Поведение глинистой почвы, усиленной каменной колонной, покрытой георешеткой, под циклической нагрузкой

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Аннотация. В статье рассматривается поведение глинистого грунта, имеющего состояние полного насыщения водой, армированного каменными колоннами, которые испытывают циклическую нагрузку. Этот вопрос имеет большое значение при проектировании железнодорожных земляных насыпей. Пластичные глинистые грунты характеризуются высокой осадкой и низкой несущей способностью из-за избыточного порового давления, вызываемого тяжелыми грузовыми поездами, в результате чего развивается дополнительное снижение несущей способности. Использование каменной колонны для армирования водонасыщенного глинистого грунта позволит снизить осадку и увеличить несущую способность. Целью настоящего исследования является изучение вариантов улучшения грунта основания путем уменьшения осадки для конструкции здания с использованием системы каменных грунтовых колонн в грунте с использованием и без георешетки под циклической нагрузкой со скоростью загрузки 5 мм/сек.

Ключевые слова. Циклическая нагрузка, лабораторные испытания, осадка, каменные колонны, глинистый грунт, деформация.

The behaviour of the clay soil reinforced by stone column encased with geogrid under cyclic load

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Abstract. The behavior of the fully saturated clay soil reinforced by stone columns subjected to cyclic load is of considerable very important in the design of railway subgrades, these soft clay soil are characterized by high settlement and low bearing capacity because of the excess pore pressure due to heavy freight trains significantly reduces the bearing capacity which causes serious problems, the used of stone column for reinforced the saturated clay soil will reduced the settlement and increase the bearing capacity. The purpose of the current research is cases study of foundation soil improvement by reduced the settlement for a building structure using stone columns system with and without geogrid encasement under cyclic load with rate of loading 5 mm/sec.

Keywords. Cyclic loading, laboratory tests, settlement, stone columns, clay soil, deformation.

Introduction. Soft clays are recent alluvial deposits probably formed within the last 10,000 years characterized by their flat and featureless ground surface. (Brand and Bernner, 1981) are identified by their low undrained shear strength \( Cu < 40 \text{ kPa} \) (B.S. C.p.8004:1986) and high compressibility \( Cc \) from 0.19 to 0.44. They are found at high natural moisture content, typically ranging from 40...60% with plasticity index ranging from 45...65% (Broms, 1987). Soils with such characteristics create serious problems to geotechnical engineering associated with stability and settlements problems. Many techniques are available to improve such soils based on reducing the water content by several mechanisms such as sand drains, wicks, electrical osmosis and thermal treatments. On the other hand some other techniques are also developed towards improving the engineering properties of these clays by introducing sand compaction piles or stone columns, where holes with specific depth and diameter are made within the soil in a grid form and backfilled with granular material. The seismic behaviour of foundations has been mainly investi-
gated through pseudo-static analysis of the bearing-capacity reduction due to seismic forces [Sarma and Iossifelis, 1990; Pecker and Salençon, 1991; Paolucci and Pecker, 1997a and 1997b], and the evaluation of the earthquake-induced settlements [Richards et al., 1993; Paolucci, 1997]. However, these investigations have been scarcely supported by parallel experimental investigations, essential to check the analytical procedures.

**Materials and methods.** Clay. The engineering properties of the site soils are identified based on a number of laboratory tests. A brown clayey soil was brought from a site east of Baghdad. Standard tests were performed to determine the physical and chemical properties of the soil, details are given in Tables below. The soil consists of 4.2% sand, 27.8% silt and 68% clay as shown in the grain size distribution (Figure 1).

| Physical properties of the clayey soil | Value |
|---------------------------------------|-------|
| Natural water content % (wc)          | 3.1   |
| Liquid limit % (LL)                   | 37    |
| Plastic limit % (PL)                  | 27    |
| Shrinkage limit % (SL)                | 20    |
| Plasticity index % (PI)               | 10    |
| Activity (At)                         | 0.6   |
| Specific gravity (Gs)                 | 2.68  |
| Gravel (larger than 2mm)%             | 0     |
| Sand (0.06 to 2mm)%                   | 4     |
| silt (0.005 to 0.06mm)%               | 28    |
| Clay (less than 0.005mm)%             | 68    |
| Classification (USCS)                 | CL    |

According to the sieve analyses test, more than 50% of the soil passed No.200 sieve and Atterberg limit tests show that the plasticity index is10% whereas the range of the liquid limit is between 37% and 40% with an average of 38.5%. According to USCS, the soils are classified as the clays (CL) with low plasticity and high plasticity (CH). Water content varied within a range between 31% and 30%.

**The crushed stone.** The crushed stone materials were obtained from a private mosaic factory. It was produced as a result of crushing big stones, the crushed stone is of white color with angular shapes. The assessment of mechanical properties of stone columns, the internal friction angle of the constructed and the relative density columns are estimated from the past studies while the grain size distribution of the stone material is presented in Figure 2.

**Procedure.** The center of the square box was properly marked and a PVC pipe of diameter (70 mm) was placed at the center of the box. Around this pipe, clay bed was formed. The clay layer was tamped with a wooden tamper frequently and gently to remove the soil inside the PVC pipe, a hand auger, manufactured for this purpose was used. After preparing the clay bed. The depth of each stone column was...
The stone required to form the column was carefully charged in the tube in three layers. Each layer was compacted using 14 mm diameter rod to get a density of 17 kN/m³, the tubes were charged with stone and compacted in layers. The PVC tube was withdrawn to certain level and charging of stones for the next layer was continued. The operations of charging of stones, compaction and withdrawal of tubes were carried out simultaneously. Further the bed thus prepared was left for 1 day to achieve uniform bed, which also ensured proper contact between clay and stone column. The test after 24 hours of preparation of the bed has also ensured gain in their strength of disturbed clay. The stone columns have a diameter of 70 mm, length to diameter ratio \((L/D)\) of 8, the installation of encased stone columns, the same procedure followed in construction of the ordinary stone columns was conducted (Figure 3).

![Figure 3. Installation of stone column.](image)

Experimental set up for the load test. To support and ensure the verticality of the pneumatic jack that used in applying the vertical load on footing, a steel frame was designed and constructed for this purpose. The steel frame consists mainly of four columns and four transverse beams. Each member was made of steel with a rectangle cross sectional area of \((120 \text{ mm} \times 65 \text{ mm})\) and wall thickness of 4 mm. The dimensions of the steel frame (length \(\times\) width \(\times\) height) are respectively \((1150 \text{ mm} \times 810 \text{ mm} \times 1520 \text{ mm})\). To strengthen the steel frame to withstand the applied load, two beams were added to support the load frame. The settlement of the footing during the application of cyclic load was measured by using LVDT (Linear Variable Differential Transformer). The LVDT has a stroke of about 70 mm with an output signal ranging \(\pm10 \text{ V}\) with a normal 10 V DC power supply as shown in the figure below.

![Figure 4. Steel loading frame.](image)

Results and discussion. As shown in the figure 2, it can be notes that the model of untreated soil will fail faster than the model of soil reinforced with stone column, otherwise the model of the soil reinforced with stone column will fail more than the model of soil reinforced with stone column encased by geogrid material, Figure 2 shows compare the result between 5 mm/sec for Experimental investigation. Figure 4 shows compare the result for rate of loading 5 mm/sec for un treated soil and soil reinforced soil by stone column.

The main reason for using stone column is that Pressure settlement response of
clay bed and stone column without geogrid increases the bearing capacity of the clay by about 51%. The load bearing capacity of clay is increased by 73% when the stone has been installed, considering that the failure load corresponds to 10% of the column diameter: Initially, the stone column bears the load and after bulging, the settlement increases rapidly as shown in the It should be note from the result below that for the models were subjected to cyclic loading with rate of loading 5 mm/sec reached the failure level faster than compare with those under rate of loading 5 mm/sec. Figure 6 shows compare the result for rate of loading 5 mm/sec for untreated soil and soil reinforced soil by stone column encased with geogrid. Figure 7 shows compare the result for rate of loading 10 mm/sec for untreated soil and soil reinforced soil by stone column encased with geogrid. Final result is shown on Figure 8.

Figure 6. Compare the result between 5 mm/sec for Experimental investigation

Figure 7. Compare the result between 10 mm/sec for Experimental investigation

Table 2
Summary of result of rate 5 mm/sec

| Point | For untreated soil | Soil reinforced with stone column | Soil reinforced with stone column encased by geogrid |
|-------|-------------------|-----------------------------------|-----------------------------------------------|
| 3     | 40 mm             | 22 mm                            | 13 mm                                         |
| 4     | 45 mm             | 25 mm                            | 14 mm                                         |

Table 3
Summary of result of rate 10 mm/sec

| Point | For untreated soil | Soil reinforced with stone column | Soil reinforced with stone column encased by geogrid |
|-------|-------------------|-----------------------------------|-----------------------------------------------|
| 3     | 30 mm             | 12 mm                            | 2 mm                                          |
| 4     | 40 mm             | 17 mm                            | 1 mm                                          |

Figure 8. Final result

Conclusion
The following points are drawn from the tests.
Stone column improves the settlement behavior of soft clay soil under cyclic load.
Relating to settlement reduction ratio Sr, the values of Sr increase with increasing the shear strength of the treated soil.
For the models with cyclic load, below the threshold rate loading 5 mm/sec, reinforced soils were less sensitive to the number of loading application than soils (no column). This is likely due to compaction of the column materials that occurs during load application, leading to increase in density and resulting in greater resistance to deformation hence lower settlement. Therefore for the stone column alone and thus encased by geogrid.
The crushed stone columns with \( L/D = 8 \) provide a settlement reduction ratio, \( S_r \), (Strengthened/Suntreated ) of (0.35) for the soil of shear strength (\( C_u = 15 \) kPa) treated with single.
The crushed stone column with \( L/D =8 \) encased by geogrid provide a settlement reduction ratio, \( S_r \), (Strengthened/Suntreated ) of (0.65) for the
soil of shear strength \( (Cu = 15 \text{ kPa}) \) treated with single.

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