Comparison of load tests done on stone columns and rammed aggregate piers

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ABSTRACT: Foundations of the buildings which will be constructed on loose and soft soil are improved by one of the soil improvement methods. Stone Column is one of these methods used also to support foundations, and foundations are also supported by Rammed Aggregate Pier (RAP) method. In this paper, performance of stone column (SC) and rammed aggregate pier (RAP) are compared with the results of loading tests done in the field. Two stone columns and two rammed aggregate piers were constructed with three different methods and all columns have the same diameter (50 cm) and the length (6.50 m). The load tests were performed to obtain the bearing capacity and stiffness of columns. All results indicate that the ratio of stiffness for SC named as displacement method to stiffness for SC named as replacement method is about four. Also, the ratio of stiffness for RAP (Impact Method) to stiffness for SC named as displacement method about 2 and is a function of applied stress. In addition, the ratio of settlement for SC named as replacement method to settlement for SC named as displacement method is about three and to the settlement of RAP (Impact Method) is about five. The loading test results show that rammed aggregate piers perform better in terms of settlement.

1 INTRODUCTION

Soil improvement needs to be done if the soil present at site is unable to support the proposed structure. After geotechnical and seismic risks considerations to the structure, if the shallow foundation system considered is not able to support the structure designed, then different soil improvement methods can be suggested according to the soil structure and the ground water table conditions. With soil improvement methods, it is aimed to improve the bearing capacity of weak soils, decrease the total settlement, increase the rate of consolidation settlements, decrease the permeability of the soils, decrease the liquefaction potential of soils and increase the stability of slopes and fills. As the weight of the structure increases, deep foundations are preferred. However from the point of view of cost, alternative soil improvements can be considered to be used along shallow foundations which could decrease the cost compared to using piles.

In this paper, rammed aggregate piers and stone columns which are constructed in cohensionless soils where the fines content is less than 20%, for the compaction of soil around the column and in soils with cohesion to form rigid columns will be explained. With the comparison of the results, which soil improvement system would be chosen as the method of improvement is explained.

According to the loading tests done by Durgunoglu et al. (1992), settlements observed in the areas where stone columns were not present has increased rapidly compared to areas where the columns were presented. Liew & Tan (2007) have investigated the behaviour of stone columns in soft soil layers with loading tests. Under 900kN maximum load, they have observed 110mm settlement values. Before the soil improvement, the estimated settlement values were around 650mm, after stone columns were placed 25-280mm settlement was expected. They have monitored the settlements for 4 months after the construction and around 115mm settlements were observed.

Stone columns can be used as a soil improvement method in soft or loose soils as they are economical. The main usage of stone columns are; to decrease the total and differential settlements, to increase the rate of consolidation, the bearing capacity and the stability of fills and slopes, and to decrease liquefaction potential. Stone columns can be constructed with different diameters and lengths according to the project and the soil conditions. They can also be constructed by different methods such as vibro compaction, vibro replacement, vibro displacement and rammed aggregate method which was developed by Dr. Fox in 1980's.

2 RAMMED AGGREGATE PIER SYSTEMS

Rammed aggregate pier system is used widely as it is an economical solution to improve soils which are not suitable as foundation soil. The main aim is to decrease settlements and improve bearing capacity (Lawton & Fox, 1994; Lawton et al., 1994; Wissmann et al., 2001; Wissman et al., 2007). These systems have many application methods. One of these methods is Geopier System. These columns are constructed with an auger that is used to drill 63 to 93cm diameter holes to depths that typically vary from about 2.5m to 8.0m below the ground surface. Then, a layer aggregate is placed at the bottom of the drill hole. A stable bottom is formed by ramming the aggregate using high-energy beveled tamper. Thin lifts (e.g. 300mm) of aggregate are then placed into the hole and rammed with the same tamper to form a dense, very stiff pier. The shape of the beveled tamper foot is important because it facilities the increase of lateral stress in the soils surrounding the installed piers (White et al. 2002). An analysis of the contribution to improving the compression characteristics due to soil lateral stress build up was developed and presented by Handy (2001).

The other method is Impact System. These columns are constructed by placing the sacrificial plate and the mandrel with a diameter of 36cm is driven to the required depth. Then the mandrel and hopper are filled with aggregate and the ramming is performed with 100cm up/67cm down (Geopier Foundation Co., 2010). The mandrel pushes the soil laterally and with the ramming gravel is densified. This system is effective in the control of total and different settlements, in increasing the bearing capacity of soils, in speeding consolidation times, stability of slopes and fills and decreasing the liquefaction potential of soils. This system is commonly used in road projects, foundation soils for single or mat foundation or under tanks and industrial structures.

3 ANALYSIS OF THE LOAD TESTS CONDUCTED ON RAMMED AGGREGATE PIERS AND THE STONE COLUMNS

Two rammed aggregate piers and two stone columns were constructed in an area in Kırklareli city, Turkey. There is one metre of fill and following that 5m thick hard clay lies over sandy gravels and sandy clays. In this paper, loading tests done on the columns are explained. 6.5m long and 50cm in diameter column were constructed. The two rammed aggregate piers were constructed by the impact method. The stone columns were constructed with the displacement and replacement methods.

The columns were loaded to 150% of their design capacities. Deformations were taken during load increments. Load deformation curves are shown in Figures 1, 2 and 3. Figure 1 shows the load deformation curves for SPI columns. The design load for the columns was 13.5 tons and they were loaded up to 20 ton. As seen the columns behave linearly and the settlements measured are less than 10 mm.

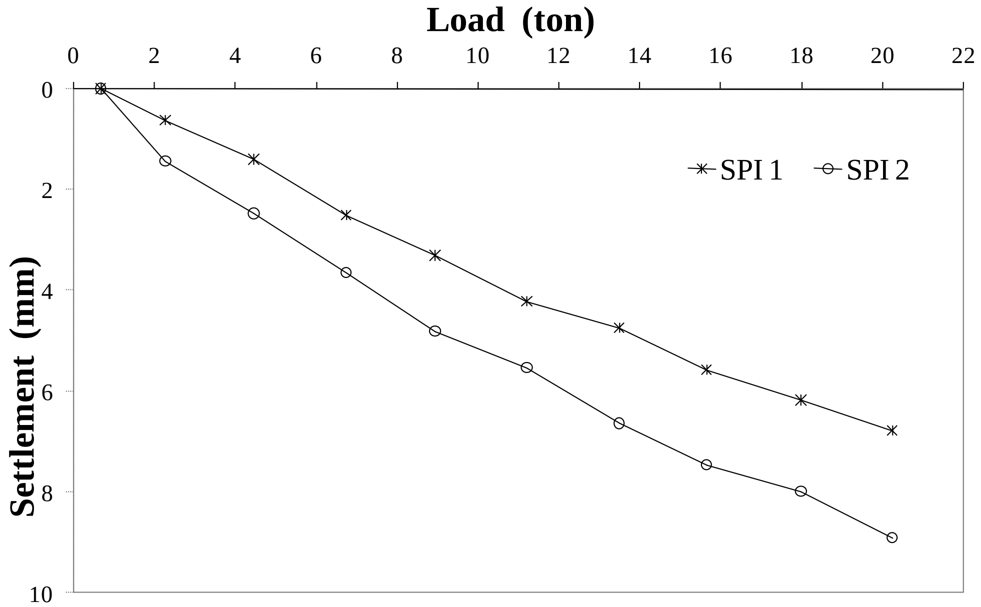

Figure 1 Load deformation curves for Single Pier Impact (SPI) columns (Kurt, 2011).

Figure 2 shows the load deformation curve for stone column constructed with SPD system where the design load was 7 tons and it was loaded to 10.5 tons. The settlement measured under this loading is around 50 mm.

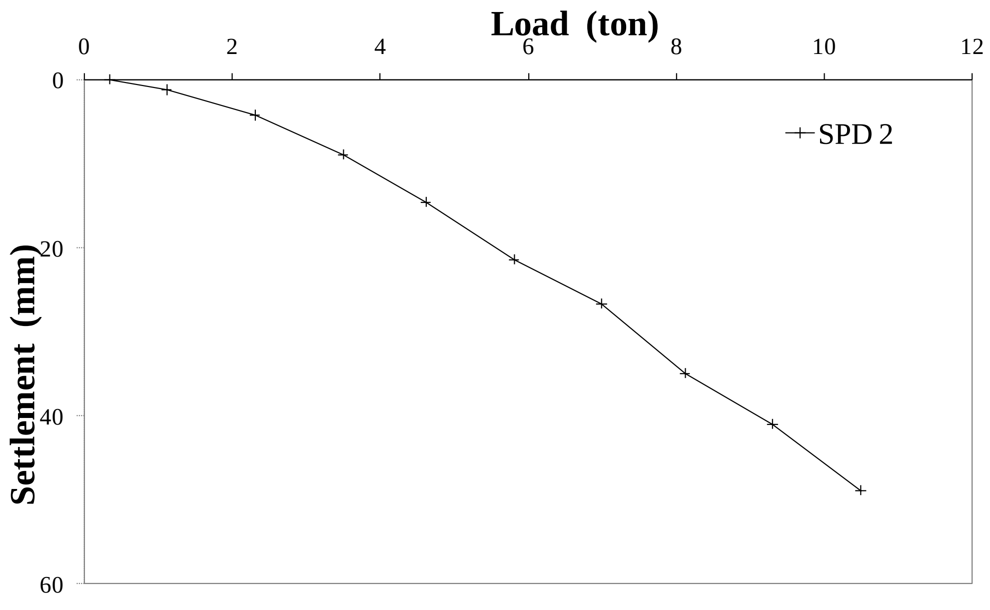

Figure 2 Load deformation curve for Single Pier Displacement (SPD) column (Kurt, 2011).

Figure 3 shows stone column constructed with SPR system, the design load is 7 tons and it was loaded to 9 tons and the settlements measured were around 95 mm.

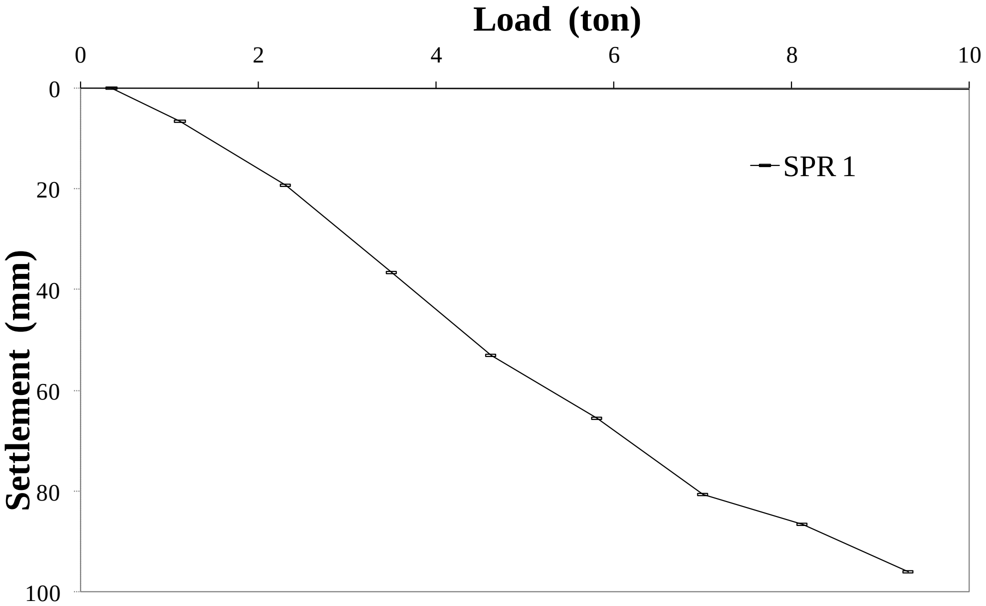

Figure 3 Load deformation curve for Single Pier Replacement (SPR) column (Kurt, 2011).

As seen from the figures, for 8 tons of loading, settlement measured for rammed aggregate piers are between 3 mm to 5 mm while with SPD about 32mm and for SPR around 85mm. Table 1 shows the stiffness values for the ratio of rammed aggregate columns compared to unrammed stone columns.

Table 1. Stiffness values for the columns for 8 tons of loading

	SPI	SPD	SPR
Rigidity (MN/m^3)	88	40	≤10
Settlement (mm)	3-5	32	85
Load (t)	8	8	8

Single Pier Impact system's rigidity is twice that of SPD and 8 times more when for SPR systems. Stiffness of unrammed stone columns (SPR and SPD) decrease from about 20-40 MN/m^3 at low levels of applied stress to less than 10 MN/m^3 at stress of about 400kPa. Stiffness values of the rammed aggregate element (SPI) decrease from 180 MN/m^3 at low level of applied stress to 80 MN/m^3 at an applied stress of 800kPa.

4 CONCLUSIONS

Two stone columns and two rammed aggregate piers were constructed with three different methods and on all columns which have the same diameter (50 cm) and the length (6.50 m), the loading tests were performed to obtain the bearing capacity and stiffness of columns. All results indicate that the ratio of stiffness for SC named as displacement method to stiffness for SC named as replacement method is about four. Also, the ratio of stiffness for RAP (Impact Method) to stiffness for SC named as displacement method ranges about 2 as a function of applied stress. In addition, the ratio of settlement for SC named as replacement method to settlement for SC named as displacement method is about three and to the settlement of RAP (Impact Method) is about five. The loading test results show that rammed aggregate piers perform better in terms of settlement.

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