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Reinforcement of gypseous soil by stone columns

Lamyaa Najah Snodi[1], Ahmed Ramadan Sayed Orabi[2]
[1] *College of Engineering of the Tikrit University; Tikrit, Republic of Iraq;*
[2] *Fayoum University (FU); Fayoum, Arab Republic of Egypt*

ABSTRACT

Introduction. Gypseous soil is one of the problematic soils that have substantial strength while dry but lose strength especially in wetting or saturation condition due to the significant reduction of its strength parameter and bearing capacity upon loading where gypseous cementing bonds have been dissolute and collapsed in the wet condition (Soil collapse occurs when increasing moisture weakens chemical or physical connections between soil particles), and therefore resulting in excessive settlements affects the stability of the engineering structures. Gypseous soils occupy about 1.865 million km^2 in the world; the percent of gypseous in Iraq is 6.7 % of the total world gypsiferous area and about 28.6 % of the total area of this country.
Materials and methods. Stone column is a soil improvement technique used for stabilization and reinforcing of soft soil (low strength soil) by increasing of bearing capacity (increasing strength) and reducing the settlement and control it (consolidation acceleration).
Results. The aim of this study is to investigate the performance of gypsum soil reinforced by stone columns, where laboratory loading tests were performed on unreinforced and reinforced gypsum soil using big steel box as modeling and stone columns was have different diameters (5, 10, 15 and 20 cm) and fixed depth (30 cm).
Conclusions. The results showed that the settlement decrease with increase the stone column diameter and the bearing capacity increase when diameter increase.

KEYWORDS: gypseous soil, stone column, settlement, model, diameter of column, depth of column, reinforcement

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Corresponding author: Lamyaa Najah Snodi, dr.lamyaanajah@tu.edu.iq.

Укрепление гипсосодержащего грунта каменными столбами

Ламьяа Наджах Сноди[1], Ахмед Рамадан Сайед Ораби[2]
[1] *Инженерный колледж Тикритского университета; г. Тикрит, Республика Ирак;*
[2] *Фаюмский университет (ФУ); г. Фаюм, Арабская Республика Египет*

АННОТАЦИЯ

Введение. Гипсосодержащий грунт — проблемный грунт, обладающий значительной прочностью в сухом состоянии. Он теряет прочность при увлажнении и намокании из-за существенного снижения прочностных параметров и несущей способности под нагрузкой вследствие растворения и разрушения цементирующих связей во влажном состоянии (просадка грунта происходит, когда из-за роста влажности ослабляются химические или физические связи между частицами грунта). Это приводит к чрезмерной осадке, влияющей на устойчивость инженерных сооружений. Гипсосодержащие грунты занимают около 1,865 млн км^2 в мире. Процент гипсовых грунтов в Ираке составляет 6,7 % от общей площади гипсосодержащих грунтов в мире и около 28,6 % от общей площади этой страны.
Материалы и методы. Каменный столб — это метод улучшения грунта, используемый для стабилизации и укрепления слабых грунтов (грунтов низкой прочности) путем увеличения несущей способности (увеличения прочности), сокращения оседания и контроля над оседанием грунта (ускорение консолидации).
Результаты. Целью данного исследования является изучение характеристик гипсосодержащего грунта, укрепленного каменными столбами. Лабораторные нагрузочные испытания проводились на укрепленных и неукрепленных гипсосодержащих грунтах с использованием большого стального ящика в качестве модели, каменных столбов различного диаметра (5, 10, 15 и 20 см) и фиксированной глубины (30 см).
Выводы. Результаты показали, что осадка уменьшается с увеличением диаметра каменной колонны, а несущая способность увеличивается при увеличении диаметра.

КЛЮЧЕВЫЕ СЛОВА: гипсосодержащий грунт, каменный столб, расчет, модель, диаметр колонны, глубина установки столба, укрепление

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Автор, ответственный за переписку: Ламьяа Наджах Сноди, dr.lamyaanajah@tu.edu.iq.

INTRODUCTION

Gypseous soil is one of the problematic soils that have substantial strength while dry but lose strength especially in wetting or saturation condition due to the significant reduction of its strength parameter and bearing capacity upon loading where gypseous cementing bonds have been dissolute and collapsed in the wet condition (Soil collapse occurs when increasing moisture weakens chemical or physical connections between soil particles), and therefore resulting in excessive settlements affects the stability of the engineering structure. Gypseous soils occupy about 1.865 million km^2 in the world; the percent of gypseous in Iraq is 6.7 % of the total world gypsiferous area and about 28.6 % of the total area of this country.

Stone column is a soil improvement technique used for stabilization and reinforcing of soft soil (low strength soil) by increasing of bearing capacity (increasing strength) and reducing the settlement and control it (consolidation acceleration).

Several researches — theoretical, numerical, and experimental and field study have performed on behaviour soft soil reinforced by stone columns [1–14]. However very little information is available on this behaviour in gypsum soil.

The aim of this study is to investigate the performance of gypsum soil reinforced by stone columns, where laboratory loading tests were performed on unreinforced and reinforced gypsum soil by stone columns with different diameters and fixed depth. Hataf et al., (2020) studied the bearing capacity of encased single stone column in both dry sand and clay bed and the influences of the length of encasement and type of aggregate materials on the improvement of bearing capacity a by conducted a series of compression tests on model encased and uncased stone column embedded in cohesive and granular soils. The results indicated that a clear improvement by encasing the half-length of the column and the smaller size of materials, encasing the stone columns makes more improvement than coarser materials. Afshar and Ghazavi (2013) conducted a laboratory tests were performed on unreinforced and reinforced (horizontally and vertically) geotextile-encased stone columns diameters of 60, 80 and 100 mm and a length to diameter ratio of 5 to study the efficiency of vertical and horizontal reinforcement on bearing capacity of soft clay. The result sowed that the bearing capacity of reinforced stone columns increases by increasing diameter of stone column.

Lajevardi et al. (2018) conducted a series of laboratory tests and 2D numerical models to study the influences of the encasement of on the behaviour of stone column. The result sowed that encasement is more effective in improving the column bearing capacity of larger diameter columns than smaller ones. Ng (2018) investigated the bearing capacity of single stone column using three-dimensional numerical analysis (Plaxis 3D), where the effect of some parameter such as column's material friction angle, undrained shear strength of the surrounding soil was studied. The result sowed that the bearing capacity of reinforced stone columns increases by increasing the strength of column's material friction angle, undrained shear strength of the surrounding soil. Hamzh, et al. (2019) Numerical study has been performed using 2D finite element (Plaxis 2D) to investigate the bearing capacity of uniform and non-uniform stone columns in soft soil. The result sowed that the highest bearing capacity obtained by the non-uniform stone column was one with the $d2{:}d1$ ratio equals to 1:5. The most economical shape for the stone column (the least volumes used to construct stone columns) was achieved at a ratio of $d2{:}d1$ = 1:2 and a length ratio of $l1{:}l2$ = 3:7. Ahmad Dar and Yousuf Shah (2020) conducted a numerical study to investigate effect of geosynthetic encasement properties, pattern of stone and stone column material on the load settlement behaviour of geosynthetic encased stone columns (GESC) under vertical stresses in soft soil using 3D finite element (Plaxis 3D).The result sowed that Bearing capacity increases with increasing the stiffness and length of encasement, length of floating column, cohesion of soil and friction angle of stone column infill. Al-Waily, et al. (2020) 24 laboratory models were carried out to investigate the bearing capacity of soft clay treated with stone columns. The result sowed that the experiments showed that the stress concentration and bearing capacity of soil treated with stone column increase with increasing the undrained shear strength (Cu), number of columns and l/d ratio. Tan and Zhao (2017) conducted a model tests and corresponding numerical analysis using (FLAC3D) on the isolated single stone column to study the failure behaviour and bulging deformation behaviour of the stone columns with and without geosynthetic encasement. The result sowed that the numerical simulated failure process of stone column shows good agreement with model tests.

DAS and DEY (2018) performed a laboratory model tests were on un reinforced and reinforced stone columns with diameter 50 mm and length 500 mm where horizontal layers of geo-textiles were provided at different depths up to 15 cm. The result sowed that settlement of stone column is decreased by 1/7 times with the use of geotextile reinforcement and the ultimate load carried by soft soil increases by 2.5 times with the use of stone columns. Fattah and Khudhair (2014) the behaviour of ordinary and encased floating stone columns in different conditions have been investigated. The effect of length to diameter ratio (l/d), end support of the stone column and the area replacement ratio on the bearing improvement and settlement reduction of the stone column were studied. The result sowed that bearing improvement ratio increases by increasing end bearing soil undrained shear strength (Cu) in case of ordinary end bearing stone columns and Strength of the encased stone column, settlement reduction ratio and effect of encasement length ratio are increased by

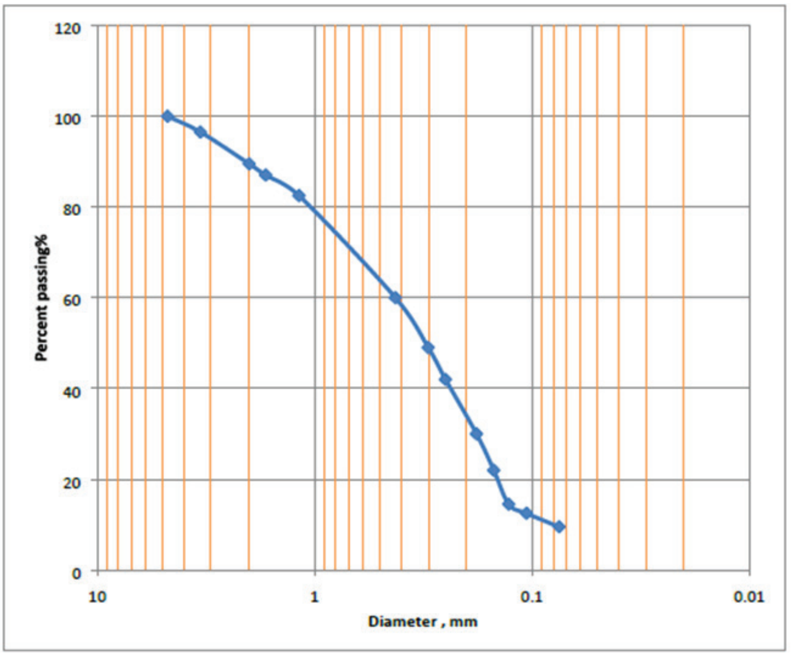

Fig. 1. Grain size distribution of gypseous soil

Рис. 1. Гранулометрический состав гипсосодержащего грунта

increasing end bearing soil undrained shear strength (Cu) in case of encased end bearing stone columns.

Madun et al. (2018) performed finite element analyses using (PLAXIS 2D) to study the effect of the diameters and lengths of column on the load bearing capacity and settlement of soft clay. The result sowed that Stone column load bearing capacity increases with the increasing diameter of the column and settlement decreases with the increasing length of the column, where the bigger column diameter, the higher load bearing capacity of soil while the longer column length, the lower settlement of soil. Nazaruddin et al., (2018) experimental data from two previous studies was collected and compare with Dimensional analysis method (Buckingham-Pi Theorem) to investigate effect of some parameter on the capacity of stone column such as angle friction of among the stones, arrangement of column, spacing centre to centre between columns, shear strength of soil, and physical size of column (diameter and length).

Fig. 2. Stone column

Рис. 2. Каменный столб

The result of the calculated data indicated that have a reasonably good agreement with the collected data and stone column load bearing capacity increases with the increasing diameter of the column and settlement decreases with the increasing length of the column.

Singh 1 and Chamling 2 (2014) finite-element analysis on behaviour of single column of 50 mm diameter using Plaxis 2D is performed to investigate effect of loading area and shear strength of soft clay on bearing capacity and effect of confining material on bulging response. The result sowed that the results indicated that diameter of bulging decreases with increase in either the loading area or the strength of the confinement material and the critical length of stone column is greater than four times of the diameter of column. Zahmatkesh and Choobbasti (2010) a series of numerical analysis has been carried out to evaluate compaction and settlement of soft clay reinforced by a group of stone columns and the results are compared with those available in the literature. The result sowed

Table 1. Dimensions of the stone columns used

Табл. 1. Размеры используемых каменных столбов

No. of col.	Depth of col., cm	Diameter of col., cm
1	30	5
2	30	10
3	30	15
4	30	20

Fig. 3. The model used

Рис. 3. Используемая модель

Fig. 5. Dial gauges for reading the settlement

Рис. 5. Циферблатные манометры для измерения осадки

Fig. 4. Stone column inside PVC pipe

Рис. 4. Каменный столб внутри трубы ПВХ

that: The load settlement behaviour of model with an entire area loaded is almost linear, Variation of stress in soft soil after installation of column with distance from column is significantly reduced and effect of the strain on the Settlement reduction ratio (SRR) is small due to vertical stress versus settlement relation is almost linear.

MATERIALS AND METHODS

Soil

The soil used was brought from Tikrit university, which located in Tikrit city/Salah-Aldeen Governorate, in the middle of Iraq at (1.5–2.0 m) depth. Soil used in this study is poorly graded (SP) as classified according to USCS. Fig. 1 shows the particle size distribution. The gypsum content was (57 %) for the soil.

Stone column

Crushed stones used in this study, which was crushed manually using metal rod. Then the size of the stones was choice that passing from sieve No. 12.5 mm and remained on sieve No. 4.75 mm. After that concrete mixture from stone and cement used the mixing ratio was (1cement:4 stone), Fig. 2. Table 1 show the dimensions of the stone columns used in tests.

The Model

Device used consists of steel box with dimensions (1 × 1 × 1 m) also have dial gauges for measure the stone

Table 2. Results the settlement with diameter of stone column

Табл. 2. Результаты расчета диаметра каменного столба

No. of col.	Depth of col., cm	Dia. of column	Settlement, mm
1	30	5	35
2	30	10	27
3	30	15	15
4	30	20	12

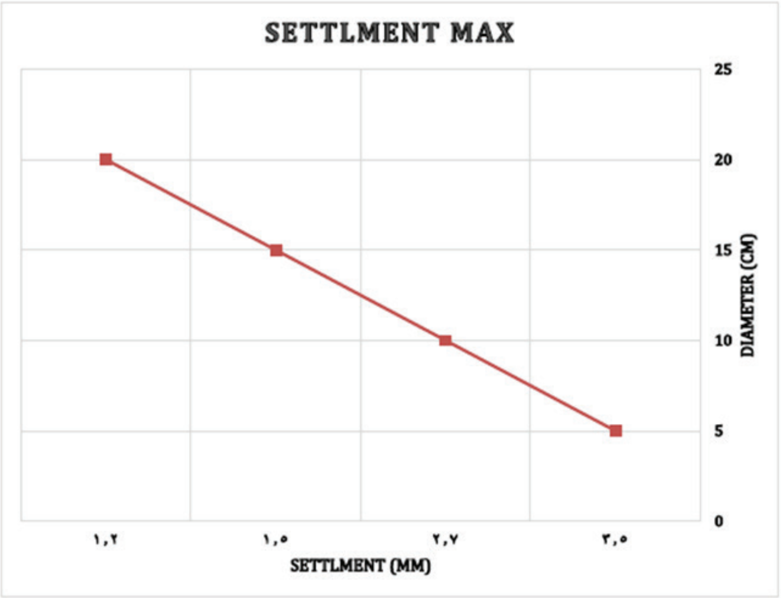

Fig. 6. Settlement for the gypseous soil with different diameter of stone column

Рис. 6. Осадка гипсосодержащего грунта с каменными столбами разных диаметров

column settlement, Fig. 3 show the model. The box filled by gypseous soil and compacted for layers 10 cm thick for each layer until reach to the upper surface of the box around 15 cm from up. The stone column was put inside PVC pipe depend on the diameters of the column, Fig. 4, and the test start by applied pressure on the stone column through moving manually and take the reading for settlement from dial gauges, Fig. 5.

RESULTS

Compaction test was carried out on gypseous soil sample to obtained the Max. dry density and optimum moisture content the values was (16.4 kN/m^3) and (14.5 %).

After that, the soil compacted in the box depend on the Max. dry density and optimum moisture content. The stone column was put in the gypseous soil then the test start. The settlement reading from the gage, the results shown in Table 2.

Fig. 6 show the settlement for the gypseous soil with different diameter of stone column. They found that when the diameter increases the settlement decrease because the area for the stone column.

CONCLUSION AND DISCUSSION

Based on the results the conclusions from this study, the stone column has good effect on the gypseous soil. It was observed when the diameter for stone column increased the settlement of soil decrease. That means the stone column with different diameter can improve the gypseous soil.

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Bionotes: **Lamyaa Najah Snodi** — **College of Engineering of the Tikrit University**; Tikrit, Republic of Iraq; dr.lamyaanajah@tu.edu.iq;

Ahmed Ramadan Sayed Orabi — master’s student, Faculty of Engineering; **Fayoum University (FU)**; Fayoum, Arab Republic of Egypt.

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Ахмед Рамадан Сайед Ораби — магистрант инженерного факультета; **Фаюмский университет (ФУ)**; г. Фаюм, Арабская Республика Египет.

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