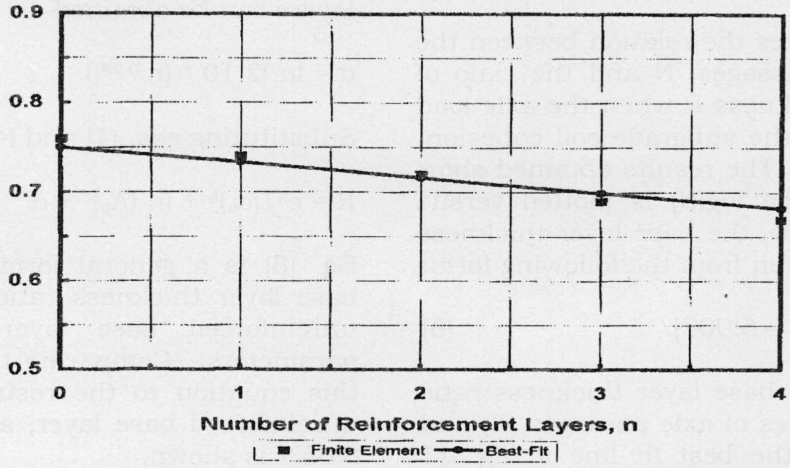

Fig. 7. Relation between variable (b) and number of reinforcement layers (n) ($A_p$=1, $c_u$=30 kN\m² and N=1000).

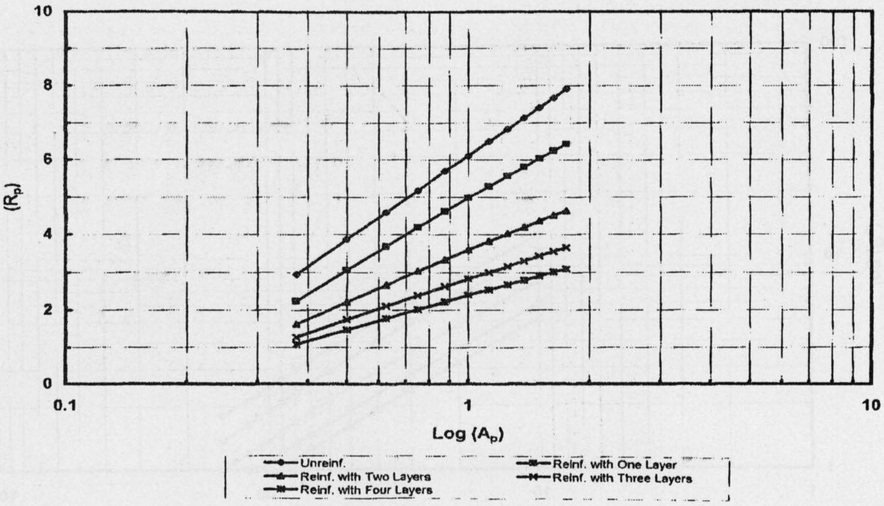

Fig. 8. Relation between $R_p$ and log ($A_p$) ($c_u$=30.00 kN\m$^2$ and N=1000).

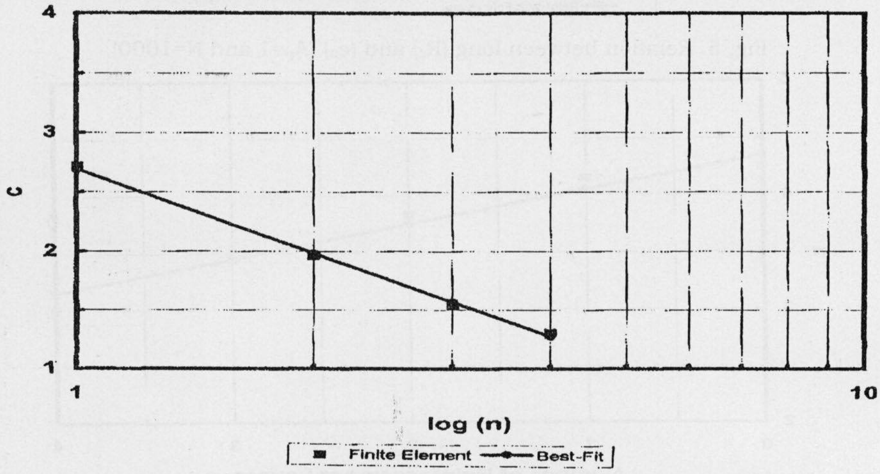

Fig. 9. Relation between variable (c) and number of reinforcement layers (n) ($A_p$=1, $c_u$=30 kN\m$^2$ and N=1000).

### *7.3. Number of axle passages, N as a variable*

Fig. 10 illustrates the relation between the number of axle passages, N and the ratio of the base layer thickness R when the axle load ratio, $A_p$ = 1, and the subgrade soil cohesion, $c_u$ = 30.00 kN/m$^2$. The results obtained show a linear trend when log(N) is plotted versus ($R_N$). From this plot, the base layer thickness ratio, $R_N$ may be given from the following form:

$$R_N = R_P + d * [\ln (N) - 6.907]. \qquad (6)$$

In which $R_N$ is the base layer thickness ratio due to various values of axle passages, N, and d is the slope of the best fit line in fig. 11 which is estimated to be 0.78 for unreinforced base layer and for reinforced base layer with n layers can be obtained as:

$$d = \ln \{2.10 * (n^{-0.28})\}. \qquad (7)$$

Substituting eqs. (1) and (4) into eq. (6) yields:

$$R = e^a/(c_u)^b + \ln (A_p)^c + d * [\ln (N) - 6.907]. \qquad (8)$$

Eq. (8) is a general formula to evaluate the base layer thickness ratio for reinforced and unreinforced base layer due to different parameters. Comparing the results based on this equation to the results given by [5] for unreinforced base layer, a difference of about 8.65% is shown.

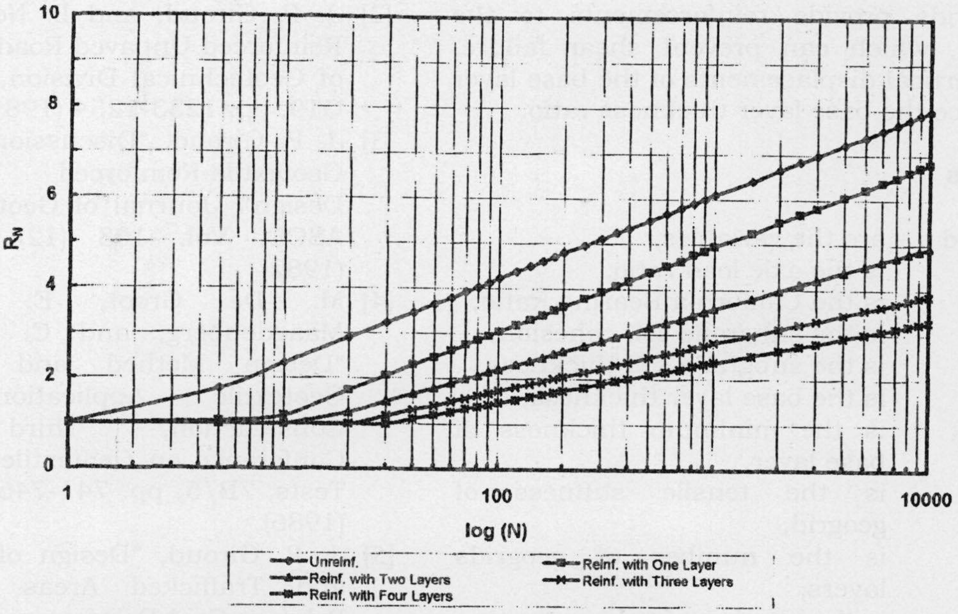

Fig. 10. Relation between ($R_N$) and log (N) ($c_u$=30.00 kN\m$^2$ and $A_p$=1).

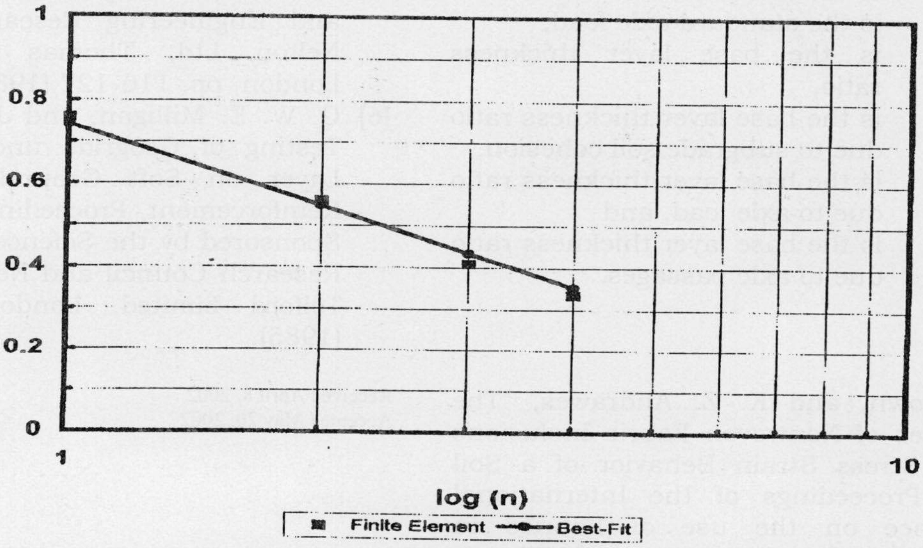

Fig. 11. Relation between variable (d) and number of reinforcement layers (n) ($A_p$=1, $c_u$=30 kN\m$^2$ and N=1000).

## 8. Conclusions

From the theoretical results presented, the following conclusions can be made:

1. The low levels of subgrade soil cohesion, $c_u$ have a great effect on the base layer thickness ratio, R.
2. The high levels of subgrade soil cohesion; $c_u$ has a moderate effect on the base layer thickness ratio, R.
3. The axle load ratio, $A_p$ has a significant effect on the base layer thickness ratio, R. It increases as the axle load ratio increases.
4. Increasing the number of axle passages, N leads to increasing the base layer thickness ratio, R.
5. Increasing the reinforcement layers, n, helps in increasing the stiffness of base layer and hence the increase of the load carrying-capacity of the structure than those without reinforcement with the same base layer thickness.

6. Geogrids provide reinforcements to the structure, which can prevent shear failure, reduce vertical displacements of the base layer and reduce the base layer thickness ratio.

## Notations

| | |
|---|---|
| a, b, c and d | are the variables, |
| $A_p$ | is the axle load ratio, |
| CBR | is the California Bearing Ratio, |
| $c_u$ | is the subgrade soil cohesion, |
| D | is the subgrade soil thickness, |
| h | is the base layer thickness, |
| $h_o$ | is the minimum thickness of base layer, |
| k | is the tensile stiffness of geogrid, |
| n | is the number of geogrids layers, |
| N | is the number of axle passage, |
| P | is the axle load, |
| $P_s$ | is the standard axle load, |
| R | is the base layer thickness ratio, |
| $R_c$ | is the base layer thickness ratio due to subgrade soil cohesion, |
| $R_p$ | is the base layer thickness ratio due to axle load, and |
| $R_N$ | is the base layer thickness ratio due to axle passages. |

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