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# Small scale behavior of stone columns encased by tires

Seyed Hamid Lajevardi* and Saeed Enami[a]

*Department of Civil Engineering, Arak Branch, Islamic Azad University, Arak, Iran,*
*Khomein Road, Imam Khomeini Square, Arak, Iran*

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**Abstract.** Stone columns are one of the best-suited methods of ground improvement for sites consisting of soft clays, silts and silty sands. Stone columns need to be supported against bulging failure as the main reason that reduces their bearing capacity. Disposal of scrap tires is one of the principal environmental problems around the world. Therefore, the reuse of scrap tires has grown globally. This paper investigates the behavior of stone columns encased by scrap tires which has the potential of replacing other encasements. Stone columns with diameters of 66, 80 and 92 mm which are one-tenth of original tire sizes have been tested in a large box, and the load-carrying characteristics of them are analyzed. Based on the results, by increasing the diameter of the encasement stone column, the benefit of the encasement increases. In addition, tests on the groups of stone columns with a diameter of 66 mm were carried out to investigate the presence effects of neighboring columns on the reference load. Furthermore, a comparison has been made with the results of ordinary stone columns and encased stone columns with geotextile to obtain the benefits of scrap tire columns. The bearing capacity of both single and group of stone columns encased with the scrap tire increases more than the ordinary stone columns. However, the bearing capacity of geotextile encased stone column is more than the other groups. Further, numerical analysis has been conducted to implement full-scale reinforced columns. The results illustrate that using scrap tires reduces bulging failure and increases the bearing capacity of stone columns. Accordingly, scrap tires replace the geotextile (as usual encasement) because their amount of bearing capacities are similar to each other especially in columns with larger diameters.

**Keywords:** laboratory tests; stone column; scrap tires; geotextile; ground improvement

## 1. Introduction

The management of scrap tires is a serious concern around the world. Numerous scrap tires are stockpiled every year which increases the risk of a major environmental problem. For instance, rainwater collected in scrap tires provides a breeding ground for mosquitoes which ends up producing dangerous diseases. Furthermore, they are durable and very bulky with a fire hazard. Therefore, it is necessary to find some ways for their alternative utilization by means of recycling (Oikonomou and Mavridou 2009). ASTM D6270, "Standard Practice for the Use of Scrap Tires in Civil Engineering Applications," provides a comprehensive list of terms and definitions for scrap tires used in civil engineering applications. Scrap tires can be used in two states in many geotechnical engineering projects such as tire-chips in lightweight fill for embankments, road construction and highway embankments (Edil and Bosscher 1994, Foose *et al.* 1996, Yang *et al.* 2002, Cetin *et al.* 2006) and original shape of scrap tire for stability of walls and slopes (Poh and Broms 1995, Garga and O'shaughnessy 2000).

In the soft soils, the construction of structures such as buildings, liquid storage tanks, earthen embankments, etc. causes the excessive settlement that results in stability problems. To solve or reduce the settlement problems, the stone columns (also known as granular piles) have been widely used based on several available techniques. Not only they improve the bearing capacity, but also they increase the consolidation rate in soft clay because of the high permeability of the stone column material. Using stone column technique started in European countries in the early 1960s, and after that, it has been used successfully. The main problem of stone columns is failing in different modes, such as bulging failure described by Hughes and Withers (1974), general shear failure described by Madhav and Vitkar (1978), and sliding and punching failure mechanism described by Aboshi *et al.* (1979).

For years, different experimental procedures have been chosen to study the behavior of stone columns. For instance, Murugesan and Rajagopal (2009a) carried out some laboratory tests to compare the shear load capacity of the ordinary and encased stone columns. Data results from the load tests indicated that using geosynthetic materials for encasing leads increased the bearing capacity of the stone columns. Miranda and Da Costa (2016) focused on increasing the strength of encased samples compared with non-encased ones using the extra confining pressure provided by the geotextiles. Results indicated that the improvement achieved when the gravel was encased with the geotextile; consequently, the encasement effect was more significant at lower confining pressures. More tests on

*Corresponding author, Assistant Professor
E-mail: sh-lajevardi@iau-arak.ac.ir
[a]Ph.D. Student
E-mail: enami.saeed@gmail.com


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columns encased by geotextile are performed by Sivakumar *et al.* (2004), Ambily and Gandhi (2007), Murugesan and Rajagopal (2009b), Wu and Hong (2009), Gniel and Bouazza (2009), Najjar *et al.* (2010), Pulko *et al.* (2011), Castro and Sagaseta (2011), Ghazavi and Afshar (2013), Dash and Bora (2013), Mohapatra *et al.* (2016), Hamidi and Lajevardi (2018).

Numerical modeling can be utilized as a key tool to assess the performance of real scale columns. For instance, Ghazavi and Afshar (2013) used a FE model for investigating the effect of geotextile encasement on the bearing capacity of actual-size stone columns. They conducted a FE analysis with Mohr–Coulomb criterion and an axisymmetric model. Their numerical results showed good agreement with their experimental study. Some researchers also conducted their analysis by the finite element (FE) method (Yoo and Kim 2009, Khabbazian *et al.* 2010, Lo *et al.* 2010, Abusharar and Han 2011, Zhang *et al.* 2014, Chen *et al.* 2015, Yoo 2015, Demir and Sarici 2017, Lajevardi *et al.* 2018, Shamsi *et al.* 2019).

In the case of alternative materials, researchers proposed different materials for the construction of columns. The use of a steel bar as reinforcement (Rezaei *et al.* 2019) and EPS geofoam as column material (Bazzazian Bonab *et al.* 2021) have been investigated in laboratory studies. Scrap tires are accessible in large numbers with different diameters. They are priceless, homogeneous, annular and prepared without sewing (unlike geotextile). Thereupon, they are considerable. Multi-tires are being used to construct concrete and stone columns (Bugaldian and Saatcioglu 2008, Neel and Navarkar 2015).

The results of the previous experimental studies as mentioned above were not compared with the other types of columns like ordinary stone columns in order to obtain its performance. In this paper, scrap tires with original shape (without any changes) are used as a suitable alternative material for stone columns. The primary purpose of the study is to evaluate the efficiency of scrap tire encased stone column (SESCs). To this purpose, some experimental tests on single and group of stone columns with various diameters are presented. These tests involve ordinary stone column (OSCs), geotextile encased stone column (GESCs) and SESCs to investigate the effect of the new encasement type. A numerical analysis by FE method could be used to skip the scale effect in order to validate and complete the experimental study.

## 2. Experimental study

### *2.1 Materials*

#### *2.1.1 Clay and gravel*

The soft clay, with CL classification, was excavated from an urban area of Arak which is a city situated 280 km far from Tehran, the capital city of Iran. The clay was taken from the depth of one meter. Therefore, the clayey soil was not included vegetation, air-dried, and pulverized particles. Table1 gives some values of the clay properties. It is worth mentioning that the tests have been conducted based on ASTM standards.

Table 1 Properties of the clay

| Parameters | Value | Standards |
|---|---|---|
| Specific gravity | 2.7 | ASTM D0854 |
| Liquid limit (%) | 30 | ASTM D4318 |
| Plastic limit (%) | 17 | ASTM D4318 |
| Plasticity index (%) | 13 | ASTM D4318 |
| Bulk unit weight at 21% water content | 19 kN/m$^3$ | - |
| Undrained shear strength | 13 kPa | ASTM D2166 |
| Modulus of elasticity (kPa) | 400 kPa | - |
| Poisson's ratio (m) | 0.25 | - |
| USCS classification symbol | CL | ASTM D2487 |

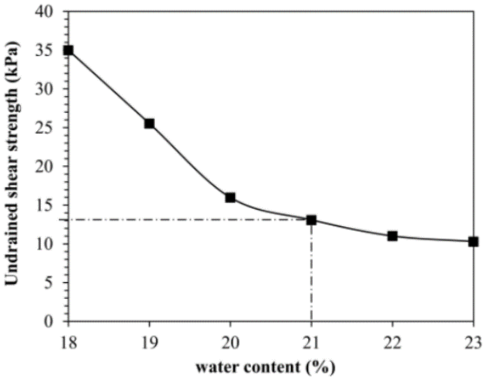


Fig. 1 Results of unconfined compressive strength tests for clay

Table 2 Properties of gravel

| Parameters | Value | Standards |
|---|---|---|
| Specific gravity | 2.7 | ASTM D0854 |
| Maximum dry unit weight | 16 kN/m$^3$ | ASTM D4253 |
| Minimum dry unit weight | 14.1 kN/m$^3$ | ASTM D4254 |
| Bulk unit weight for test | 15.5 kN/m$^3$ | - |
| Internal friction angle (φ) | 40$^o$ | ASTM D3080 |
| Uniformity coefficient ($C_u$) | 1.57 | - |
| Curvature coefficient ($C_c$) | 0.94 | - |
| Modulus of elasticity (kPa) | 40000 kPa | - |
| Poisson's ratio (m) | 0.3 | - |
| Unified system classification | GP | ASTM D2487 |

A series of unconfined compressive strength tests (UCS) on the cylindrical specimens with the diameter of 38 mm and the height of 76 mm were carried out for determining the moisture content corresponding to 13 kPa undrained shear strength of the clay. Results of these tests are depicted in Fig. 1. The resulting water content of the clay was 21% and this amount was the same in all tests. The UCS test has been conducted based on ASTM D2166 standard.

Gravel with the sizes between 2 to 19 mm was used to form stone columns. Properties of gravel are presented in Table 2. Consequently, Fig. 2 showed the particle size distribution for both the kaolin clay soil and stone aggregates with ASTM standards of D7928 and D6913, respectively.

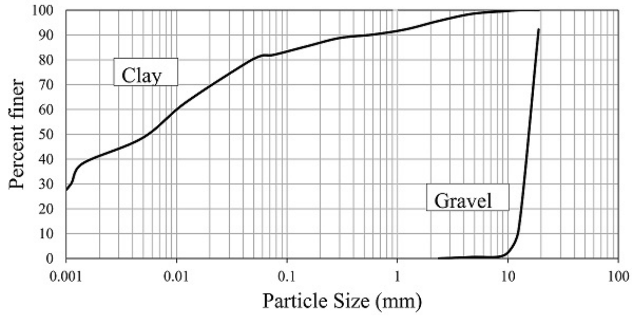



Fig. 2 Clay and Gravel particle distributions


Fig. 3 Scrap tire size and direction of the tensile test

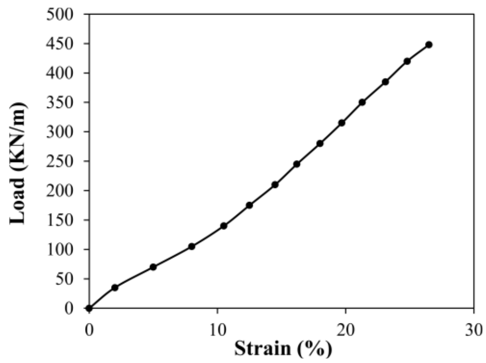



Fig. 4 Stress-strain figure of the tire

Table 3 Properties of scrap tire and geotextile

| Parameters | Scrap tire | Geotextile |
|---|---|---|
| Ultimate tensile strength (kN/m) | 448 | 9 |
| Strain at ultimate strength (%) | 27 | 55 |
| Secant stiffness at ultimate Strain (J) (kN/m) | 1659 | 16.36 |
| Thickness (mm) | 28.5 | 1 |

### *2.1.2 Reinforcement*

The tires consist of polymer matrix – rubber and long-filament reinforcement – cords, therefore the tires are fall within as very complex long fiber composite with particular deformation characteristics which present a good potential to be used as a suitable encasing material. A tensile test is performed on chosen radial tire 245/40 R18 (Fig. 3) to obtain information about its characteristics. The result of this test is shown in Fig. 4 and tire properties are presented in Table 3.

To model tires in the large test box by considering the scale factor, geotextile is used. In practice, geotextile sleeves are being used as encasement material in the diameter ranges from 40 to 100 cm and the tensile strength up to 400 kN/m with the stiffness from 1000 to 4000 kN/m. The stiffness of the tire is 1659 kN/m and falls in this range. For the experimental tests, the diameter of the stone column was chosen one-tenth of real scale. Considering the scaling law proposed by Lai (1989), the relationship between stiffness of real-scale reinforcement ($J_r$) and the model scale ($J_m$) is $J_r=J_mL^2$, where 1/L is the model scale. The amount of L equals 10 in this paper. Therefore, the annular form of geotextile (SESC) with the stiffness of 16.36 kN/m (Table 3) which has 1/100 of tire stiffness is used to simulate the scrap tire in the laboratory (Fig. 5).

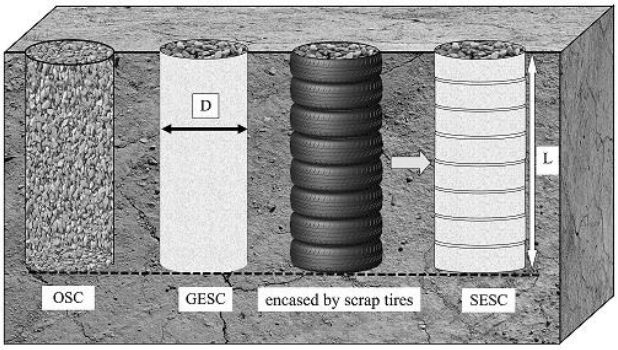



Fig. 5 Different form of columns

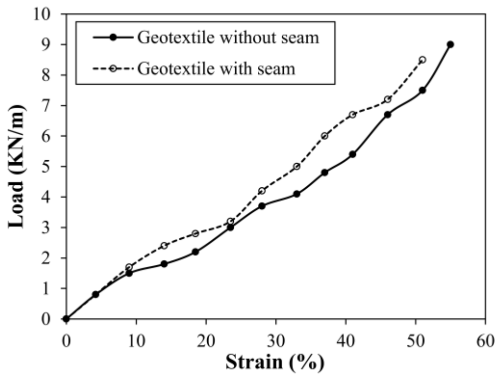



Fig. 6 Load-strain behavior of the geotextile

For all tests, the overlapping width of 15 mm was stuck with a special polypropylene glue to make encasing sleeves. The tensile load-strain behavior of geotextile with and without a seam is shown in Fig. 6. Care was taken that the stuck seam had the sufficient strength.

### *2.2 Test setup and procedure*

This test included a rigid loading box with plan dimensions of 1.20 m×1.20 m and 0.90 m height, similar to some studies (Rezaei *et al.* 2019, Bazzazian Bonab *et al.* 2020), which provided enough space for the soft soil, and stone columns were such a way that boundary of the box did not have any effect on bearing capacity of columns (Fig. 7).

The loading system was based on a displacement control and was powered by an electrohydraulic system that applied the vertical load on the center of the single columns. The

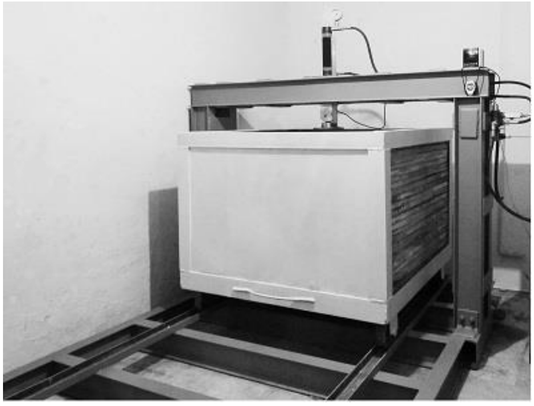


Fig. 7 Large test box and loading frame

Table 4 Tests on single stone columns

| Test description | Plate size (mm) | Diameter of stone columns (mm) | | | Number of tests |
|---|---|---|---|---|---|
| | | 66 | 80 | 92 | |
| Clay bed | 180 | | | | 1 |
| OSC | | 1 | 1 | 1 | 3 |
| GESC | | 1 | 1 | 1 | 3 |
| SESC | | 1 | 1 | 1 | 3 |

Table 5 Tests on group stone columns with triangle arrangement. (Note: S/D = center-to-center distance of columns)

| Test description | Plate size (mm) | Diameter of stone columns (mm) | Number of columns | Area replacement (%) | S/D | Number of tests |
|---|---|---|---|---|---|---|
| OSC | | | | | | 1 |
| GESC | 270 | 66 | 12 | 17.93 | 2.5 | 1 |
| SESC | | | | | | 1 |

load applied to reach the 50 mm settlement, and its speed was fixed by a particular valve on the rate of 2 mm/min in all tests.

In this study, three tests were performed on stone columns encased by the annular type of geotextile (SESCs) to simulate the tire in the small scale. To realize how much this kind of encasement will be useful, seven tests were performed on clay bed, OSCs, and GESCs, then results were compared. Furthermore, three tests were carried out on the groups of stone columns. Tables 4 and 5, show a list of all tests which were performed on the single and the group of stone columns.

A rigid steel plate with the diameter of 180 mm and the thickness of 20 mm was used as the loading object for single columns while it was attached to a load cell to measure the amount of stress on the stone columns. Additionally, a plate with a diameter of 270 mm was used for the group tests. To ensure the accuracy of the test results each test has been performed twice.

### *2.3 Preparation of materials*

#### *2.3.1 Soft clay bed*

To prepare the moisture content of 21% corresponding to 13 kPa undrained shear strength (see Fig. 1), the amount of calculated additional water, with considering the initial natural water of the clay, was added. To reach a uniform moisture, the mixture was kept for five days in a side box covered by nylon sheets from inside. On the $5^{th}$ day, the large box was filled with layers of 60 mm thick and bulk unit weight of 19 kN/$m^3$. It was necessary to ensure that no significant air voids were left out in each layer with a proper compaction. The final surface was horizontally leveled to have a suitable surface for loading in tests.

In all tests, moisture changes were controlled, and its variations were less than 1%. To ensure that the undrained shear strength remained the same, three unconfined compression tests were performed on the specimens taken from different depths of the clay bed. As a result, unconfined compression tests showed a good agreement with 13 kPa undrained shear strength of the clay.

#### *2.3.2 Stone columns*

All stone columns were constructed by a replacement method at the center of the large box, ensuring that test results would not be affected by walls of the box. To replace stone columns in clay, three thin steel pipes with the outer diameters of 66, 80 and 92 mm and the wall thickness of 2 mm were prepared and used to push into the clay. In this study, stone columns were constructed with the length to diameter ratio of five which satisfied minimum L/D = 4 necessaries for controlling the bulging failure mode (Barksdale and Bachus 1983 and Sivakumar *et al.* 2011).

By using a handy jack, care was taken that the greasy pipes (on both inner and outer surfaces) slightly and vertically penetrated without causing any significant disturbance on columns surrounding and no pressing on the soil of its bottom. Subsequently, the clay within each pipe was scooped out by using an auger with the diameter of 50 mm. After excavating the whole clay inside the columns, the pipes were taken out slowly by ensuring that no significant soil movement occurred around the top level of each of the stone column. Stones were charged into prepared hole with a measured weight, and a compaction was provided with a tamper to achieve a 50 mm thickness of a layer and a uniform density to reach a bulk unit weight of 15.5 kN/$m^3$. A light compaction was adopted to ensure that no significant lateral bulging occurred during the columns construction. Additionally, a visual control always made of the column material to make sure that no breakage happened upon the column loading. The similar procedure was followed to prepare the reinforced stone columns.

For encasing geotextile in the field and the laboratory conditions, an open-toe, a thin-walled steel tube (casing) equal to diameter to geotextile sock was pushed from the surface down to the underlying founding layer. The geotextile was then placed inside the casing and filled from the surface with the stone aggregates by the method which mentioned for the non-reinforced stone column. After the geotextile sock has been filled, the steel casing was raised around the encased column, leaving it in-situ. For placing the scrap tire, after making the borehole, circular tires with a diameter of the column was put in the borehole. After that, the column was filled with stone aggregates. Noticeably, the scrap tires are very easy to install moreover, they save both cost and time.

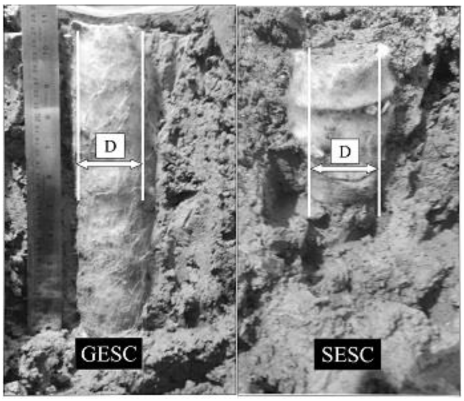
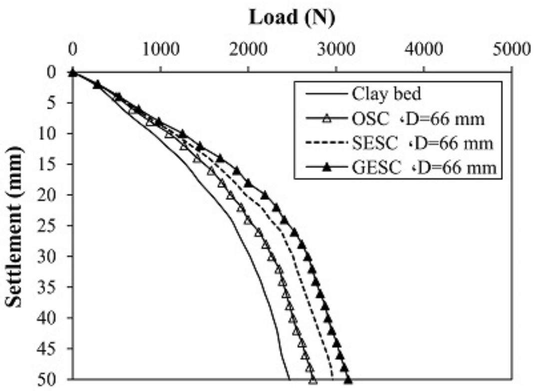
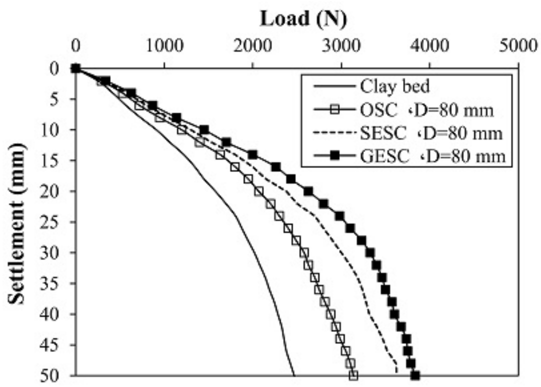


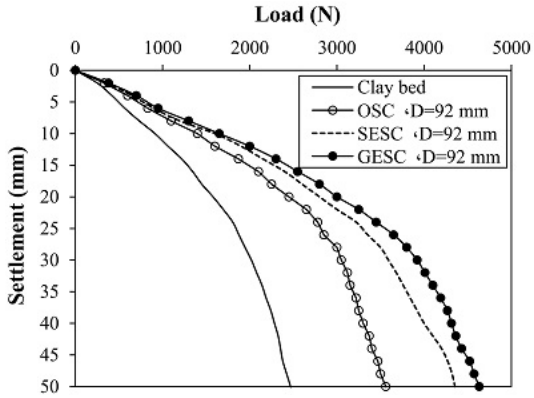

Fig. 8 Axisymmetric deformation of both SESCs and GESCs




(a) D= 66 mm




(b) D= 80 mm




(c) D= 92 mm

Fig. 9 Load-settlement behavior of different columns

## 3. Experimental results

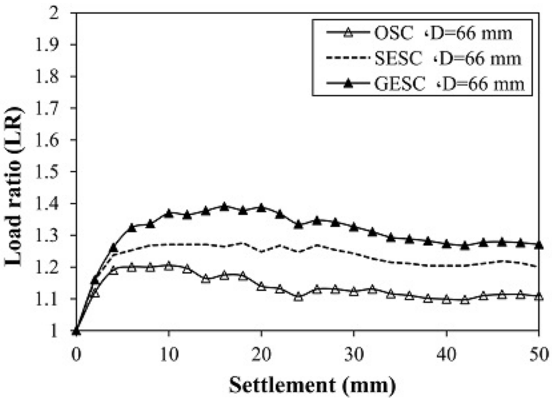
### *3.1. Single stone columns*

#### *3.1.1 Deformation and failure mode*

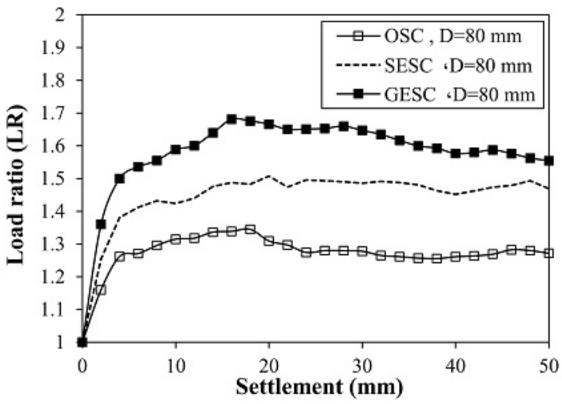
To check the deformed shape of stone columns, the clay around columns was softly cut, after the tests. Fig. 8, shows the axisymmetric deformation of both SESCs and GESCs. As seen, for SESCs the bulging failure occurred at the top of the column to the depth of D, while for GESCs it occurred from D to 2D of the column head. For SESCs, due to the annular form of encasement gravel, it may tend to move out of the stone columns which causes different deformation of encasement (deformed edges of rings at the top of SESC).

#### *3.1.2 Comparison between SESCs with GESCs and OSCs*

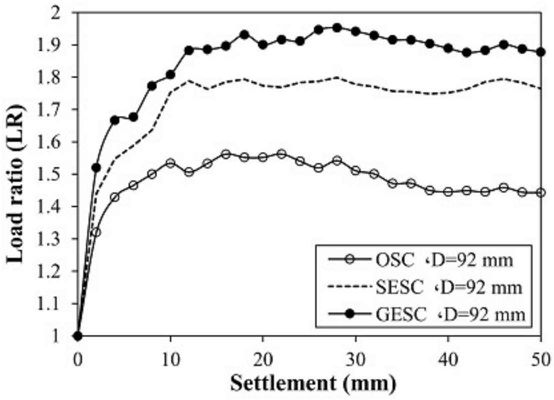
Fig. 9(a)-9(c) illustrates the comparison between the load-settlement behavior of different columns (OSCs, SESCs and GESCs) with diameters of 66, 80 and 92 mm. SESC showed 8.2%, 15.5% and 22.3% increase in the bearing capacity in comparison with OSC for diameters of 66, 80 and 92 mm, respectively. Furthermore, the ultimate bearing capacity of SESC decreased approximately 5.7% compared with GESC, in average. As a result, the bearing capacity of SESCs is more than the bearing capacity of OSCs. However, this amount is smaller than GESCs. This




(a) D= 66 mm




(b) D= 80mm




(c) D= 92 mm

Fig. 10 Variation of LR for SESC, GESCs, and OSCs

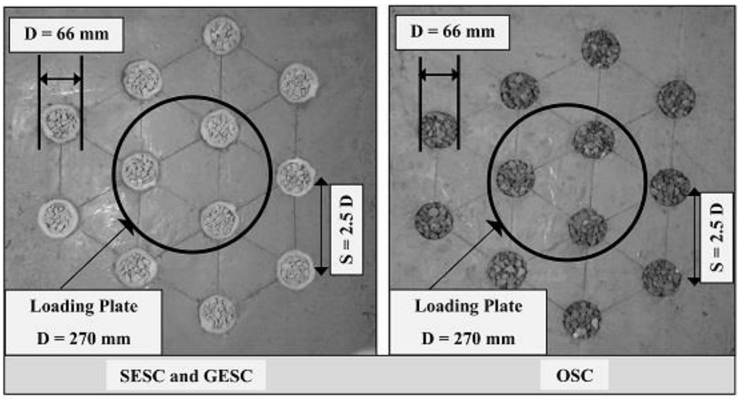



Fig. 11 Arrangement of different groups of stone columns

result indicates that the stiffness created by reinforcement materials plays an important role in the bearing capacity of the stone columns. It is also revealed that with increasing the diameter of SESC and GESC the encasement effectiveness increases.

### *3.1.3 Load ratio (LR)*

To determine the efficiency of stone columns from the viewpoint of ultimate bearing capacity of the soft clay during loading, the load ratio (LR) parameter which is known as the ultimate load obtained from reinforced soil by the stone columns divided by the ultimate load obtained from the soft soil without stone columns (clay bed). The variation of LR for SESC, GESCs, and OSCs with diameters of 66, 80 and 92 mm are shown in Fig. 10. LR graphs began from the point of (0,1) because its amount will be meaningful from this point.

As seen in Fig. 10(a)-10(c), the variation of LR for diameters of 66, 80 and 92 mm are in the ranges of 1.21─1.39, 1.35─1.68 and 1.56─1.95, respectively. The LR values increased for SESCs with increasing the column diameters from 66 to 92 mm. Additionally, the LR values obtained from OSCs are less than the encased stone columns because of the lateral confinement provided by the geotextile encasement that reduces bulging. The minimum LR is for OSCs, and the maximum LR is for columns with

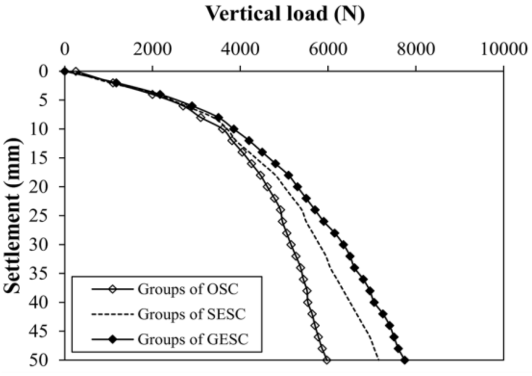



Fig. 12 Load-settlement behavior of different groups of 12 stone columns

the continuous geotextile (GESCs). Using LR diagram, buging failure during settlement can be realized. For instance, in Fig 10(a)-10(c), values of LR increased up to the settlement of 15 mm in OSCs with the different diameters and then decreased gradually. Therefore, with bulging occurrence in this point, the column reaches to its final strength.

### *3.2 Group of stone columns*

To study the effect of the scrap tire encasement in groups of stone columns, three tests were performed on groups of SESCs, GESCs and OSCs. Twelve stone columns with the triangle arrangement were placed in each group with the same procedure of single columns (Fig. 11). Table 5 presents a list of tests on a group of stone columns.

#### *3.2.1 Comparison between the group of SESCs with the groups of GESCs and OSCs*

Fig. 12 illustrates the comparison between the load-settlement behavior of the different groups of columns (SESCs, GESCs and OSCs) with diameters of 66 mm. The group of SESCs showed an increase in comparison with OSCs and the ultimate bearing capacity of SESCs decreased approximately 7.6% compared with GESCs. This is due to more resistance against the lateral deflection provided by the GESCs compare with SESCs.

## 4. Scale effects for experiments

Numerical modeling is often used to develop and complete the experimental modeling, through which engineering problems can be solved and the behavior of materials can be predicted in the ield conditions. In this section, axisymmetric finite element model was developed on Plaxis 2D to achieve this purpose. Results of this investigation were taken from the small-scale model tests that give an opportunity to make a complete study on the encased columns with geotextile and scrap tires. Studying the scale effects of models in experiments is essential in order to connect the results from small-scale tests to real scale design. Nonetheless, to study scale effects of the model geometry and the scrap tire stiffness ($J_t$), some

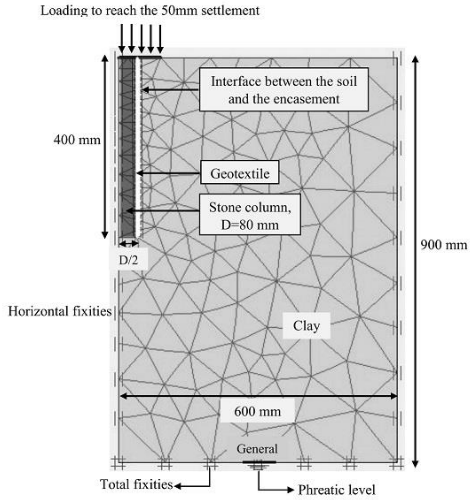



Fig. 13 Numerical model

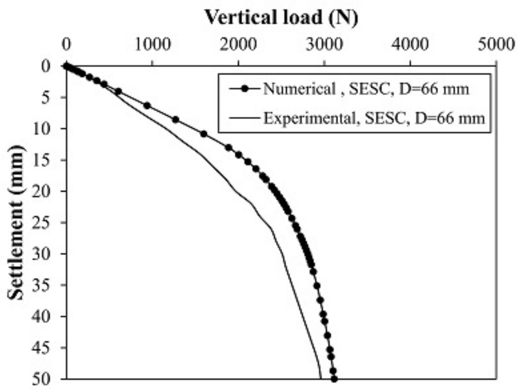



Fig. 14 Model validation

selected results of the experimental tests are compared with results of FEM analysis conducted using PLAXIS 2D software (Rezaei *et al.* 2020). The constructed numerical soil-column system behavior was confirmed using experimental data achieved for SESC tests.

In this paper, stone columns were analyzed by using an axisymmetric finite element analysis to take into account the shape of the columns in z-direction (Fig. 13). The analyses simulate the same geometry and boundary conditions as in the laboratory tests. The Mohre-Coulomb failure criterion was considered to govern the failure stage of the clay and stone column material. The geotextile material was assumed as a linear-elastic material. In the finite element discretization, 6-noded triangular elements with geometry and boundary conditions as presented in tests were used. All analyses were conducted by applying displacement increments.

In numerical modelling displacement of a point under the loading plate is considered the same as experimental tests to make a logical comparison. The results obtained from both experimental tests and FEM analysis on SESC with a diameter of 66 mm are compared in Fig. 14. As illustrated, this comparison is satisfying.

Table 6 compares the maximum LR values of the single SESCs for both experimental and numerical results. In

Table 6 Results of experimental tests in comparison with numerical tests

| Type of tests | Diameter of stone column (mm) | Maximum load ratio (LR) | |
|---|---|---|---|
| | | Experimental | Numerical |
| SESC | 66 | 1.31 | 1.27 |
| | 80 | 1.51 | 1.5 |
| | 92 | 1.7 | 1.57 |

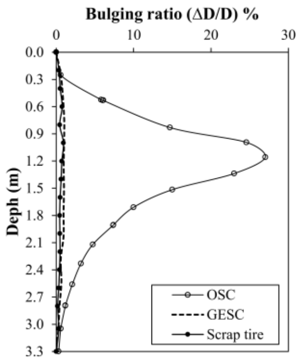



Fig. 15 Bulging ratio versus the depth (D=66 cm)

numerical modelling displacement of a point under th loading plate is considered the same as the experimental tests to make a logical comparison. As seen, there is a very good agreement between experimental and numerical results.

In numerical analyses, the scrap tires (with the real scale) are compared with the geotextile encasement with the same stiffness. The maximum values of LRs are obtained 1.02, 1.14 and 1.15 for OSC, SESC and GESC, respectively. Therefore, tires can be replaced the ordinary form of encasement due to the close amount of LRs.

### *4.1 Bulging failure*

The bulging observed in the constructed stone columns resulted from columns modeling are compared with each other in Fig. 15. The lateral bulging presented with bulging ratio ($\Delta D/D$). D and $\Delta D$ are the initial diameters of the column and changes of the column diameter due to loading, respectively. It is observed that the stone column encasement with the geotextile reduces the column bulging for about (up to) 26%. As a result, using tire instead of an ordinary form of encasement did not cause any considerable change in the bulging mechanism as illustrated in Fig. 15.

This research shows that small-scale models for investigating the stone columns behavior present acceptable results. It is recommended that some tests on the real columns encased by tires can be performed then it is possible to consider this encasement effective on reducing the bulging and increasing the bearing capacity of the stone columns the same as geotextiles. Tires are accessible with various diameters and using them as columns encasement helps to solve the environmental problems. In addition, they are priceless, homogeneous, annular and prepared without sewing (unlike geotextile). These properties make tires suitable and special in this field. There are also some problems when it comes to real projects. These recommendations are notable:

• Tires can be sewn or fixed like a column using wide and strong tapes (for instance with two-meter high) moreover, they can be set in the excavated place the same as geotextile sleeves.

• Both sidewalls of each tire are removed to form a cylinder which stones can become well-compacted in. Furthermore, a suitable vibration provides a satisfactory compaction.

## 5. Conclusions

In this paper, some laboratory tests have been performed on the single and the groups of stone columns. Tests on the stone columns encased with the scrap tire were conducted, and the results were compared with those obtained from the ordinary and the geotextile stone columns.

Results of this research showed that the small-scale tests have some valuable results. It is recommended that tests with in-situ real size columns with tires as confinement can be profitable. This study represents the tire as a new confinement material the same as geotextile to bear bulging failure and then increase the bearing capacity of the stone columns. It investigates the effect of buried columns encased by tires. The numerical approach also is made to investigate the scale factor of the columns.

Based on the results, the following conclusions are extracted:

• Encasing stone columns with the scrap tires as annular encasement material increases the bearing capacity of the ordinary stone columns (OSC) and presents the satisfying result compared with geotextile.

• The bearing capacity of SESCs is more than the bearing capacity of OSCs. However, this amount is smaller than GESCs. This shows that the stiffness created by reinforcement materials plays a fundamental role in the bearing capacity of the stone columns.

• By increasing the diameters of stone columns, the scrap tire as encasing material is more efficient in increasing the bearing capacity.

• SESCs reduce the bulging failure in comparison with OSCs because of more lateral confinement provided by the scrap tire thus, ultimate load increases by using them.

• The scrap tires could be a good alternative material because they have the good performance in comparison with the ordinary stone columns and are very easy to install and save both cost and time.

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