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Numerical simulation of use of lightweight fill in construction of embankment on Soft peaty clays

Simulation Numérique de l'utilisation de Matériaux de Basse Densité Pour la Construction de Remblai sur des Argyles Molles

S.A.S. Kulathilaka & A.Muhunthan
University of Moratuwa, Sri Lanka

ABSTRACT
Lands underlain by very soft peaty clays are widely distributed in an around the capital city of Colombo. Peaty clays are with high natural water content and are very problematic due to their very low shear strength and very high compressibility. Special construction techniques or various ground improvement methods are to be used when constructions are done on peaty clays. In this study, a construction process with the use of lightweight fill materials is proposed for construction of road embankments on soft peaty clays. Lightweight fills were developed using locally available low cost materials. The proposed construction process was numerically simulated using the SAGE CRISP package to check its effectiveness. The results of the analysis indicated that the developed lightweight fill materials could be very effectively used to reduce the in-service settlement and construction period of the road embankment.

RÉSUMÉ
Les terres sur argile tourbeuse molle sont largement répandues aux alentour de la ville de Colombo. Les argiles tourbeuses ont une large teneur en eau et posent des problèmes importants du fait qu'elles ont une très faible résistance au cisaillement et une très forte compressibilité. Des techniques spéciales de construction et des méthodes variées d'amélioration du sol sont nécessaires quand des constructions sont entreprises sur ce type d'argile. Dans cette étude, un processus de construction impliquant l'utilisation de matériaux de remblai de faible densité est proposé pour la construction des remblais d'une route sur argile tourbeuse molle. Les matériaux de remblai ont été développés à partir de matériaux économiques disponibles localement. Le processus de construction proposé a été simulé numériquement grâce à l'utilisation du programme SAGE CRISP pour tester son efficacité. Les résultats de l'analyse ont indiqué que les matériaux de remblai de faible densité qui ont été développés peuvent être efficacement utilisés pour réduire le coût et le temps de construction des remblais routiers.

1 INTRODUCTION

Large number of sites underlain by soft peaty clays are now being used for various constructions due to the scarcity of land. These are used for the construction of buildings as well as for the development of new infrastructure facilities such as highways. Soft peaty clays are of very low shear strength and are extremely compressible due to their very high water contents and void ratios. Constructions done on peaty clays could be subjected to very large settlements due to their high compressibility. Catastrophic failures are also possible due to very low shear strength. Problems due to these characteristics can be overcome by either transferring the loads to harder strata underneath through piles or by improving the engineering properties of Peat to a desired level.

Use of a fill material of lower density is another possible approach that can be adopted in some constructions done on soft peaty clays. This would be particularly useful in the construction of embankments (Clarken, 1986) Lightweight fill materials impose lower loads on the underlying soft soils resulting in lower settlements and reducing the possibilities of shear failure. Lightweight fill materials such as polystyrene blocks were used successfully in countries like U.K in construction over soft soils. However, it is not economical to import such material to the country. To provide an economical solutions lightweight fill materials should be developed locally.

As such, attempts were made at University of Moratuwa to develop lightweight fills by mixing different proportions of tyre chips with lateritic soil, sawdust with lateritic soil and paddy husk with lateritic soil. Tyre chips were obtained by shredding the discarded motorcar tyres. Sawdust is obtained from wood mill waste and paddy husk is obtained from rice mill waste. Different mix proportions were tried out to get several suitable mixes of sufficiently low density. The developed material should be sufficiently incompressible and should possess adequate shear strength. Further detailed tests were conducted on selected mixes to establish their engineering characteristics in relation to strength and stiffness. A construction process incorporating lightweight fill is proposed for the construction of embankments in soft peaty clays. The criterion to be achieved is that the in-service settlement should be less than 50mm.

2 DEVELOPMENT OF LIGHTWEIGHT FILLS

Different mix proportions of the lateritic soil: lightweight material were tried out. The density of the mix decreased with the increase of lightweight material contents but the workability of the mix decreased. As such, only several selected mix proportions were used for further studies. The maximum dry density and optimum moisture content (under proctor compaction effort) for the selected mix proportions (by weight) are presented in Table 1.Their compressibility characteristics are summarized in Table 2 and shear strength properties are given in Table 3.

Table 1: Compaction properties of lightweight fills.

Fill	Mixes	Optimum moisture content (%)	Maximum Dry Density (kg/m^3)
Lateritic soil		17.55	1780
Tyre chips: Soil	1:3	17.40	1443
	1:2	17.00	1288
Sawdust: Soil	1:1	82.95	657
	3:2	103.55	553
Paddy husk: Soil	1:1.5	98.00	508
	1:1	112.94	432

Table 2: -Compressibility characteristics of lightweight fill

Fill	Mixes	$\frac{Cc}{(1+e_0)}$ Compacted	$\frac{Cc}{(1+e_0)}$ Saturated
Lateritic soil		0.018	0.052
Tyre chips: Soil	1:3	0.062	0.113
	1:2	0.058	0.143
Sawdust: Soil	1:1	0.158	0.152
	3:2	0.257	0.181
Paddy husk: Soil	1:1.5	0.116	0.195
	1:1	0.182	0.236

Table 3: Shear strength parameters of lightweight fill

Fill	Mixes	c_u	ϕ_u	c_d	ϕ_d
Lateritic soil		108	0^0	40	33^0
Tyre chips: Soil	1:3	50	13^0	18	37^0
	1:2	22	19^0	10	38^0
Sawdust: Soil	1:1	46	15^0	10	34^0
	3:2	27	17^0	10	37^0
Paddy husk: Soil	1:1.5	24	16^0	30	30^0
	1:1	24	15^0	12.5	35^0

3 ANALYSIS OF THE PROBLEM

The effectiveness of the use of lightweight fill material in the embankment construction was analyzed in detail by the finite element package CRISP. Comparisons were done for the constructions done with lateritic soil in the conventional manner and for the construction done with developed lightweight fills under the proposed construction process. Further parametric analyses were done varying the thickness of the embankment and the peaty clay.

The case analyzed was similar to some sections in Colombo Katunayake expressway embankment. Figure 1 shows the soil profile and the shape of the analyzed embankment. Embankments are elevated by 3-5m and are of widths around 30m. The subsoil consisted of a layer of peaty clay underlain by dense sand. The ground water table is at the ground surface.

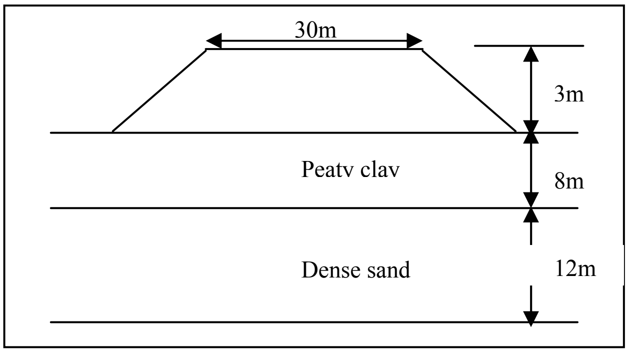

Figure 1. The soil profile and the embankment geometry

4 PROPOSED CONSTRUCTION PROCESS

The highway embankments should be constructed so that the in-service settlements should be within acceptable limits. It is taken as 50mm in this study. This could be achieved if the embankment is preloaded with a surcharge fill greater than the load of the pavement and the traffic. In this proposed process a lightweight fill is incorporated into the preloading process with the objective of reducing the required construction period and the quantity of fill.

The Construction sequence was selected by conducting several trial analyses. The selected construction process (process 1) consists of following stages.

1. Embankment was constructed by placing soil in layers at a rate of 10cm/day. This process was continued till the maximum possible safe height of the embankment is achieved.
2. Soft ground was allowed to consolidate for some time (degree of consolidation U= 70%) under the weight of the embankment fill placed.
3. If the required height of the embankment is greater than that placed already, second stage of filling was done to the maximum safe height at the same rate.
4. Soft ground was allowed to consolidate for some time (degree of consolidation U=70%)
5. If further filling is needed it is done in another stage and soft soil was allowed to consolidate further.
6. The lateritic fill above the water table was removed and refilling was done by the proposed lightweight fill material.
7. Pavement is constructed gradually with lightweight fill. (Within 90 days)
8. Vehicle load (a load of $10kN/m^2$) is applied.

The height of the lateritic fill placed and the degree of consolidation (U=70%)to be allowed was selected by doing number of trial analyses in order to satisfy the criterion that the in-service settlement is less than 50 mm.

Although the construction process named as process 1 indicates that the use of lightweight fill materials reduces the total settlement and the construction periods, it is evident from the Figure 4, that the reduction in the total construction period is not very significant. In the construction process 1, care was taken to ensure that the proposed lightweight fill materials does not get mixed with the water (submerged) after the construction of the embankment. But in the literature number of studies were reported by many researchers to show that the tyre shreds would not cause undesirable effects when it is mixed with water (Downs et al., 1997). Therefore, another construction process-2 was proposed.

The Construction sequence of process 2 was selected by conducting several trial analyses. The selected construction process consists of following stages.

Embankment was constructed by placing proposed lightweight fills in layers at a rate of 10cm/day. This process was continued till the maximum possible safe height of the embankment is achieved.

1. Soft ground was allowed to consolidate for some time under the weight of the embankment fill placed.
2. If the required height of the embankment is greater than that placed already, second stage of filling was done by the lightweight fill to the maximum safe height at the same rate.
3. Soft ground was allowed to consolidate for some time
4. If further filling is needed it is done by the lightweight fill in another stage and soft soil was allowed to consolidate further.
5. Surcharge for pavement load and traffic load was done by the conventional lateritic fill and ground was allowed to consolidate to some level.
6. Thereafter the surcharge was removed
7. Pavement is constructed gradually with lightweight fill. (Within 90 days)
8. Vehicle load (a load of $10kN/m^2$) is applied.

The height of the lightweight fill or lateritic fill placed and the degree of consolidation to be allowed was selected by doing number of trial analyses to satisfy the criterion that the in-service settlement is less than 50 mm.

5 FINITE ELEMENT MODELLING OF THE PROCESS

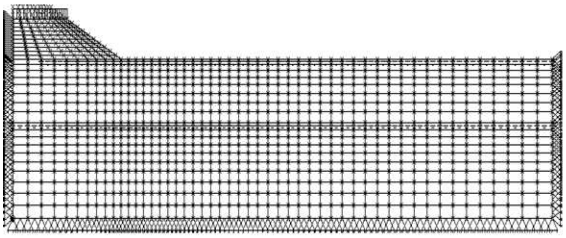

Figure 2. Finite element mesh

The finite element program SAGE CRISP was used for the analysis. A fully coupled consolidation analysis was used for this problem where construction loads are applied over a finite time period and consolidation was also going on for a long period.

Considering the symmetry of the problem a finite element mesh as shown in Figure 2 was used. The distance between the toe of the slope and the right lateral boundary was taken to be approximately 5-6 times the thickness of the soft layer. Analyzed ground consisted of layers of peat and dense sand.

Modified Cam clay model was developed as a model to overcome the problems of original cam clay model and it successfully reproduces the major deformation characteristics of soft clay, and is more widely used for numerical prediction than the original cam clay model. It has been used successfully in several applications (Wroth, 1985)

In this study initial idea was to model all the layers by modified cam clay but this model require the stress history detail such as preconsolidation pressure. The simulation of embankment filling and removing in the CRISP is done by adding and removing layers, for these types of operations CRISP does not allow the fill material to modelled by stress history models such as CSSM. As such, the peat layer was modeled by modified cam clay model and original Mohr Coulomb elastic perfectly plastic model was used for the dense sand and embankment fill material. The elastic perfectly plastic model represented the behavior of these layers adequately.

Only vertical directional deformation was permitted on the axis of symmetry and along the right lateral boundary and no deformation was permitted along the lower boundary. Doubly drained conditions were assumed in the peat layer.

6 MODEL PARAMETERS

The parameters for the Modified Cam clay model were derived from the data obtained from consolidated drained triaxial test and consolidation test conducted on typical peaty clay from Colombo Katunayake expressway. The model parameters obtained for the peaty clay are listed in Table 4. The coefficient of permeability was varied with stress level based on the data from back analysis of a large scale consolidation test (Kugan, 2003).

For the dense sand, typical properties were derived based on SPT data. For the developed lightweight fill material types and lateritic fill, properties were determined from the respective laboratory tests. The poison ratios values assumed for materials are shown in Table 5.

Table 4: Cam clay parameters for peaty clay

Slope of N.C line (λ)	0.603
Slope of swelling line (k)	0.083
Slope of C.S line (M)	1.2
Poison ratio (ν)	0.3
Void ratio (e_{cs})	5.264
Permeability ($k_x = k_y$)	1.2E-8m/s (stage 1) 6.5E-9m/s (stage 2,3)
Unit weight (γ)	14kN/m^3

Table 5: Elastic perfectly plastic model parameters for fill materials and dense sand.

Material	Dense sand	Lateritic soil	Developed light weight fill materials
E' (kN/m^2)	70, 000	10,000	5000-10000
C' (kN/m^2)	0	40	15,10,30
ϕ'	30	32	35,35,33
ν	0.3	0.3	0.3
K_x (ms^{-1})	-	2.75E-10	1.8E-9
K_y(ms^{-1})	-	2.75E-10	1.8E-9
γ (kN/m^3)	20	20.5	8.5-14

One series of analysis were done assuming the peaty clay is normally consolidated. In the other series a preconsolidation pressure of 10kN/m^2 was assumed.

7 RESULTS OF THE FE ANALYSIS

When the analysis was done assuming that the peaty clay is normally consolidated, the settlement vs time curves obtained with the process 1 and process 2 are presented in Figure 4 and Figure 5 respectively. It could be seen that as the density of the fill becomes lighter, the construction period needed and the overall settlement is reduced. This is very significant with the ultra lightweight polystyrene blocks.

A parametric study (Muhunthan, 2004) revealed that the advantages of the process are more significant when the height of the embankment and the thickness of the soft peaty clay layer increases.

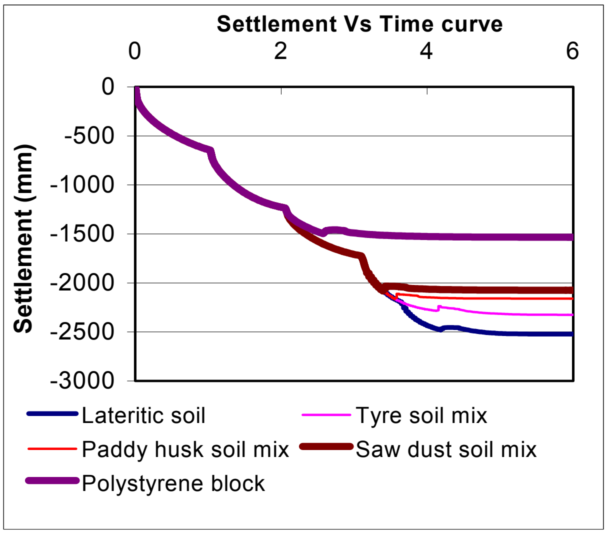

Figure 4. Construction results of 3m embankments over 8m depth peaty clay - process.

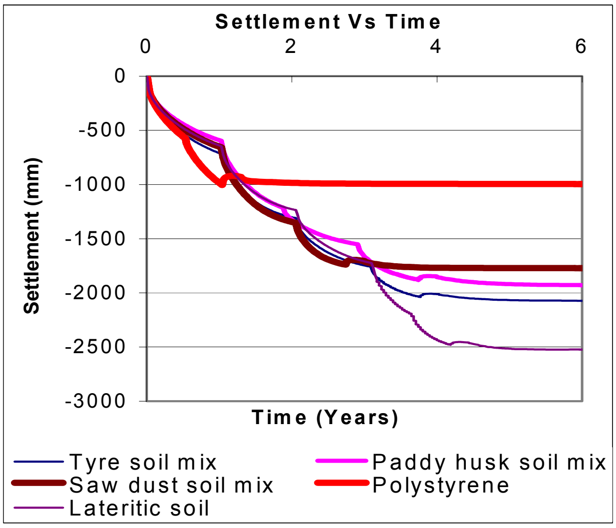

Figure 5 Construction results of 3m embankments over 8m depth peaty clay –process2.

8 INFLUENCE OF PRECONSOLIDATION PRESSURE

Over consolidation effect could get induced in the top crust of the Peaty clay layer due to seasonal fluctuations of the water table (Mair, 1992). This effect was simulated by assuming a very small (10kN/m^2) pre-consolidation pressure. The results obtained under this assumption are presented in Figure 6.It is evident that if a small over consolidation effect is present the construction could be completed much earlier.

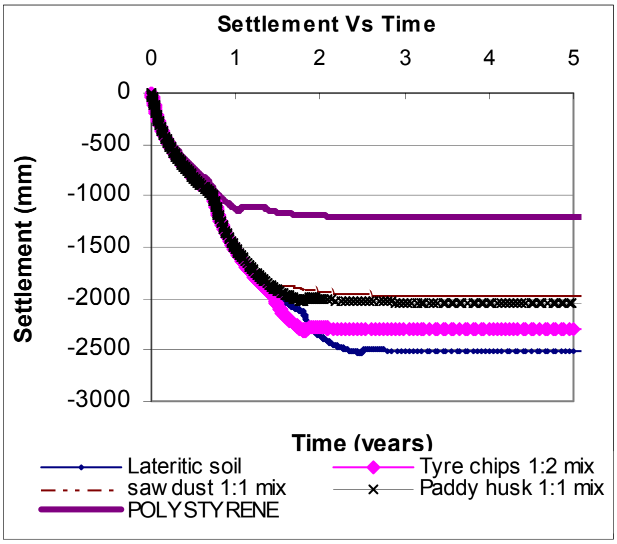

Figure 6. Construction result of 3m embankments over 8m depth peaty clay with 2m crust.

9 CONCLUSIONS

Different construction procedures were proposed incorporating a lightweight fill into the preloading process. Proposed construction processes were numerically simulated by the finite element program SAGE CRISP. Proposed processes were found to be helpful in reducing the construction time and the volume of the fill consumed. Construction process – 2 was found to be more effective than construction process – 1.

As the height of the embankment or the thickness of the peaty clay increases the effectiveness of the proposed construction process becomes more significant. As the density of the developed lightweight fill decreases, the effectiveness of the proposed process becomes more significant. Very significant advantages in the use of an ultra light weight material like polystyrene blocks are well demonstrated in the results presented in Figures 4, 5 and 6.

As such, further research should be carried out to develop ultra lightweight fill materials economically with local raw materials. Also, attempts should be made to find methods to retard the degradation of sawdust and paddy husk so that they would be chemically stable during the design period of the embankment.

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