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THE USE OF SAND COLUMNS IN THE REINFORCEMENT OF WEAK LAYERS IN ROAD ENGINEERING

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Abstract: It is an established fact that when roads are planned and constructed, consideration needs to be given to ensuring the strength of the road surface. It is, however, also the case that when an existing road is being rebuilt or is under maintenance, its base may need to be fortified to increase the road's vehicle-carrying capacity. The base may, for example, contain a high proportion of weak soil that would be difficult, time-consuming, and costly to remove. This paper aims to investigate the efficacy of using sand-filled piles to reduce road deformation. Experiments conducted on sponge samples confirm that there is a relationship between the total area of sand-filled piles and relative reduction in deformation. It finds that the relationship is non-linear, but that the relationship can be made linear by adjusting the area of sand-filled piles. When the area of sand-filled piles increases from 7.8% to 19.4%, the deformation module can change by up to 100%. Relative reduction in deformation can change from 14% to 45.5% when the area of sand-filled piles increases from 7.8% to 11.7%. The maximum reduction in deformation – 92.4% - occurs when the area of sand-filled piles exceeds 19.5%. Changing the loads borne also affects the deformation module. This paper found that when there was a 10 to 15kg load, and the number of sand-filled piles was increased, there was a change in the deformation module by 380-470%. When there was only a 5kg load on the sample, and the number of sand-filled piles was increased, there was a change in the deformation module by up to 1217%.

Keywords: *Sand-filled piles, relative deformation, rebuilding, roads.*

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1. INTRODUCTION

To increase the strength of a road's foundations, it is imperative to fortify weak soils – and to calculate the degree of weakness. Weak soils, such as those found by the sea, rivers, swamp areas and lakes, are those which are saturated with water or which have a high degree of salinity. Problems with poor soil are particularly evident in areas where water saturation reaches 90%. The issue also becomes apparent in regions where hundreds of miles of roadway are being built. It is more difficult and expensive to build roads in areas with poor-quality soil, and different possible solutions have been used throughout the 20th Century [1-5], the 21st Century [6-11] and in railway construction [12-13]. Practical experiments, influenced by geoengineering and soil mechanics theories, have also investigated the effect of poor soil in road layers [14-17]. Studies of hydraulic and land reclamation works [18-19], of industrial construction practices [20-21] and of the characteristics of soil itself [22-23] have all revealed the importance of understanding how weak soil works. For example, Crawford (2011) and Tiner (2016) have conducted new research into the issues surrounding the construction of modern roadways through peat bogs [24-25]. In addition, there have been studies conducted on the foundations calculations required, as well as on the development of engineering structures, in a number of different countries – such as the United States [26-28], Canada [29-31], France [32], Germany [33], the Netherlands [34] and Japan [35]. This research paper is based on the concept that where weak soil is found in the earth, it is imperative that the strength and rigidity of the surface is ensured – by making sure that soil does not seep out from the edges of the different layers of road. It is also necessary to establish the resultant surface pressure exercised on the different road layers. When roads, which built on weak soils, are under the process of reconstruction, it is important not to accelerate the surface compaction of the existing soil. The soil surface would already have been sufficiently compacted – by the various road layers - when the highway originally built. Instead, what is required is for the strength of the existing soil to be increased – to create the optimum conditions for new road layers installed. The speed of compaction of the water-saturated soil that is under the influence of a permanent weight depends on the duration of this effect. Therefore, to expel water from the soil, vertical pegs are created that increase the speed of water expulsion and reduce the time of relaxation of the soil layers to reach a high degree of compaction. This paper suggests using piles filled with a different type of material (sand). This idea was taken from previous experiences in using vertical pegs necessary to expel water. These piles will be better able to withstand displacement, will be better equipped to withstand any side pressures affecting the road and will be able to help facilitate the process of compacting the soil itself. In this way, the piles can improve the strength of the weak soil. Meanwhile, the ground surface compaction avoided.

1.1. THEORETICAL ANALYSIS

In primitive soil, i.e. soil without piles, durability and resistance to deformation remains the same when the degree of static load - such as increased thickness of road layers – is increased. By substituting weak layers soil with piles filled (sand) - which has increased soil strength - the aim is to increase the surface's durability and resistance to deformation. The realistic mean position between the primitive (without piles) and the final status (with piles) where it can be said that the surface of the earth has the characteristics of both weak soil and the soil of piles together means a complex surface of the earth, concerning the stress that causes the deformation, consider the landing of the piles' soil at the same time without any mixing or friction between them, the importance of the unequal distribution of road weight pressure was not taken into consideration, as it was considered that the layers of the roads were working to redistribute pressure on soil and piles, the weight of both soil and piles was not taken into account. It can be considered that the realistic or mean position of the ground's surface, in between its primitive state (without piles) and its final state (with piles), is a complex one. In terms of its resistance to deformation, it has characteristics of both weak soil and the stronger soil of piles. It assumed that there is no contact or friction between the different piles. Any degree of unequal road pressure also disregarded as it assumed that the different road layers are working to redistribute pressure across both weak soil and piles. In addition, the weight of the soil and piles themselves also disregarded

2. EXPERIMENTAL DESIGN

Two series of experiments conducted in the laboratory to assess how pressure distributed across the foundations. The first set of experiments (A) conducted on sponge samples without holes. The second set (B) was conducted on the same samples, but this time the samples had holes filled with fine (<1mm) sand as shown in (Fig.1). The experiments noted the change in deformation with the change of load. The following terms were used in the experiments: HO - original device reading before any loads were applied, Δh - HO minus device reading after loads were applied; h - height of sample (3.5cm); $\Delta\lambda$ - deformation ratio; $\Delta\delta$ – stress; ΔP – load applied (kg), A - area of sample = l * w = 163 cm^2, where 16.3 cm length * 10 cm width); Ep - Deformation model (1 Kg/cm^2 =100 KPa), hole diameter = 2 cm, a - hole area (3.14 cm^2).

Fig 1. Sandy soil used in experimental design of piles

2.1 EXPERIMENT [A]

Four sponge samples, all without any holes, were used. Loads of 5 kg, 10 kg and 15 kg were placed on each sample in turn. At each point, readings were taken, and calculations made. The results are presented in (Tables 1-4) below:

Table 1: Sponge sample 1 (without holes):

Load, kg	Device reading, cm	$\Delta\lambda=\Delta h/h$	$\Delta\delta=\Delta P/A$, kg/cm^2	Ep $=\Delta\delta/\Delta\lambda=1/\tan\alpha$, kg/cm^2	α
0	37.6	0	0	0	0
5	37.05	0.15	0.031	0.200	78.70
10	36.10	0.43	0.061	0.142	82.0
15	35.70	0.54	0.092	0.170	80.35

Table 2: Sponge sample 2 (without holes):

Load, kg	Device reading, cm	$\Delta\lambda=\Delta h/h$	$\Delta\delta=\Delta P/A$, kg/cm^2	Ep $=\Delta\delta/\Delta\lambda=1/\tan\alpha$, kg/cm^2	α
0	37.85	0	0	0	0
5	37.50	0.10	0.031	0.310	72.80
10	36.80	0.30	0.061	0.203	78.50
15	36.20	0.47	0.092	0.200	78.70

Table 3: Sponge sample 3 (without holes):

Load, kg	Device reading, cm	$\Delta\lambda=\Delta h/h$	$\Delta\delta=\Delta P/A$, kg/cm^2	Ep $=\Delta\delta/\Delta\lambda=1/\tan\alpha$, kg/cm^2	α
0	37.9	0	0	0	0
5	37.55	0.10	0.031	0.310	72.77
10	36.35	0.271	0.061	0.225	78.30
15	36.05	0.443	0.092	0.207	78.94

Table 4: Sample 4 (without holes):

Load, kg	Device reading, cm	$\Delta\lambda=\Delta h/h$	$\Delta\delta=\Delta P/A$, kg/cm^2	Ep $=\Delta\delta/\Delta\lambda=1/\tan\alpha$, kg/cm^2	α
0	37.8	0	0	0	0
5	37.20	0.17	0.031	0.182	79.77
10	36.40	0.40	0.061	0.152	81.30
15	35.95	0.53	0.092	0.174	80.13

The relationship between the degree of stress applied and the relative deformation of each sample used in Experiment A is shown below (Fig. 2):

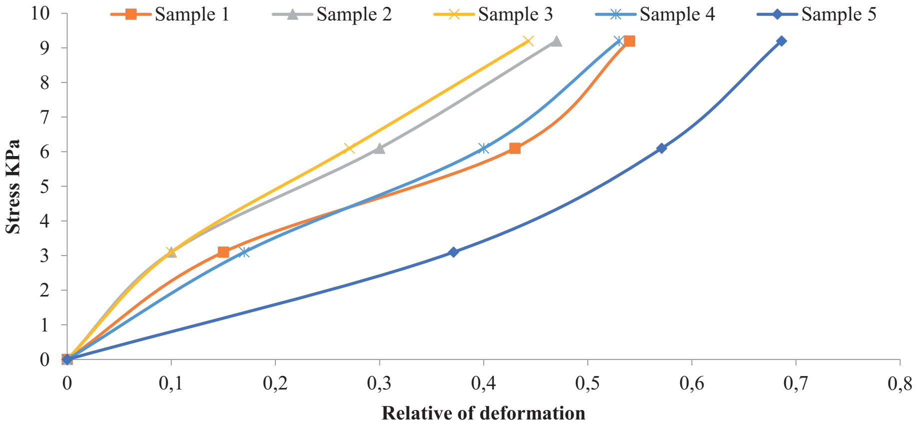

Fig 2.The relationship between stress applied and relative deformation in natural samples (without holes).

The dispersion in the deposition results of the raw materials (sponge) is due to the difference in their physical and chemical properties for each sample, although they are of the same type, and this in turn affects the resistance of each sample to the loads differently.

2.2. EXPERIMENT [B]

The same four samples as used in Experiment A were used in Experiment B. In Experiment B, however, all samples contained holes filled with fine (<1mm) sand. Loads of 5 kg, 10 kg and 15 kg were again placed on each sample in turn. At each point, readings were taken, and calculations made. The results are presented in (Tables 5-10) below:

Table 5: Sample 5 (without holes):

Load, kg	Device reading, cm	$\Delta\lambda=\Delta h/h$	$\Delta\delta=\Delta P/A$, kg/cm^2	$Ep=\Delta\delta/\Delta\lambda=1/\tan\alpha$, kg/cm^2	α
0	37.3	0	0	0	0
5	37.00	0.371	0.031	0.084	85.2
10	36.30	0.571	0.061	0.107	83.9
15	35.90	0.686	0.092	0.134	82.91

Table 6: Sample 1, 4 holes

Load, kg	Device reading, cm	$\Delta\lambda=\Delta h/h$	$\Delta\delta=\Delta P/A$, kg/cm^2	$Ep=\Delta\delta/\Delta\lambda=1/\tan\alpha$, kg/cm^2	α
0	37.7	0	0	0	0
5	37.20	0.143	0.031	0.217	77.80
10	36.70	0.286	0.061	0.213	80.00
15	36.40	0.371	0.092	0.248	76.00

Table7: Sample 2 and 6 holes

Load, kg	Device reading, cm	$\Delta\lambda=\Delta h/h$	$\Delta\delta=\Delta P/A$, kg/cm^2	$Ep=\Delta\delta/\Delta\lambda=1/\tan\alpha$, kg/cm^2	α
0	37.7	0	0	0	0
5	37.4	0.08	0.031	0.360	70.2
10	37.0	0.20	0.061	0.305	73.0
15	36.8	0.25	0.092	0.358	70.3

Table 8: Sample 3, 8 holes

Load, kg	Device reading, cm	$\Delta\lambda=\Delta h/h$	$\Delta\delta=\Delta P/A$, kg/cm^2	$Ep=\Delta\delta/\Delta\lambda=1/\tan\alpha$, kg/cm^2	α
0	37.9	0	0	0	0
5	37.6	0.08	0.031	0.360	70.0
10	37.25	0.18	0.061	0.32	71.8
15	37.05	0.24	0.092	0.37	69.0

Table 9: Sample 4, 10 holes

Load, kg	Device reading, cm	$\Delta\lambda=\Delta h/h$	$\Delta\delta=\Delta P/A$, kg/cm^2	Ep $=\Delta\delta/\Delta\lambda=1/\tan\alpha$, kg/cm^2	α
0	37.8	0	0	0	0
5	37.35	0.19	0.031	0.164	80.7
10	37.10	0.20	0.061	0.305	730.
15	36.90	0.26	0.092	0.358	700.

Table 10: Sample 5, 12 holes

Load, kg	Device reading, cm	$\Delta\lambda=\Delta h/h$	$\Delta\delta=\Delta P/A$, kg/cm^2	Ep $=\Delta\delta/\Delta\lambda=1/\tan\alpha$, kg/cm^2	α
0	37.9	0	0	0	0
5	37.40	0.028	0.031	1.107	42.0
10	37.15	0.100	0.061	0.610	58.6
15	37.00	0.143	0.092	0.643	57.3

The relationship between the degree of stress applied and the relative deformation of each sample used in Experiment B is shown below (Fig. 3):

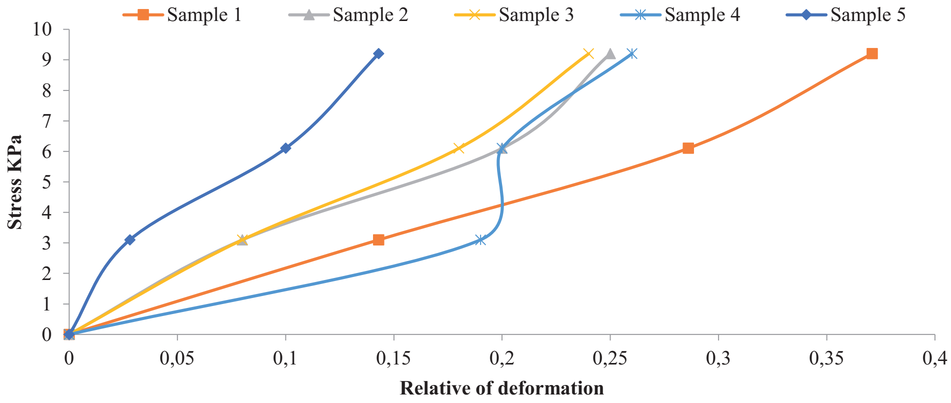

Fig 3.The relationship between stress applied and relative deformation in treated samples (with sand-filled holes).

By comparing (Fig. 2 and Fig 3), it becomes apparent that samples without holes are subject to greater deformation than those with sand-filled holes. With each load applied, the lowest degree of deformation occurred in the sample with 12 sand-filled holes while the largest amount of deformation occurred in the sample without any sand-filled holes. In both experiments, the maximum amount of deformation was caused when the 15 kg load was placed on the sample – but the amount of deformation caused by the 15kg load was most when the sample had no holes and least when the sample had 12 sand-filled holes. These results show the impact of using sand-filled holes in the sample. Data from Experiment A was also used to calculate an indicator of relative deformation (℩ %) in Experiment B. This shows that, as indicated in (Tables 11 and 12), and in (Fig. 4, that with a load of 5 kg, the deformation ratio (Δλ) increases when there are four, six, eight and twelve holes filled with sand. With a load of 10 kg, the deformation ratio increases when there are four, ten and twelve holes filled with sand. With a load of 15 kg, the deformation ratio increases when there are four, six, ten and twelve holes filled with sand.

Table11: Data enabling the calculation of an indicator of relative deformation

Number of holes	Weight (P), Kg	Δλ		Δλ	℩%=[(NA-NB)/NA]100%
		NA	NB	NA-NB	
4	5	0.150	0.143	0.014	8.9 %
	10	0.430	0.286	0.144	33.48 %
	15	0.540	0.371	0.169	31.29 %
6	5	0.100	0.080	0.014	14.00 %
	10	0.300	0.200	0.100	33.30 %
	15	0.470	0.250	0.214	45.55 %
8	5	0.100	0.086	0.014	14.00 %
	10	0.271	0.186	0.085	31.36 %
	15	0.443	0.243	0.200	45.14 %
10	5	0.170	0.190	0.019	11.17 %
	10	0.400	0.200	0.200	50.00 %
	15	0.530	0.260	0.271	51.30 %
12	5	0.371	0.028	0.343	92.40 %
	10	0.571	0.100	0.471	82.48 %
	15	0.686	0.143	0.543	79.15 %

Table 12: The relation between the Weights, relative total drilled area filled sand and the Indicator of relative deformation

P=5kg	P=10kg	P=15kg	$N\% = \sum_{4}^{12} \frac{f}{F}$
8.90%	33.48%	31.29%	7.8
14.00%	33.30%	45.55%	11.7
14.00%	31.60%	45.14%	15.4
11.17%	50.00%	51.30%	19.4
92.40%	82.48%	79.15%	23.4

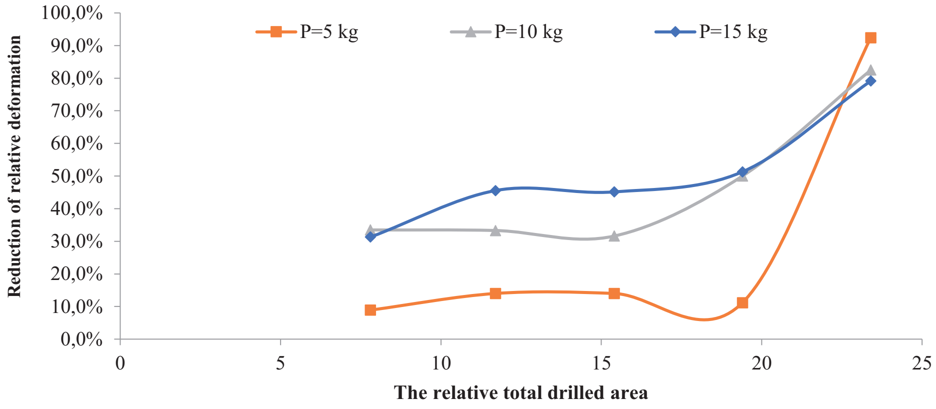

Fig 4: The nature of decreasing in relative deformation according to the relative total drilled area filled sand

Data from Experiment A was used to help calculate an indicator of deformation model (ʅ %) for Experiment B. This shows that, as indicated in (Tables 13 and 14), and in (Fig. 5), that with a load of 5 kg, ΔEp increases when there are four, six eight and twelve holes filled with sand. With a load of 10 kg, ΔEp increases when there are four, six, eight, ten and twelve holes filled with sand. With a load of 15 kg, ΔEp increases when there are four, six, eight, ten and twelve holes filled with sand.

Table 13: Data enabling the calculation of an indicator of deformation model

Number of holes	Load,(P), Kg	Ep, kg/cm^2		ΔEp, kg/cm^2	ʅ %=[(EpA-EpB)/EpA]100%
		EpA	EpB	EpA-EpB	
4	5	0.200	0.217	0.017	8.50 %
	10	0.142	0.213	0.071	50.00 %
	15	0.170	0.248	0.078	45.90 %
6	5	0.310	0.360	0.05	16.00 %
	10	0.203	0.305	0.102	50.20 %
	15	0.200	0.358	0.158	79.00 %
8	5	0.310	0.360	0.05	16.10 %
	10	0.225	0.328	0.154	68.40 %
	15	0.207	0.379	0.172	83.10 %
10	5	0.182	0.164	0.018	9.90 %
	10	0.152	0.305	0.152	99.30 %
	15	0.174	0.358	0.184	105.70 %
12	5	0.084	1.107	1.023	1217.80 %
	10	0.107	0.610	0.530	470.10 %
	15	0.134	0.643	0.509	379.90 %

Table 14: The relation between the Weights, relative total drilled area filled sand and the Indicator of the deformation model

P=5kg	P=10kg	P=15kg	$N\% = \sum_{4}^{12} \frac{f}{F}$
8.50%	50.00%	45.90%	7.8
16.00%	50.20%	79.00%	11.7
16.10 %	68.40 %	83.10 %	15.4
9.90%	99.30%	105.70%	19.4
1217.80%	470.10%	379.90%	23.4

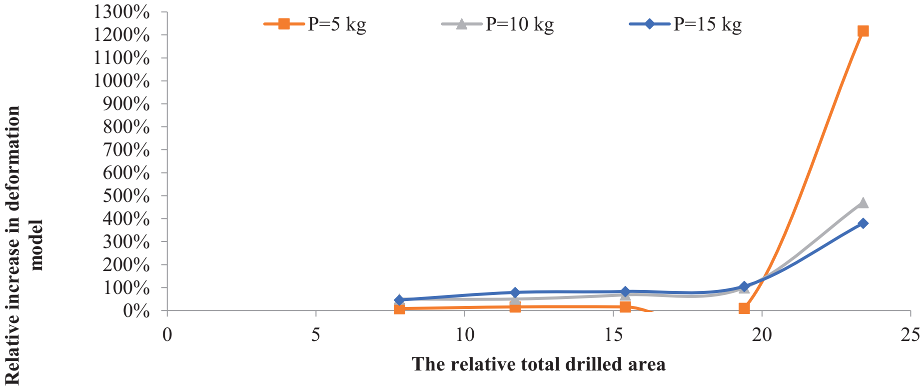

Fig 5: Dependence of the relative increase in the deformation model on the relative total drilled area filled sand

3. CONCLUSION

The present work aimed of to investigate the efficacy of using sea sand available in abundance with low cost to reduce road deformation in real life by applying this new technique compared to regular methods. Sand-filled piles one of an effective way of increasing soil strength when roads improved because of convenience to install and a relatively low-cost. The experiments conducted as part of this research on both natural and sand-piled sponge samples. The reduction in relative deformation changes from 14% to 45.5% when sand-filled piles proportion increases from 7.8% to 11.7%. The maximum reduction in deformation occurs when sand-filled piles exceeds 19.5% of the sample's area to reached 92.4%. Deformation module changes by up to 100% when the area of sand-filled piles increases from 7.8% to 19.4%. Relationship between the reduction of deformation and the total area of sand-filled piles is non-linear, and possible to make it linear by changing the total area of the piles. An increment by 4% the total area of the sand-filled piles reduced relative deformation by 9% to 14% and the deformation module approximately doubled. Effects of changing loads borne investigated in a research work and found that increasing applied load from 5 kg, 10 kg and 15 kg and increasing number of sand-filled piles deformation module was a change by 380 -470% - 1217% respectively.

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