Influence of Repeated Loading and Geosynthetic Reinforcement on Base Course Thickness over Soft Soil

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Abstract— **Vehicle wheels at surface of pavement will pass through it many times. Pavement or base course over soft soil always needs a reinforcement. Influence of repeated loading to thickness of base course and base course reinforced by geosynthetic is presented. Several existing methods as Giroud-Han, USA Corps of Engineers and DuPont Typar method respectively to calculate thickness of base course over soft soil using reinforcement material either geotextile or geogrid is presented and the influence of repeated loading will be compared. Results from calculation and analysis indicate that Giroud-Han method gives thickness of base course higher than other methods when CBR values of subgrade at least 2 %.**

Keywords— **Base course; geosynthetic; repeated loading; reinforcement; soft soil.**

I. INTRODUCTION

Loading at surface of pavement is repeated loading. It will be distributed at the surface of subgrade layer. When subgrade is soft soil, reinforcement using geosynthetics are usual be done as a treatment. Type of reinforcement for soft soil is *restraint subgrade* whereas reinforcement for base course is *base course reinforcement*. Influence of repeated loading over pavement reinforced geosynthetic at surface of subgrade is presented. Subgrades having low bearing capacity lower than CBR 3 % is poor soil even soft soil. Bearing capacity of subgrade can also use another parameter namely undrained shear strength (Cu). The soil is soft soil when Cu value is lower than 25 kPa.

Because of repeated loading, thickness of base course becomes higher than only subjected by static loading. Soil reinforcement using geosynthetic material (geotextile and/or geogrid) accommodated in some methods as Giroud-Han, USA Corps of Engineers and DuPont Typar method respectively, but they give divergence results. For instance USA Corps of Engineers is applied for low traffic originally in the forest region particularly in USA and did not accommodate the repeated loading and DuPont Typar method only focuses on reinforcement using geotextile. Otherwise Giroud-Han method offers for design of soil reinforcement using both geotextile and geogrid and also accommodate the repeated loading of vehicles. The last method is a improvement of previous one so-called Giroud-Noiray method [1].

In some parts in the world are covered by soft soils either peat or organic soil. In south east of Asia for peat soil there is more or less 20 million hectares and in Indonesia almost 30 percent of land area was covered by soft soil comprising of peat and organic soil [2]. Use of geosynthetic can increase the bearing capacity of base course at top surface for case of soil improvement and on the other hand it can also reduce the thickness of base course for case of base course reinforcement [3].

II. LITERATURE REVIEW

Some researchers have given formulas to the bearing capacity of soil based on unconfined compressive strength and/or undrained shear strength as a parameter. Although other parameters like CBR or R-value is often met in the pavement design

2.1. Bearing Capacity of Soft Soil

Bearing capacity for soft soil can be revealed as CBR, Cu and qu. Bearing capacity for soil without confining pressure is :

$$qu = 2 \cdot Cu \qquad (1)$$

Before a complete failure of soil subgrade occurs, local-stressing in shear takes place and results in punching shear failure or local failure in the soil. The bearing capacity of the subgrade under such conditions is low and can be quantified by

$$qu = \alpha \cdot Cu \qquad (2)$$

When localized shear failure of the subgrade can be prevented in the case any reinforcement for soil (i.e. a general shear failure can be reached), the bearing capacity of the subgrade can be increased to

$$qu = \beta \cdot Cu \qquad (3)$$

Several methods give value of α and β as shown Table 1.

TABLE 1
BEARING CAPACITY OF SUBGRADE

Researchers and/or Sources	Unreinforced	Reinforced
Giroud and Noiray (1981)	qu = 3.14 Cu	qu = 5.14 Cu
Barenberg (1992)	qu = 3 Cu	qu = 6 Cu
Philips (1987)	qu = 2.8 Cu	qu = 5. Cu
Rodin (1965)	qu = 3.14 Cu	qu = 6.2 Cu
DuPont Typar SF (2010)	qu = 3.14	qu = (2+π) Cu
Roadex III (2008)	qu = 4 Cu	-

Empirical relation between CBR value and undrained shear strength can be used if subgrade value is provided :

$$Cu = 30 \cdot CBR \qquad (4)$$

Many conventional pavement design methods can be applied when subgrade has CBR value minimum 3 %. In this paper, Austroads (1992) using chart method to calculate thickness of base course is presented as a comparison with other methods.. The method presents thickness of unreinforced base course. Minimum CBR value for subgrade in this design method is 2 %. It is impossible to design thickness of pavement if subgrade has the bearing capacity (CBR value) below 2 % as shown in Figure 1.
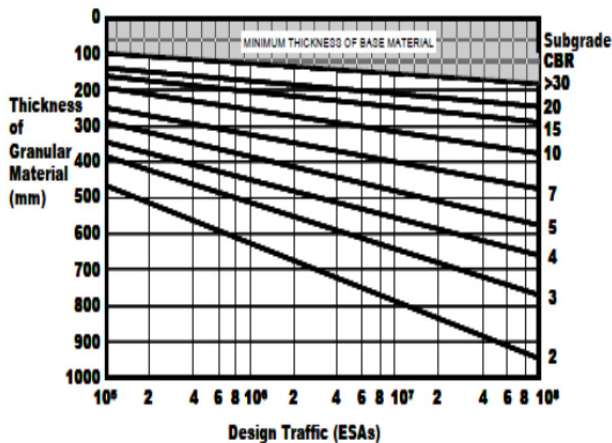

Fig. 1 Pavement thickness chart for thin-surface granular [4]

2.2. Geosynthetic reinforcement

J.P. Giroud and Jie Han (2004) published a design method in the August edition of the American Society Civil Engineers ([1],[7]).

$$h = \frac{0.868 + (0.661 - 1.006 J^2)\left(\dfrac{r}{h}\right)^{1.5} \log N}{\left[1 + 0.204\left(\dfrac{3.48 CBR_{bc}^{0.3}}{CBR_{sg}} - 1\right)\right]} \left(\sqrt{\frac{\dfrac{P}{\pi r^2}}{\dfrac{s}{f_s}\left[1 - 0.9 e^{-\left(\frac{r}{h}\right)^2}\right] N_c f_c CBR_{sg}}} - 1\right) r \qquad (5)$$

where:
  Nc = 3.14 and J=0 for unreinforced base course
  Nc = 5.14 and J=0 for geotextile-reinforced base course
  Nc = 5.71 and J=0.32 m-N/degree for Tensar BX 1100 reinforced base course
  Nc = 5.71 and J=0.65 m-N/degree for Tensar BX 1200 reinforced base course

In February 2003, the Corps of Engineers published a design method consideration the use of geogrids and geotextiles for paved and unpaved roads [1]. Its approach for unpaved surface based on methodology originally by US Forest Service, distinguishes the performance of geogrids and geotextiles as reinforcement component. Bearing capacity factor, Nc, for the geosynthetic type being considered. The corps recommended the following Nc values: Nc = 2.8 without a geosynthetic, Nc= 3.6 with a geotextile for conservative designs an Nc= 5.8 with a geogrid.

The in situ shear strength can be measured directly using vane shear devices or indirectly using bearing capacity correlation from California Bearing ratio (CBR) or Dynamic Cone Penetrometer (DCP) tests. The 75th percentile strength is the value at which 75 percent of recorded soil strength readings are higher than this value. Figure 2 can be used to convert design strength from cone index values and CBR to shear strength (C) in psi.
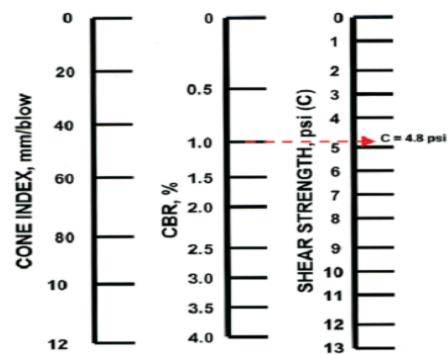

Fig. 2 Relationship between cone index,CBR and shear strength [5]

$$\text{Subgrade bearing capacity } = C \cdot Nc \qquad (6)$$

This method uses graphical way to determine thickness of reinforced base course depending on wheel configuration.

DuPont Typar SF [5] presents a design method using geotextile to calculate thickness of reinforced base course. Bearing capacity for soft soil can use the correlation chart for estimating the subgrade CBR value as Figure 3 below.
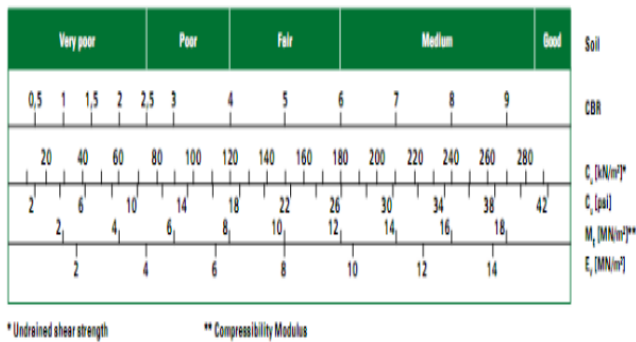

Fig. 3 Correlation chart for estimating the subgrade CBR value [6]

Factors to determine To using this method as shown in Table 2 and thickness of base course for To is equal to repetition 1000 times.

TABLE 2

FACTORS TO DETERMINE To [5]

Thickness of reinforced base course using this method is

$$T = C.To = (0.27\log(\Sigma Ni.ESAL) + 0.19)To \qquad (7)$$
$$ESAL = (Pi/Po)^{3.95} \qquad (8)$$
$$Ne = \Sigma Ni . ESAL \qquad (9)$$

III. CALCULATION OF BASE COURSE THICKNESS

Thicknesses of base courses using input parameters for reinforced and unreinforced base courses which subjected by repeated loading with some methods are presented.

3.1. Input Data for Calculation

Input data for calculation using several design methods to calculate thickness of base course without reinforcement and with reinforcement are needed. Input data comprise of axle load, wheel configuration, bearing capacity of subgrade, number of load passing. Input data used in this calculation as presented in Table 3 below.

TABLE 3
MAIN INPUT DATA FOR CALCULATION

Input Data	Value	Unit
Standar Axle load	80	KN
Tire pressure	82	psi
Number of passes	1 to 1.000.000	-
Base course strength	CBR 80	%
Subgrade strength	CBR 0.5 to 4	%
Radius of tire contact	15	centimeter
Rut depth	50.8	milimeter

3.2. Thickness of Base Course

Calculations for thickness of base course using several methods both reinforced and unreinforced are presented in Table 4(a) to 4(c) below. These tables comprise of three kind of analysis i.e., thickness of unreinforced base course, thickness of geotextile reinforced base course and thickness of geogrid reinforced base course.

TABLE 4 (A)
THICKNESS OF UNREINFORCED BASE COURSES

CBR sg (%)	Thickness of Unreinforced Base Courses for N in mm							
	Austroads Method		Giroud Han Method				USACoE Method	DuPont Typar SF
	10^5	10^6	N=1	10^3	10^5	10^6	N=1	To=> N=10^3
0.5	>470	>625	120	383	462	494	686	405
1	>470	>625	170	467	548	581	508	289
1.5	>470	>625	199	502	584	617	432	232
2	470	625	200	514	597	630	355	201
2.5	430	580	190	516	599	633	317	192
3	390	510	166	510	595	628	279	184
3.5	370	485	138	444	588	620	254	175
4	350	450	119	432	578	610	229	167

Table 4 (b) and Table 4 (c) indicate the thickness of base course using reinforcement of geotextile and geogrid respectively for several methods as previously mentioned.

TABLE 4 (B)
THICKNESS OF REINFORCED BASE COURSES USING GEOTEXTILE

CBR sg (%)	Thickness of BaseCourses Using Geotextile for N in mm								
	USACoE Method	Giroud Han Method				DuPont Typar SF			
	N=1	N=1	10^3	10^5	10^6	N=1	10^3	10^5	10^6
0.5	635	80	290	365	394	77	405	624	733
1	432	90	346	426	458	55	289	446	524
1.5	343	90	366	449	482	44	232	357	419
2	305	84	370	455	489	38	201	309	364
2.5	254	78	366	453	486	36	192	296	348
3	229	71	357	445	479	35	184	283	333
3.5	203	66	345	435	470	33	175	270	317
4	191	58	331	423	458	32	167	257	302

TABLE 4 (C)
THICKNESS OF REINFORCED BASE COURSES USING GEOGRID

CBR sg (%)	Thickness of Base Courses Using Geogrid for N in mm								USACoE Method
	Giroud-Han Method								
	Geogrid Uniaxial TX110				Geogrid Biaxial BX220				
	N=1	10^3	10^5	10^6	N=1	10^3	10^5	10^6	N=1
0.5	74	253	321	350	74	171	215	234	483
1	82	300	375	405	82	202	255	278	305
1.5	80	316	395	426	80	209	268	292	228
2	75	317	398	430	75	205	268	293	190
2.5	69	310	394	427	69	194	259	286	152
3	63	301	386	418	63	179	246	274	100
3.5	56	286	374	407	56	163	230	259	89
4	50	271	361	395	50	146	214	243	89

IV. RESULTS AND DISCUSSIONS

4.1. Bearing Capacity

Bearing capacity for very poor soil using Barenberg chart is lower than CBR 2.5 % and poor soil between 2.5 and 4 % in CBR value. Bearing capacity in several methods use undrained shear strength (Cu) therefore empirical relation for CBR value and Cu value have to be taken. Undrained shear strength is taken 30 times CBR value.

4.2. Thickness of Base Course

From Table 4 above can be depicted the trend line in other to give illustration better. Thickness of unreinforced base course from three methods namely Austroads, Giroud-Han and US Army Corps of Engineer respectively as shown in Figure 4.
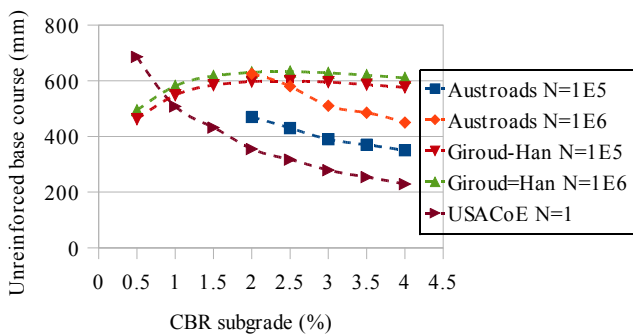

Fig. 4 Thickness of unreinforced base course

Thickness of unreinforced base course using US Army method is lowest for CBR subgrade value more than 2 %. Thickness base course using Giroud-Han method is highest but for CBR subgrade values lower than 2 % indicate wrong trend line because softer subgrades will need thicker base course layers. Thickness resulted from Giroud-Han is higher than thickness using Austroads method for the same number of repetition N=1E5 and N=1E6.

Thickness of geotextile reinforced base course from three methods namely Giroud Han , US Army, DuPont Typar as shown in Figure 5.
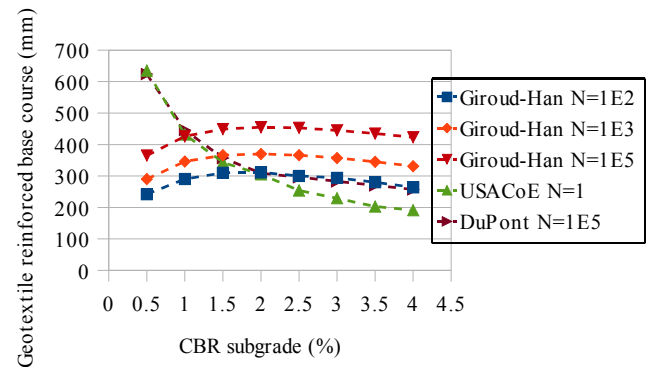

Fig. 5 Thickness of geotextile reinforced base course

Thickness of geotextile reinforced base course using USArmy Corps of Engineer is lowest. In contrary, Giroud-Han method gives the highest. It is interesting that the thickness for CBR subgrade values more than 2 % between the method of DuPont N=1E5 and Giroud-Han method N=1E2 superimposes each other whereas CBR subgrade values lower than 2 % between US Army Corps of Engineer and DuPont Typar SF N=1E5. Furthermore, Giroud-Han method gives wrong trend line for CBR subgrade lower than 2 %.

Thickness of geogrid reinforced base course from three methods namely Giroud-Han, US Army Corps of Engineer, DuPont Typar as depicted in Figure 6.
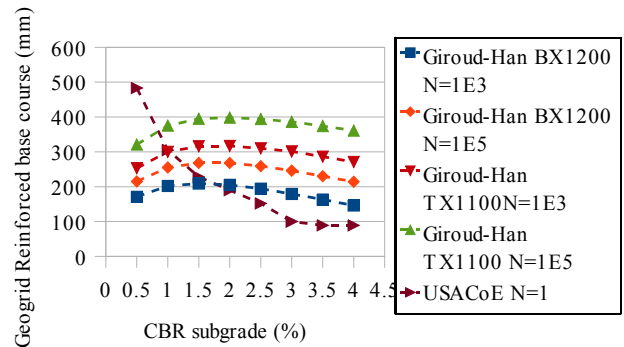

Fig. 6 Thickness of geogrid reinforced base course

Geogrid reinforcement for biaxial gives lower thickness of base course than uniaxial using Giroud-Han method. It is like previous trend line using Giroud-Han method indicates wrong trend line for CBR subgrade lower than 2 %. It is also similar trend line for US Army Corps of Engineers method that presents lowest result.

V. CONCLUSIONS

From description and explanation above that Giroud-Han method gives a design pavement method relatively safe than other for CBR subgrade value more than 2 % and misleading when applied on lower CBR values of subgrade . US Army Corps of Engineer method actually be applied for low traffic

volume so that gives lowest thickness of base course. Finally, Austroads method actually is not addressed for designing pavement on soft soil. Herein, it is aimed to make comparison when CBR subgrade at least 2 % and more. Geogrid reinforcement give higher reduction of base course thickness than geotextile as well biaxial geogrid than uniaxial one.

NOMENCLATURE

qu	unconfined compressive strength	kPa
Cu	undrained shear strength	kPa
CBR	california bearing ratio	%
h	required base course thickness	m
J	geogrid aperture stability modulus	m-N/degre
N	number of axle passes	[-]
P	wheel load	kN
r	radius of equivalent tire contact area	m
s	allowable rut depth	mm
fs	factor equal to 75 mm	[-]
Nc	bearing capacity factor	[-]
C	cone index value	[-]
T	thickness	[-]
ESAL	equivalent single axle load	[-]
Po	standard axle load	80 kN
Pi	actual number of passes	[-]
Ni	actual number of passes	[-]
To	compacted crushed stone thickness	m

Greek letters

α	constant	[-]
β	constant	[-]

Subscripts

sg	subgrade
bc	base course

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