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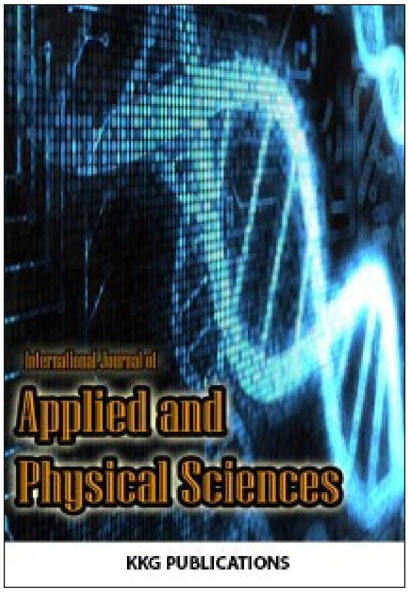

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Experimental Modelling of a Reinforcement Theoretical Model on Peaty Soils

ALI A. MAHMOOD [1], LENNY LIM EE CHUNG [2]

[1, 2] Department of Civil Engineering, University College of Technology Sarawak, Sarawak, Malaysia

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EXPERIMENTAL MODELLING OF A REINFORCEMENT THEORETICAL MODEL ON PEATY SOILS

ALI A. MAHMOOD [1]*, LENNY LIM EE CHUNG [2]

[1, 2] Department of Civil Engineering, University College of Technology Sarawak, Sarawak, Malaysia

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Abstract. Peaty soils are highly organic soils with high moisture contents, low shear strengths and high compressibility. It was shown through years of experience that construction on such soils will yield unexpected failures. Several researchers have undertaken studies to investigate the reinforcement effects of various geosynthetics. Peat however was less investigated especially with regards to geogrid reinforcement. Since peat covers an appreciable area in Malaysia and several other countries, this study is an attempt to evaluate the applicability of using Giroud and Han's [1] model for the design of unpaved roads on Malaysian peaty soils. It was found that as the tire inflation pressure increased and as the subgrade shear strength decreased, more aggregate thickness was required to offset settlements. It was shown that, although this model was applicable to these soils, a separate theoretical model addressing the particular qualities of peaty soils, should be attempted. Geotechnical engineers working in this field are advised to analyze and document tire inflation pressures and subgrade strengths as a prerequisite to constructing reinforced unpaved roads. Also it is advisable to investigate the effect cyclic loading has on reinforced peaty soils.

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INTRODUCTION

Peaty soils are soils that contain a large percentage of organic matter (peat). These soils are ubiquitous in Malaysia. Constructing highways on these soils is more problematic due to their lower shear strength, higher compressibility and higher water content, relative to typical inorganic soils. Peaty soils are formed from dying and decomposed plant remains. This is done through an anaerobic process, where oxygen is used up for decomposition [2]. The formation of peat soil results from decomposed matter, which is left for a long period of time [3]. The degree of peat decomposition depends on other conditions, as well, such as temperature and aeration of the region, chemistry of surrounding water and biochemical stability of the peat forming plants [4]. Peat can be classified into three types, according to its degree of humification or decomposition; fibric, hemic and sapric. Fibrous peat is highly organic and the fiber content is characterized by a low degree of humification. It contains low decomposed fibrous materials and is extremely acidic. While sapric peats have more decomposed peat material, the plant fibers are less and the water holding capacity is generally less than fibrous and hemic. Hemic is in intermediate decomposition, while sapric, known as amorphous is the most decomposed and contains less than 33% of fibre content. Fiber, temperature and humidity of peat differ and vary spatially [5]. It is also quite stable in its physical properties [2]. Peat is formed by decomposition of organic matter from plants and animals. It has high capacity for taking up and holding water.

Due to its high water content, it has low bulk density and low bearing capacity [6]. Peat soils have low shear strength and high compressibility due to their structural composition [2]. Peat soils have high moisture content and low bearing capacity, which make them poor foundation material for construction. Construction on peat without proper treatment could lead to sever structural problems such as immediate settlement and long term secondary compression [7]. Studies have showed that the engineering properties of peat soils may be enhanced by chemical stabilization. For example Aminur et al. [8] have shown Ordinary Portland cement (OPC) to be an effective stabilizer for local peat or organic soils. Additionally, there have been research studies using fly ash and gypsum to stabilize peaty soils. Tests were conducted by using varying amounts of fly ash and gypsum, to find the suitable amount of admixture needed. Results showed that through the addition of fly ash and gypsum, strength of peaty soils increased substantially with the curing period [9]. Other researchers used a mixture of OPC, Ground Granulated Blast Furnace Slag (GGBFS) and siliceous sand. They showed that the admixture was capable of increasing the unconfined compressive strength and reducing initial permeability of the peaty soil [10]. It was found that the tested peaty soil's plastic limit, liquid limit and plasticity index were decreasing

*Corresponding author: Ali A. Mahmood
†Email: alimahmood45@yahoo.ca

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with the increase of the amount of additives. Also, swelling of the soil decreased when the amount of additives was increased [11] Mahmoud [12]. Another study by Mahmoud [12] showed that by adding lime and OPC to peat, strength was improved. These additives were added to a peat soil sample, as percentage of the dry soil mass in the amounts of 10%, 30% and 50%. With the increase of the percentage of additives, the maximum dry density of soil and unconfined compressive strength was seen to increase. The experimental results showed that OPC had better stabilizing characteristics than hydrated lime [13]. Other researchers [14] have used geotextile as a reinforcement for a model unpaved road on a peaty soil to validate the applicability of Burd's [15] and Love's [16] analytical models. They showed that these models are applicable prediction tools for stresses and strains on this type of peaty soil. Others [17] used geogrids to evaluate the in-soil tensile loads, while Harikumar et al. [18] and Yusuf et al. [19] used multi-directional reinforcing elements to reinforce a model footing on sand. They proved that these reinforcing elements are a viable alternative to the conventional planar geosynthetics. The objective of this study is to validate the applicability of the theoretical model: Giroud and Han [1] in analysing Malaysian peaty soils. The results will be used to give thickness design recommendations to practicing engineers when constructing unpaved roads on peaty soils.

THEORETICAL MODELLING OF SOILS

In order to construct structures over soft or peaty soils, the use of geogrid reinforcement is introduced. A geo grid is defined as a geo synthetic material consisting of connected parallel sets of tensile ribs with apertures of sufficient size to allow the strike through of surrounding soil, stone or geo technical materials. The use of geo grids also has the same benefits when compared to excavation and replacement with select material. In this context, several design methods were used to design the geo synthetic reinforcement soil sections. These include the Giroud and Han's [1] and U.S. Army Corps of Engineer's [20] design methods.

Giroud and Han [1] and Giroud and Noiray [21] proposed a design method to calculate the required thickness of graded aggregate for unpaved road and sub grade stabilization design. Publication of the design method in 2004 in the ASCE Journal of Geo technical and Geo environmental Engineering culminated after several years of research, dating back to the famous Giroud-Noiray study published earlier in 1981 [22]. This method is recognized and widely accepted for determining the structural contribution of both geo textiles and geo grids in aggregate based roadways. The equation used for G-H design is the following [1]:

$$h = \frac{\{0.868 + CF(\frac{r}{h})^{1.5}\}log_{10}N}{(1 + 0.204[R_E - 1])} \times \left(\sqrt{\frac{\frac{P}{\pi r^2}}{(\frac{s}{f_s})\{1 - 0.9\exp[-(\frac{r}{h})^2]\}N_c C_u}} - 1\right)r \quad (1)$$

Where: h = Required compacted aggregate (gravel) thickness (m).

CF = Calibration factor for the geosynthetic used in design (= 0.661 - 1.006J2 / for punched and drawn biaxial geogrids) .

N = Number of axle passes.

R_E = Limited modulus ratio of compacted aggregate to subgrade soil (maximum = 5).

P = Wheel load (KN).

r = Radius of the equivalent tire contact area (m).

s = Allowable rut depth (mm; for rut depths between 50 mm and 100 mm).

f_s = Reference rut depth (75 mm).

N_c = Bearing capacity factor (3.14 for unreinforced; 5.14 for geotextile reinforced; 5.71 for geogrid reinforced).

C_u = Undrained shear strength of subgrade (taken as 30 kPa x CBR of the subgrade soil for CBR's between 1% and 5%).

$\frac{P}{\pi r^2}$ = Tire contact pressure (kPa) and is equivalent to the tire pressure (p).

The earlier design methods proposed by Giroud and Noiray [21] and Giroud et al. [22] were also adopted in conjunction with the properties of ADS geogrids. A computer program was developed to compute the required aggregate thickness of unpaved roads. Both unreinforced and reinforced unpaved road were included. As such, it was shown that the use of ADS geogrid in unpaved road application can result in a reduction in the aggregate thickness [23].

Generally, the Giroud-Han method [1] has been widely used to design geosynthetic-reinforced unpaved roads with success. But it might give unsatisfactory results if the limitations are ignored. 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. The Basic generic equation, however, is same as equation 1 above [24].

Base and subgrade layer variability have a big influence on the performance of an unpaved road. The subgrade strength may decrease after soaking or disturbance for sensitive soils. In this case the remolded shear strength and soaked CBR strength of the subgrade soils should be used in the design. Aggregates used for the base should be compacted to ensure they provide sufficient strength and stiffness to sustain traffic loading. 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 [24].

Generally, no researcher has attempted to model theoretically the stresses and strains of Malaysian peat using this method. This project proposes to analyse the stresses and strains of Malaysian peat using this model. The analysis will be based on a reinforcement model of an unpaved road configuration. For this purpose experimental site and laboratory data will be used in this analysis. Subsequently, recommendations will be drawn for the development of future theoretical models for reinforced unpaved road sections on peaty subgrade and, as such, design recommendations will be provided for practicing engineers.

METHOD AND SETUP

To perform this study, the data in Tables 1 and 2 were used. Table 1 shows the undrained shear strengths, C_u, taken from previous research studies while Table 2 shows the tire inflation pressures with wheel load and tire size information [25].

TABLE 1
VALUES OF UNDRAINED SHEAR STRENGTH C_u TAKEN FROM PREVIOUS RESEARCH

Sample Number	C_u (kPa)	Reference
1	5	[13]
2	5.99	[27]
3	10	[13]
4	10.76	[27]
5	87	[10]
6	90	[10]
7	93	[10]
8	102	[10]
9	111	[10]
10	114	[10]
11	117	[10]
12	126	[10]
13	132	[10]
14	150	[10]

The undrained cohesion (C_u) values shown in Table 1 were numbered from one to fourteen in ascending order. The tire inflation pressures shown in Table 2 show relevant information needed in the analysis. For example LT215/75R15 means the rim size is 15 inches, the tire tread width 215 mm and the height of the tire tread from the rim is 75% of 215 mm. The second column is used for single or dual axle. The upper row is the inflation pressure for the tire. Data shown in the rest of the table are the wheel loading that results from the first and second columns and the upper row of data. With the help of a Microsoft Excel spreadsheet, all these information have been entered into the theoretical model. The radius of the equivalent tire contact area, *r*, was calculated in meters by using the tire information table and formula $\frac{P}{\pi r^2}$. Then, after getting the radius of the equivalent tire contact area, assumptions were made to calculate the h value using the theoretical model. To find h an iteration process was made. This mean that for the first time the h value must be assumed, for example 0.6 meter. Then, after obtaining the second value, another iteration starts. After that a third value (h) is obtained. The error resulting from any subsequent 2 values is recorded and when this error reaches a very small insignificant number, the iteration process is stopped and the last h value is used as the aggregate thickness. The error equation used is the following: $\frac{(h_2-h_1)}{h_1}x100\%$. After getting the h value, the process was repeated for the next thirteen Cu values. Figures 1-8, show the results of these calculations with the required design aggregate thickness versus the undrained shear strength expressed as a case number from Table 1. Table 3 shows the variables used in this analysis.

TABLE 2
TIRE INFLATION PRESSURE, WHEEL LOAD AND TIRE SIZE INFORMATION [25]

Tire Size	Single (S)/Dual (D)	Wheel Load, P (kN) Inflation Pressure (kPa)									
		241	276	310	345	379	414	448	483	517	552
LT215/75R15	S	5.98	6.56	7.12	7.85	8.21	8.72	9.32			
	D	5.45	5.96	6.47	7.16	7.47	7.94	8.59			
LT235/75R15	S	6.81	7.47	8.12	8.43	9.34	9.92	10.39			
	D	6.18	6.81	7.38	8.1	8.5	9.03	9.56			
LT225/75R16	S	6.67	7.34	7.96	8.63	9.16	9.74	10.39	10.83	11.39	11.92
	D	6.07	6.67	7.25	7.85	8.34	8.87	9.56	9.79	10.36	10.99
LT245/75R16	S	7.56	8.3	9.03	9.81	10.39	11.03	11.67	12.3	12.9	13.53
	D	6.87	7.54	8.21	8.92	9.45	10.03	10.59	11.19	11.74	12.36
LT215/85R16	S	6.65	7.3	7.94	8.63	9.12	9.7	10.39	10.81	11.34	11.92
	D	6.05	6.63	7.23	7.85	8.3	8.83	9.56	9.83	10.32	10.99
LT235/85R16	S	7.56	8.32	9.03	9.81	10.39	11.05	11.67	12.3	12.92	13.53
	D	6.87	7.56	8.21	8.92	9.45	10.05	10.59	11.19	11.77	12.36
7.5R16LT	S	7.21	7.87	8.59	9.07	9.74	10.28	10.99	11.39	11.88	12.25
	D	6.36	6.96	7.52	8.1	8.59	9.07	9.56	9.99	10.34	10.99
8.75R16.5	S						9.96	10.7	10.99	11.43	11.92
	D						8.76	9.32	9.67	10.05	10.7

TABLE 3
THE VARIABLES USED IN THE ANALYSIS

Limited Modulus Ratio,	RE	4
Allowable Rut Depth,	s (mm)	50
Reference Rut Depth,	f_s (mm)	75
Calibration Factor,	CF	1
Bearing Capacity Factor,	Nc	5.71
Number Of Axle,	N	100000

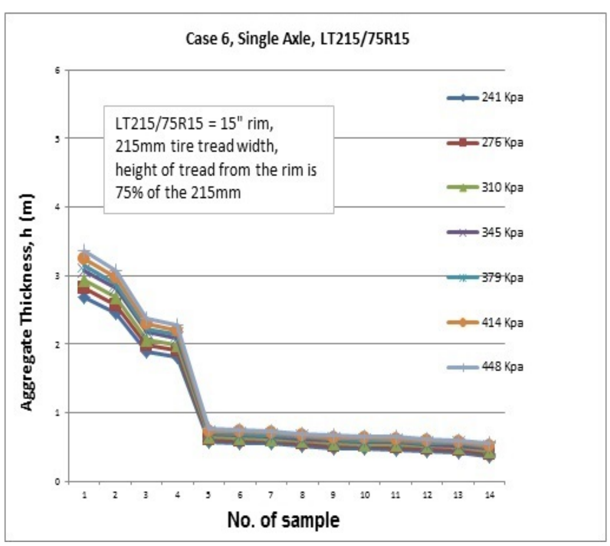

Fig. 1 . Single axle tire size of LT215/75R15

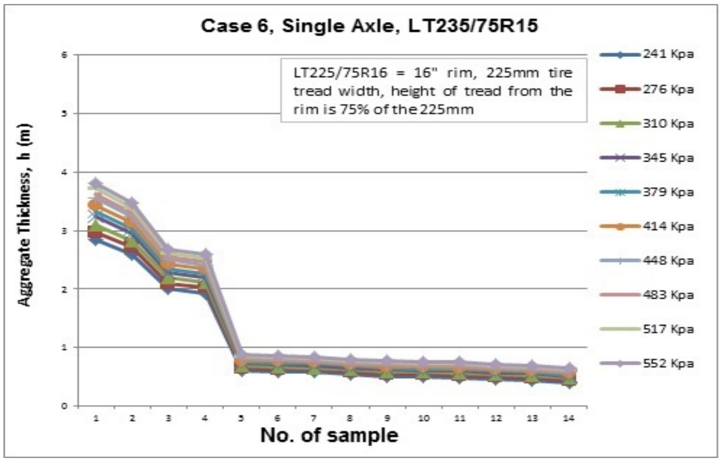

Fig. 2 . Single axle tire size of LT235/75R15

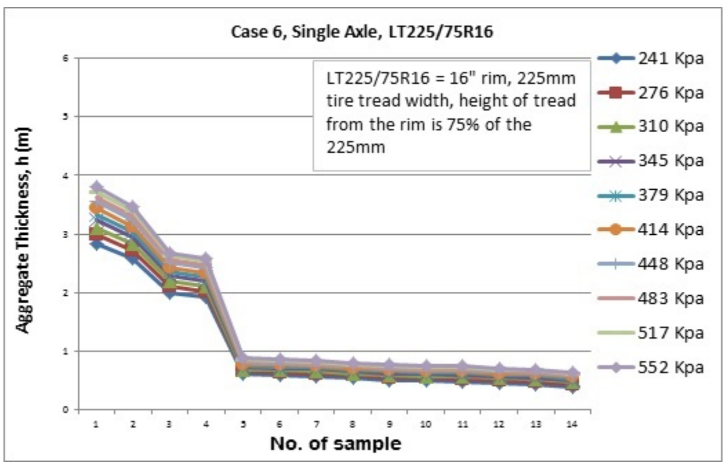

Fig. 3 . Single axle tire size of LT225/75R16

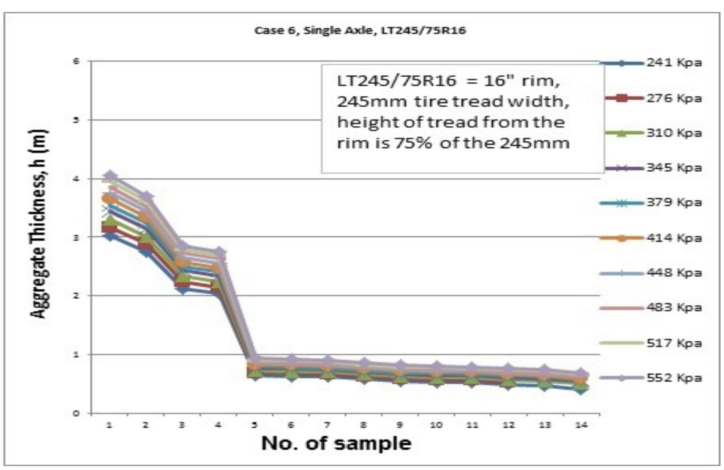

Fig. 4 . Single axle tire size of LT245/75R16

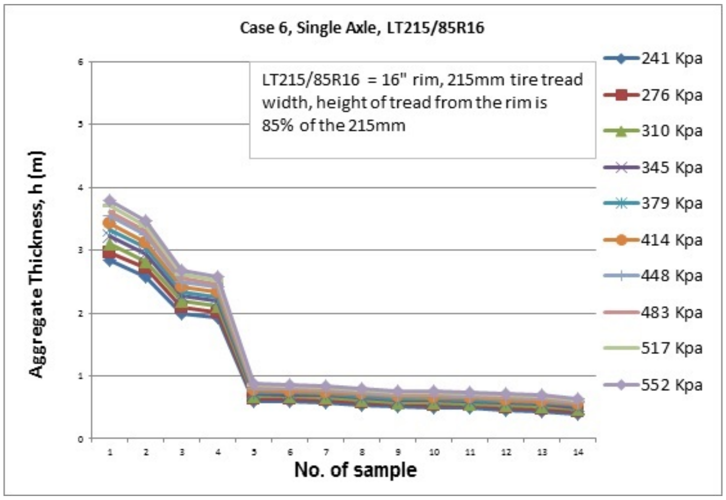

Fig. 5 . Single axle tire size of LT215/85R16

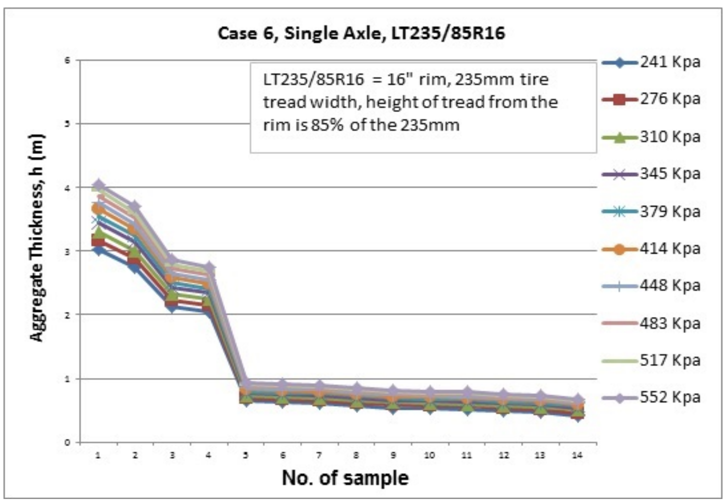

Fig. 6 . Single axle tire size of LT235/85R16

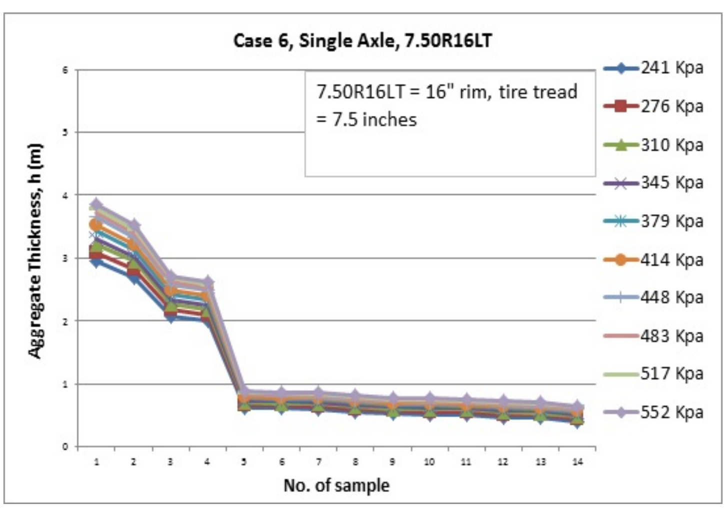

Fig. 7 . Single axle tire size of 7.50R16LT

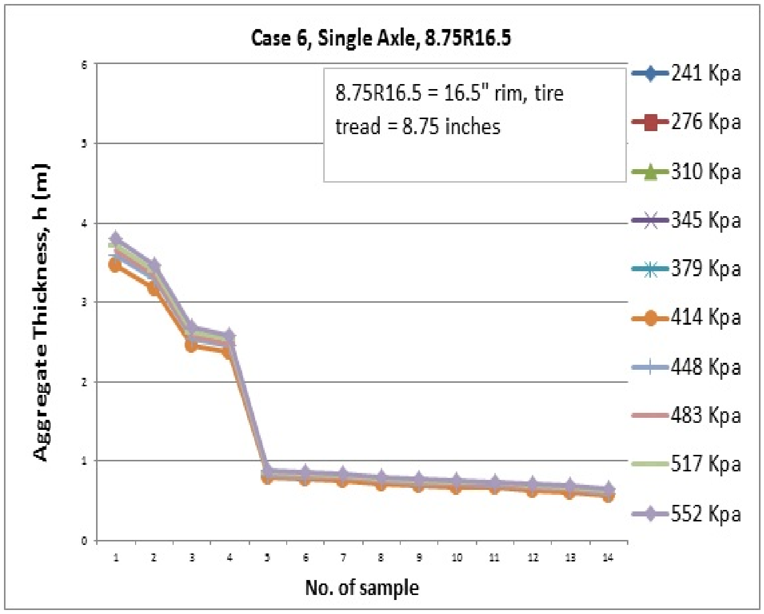

Fig. 8 . Single axle tire size of 8.75R16.5

Limited modulus ratio, Rε	4	
Allowable rut depth, s	50	mm
Reference rut depth, fs	75	mm
Calibration factor, CF	1	
Undrained Shear Strength, Cu	5	Kpa
Bearing Capacity Factor, Nc	3.14	
Number Of Axle, N	10000	

Case 1 Required Compacted Aggregate Thickness, h1 (m)											
Tire	Single (S)	Inflation Pressure (Kpa)									
Size	Dual (D)	241	276	310	345	379	414	448	483	517	552
LT215/75R15	S	2.82368	2.96278	3.09090	3.24712	3.32638	3.43150	3.54928			
	D	2.70403	2.83271	2.95515	3.10987	3.18165	3.28309	3.41524			
LT235/75R15	S	2.99871	3.14698	3.28588	3.35699	3.53308	3.64513	3.73494			
	D	2.86715	3.01486	3.14311	3.29506	3.38098	3.48829	3.59199			
LT225/75R16	S	2.97015	3.12154	3.25571	3.39382	3.50120	3.61411	3.73494	3.82101	3.91765	4.01052
	D	2.84335	2.98584	3.11715	3.24712	3.35100	3.45913	3.59199	3.64076	3.74677	3.86000
LT245/75R16	S	3.14586	3.30330	3.45092	3.60112	3.71195	3.82923	3.94249	4.05123	4.15221	4.25534
	D	3.01084	3.16056	3.30270	3.44630	3.55238	3.66391	3.76835	3.87658	3.97361	4.07931
LT215/85R16	S	2.96604	3.11365	3.25191	3.39382	3.49407	3.60717	3.73494	3.81441	3.90957	4.01052
	D	2.83899	2.97748	3.11313	3.24712	3.34345	3.45179	3.59199	3.64777	3.73993	3.86000
LT235/85R16	S	3.14586	3.30694	3.45092	3.60112	3.71195	3.83244	3.94249	4.05123	4.15520	4.25534
	D	3.01084	3.16443	3.30270	3.44630	3.55238	3.66732	3.76835	3.87658	3.97836	4.07931
7.50R16LT	S	3.07838	3.22359	3.37247	3.47303	3.60260	3.70615	3.83405	3.90880	3.99571	4.06225
	D	2.90555	3.04555	3.17077	3.29506	3.39770	3.49554	3.59199	3.67563	3.74335	3.86000
8.75R16.5	S						3.65197	3.78657	3.84402	3.92410	4.01052
	D						3.43890	3.54928	3.61964	3.69338	3.81153

Fig. 9 . Example on the calculation of "h"

Figure 9 shows an example for calculating the value of "h" in the theoretical model (Eq. 1). An iteration process was employed to find "h" until the error between the last 2 consecutive trials reaches an insignificant small number.

RESULTS AND DISCUSSION

The graphs that show aggregate thickness versus subgrade undrained cohesion (C_u) showed that the higher the subgrade shear strength, the lower the required design aggregate thickness. This was manifested in Figures 1-8 above. Peat soils with low shear strength; the first 4 cases, showed an impractical aggregate thickness requirement of 3 m and above for the 8 cases shown. However, as the undrained subgrade soil strength increased to 87 kPa (case 5) and above, aggregate thickness requirements substantially reduced to more reasonable measures. This was manifested by cases 5-14 shown in Figures 1-8. Not much difference in aggregate thickness was seen to occur between a shear strength of 87 kPa (case 5) and the highest shear strength of 150 kPa (case 14). This suggests that an optimum aggregate thickness can be adopted for this range of shear strengths. Previously, Archer [26] had reported similar results where he showed that aggregate fill thickness reduced with the increase in subgrade CBR. This was shown for unreinforced, geotextile-reinforced and geogrid-reinforced soils [27].

The increase in tire inflation pressures, for the same subgrade undrained shear strength, increased the aggregate requirement for all cases presented above. All cases above showed that the tire inflation pressure of 552 kPa had the biggest aggregate thickness requirement compared to other inflation pressures. While tire inflation pressure of 241 kPa had the smallest aggregate requirement. Also, it seems that cases 5 and 6 offer the best performance, since the variables used show the optimum amount of aggregate thickness required compared to other cases. It seems, however, that for cases 5-14 presented above the change in aggregate thickness as a function of inflation pressure is relatively small. Hence an optimum aggregate thickness can be adopted for all the cases presented. This optimum aggregate thickness can be adopted as the basis for future road tests on peat soils. The study by Al-Sinaidi and Ali [28] further confirms the results of this study. They had performed a full-scale laboratory testing on geogrid reinforced soil and showed that the bearing capacity of the soil improved with the addition of a geogrid layer. However, it seems that performance data of a geogrid reinforced unpaved road is still lacking. Therefor these tests should, initially, use geogrid as the reinforcement material on peaty soils to elucidate the practical and theoretical findings of this study. Later on, other reinforcement materials, such as geotextiles and other geosynthetics, can be used and compared to geogrids for performance.

CONCLUSION

It was shown above that constructing a road on peaty soils that have undrained shear strengths of 5 to about 11 kPa, as manifested in cases 1-4 above, is not practical, since the thickness of the aggregate layer needed was unpractically large. Hence, for all practical purposes, it is recommended to employ chemical additives and attempt an additional modifying technique on these soils before any reinforcement or construction could take place.

As for soil samples 5-14, the aggregate thickness needed was reasonable taking into account peat conditions. And it was shown that the higher the soil strength, the less was the required aggregate thickness. While, the decrease of tire inflation pressure resulted in the decrease of the required aggregate thickness since high inflation pressures mean higher wheel loading.

Giroud and Han's [1] model used in this research project, can be used for peaty or organic soil. Although this theoretical models was developed for inorganic soils, it showed an acceptable range of aggregate thicknesses when used with peaty soils. Although the results focused mainly on Malaysian peaty soils, data obtained can be used for analysis and comparison purposes with peaty soils from other regions.

This study contributes to the existing body of knowledge on the design of unpaved roads over peaty or organic soils. More specifically, the need for more tests on peaty ground is highlighted. These tests will provide the backbone for any potential theoretical model for the design of unpaved roads on peat soil. The current study has provided theoretical knowledge on the range of peat soil strengths that can be considered suitable for this purpose. The location of the study is Malaysia, regionally known for its vast peatland areas. Constructing roads on these peatlands, using traditional design methodologies, is costly. Hence the need for alternative design methods, which rely on peat soil properties rather than inorganic soil properties, will enhance, it is thought, both the cost effectiveness and engineering performance of the said roads. The comparison of various peat soil strengths shows the extent to which this objective can be realized. However, the study scope was limited by the fact that only data from Malaysian peat studies was obtained and one particular theoretical model was used in the analysis. In the future, since there is no specific peat soil theoretical models, it would be desirable to use a few theoretical models to determine which one is more suited to represent reinforcement on peat land.

RECOMMENDATIONS

Using geogrid reinforcement is recommended before any aggregate thickness is calculated, since geogrids will add a tensile component coupled with an interlocking effect to the soil and will help decrease the aggregate thickness requirement.

It is thought that a theoretical model for peaty soils should be attempted to address this need. This model, however, should take into account the undrained shear strength of the soil (C_u), since this parameter will determine the amount of aggregate and strengthening that the soil will require. This model, it is hypothesized, should use geogrids as the reinforcing element.

Field geotechnical engineers are advised to take into consideration the optimum aggregate thickness adopted in this study when designing an unpaved road over peaty soils. However, care should be taken to address the issue of cyclic loading on reinforced peaty soils. This effect has not been addressed before, hence the need for full-scale and field tests that can gauge the correlation between theoretical and field data. Subgrade soil data vary spatially, hence it is advised to use an optimum aggregate thickness in a procedure similar to the one adopted in this study. In addition the following issues are to be taken into account when designing reinforced unpaved roads on peat land:

- The expected tire inflation pressures and vehicle weights,
- An accurate measurement of peat soil shear strength and bearing capacity and the extent peat soil stretches in depth
- The most accurate reinforcement theoretical model as determined from laboratory and theoretical analysis should be used

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— This article does not have any appendix. —