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# Experimental and Numerical Studies on Load-Carrying Capacity of Single Floating Aggregate Piers Reinforced with Vertical Steel Bars

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**ABSTRACT:** The load-carrying capacity of the aggregate piers increases by circumferential confinement created by the surrounding soil. In soft clay soils, the amount of confinement is usually not sufficient to develop a load-carrying capacity. Because of that, it is practical to use geosynthetic reinforced aggregate piers in this type of soils. This paper intends to evaluate the use of vertical steel bars as an alternative for geosynthetics. In this study, some small-scale laboratory tests were performed on floating aggregate piers with diameters of 80 and 100 mm and a length of 400 and 500 mm, respectively reinforced with vertical steel bars. Moreover, two-dimensional numerical modeling using the Plaxis software was conducted. The results show that using bars with more stiffness leads to more increase in load-carrying capacity. Reinforcing the full length of the aggregate piers, compared to half-length, will further improve the load-carrying capacity of the aggregate piers. In the early stages, by applying the load, the stone aggregates tend to compress, so load-carrying capacity increases and by continuing this process, the tendency to the occurrence of lateral bulging is seen and due to the low resistance of kaolin clay to the bulging, the increase of load-carrying capacity is negligible. Also, numerical modeling results show that the floating aggregate pier penetrated into soft clay soil in the full-length case, and the failure state changed from bulging to slip.

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## 1. INTRODUCTION

One of the methods to improve soft soils is the construction of aggregate piers under the foundation of structures. After loading, bulging is observed in the aggregate piers, which causes the column to pressurize the surrounding soil in a radial direction and also the surrounding soil creates confinement in the aggregate piers [1]. In soft clay soils due to the low lateral pressure-resistant of the soil, the aggregate piers (in the form of bulging) failure occur at the top of the column. To deal with this phenomenon, reinforced aggregate piers are used [2]. The stiffness of the column increases by using the vertical reinforcing elements and it leads to an increase in load-carrying capacity and decreases the bulging and settlement of aggregate piers [3-6].

In this study, small-scale laboratory tests were carried out on single floating aggregate piers 80 and 100 mm in diameter, with a length to diameter ratio of 5 and reinforced by vertical steel bars of 2 and 3 mm in diameter with different arrangements. Numerical modeling is also conducted using two-dimensional finite element Plaxis software, which investigates the mechanism of failure of the aggregate piers.

## 2. LABORATORY TESTS

Materials used in this study include kaolin clay with 15 kPa undrained shear strength for kaolin clay bed, broken stone aggregates with the particle size of 2 to 10 mm for the construction of aggregate piers and steel bars of 2 and 3 mm in diameter as a reinforcement.

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In order to perform physical model tests on the aggregate piers a loading device was constructed. The test setup consists of a large rigid steel box of 1.2x1.2 m in plan and 1 m in height and loading system by a hydraulic jack to the center of the box. Steel plate with a diameter of 200 mm and the thickness of 30 mm was used as a plate load. The load was applied based on the displacement control method with a constant displacement rate of 1 mm/min.

The geometric percentage of the bars used in aggregate piers was defined as $\rho=As/Ac\times100$, where As was the total cross-section of the bars, and Ac was the area of the stone column. The stone columns in all tests were approximately reinforced with $\rho=0.50\%$. In Fig. 1 various arrangement of vertical reinforced aggregate piers (VRSCs) with circumferential bar for the same $\rho= 0.50\%$ is shown. A summarized list of performed tests was shown in Table 1.

### 2.1. Results and Discussion

Load-vertical strain behaviour of kaolin clay bed, ordinary aggregate piers (with the diameter of 80 and 100 mm) and reinforced with vertical steel bars of 2 and 3 mm in diameter

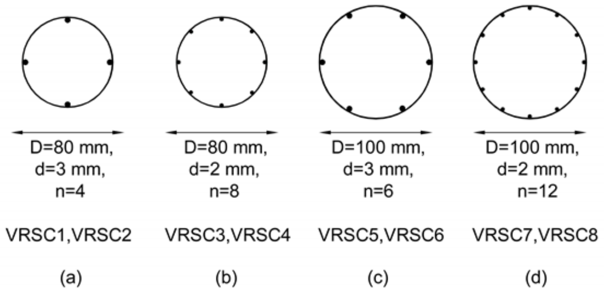



**Fig. 1. Various arrangement of VRSCs with circumferential bar for the same $\rho$= 0.50%**

**Table 1. List of the single stone column tests**

| Number of tests | Test type | *d* (mm) | *Lr* | *n* | *D* (mm) | |
|---|---|---|---|---|---|---|
| | | | | | 80 | 100 |
| 1 | Kaolin Clay bed | - | - | - | - | - |
| 2 | OSC | - | - | - | ✓ | ✓ |
| 8 | VRSC 1 | 3 | *L* | 4 | ✓ | - |
| | VRSC 2 | 3 | *0.5L* | 4 | ✓ | - |
| | VRSC 3 | 2 | *L* | 8 | ✓ | - |
| | VRSC 4 | 2 | *0.5L* | 8 | ✓ | - |
| | VRSC 5 | 3 | *L* | 6 | - | ✓ |
| | VRSC 6 | 3 | *0.5L* | 6 | - | ✓ |
| | VRSC 7 | 2 | *L* | 12 | - | ✓ |
| | VRSC 8 | 2 | *0.5L* | 12 | - | ✓ |

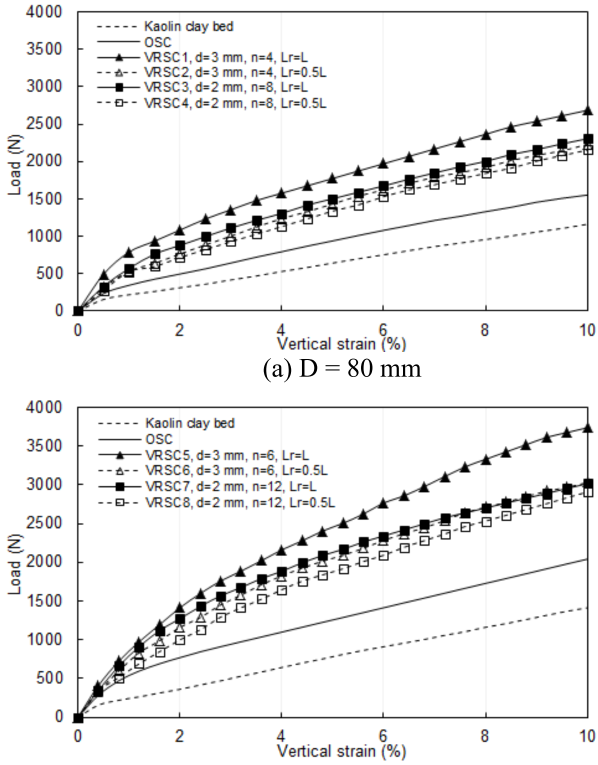
Note: *d*: diameter of reinforcement, *Lr*: length of reinforced, *n*: number of reinforcement, *D*: diameter of stone column, OSC: ordinary aggregate piers

with different arrangements up to strain of 10% were studied (Fig. 2).

Comparison of the results shows that by increasing the diameter of the aggregate piers from 80 to 100 mm, the load-carrying capacity improves by 31.5%. Steel bars with larger diameters are more stiffness so, their distribution in the aggregate piers increases the stiffness of the column. Thus, the load-carrying capacity of these piers is higher. Also, the effect of changing the arrangement of vertical steel bars in a half-length reinforced of the aggregate piers for both diameters is negligible. It is observed that aggregate piers, which are reinforced in full-length due to more confinement by reinforcement, have a better performance than the half-length reinforced aggregate piers.

## 3. NUMERICAL MODELLING

In this study, for modeling of kaolin clay bed, soft soil model




(a) D = 80 mm

(b) D = 100 mm

**Fig. 2. Load-vertical strain behaviour**

behaviour, for modeling stone aggregate, Moher-Coulomb criterion, for rigid plate loading, plate element and to model the reinforced bars the geogrid element were used. Numerical modeling is performed in the form of axisymmetric using fine mesh made of 15 node triangular elements.

Results show that, by increasing the values of the replacement area ratio (increasing the diameter of the aggregate piers), the reinforcement ratio value is increased in both cases $(L_r = L, 0.5L)$. In other words, the use of steel bars is more effective in larger diameters. The values of the improvement factor *(IF)* obtained from numerical modeling at full-scale have a very good agreement with the *IF* values obtained from laboratory tests. In this way, it is concluded that the results of small-scale laboratory tests can be used to study the performance of reinforced aggregate piers with vertical steel bars on a real scale.

## 4. CONCLUSIONS

In this study, small-scale laboratory tests were carried out to examine the effect of reinforcing aggregate piers of 80 and 100 mm in diameter with vertical steel bars on load-carrying capacity. Moreover, numerical modeling was performed by finite element Plaxis software. The following results are presented in this study:

1. In reinforced aggregate piers with vertical steel bars with a geometric percentage of vertical bars, 0.5%, the arrangements which have more stiffness have better performance.
2. Reinforced full-length aggregate piers have a better performance than half-length reinforced.

3. The bulging in the reinforced aggregate piers has been reduced by using vertical steel bars. Also, full-length reinforced aggregate piers have penetrated to the kaolin clay bed to a certain extent, and the shape of the failure has changed from bulging to slip.
4. The improvement factor derives from real-scale numerical modeling for aggregate piers reinforced with vertical steel bars is highly compatible with the improvement factor obtained from small-scale laboratory tests.

## 5. REFERENCES

[1] Hughes, J.M.O, Withers, N.J., 1974. Reinforcing of soft cohesive soils with stone columns. *Ground Engineering*, 7(3): pp. 42-49.

[2] Madhav, M.R., Miura, N., 1994. Soil improvement. Panel report on stone columns. *Proceedings of the 13th International Conference on Soil Mechanics and Foundation Engineering*, New Delhi, India, 5:163-164.

[3] Van Impe, W.F., 1989. Soil improvement techniques and their evolution, Balkema, Rotterdam, the Netherlands.

[4] Raithel, M., Kempfert, H.G., 2000. Calculation model for dam foundations with geotextile coated sand columns. *International Conference on Geotechnical and Geological Engineering*, Melbourne, Australia.

[5] Shivashankar, R., Babu, M.R.D., Nayak, S., 2011. Performance of stone columns with circumferential nails. *Proceedings of the ICE-Ground Improvement*, 164(2): pp. 97-106.

[6] Rezaei, M.M., Lajevardi, S.H., Saba, H.R., Ghalandarzadeh, A., Zeighami, E., 2019. Laboratory study on single stone columns reinforced with steel bars and discs. *International Journal of Geosynthetics and Ground Engineering*,5(2): pp. 1-14.

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