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Performance of Lime-Cement as Column and Raft in Soft Clay Bed

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Abstract. Owing to high compressibility and low shear strength of soft clay deposits, they are generally unfit for geotechnical engineering applications. However, such soft clays can be readily used after they have been subjected to ground treatment methods such as stone column, lime column, compaction granular piles etc. An attempt is madein this paper to study the influence of lime pile, lime-cement pile and composite raft (lime + geogrid) in the remoulded soft clay bed. From the model load test, load- settlement characteristics were evaluated for the above combinations. From the test results, it is found that the load carrying capacity of lime, cement, lime-cement pile andlime-cement pile with composite raft are 100 to 400% higher than that of untreated softclay. However, the order of increase in load carrying capacity is lime-cement pile with composite raft > lime-cement pile > cement pile > lime pile.

Keywords: Soil stabilization; soft clay; lime pile.

1 Introduction

In this rapidly growing world, availability of land with good bearing capacity has become less. Development of industries, housing, and pavement has become a major problem, especially in urban areas. Construction of any structure on low lying areas is very difficult, because they have low bearing capacity. Hence, the land with low bearing capacity has to be improved with some techniques such that improving its engineering performance by either adding chemical additives or reinforcing them. Detailed investigations have been carried out on the stabilization of soft clay soil using lime-cement column technique to improve its bearing capacity and to reduce the differential settlement (Mansour et al (2015) and Carlsten (1996)).

Sujit Kawade et al (2014) conducted an experiment on stabilization of Black Cotton (BC) Soil with lime and geo-grid. The optimum lime content for the BC soil block was obtained as 15 percent. For the 15% lime content alone, the maximum compressive strength of the BC soil block was observed as 8.29 kg/cm^2, 9.61 kg/cm^2, 17.55 kg/cm^2 and 16.38 kg/cm^2 for 3, 7, 14 and 28 days curing periods respectively. For the 15 percent lime content along with geogrid reinforcement, the maximum compressive strength of the BC soil block was observed as 10 kg/cm^2, 9.66 kg/cm^2, 18.76 kg/cm^2 and 22.50 kg/cm^2 for 3, 7, 14 and 28 days curing periods respectively. Thus, the maximum value of compressive strength was obtained for BC soil blocks with geo-grid reinforcement and with addition of 15 % lime for 28 days of curing period. Dallas Little (2006) listed various test procedures to be followed for stabilizing the soil using lime. He found that soil with at least 25% passing a 75 micron screen and having a plasticity index of 10 or greater are suitable for lime stabilization. Soils containing soluble sulphates greater than 0.3% can be successfully stabilized with lime, but may require special precautions. The lowest percentage of lime in soil that produces a laboratory pH of 12.4 is the minimum lime percentage for stabilizing the soil.

In this paper, an attempt is made to study the behavior of lime pile, cement pile and lime-cement pile with composite raft in the remoulded soft clay.

2 MATERIALS

The soil for the proposed study was collected from Pallikaranai, Chennai. The collected soil was then air dried and stored. Then it was crushed and powdered. The index property tests and grain size analysis were conducted according to IS 2720:1985.The properties of soil are shown in table 1. Commercially available hydrated lime (purity 95%) was collected. The properties of lime are shown in table 2. Portland cement was used in this study. And the geogrid used was a biaxial product, which takes the load in transverse as well as longitudinal directions. The tensile strength of the geogrid was found to be 46 kN/m.

Table 1. Physical Properties of soil

Properties	Values
Clay %	65
Silt %	18
Sand %	17
Liquid Limit %	61
Plastic Limit %	23
Plasticity Index %	38
Shrinkage Limit %	6.7
Specific Gravity	2.73
Free Swell Index %	133
Optimum moisture content (%)	19.6
Maximum dry density (kN/m^3)	17.88
Soil Classification	CH

Table 2. Properties of Lime

Description	Properties
Molecular formula	$Ca(OH)_2$ (Hydrated Lime)
Molecular weight	74.09
Description	A fine powder
Chlorides	0.01%
Sulphate	0.2%
Lead	0.001%
Arsenic	0.0004%

3 METHODS

A plastic tube filled with a mixture of lime, cement and soil, having diameter of 30mm was selected as model pile with height of 100mm, spacing between the piles is 2.5D and a lime treated platform with geogrid of 50mm thickness was used as a load transfer platform placed at the top of the lime-cement pile. Schematic view of the load test in model tank is shown in figure 1. The optimum amount of chemical admixture tobe added was found using unconfined compression test. The soil was air dried and was sieved in 0.425mm sieve. Then it was mixed with chemical admixture for various percentages. Finally, to this dry mix, water (two times the Optimum Moisture Content) was added to conduct UCC tests and optimum percentage of chemical admixture was obtained. The pH tests were conducted to find the lime fixation point. Various percentages of lime of (95% purity) was mixed thoroughly with the soil. The lime fixation point was found to be 3%, beyond that the pH remained almost constant. Model tests were conducted in model tank to study the behavior of different material of piles, different thicknesses of composite raft. The number of piles are 1 and 3. The dimensions of the tank were 250mm diameter and 280mm height, which were arrived based on significant depth (10%q) for pile foundation, which is sufficiently large enough to avoid boundary effect.

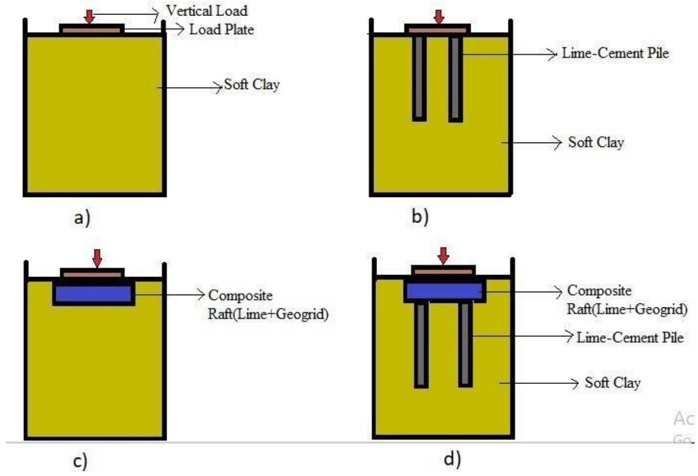

Fig 1. Schematic diagram of load test in model tank with following cases a) soil alone, b) soil+ lime-cement pile, c) soil+ composite raft, d) soil+ lime-cement pile+ composite raft

4 RESULTS AND DISCUSSIONS

4.1 Optimum lime percentage in soil

The percentages of lime added to conduct unconfined compressive strength test were 4%, 5%, 6%, 7%. Since the lime fixation point was obtained as 3%, lime requiredfor the cementation purpose will be more than 3%. UCC tests were done for 0 and 7 days curing. For soil along with lime without curing, the maximum unconfined com- pression strength for 4%, 5%, 6% and 7% was obtained as 201.81, 285.96, 393.3, 182.86 kN/m^2 respectively. For Soil along with lime for 7 days curing, the maximum unconfined compression Strength for 4%,5%,6%,7% was obtained as 287.88, 518.73, 637.51, 342.68 kN/m^2 respectively. Thus, the optimum lime content at which the soil yielded the highest UCC strength is at 6%.

4.2 Optimum cement percentage in soil

The percentages of cement added to conduct unconfined compressive strength test were 8%, 10%, 12%, 14%, 16%. For soil along with cement without curing, the maximum unconfined compression strength for 8%, 10%, 12%, 14% and 16% was obtained as 296, 317, 400, 545, 476kN/m^2 respectively. For soil along with cement for 7 days curing, the maximum Unconfined Compression Strength for 8, 10, 12, 14, 16% was obtained as 1200, 1400, 1450, 1503, 1360 kN/m^2 respectively and thus 14% is obtained as optimum percentage of cement.

4.3 Optimum lime-cement content in soil

Soil was mixed with lime and cement at various proportions. UCC tests for Lime and cement (of ratio 50:50, 75:25, 25:75) was done, and from that, it was found that asthe lime percentage decreased, the strength increased. Thus, the optimum value was found for lime and cement as 25 and 75 respectively. For soil along with lime-cement without curing, the maximum unconfined compression strength for 6%, 7%, 8%, 9% was obtained as 644, 750, 1234, 1176 kN/m^2 respectively. For soil along with lime- cement for 7 days curing, the maximum unconfined compression strength for 6%, 7%,8%, 9% was obtained as 841, 945, 1383, 1287 kN/m^2 respectively, and thus 8% lime- cement is obtained as optimum percentage.

4.4 Performance of Lime pile, Cement pile and Lime-Cement pile (1 number) without curing

The performance of lime pile, cement pile and lime-cement pile is compared in this section. When model tests were conducted on soil alone without any stabilization, for 2mm, 5mm, 10mm settlement, the load obtained was 20N, 63N, 90N respectively. The load-settlement curve of virgin soil is shown in figure 2. Based on the strength, it is compared as follows, figure 3 shows the comparison of load-settlement curve of lime pile, cement pile, lime-cement pile (1 number) without curing. For 2mm settlement, the corresponding load for single lime pile, cement pile and lime-cement pile are 30N, 55N and 60N respectively. The percentage increase in strength is 50%, 175% and 200% compared to soil alone. For 5mm settlement, the corresponding load for single lime pile, cement pile and lime-cement piles, are 65N, 115N and 138N respectively. The percentage increase in strength is 3%, 82% and 119%, compared to soil alone. For 10mm settlement, the corresponding load for single lime pile, cement pile and lime-cement piles, are 100N, 160N and 185N respectively. The percentage increase in strength is 11%, 100% and 105 % compared to soil alone.

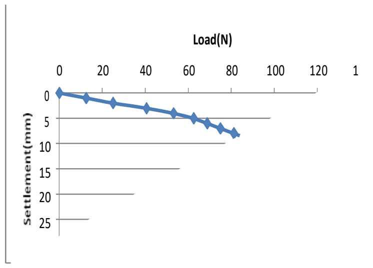

Fig 2. Load - Settlement curve for soil alone

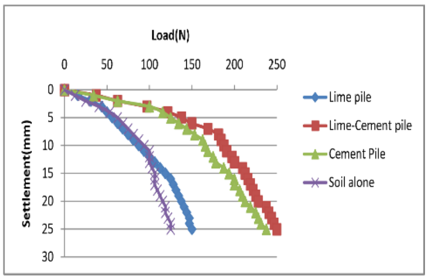

Fig 3. Load-Settlement curve for Lime, Lime-Cement, Cement Pile without curing (1 number)

4.5 Performance of Lime pile, Cement pile and Lime-Cement pile (3 numbers) without curing

The comparison of load-settlement curve of lime pile, cement pile, lime-cement pile (3 numbers) without curing is shown in figure 4. For 2mm settlement, the corresponding load for three lime pile, cement pile and lime-cement piles, are 90N, 100N and 100N respectively. The percentage increase in strength is 350%, 400%, 400% compared to soil alone. For 5mm settlement, the corresponding load for three lime pile, cement pile and lime-cement piles, are 170N, 170N and 195N respectively. The percentage increase in strength is 169%, 169% and 209%, compared to soil alone. For 10mm settlement, the corresponding load for three lime pile, cement pile andlime- cement piles, are 250N, 280N and 300N respectively. The percentage increase in strength is 177%, 211% and 233% compared to soil alone.

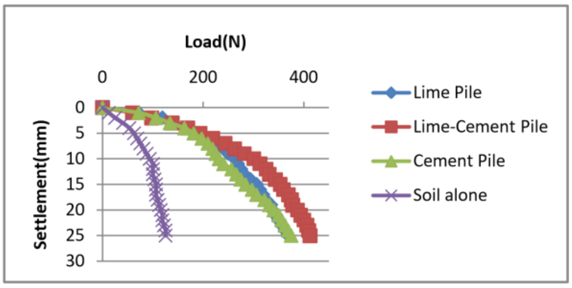

Fig 4. Load-Settlement curve for Lime, Lime-Cement, Cement Pile without curing (3 numbers)

4.6 Performance of Lime pile, Cement pile and Lime-Cement pile (1 number) with 7 days curing

The performance of lime pile, cement pile and lime-cement pile with 7 days curing is compared in this section. Figure 5 shows the comparison of load-settlement curve of lime pile, cement pile, lime-cement pile (1 number) with 7 days curing. For 2mm settlement, the corresponding load for single lime pile, cement pile and lime-cement piles, are 90N, 85N and 115N respectively. The percentage increase in strength is 350%, 325% and 475% compared to soil alone. For 5mm settlement, the correspondingload for single lime pile, cement pile and lime-cement piles, are 150N, 158N and 280N respectively. The percentage increase in strength is 138%, 150% and 344%, compared to soil alone. For 10mm settlement, the corresponding load for single lime pile, cement pile and lime-cement piles, are 200N, 210N and 400N respectively. The percentage increase in strength is 122%, 133% and 344% compared to soil alone.

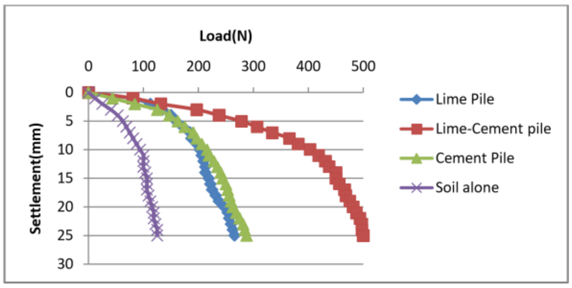

Fig 5. Load-Settlement curve for Lime, Lime-Cement, Cement Pile with 7 days curing (1 number)

4.7 Performance of Lime pile, Cement pile and Lime-Cement pile (3 numbers) with 7 days curing

Figure 6 shows the comparison of load-settlement curve of lime pile, cement pile, lime-cement pile (3nos) with 7 days curing. For 2mm settlement, the corresponding load for three lime pile, cement pile and lime-cement piles, are 130N, 110N and 120N respectively. The percentage increase in strength is 550%, 450% and 500% compared to soil alone. For 5mm settlement, the corresponding load for three lime pile, cement pile and lime-cement piles, are 260N, 210N and 315N respectively. The percentage increase in strength is 312%, 233% and 400%, compared to soil alone. For 10mm settlement, the corresponding load for three lime pile, cement pile and lime-cement piles, are 380N, 390N and 505N respectively. The percentage increase in strength is 322%, 333% and 461% compared to soil alone.

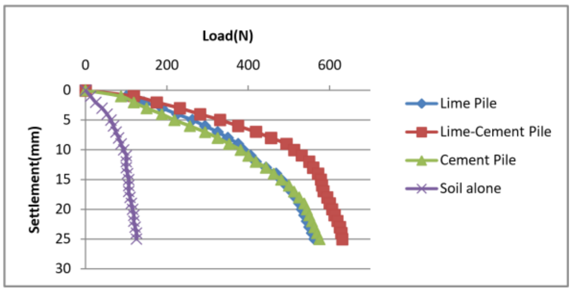

Fig 6. Load-Settlement curve for Lime, Lime-cement, cement pile with 7 days curing (3 numbers)

4.8 Performance of Lime-Cement Pile with Composite Raft without and with 7 days curing

The load-settlement curve of soft clay with lime-cement pile with composite raft without and with 7 days curing is shown in the figure 7. For 2mm settlement, the corresponding load for Lime-Cement pile with Composite raft for without and with 7 days curing, are 120N and 150N respectively. The percentage increase in strength is 500% and 650% compared to soil alone. For 5mm settlement, the corresponding load for Lime-Cement pile with Composite raft for without and with 7 days curing, are 260N and 340N respectively. The percentage increase in strength is 313% and 439%, compared to soil alone. For 10mm settlement, the corresponding load Lime-Cement pile with Composite raft for without and with 7 days curing, are 440N, 520N respectively. The percentage increase in strength is 388% and 477% compared to soil alone.

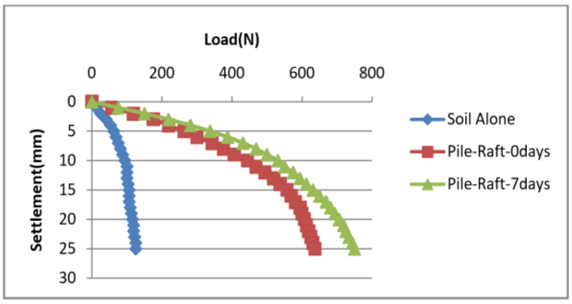

Fig 7. Load-Settlement curve for Lime-Cement pile with Composite raft for without curing (0 days) and 7 days curing.

5 CONCLUSIONS

The experimental investigation on the behavior of lime pile, cement pile and lime-cement pile with composite raft in soft clay was performed. Based on the analysis of experimental results, the following conclusions are obtained.

1. The variation of UCC strength revealed that the optimum percentage of lime, cement and lime-cement is 6%, 14% and 8% respectively in expansive clay. From the results, 3% of lime added to soil was enough to increase the plastic limit of the soil.

2. Load carrying capacity of single lime pile in soft clay is 11% and 122% higher than that of untreated soft clay respectively for 0 days and 7 days curing. For three lime piles, the increase in load carrying capacity of soft clay is 177% and 322% higher respectively for 0 days and 7 days curing period.

3. In case of a single cement pile, the increase in load carrying capacity is 100% and 210% for 0 days and 7 days curing period respectively in comparison with the untreated soft clay. For three cement piles, the increase in load carrying capacity of soft clay is 211% and 333% for 0 days and 7 days curing period respectively.

4. Load carrying capacity of single lime-cement pile in soft clay is 105% and 344% higher than that of untreated soft clay respectively for 0 days and 7 days curing. For three lime piles, the increase in load carrying capacity of soft clay is 233% and 461% higher respectively for 0 days and 7 days curing period. As the curing period and number of piles increases, the load carrying capacity also increases.

5. For lime-cement pile (3 nos) with composite raft (50mm thickness), the percentage increase in strength for 0 days and 7 days curing is 388% and 477% respectively.

It is thus inferred from the results that, the percentage increase in load carrying capacity is in the order of, lime pile< Cement pile< Lime-Cement pile<Lime-Cement pile with composite raft.

Hence, it is recommended that lime-cement pile with composite raft may be used in soft clay as an enhanced foundation system for low to moderately loaded structure.

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