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# A physical modeling study on the load -deformation behavior of geosynthetic reinforced stone columns

**Sadi Berkay Dural** *1, **Özgür Lütfi Ertugrul** 1

1Mersin University, Civil Engineering Department, Mersin, Türkiye, sadiberkaydural@gmail.com, ertugrul@mersin.edu.tr

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**Abstract**

The stone column applications have emerged in Europe as a soil improvement method half a decade ago. This method can be applied on all kinds of soils, and it is generally preferred in places where soft and medium clays are present and soft soil layers are not very deep. Within this study, physical tests were performed on small scale single stone column models. As a result of the performed tests, it was observed that the settlement amount of the stone column decreased significantly when the stone column is surrounded by geotextiles and/or geogrids. It was observed that settlement of a shallow foundation supported by geotextile reinforced stone columns may reach up to 36%.

## Introduction

Although soil improvement methods are emerged long time ago, well established applications are frequently observed in the last few decades. The rapid development of machine technology a and the studies on engineering solutions paved the way for the frequent use of soil improvement techniques. In recent years, because of industrial and infrastructure developments in urban and metropolitan areas and also significant rises in land prices, researchers have been looking for soft soil reclamation techniques that were previously considered to be too expensive to develop [1]. The construction of structures, such as a building, storage tanks, warehouse, etc., on weak soils usually involves excessive settlement or stability problems [2]. The main goal of soil improvement methods is to improve the weak and soft soils with low bearing capacity, high compressibility and high liquefaction potential to fulfill the project requirements of a civil engineering structure. As a result of soil improvement methods, bearing capacity, tensile strength, deformation modulus and shear strength of the problematic soils increase. Besides, liquefaction and settlement potential as well as hydraulic permeability values decrease. In addition, consolidation settlements of the clayey soils are accelerated, swelling and shrinkage potential is controlled.

Stone columns are produced by filling the boreholes drilled in the soft ground using coarse aggregate, which has more strength compared to the soft ground. The material is further compacted with the help of a probe to increase the deformation modulus of the stone columns. This probe can vary in diameters ranging from 30cm to 46 cm. Compaction is applied in layers of 0.4m-1,2m thickness during forming the column height. With the installation of stone columns, the volume of the ground is replaced with coarse aggregate filling material between percentage values of 15-35% [3].

One of the biggest problems on the widespread use of stone column method, which is an economical and environmentally friendly soil improvement technique, is the bulging of the cylindrical stone column under high structural loads. This bulging leads to the intermixing of column materials with the neighboring soil [4]. When this problem occurs, stone columns cannot sufficiently resist to the deformations under high building loads and therefore deform over time and lose their effectiveness under loading. Although it has similar properties to reinforced concrete bored piles under the foundation in general, the lateral soil pressures on the upper portions of the stone columns increase, especially with the high loads, causing the stone column to expand.

## Material and Method

For ordinary stone columns which are not reinforced with geotextiles or geogrids, the horizontal support of the soil around the column must be equal to the horizontal pressure exerted on the column surface in order to prevent bulging. The effectiveness of the load carried by stone columns essentially depends on the lateral stress exerted by the surrounding soft soil [2]. In a stone column wrapped along the shaft with geotextiles or geogrids, although the lateral support of the surrounding soil may be much less, the confining effect of the geogrid provides additional support. This support basically arises from the friction force between the geotextiles and the stone column material. The geosynthetic encased stone column technique has gained wide acceptance as a means of increasing the load carrying capacity of ordinary stone columns installed in soft ground [5].

In this study, the similar size stone column model was fabricated and tested in a rigid sand box specially manufactured for this study. The prepared steel sand tank with the dimensions of 1000×1000×600 mm was filled with sand material up to a height of 500 mm. The sand filling process was made in 5 lifts of 100 mm height and by applying equal compactive effort at each lift.

**Figure 1.** Steel sand tank used in the physical tests

For the unwrapped stone column production process, bedding sand was filled up to a height of 500 mm and placed properly by the help of the fixed guide installed at the corners of the sand box. The filling process of the tank was made in five stages and each stage were compacted by dropping a fixed plate from 500 mm height 25 times. The compression process was applied every 100 mm and the tank surface was reached. Stone column material was also filled into the prepared guides, together with bedding sand, and compacted at every 100 mm lift.

For stone columns prepared together with geogrid or geotextile material, first geotextile and geogrid material were placed inside the guide pipe, and then the same processes were applied similarly to unwrapped stone columns.

**Table 1.** Geogrid properties used in the tests

| | |
|---|---|
| Raw Material | Polypropylene |
| Grid | Bi-axial |
| Tensile Strength, KN/m (EN ISO 10319) | 10/10 |
| Aperture Size, mm (ID/IDD) | 40×40 |
| Ph Resistance | 2-13 |

**Table 2.** Geotextile properties used in the tests

| Items | G-300 | G-1000 |
|---|---|---|
| Raw Material | Polypropylene | Polypropylene |
| Unit Area, gr/m² (EN ISO 9864) | 300 | 1000 |
| Thickness, mm (EN ISO 9863-1) | 2,5 | 6,7 |
| Tensile Strength, KN/m (EN ISO 10319) | 17/19 | 47/49 |
| Strain Failure, % (EN ISO 10319) | 50 | 50 |
| Statics Puncture Resistance, N (EN ISO 12236) | 3000 | 8000 |
| Dynamic Puncture Resistance, mm (EN ISO 13433) | 16 | 0,3 |

The prepared test setups were placed in the custom-made hydraulic loading press. The hydraulic system is controlled with a special load controller in order to adjust the displacement rate of the load piston. The foundation plate is positioned so that the stone column is located at the center of the plate. The load cell assembly is attached to the foundation plate and the deformation potentiometer is fixed to the plate. 11 kN loading was applied on the rigid plate with the help of a motor driver, and the load/deformation pattern of the investigated model is model through a high-resolution multi-channel data acquisition system.

## Results

Based on the physical test results, the soil improvement provided by the unwrapped and wrapped stone columns were compared and the effect of geogrid wrap on the deformation improvement performance obtained with the stone columns were evaluated.

For the analyses performed in a bedding sand with a relative density value of 40%, the deformations that occurred during the vertical loading are monitored with the help of the displacement meter connected to the foundation plate. The data acquired with the computer environment and load-deformations graphs are plotted in Figure 2.

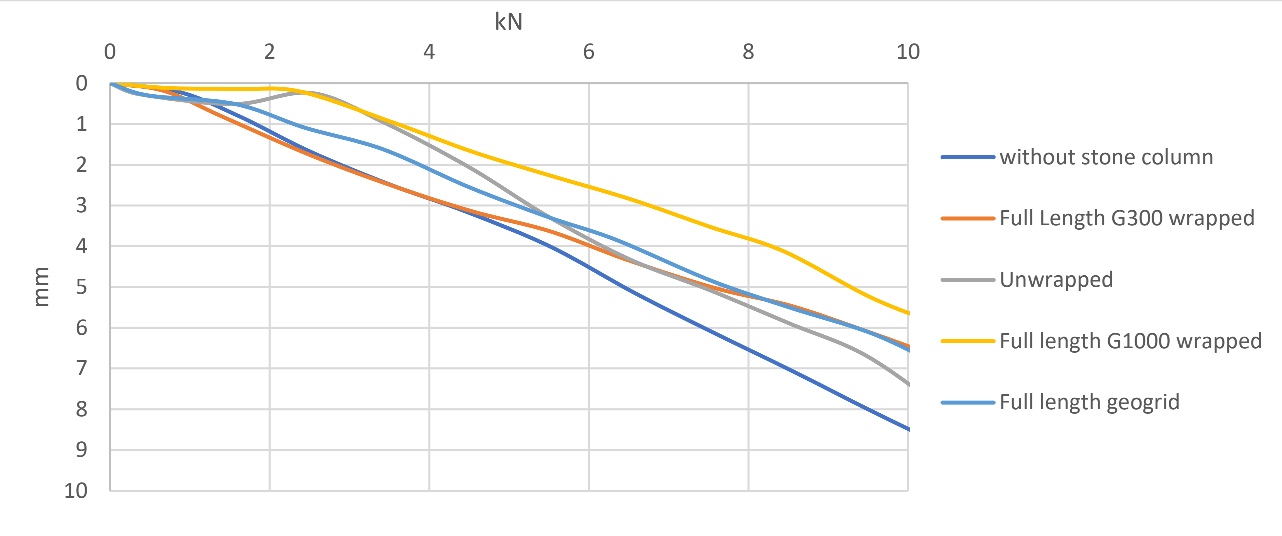


**Figure 2.** Comparison of the load-deformation characteristics for various stone column configurations

According to the results of the physical tests, for loading values up to 10-11 kN, the G1000 geotextile wrapped, G300 geotextile wrapped, geogrid wrapped, unwrapped stone column models provide the best deformation reduction efficiency values, respectively. To get a visual image of the stone column after loading, the sand bedding was partially excavated without damaging the stone column body. The deformation of the wrapped stone column after loading is shown in Figure 3. In general, it is seen that the deformations that occur on the stone column is concentrated on the upper portion up to a depth of two times the column diameter.

**Table 3.** Peak deformation values for the various tests

| | |
|---|---|
| No stone column | 9.00 mm |
| Ordinary Stone Column | 8.16 mm |
| Geogrid | 6.96 mm |
| G300 | 6.82 mm |
| G1000 | 5.98 mm |

**Figure 3.** Deformed shape of the geotextile wrapped (G-300) stone column model after loading

## Conclusion

As a result of the physical tests, it was observed that the unwrapped stone columns can improve the settlement amount of the loose bedding material by 10.29%. When vertical geotextile wrapping is present around the stone column surface, settlements decrease by an amount 17.24% in the geogrid wrapped model, 19.65% in the G300 geotextile wrapped model and 36.45% in the G1000 geotextile wrapped model. Contrary to typical reinforced concrete bored piles, stone columns generally fail to the low confining stresses coming from the soft and loose soils. In order to overcome this problem, geotextile or geogrid wrapping can be a good alternative for soil improvement. It has also been observed that the bulging occurs under high vertical loads at the upper portion of the soil up to 2D-3D distance from the surface.

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