Soil improvement with mini jetgrout columns and geogrid reinforced mechanical fill system under a machine foundation

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ABSTRACT: A shallow (mat) foundation of 21 m x 21 m plan dimensions was constructed using fiber reinforced concrete in an automotive spare part factory in Kocaeli, Turkey. After placing two similar machines of 785 tons and 605 tons weight on the same foundation, differential settlements were observed. The machines are 5,2 m wide and 15,7 m long each, and the clear distance between them is 6,0 m. Both of the machines were leveled with adjustment screws on their frames a couple of times, but the settlements of 0,5 – 2,0 millimeters continued after each adjustment without coming to an end. As it was reported by the owner that the machines cannot be put into service unless the settlements finish, a soil improvement system has been designed, which aimed at finishing the settlements in a very short time. According to the borings, the subsoil profile consists of soft to very stiff gravelly clay layer under a 1,5 m thick uncontrolled manmade fill layer. Geogrid reinforced mechanical fill laid over mini jetgrout columns is thought to be the most suitable solution. As compaction problems occurred on the clay layer, lime stabilization has also been applied at the excavation base. After finishing the soil improvement the RC foundation has been reconstructed and the machines have been reassembled by the end of year 2011. Geotechnical engineering works were performed by GEOCON on a “design and construct” basis. Both the structural and geotechnical design engineers have signed and stamped a “zero settlement commitment” after finishing the works, stating that “no settlement will occur” under the machine working loads. Until March 2018, no further settlement has been reported by the owner of the factory. Both of the machines are still in operation as of the preparation date of this paper. Summary information about the soil conditions, soil improvement system design and construction processes and the foundation system have been presented in this study.

Keywords: Geogrid, differential settlement, machine foundation, jetgrout, lime stabilization

1 INTRODUCTION

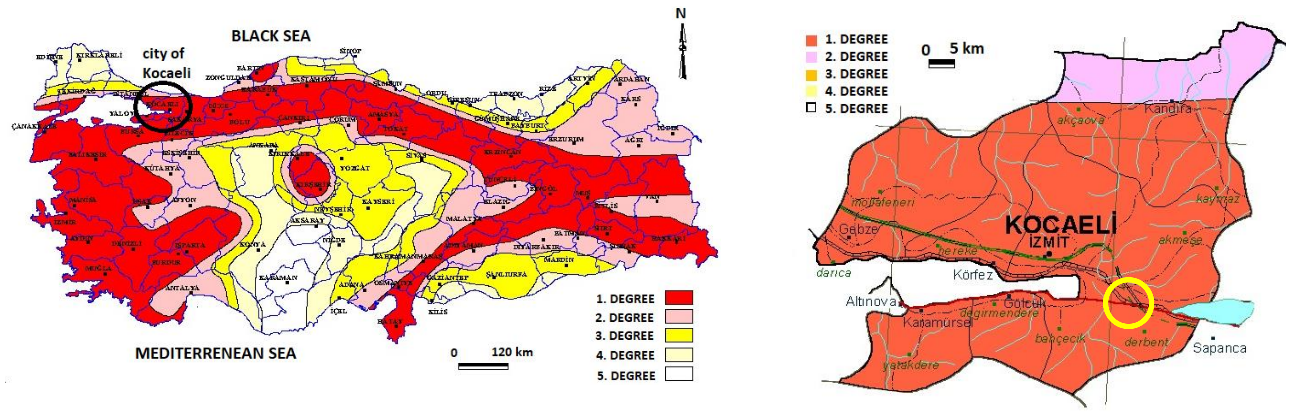
Geogrid-reinforced soils are used worldwide as a ground improvement solution for bearing capacity and settlement-related problems under shallow foundations. Results of laboratory model tests and finite element analyses are reported in the literature to demonstrate the benefits of geogrid-reinforced soils (Mandal and Sah 1992, Das et al. 1994, Yetimoglu et al. 1994, Chen et al. 2007, Sharma et al. 2009, Kolay et al. 2013, Biswas et al. 2015, Ren 2015). Some of these studies used bearing capacity ratio, which is calculated as the ratio of reinforced foundation soil bearing capacity to the bearing capacity of unreinforced foundation soil and found values up to 1,80. According to Chen et al. (2007), (1) the best top layer spacing between the geogrid reinforcement and foundation base level was around 0,33B (B being the foundation width) for a square footing resting on geogrid-reinforced clay; (2) the higher bearing capacity could be achieved by shortening the interlayer spacing between adjacent reinforcement layers; (3) immediate settlement of the footing was reduced up to 50% by adding reinforcement layers; (4) clays reinforced with higher stiffness geogrids generally yielded higher bearing capacity ratios than those reinforced with lower stiffness geogrids. For geogrid-reinforced clay, limited studies (Mandal and Sah 1992, Das et al. 1994, Chen et al. 2007) have shown that the optimal top geogrid layer spacing is from 0,175B to 0,4B below the base of the foundation, and the optimal interlayer spacing between two adjacent reinforcement layers was discovered to be ranging from 0,2B – 0,5B (Ren 2015).

Existing literature on the use of geogrid-improvement under machine foundations and/or cyclic loading is rather limited. Das and Shin (1994) carried out laboratory model tests for a strip foundation located on the surface of a geogrid-reinforced saturated clay, to investigate the permanent settlement under a low-frequency cyclic load in addition to a static load applied to the foundation. Allahbakhshi and Sadeghi (2014) carried out model tests and parametric finite element analyses to investigate the effects of number of reinforcement layers, their spacing, length and depth below the base of foundation, for an industrial machine foundation on reinforced silty sand embankment slope on peat and soft clay under static load.

This paper presents a case study of foundation soil improvement solution in Turkey. Uniaxial PP (polypropylene) geogrid reinforcements were used in a mechanically stabilized granular fill layer laid over soft to very stiff clay, in order to meet the “zero settlement requirement” under a machine foundation.

2 INFORMATION ABOUT PROJECT SITE

The factory site is located in Kocaeli, Turkey. The site is in 1st degree (highest peak ground acceleration, PGA) earthquake zone in Turkey (Figure 1a and Figure 1b) according to the Turkish National Disaster Agency earthquake zonation map, with expected possible PGA of minimum 0,4 g. A very destructive earthquake happened in 1999, the epicenter of which was Kocaeli city. According to the official records, more than 17.000 people died and more than 23.000 people were injured at this earthquake event, and more than 285.000 buildings were damaged at different levels (light to severe).



(a) (b)

Figure 1. (a) Earthquake Zonation Map of Turkey (https://deprem.afad.gov.tr/deprem-bolgeleri-haritasi#),
(b) Earthquake Zonation Map of Kocaeli (https://deprem.afad.gov.tr/deprem-bolgeleri-haritasi#)

The total surface area of the site and footprint area of the factory building are 21.127 m^2 and 16.900 m^2, respectively. The site is located at +76,0 m elevation above mean sea level and is known to have very thick young alluvial deposits as soil profile below the ground surface.

3 PROBLEM DEFINITION

Two machines of similar dimensions have been placed on a fiber reinforced concrete slab of 50 cm thickness, in the northwest corner section of the factory. The slab was also functioning as the mat foundation of 21 m x 21 m plan dimensions under the machines. The machines, having 785 tons and 605 tons weight, are 5,2 m wide and 15,7 m long. The dynamic loads acting on the foundation from the machines were represented with equivalent static loads on the technical drawings prepared by the manufacturer (Figure 2). Short time after placing them with a clear distance of 6.0m from each other, differential settlements were observed. Both of the machines were leveled with adjustment screws on their frames a couple of times, but the settlements continued after each adjustment. The last adjustment before the soil improvement was done on 20.09.2011, and the settlements measured were 1,5 mm on 26.09.2011 and 3,0 mm on 03.10.2011. Then the owner reported that the machines cannot be put into service unless the settlements come to an end and contacted GEOCON company to develop a solution to this problem.

After a site visit it was decided to make a new soil investigation to confirm the findings obtained from the existing soil investigation reports prepared for the whole building area, so a new borehole was drilled between the machines for this purpose. Then a soil improvement system was designed, keeping in mind that “zero settlement” is strictly required by the manufacturer. The detail of the designed system is given in Figure 3 in Section 5 below.

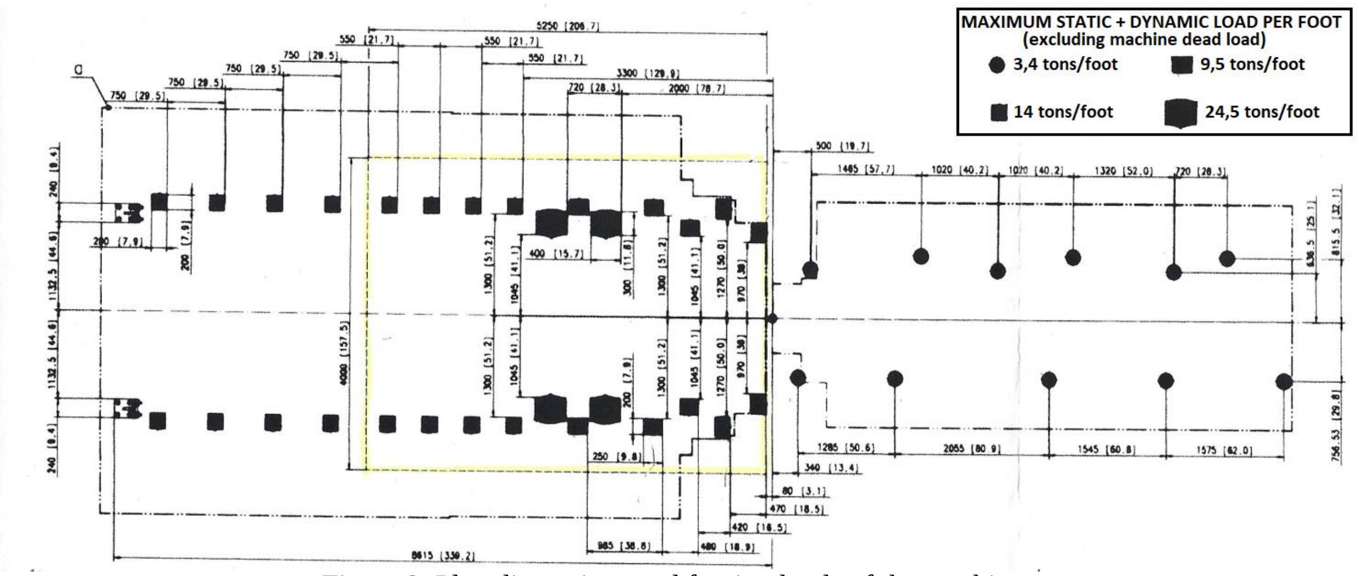


Figure 2. Plan dimensions and footing loads of the machines

4 SITE INVESTIGATIONS AND SOIL PROFILE

There are different site investigations carried out at the project site. First GEOS Geotechnics company (2004) carried out 12 boreholes reaching to 20 to 25,8 m depths from ground surface. In their report the groundwater table was reported to be at 2,70 to 4,30 m below ground surface. The soil profile is composed of brown stiff clay (CL) with gravel (2,5 to 14 m thick), underlain by very stiff clay with gravel (1,0 to 23 m thick). The Standard Penetration Test-N values, natural water content, liquid limit, plasticity index and unconfined compressive strength ranges of upper stiff clay layer are reported as N=8 - 15, w_o=26 - 29%, LL=32 - 49%, I_p=21 - 25%, c_u(UU-triaxial)=104 - 107 kPa. For very stiff clay layer encountered as the lowest layer in the boreholes these values are N=15 - 33, w_o=20 - 24%, LL=33 - 49%, I_p=7 - 25%, c_u(UU-triaxial)=76 - 148 kPa. Laboratory UU-triaxial test results indicated undrained modulus of E_u=8.0 - 16.6 MPa. Then AB Soil company carried out 4 boreholes to 15 m depths in 2011. Groundwater table is encountered at 4,5 to 6,1 m depths from ground surface. Soil profile is reported as 0,5 – 0,7 m thick top soil, 1,3 – 2,0 m thick uncontrolled manmade fill, and finally silty clay layer, beginning from the surface. Natural water content, liquid limit, plasticity index and unconfined compressive strength ranges of silty clay layer are reported as w_o=21 - 22%, LL=40 - 43%, I_p=18 - 21%, q_u=164 - 172 kPa. Finally GEOCON (2011) carried out one borehole to a depth of 30 m, and groundwater table was reported to be at 3,0 m depth from the surface. Soil profile is composed of 1,5 m thick fill, 2,5 m thick stiff clay (SPT N=14), 1,4 m thick soft clay (SPT N=10), 5,0 m thick stiff clay (average SPT N=18 (16-19)), 1,2 m thick soft clay (SPT N=10), 4,4 m thick stiff clay (SPT N=17 (16-18)), and very stiff – hard clay (SPT N=refusal) at the borehole base level. Liquid limit of all clay layers is in the range of 36 - 57% with average of 48% and plasticity index is in the range of 20 - 42% with an average of 33%.

5 DESIGNED SOIL IMPROVEMENT SYSTEM

Because of the “zero settlement” requirement of the manufacturer under the machine foundations, high factor of safety values were used in the design in all aspects. At the beginning of the project, the initial proposed solution was to install mini jetgrout columns and place geogrid-reinforced mechanical fill over the jetgrout-improved soil. But when the construction of mini jet-grout columns started at the site, additional low pressure cement grout injection columns were deemed necessary between the mini jetgrout columns, to ensure an extra improvement. The base of the excavation was 20-30 cm above the groundwater table, and a 10 cm thick mechanical fill placed on the clayey base was not enough to eliminate the balloon effect during the compaction process (the ground was heaved/ondulated right behind the vibrating roller). After this observation, lime stabilization is carried out to stabilize the clayey foundation soil, and the compaction operations were carried out successfully. The designed soil improvement system can be seen in Figure 3.

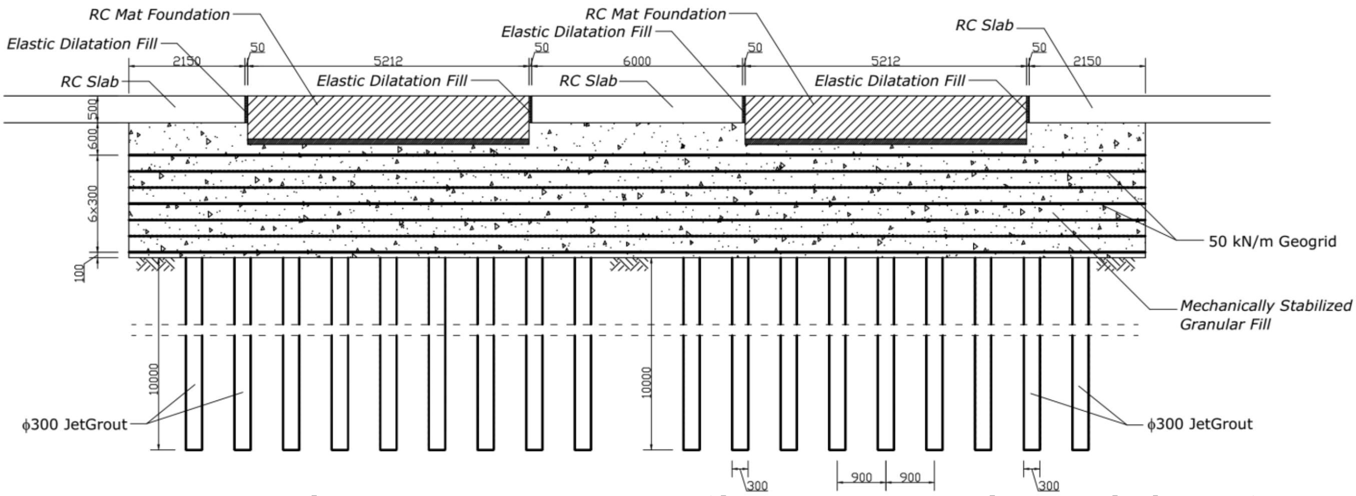
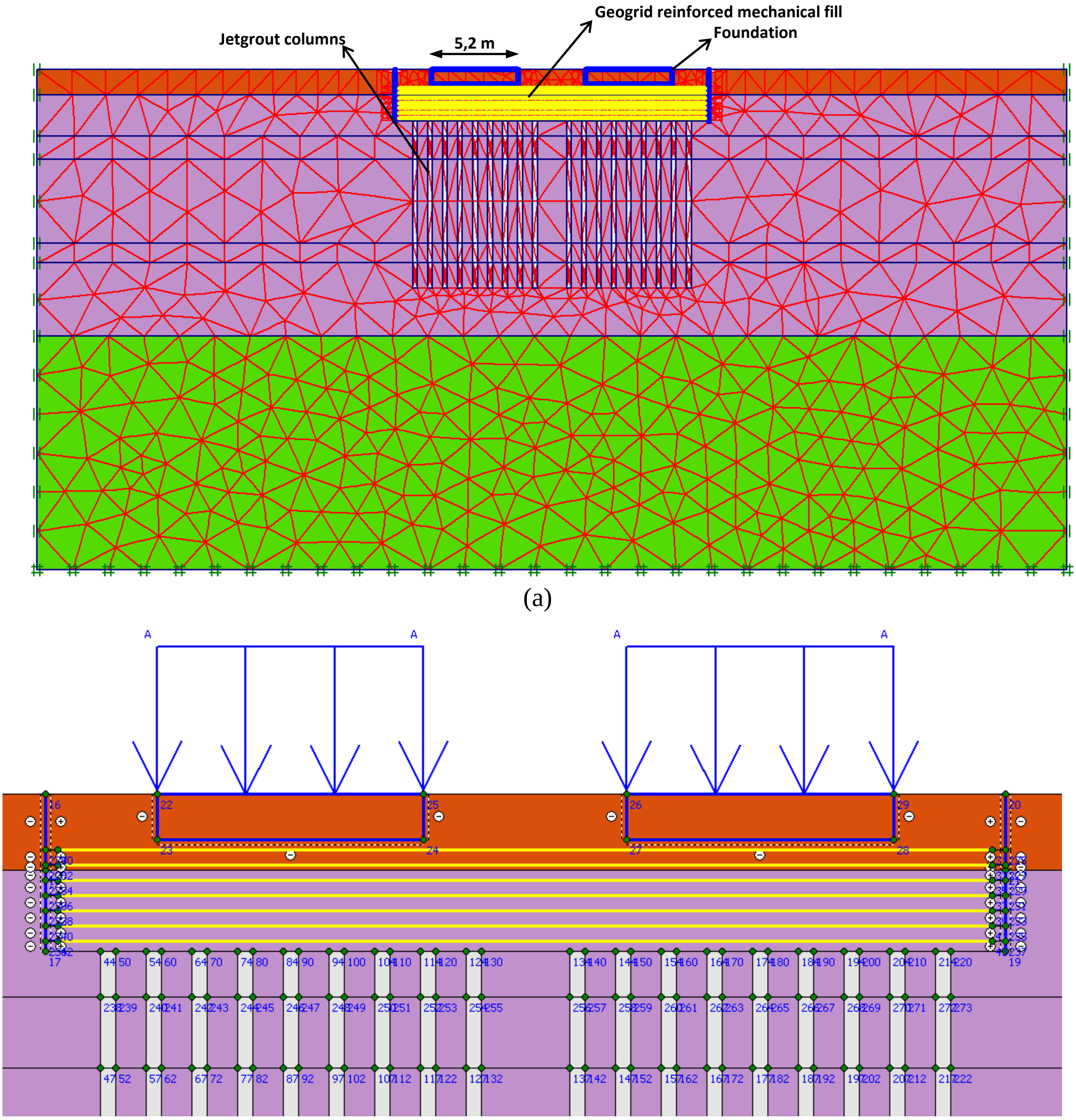


Figure 3. Soil improvement system section (dimensions in mm unless stated otherwise)

The design idea is based on partially solidifying the saturated soft to medium clay layers and apply a certain base pressure a couple of times more than the machine loading, before the machines were installed. This way both strengthening and compaction of the foundation soil was aimed. So the designed soil improvement system consists mainly of 30 cm diameter mini jetgrout columns and a geogrid reinforced mechanically stabilized granular fill layer above it. The length of the jetgrout columns were 10 m and they were applied at 90 cm x 90 cm spacing in both directions, building up a square pattern. Between the jetgrout columns, drainage pipes were installed, which are later used as cement injection wells. These were 10 m long, and drilled at 1,8 m x 1,8 m spacing, again in a square pattern.

Above the jetgrout columns is a 230 cm thick mechanically stabilized granular fill layer with 7 layers of 50 kN/m uniaxial PP geogrid reinforcement. The thickness of the fill layer was given to enable the maximum possible excavation depth, which is limited with the groundwater table elevation. And the number of reinforcement layers was selected according to the maximum fill layer thickness that can be effectively compacted using vibratory rollers, which is 30 cm. The thickness of the reinforced concrete mat was selected by the structural designer, NODUS Engineers Consulting Co., as 80 cm. Steel bars are used as reinforcement.

2D plane strain finite element analyses were conducted for the section given above, however the results of the finite element analyses did not indicate the desired “zero settlement”. Jet grout improved clay layers are considered to have equivalent improved parameters using weighted average strength and stiffness parameters of undrained shear strength of 100 kPa and undrained modulus of around 50 MPa. More advanced constitutive models could have been used to model the soil behavior and to represent the improvement effects in the ground with more accuracy. However, due to time limitation, further site investigation and soil testing was not possible to determine the parameters required for more advanced constitutive modelling. So, making use of previous experience, a soil improvement system to minimize the settlement was designed and applied, keeping the safety factors very high. This way the project was completed on time. Briefly, the applied soil improvement design is based on engineering judgement and experience with certain level of conservatism, rather than detailed finite element analyses performed on complex soil models. Figure 4 shows the finite element model of the designed soil improvement system.



(a)

(b)

Figure 4. Finite element model (FEM) of the soil improvement system (a) whole model and finite element mesh, (b) closer look to the system elements

6 SEQUENCE OF CONSTRUCTION WORKS

After completing the design, construction works started at the beginning of December 2011. The sequence of the construction works were as follows: 1) Demolishing of the existing RC slab, 2) Application of jet-grout columns from the top to 13,0 meters depth with 3,0 meters preboring at the top (so the column length was 10,0 meters), 3) Application of low pressure grout injection between the jetgrout columns, 4) Excavation to 3,0 m depth from the top (RC slab upper level), 5) Stabilization of the clayey base soil with lime for efficient compaction, 6) Placement of the first layer of mechanical fill, levelling and compacting, 7) Placement of the first layer of geogrid reinforcemet, 8) Placement of the 2nd to 7th layers of mechanical fill, levelling, compacting, simultaneously with geogrid reinforcements, 9) Construction of the 80 cm thick new foundations and slab.

The balloon effect of the clay layer at the base was seen also during the compaction of the third mechanical fill layer. A rise in the groundwater level was noticed at this stage, which caused the balloon effect. The reason for this is thought to be the rainfall a couple of days before and also the change in the porewater pressure due to the excavation.

Sand cone tests have been performed at each layer to obtain the field density after compaction in order to obtain the compaction ratio in terms of Proctor density. At the upper most layer also plate loading tests were performed. The compaction ratio was obtained between 87,7 - 100,7 % of the Proctor density. The fines content in the granular fill material was between 10,96 – 13,77 % according to the sieve analyses. And the settlement of 30 cm diameter steel plate at the plate loading tests were obtained between 6,12 to 8,37 mm under 440 kPa plate pressure. Some pictures from the construction and testing works are given in Figure 5 through Figure 11 below.

(a) (b)

Figure 5. (a) Additional boring next to the machine, (b) general view of the site after demolition of the existing slab

Figure 6. Jetgrout application

(a) (b)

Figure 7. (a) Excavation and groundwater table, (b) first layer of geogrid.

Figure 8. Lime stabilization

(a) (b)

Figure 9. Works at upper most layer (a) fill placement, (b) compaction.

Figure 10. Sand cone test

Figure 11. Plate loading test

7 SUMMARY AND RESULTS

A shallow (mat) foundation of 21 m x 21 m plan dimensions was constructed using fiber reinforced concrete in an automotive spare part factory in Kocaeli, Turkey. After placing two similar machines of 785 tons and 605 tons weight on the same foundation, continuous differential settlements were observed. A soil improvement system was designed, which aimed at finishing the settlements in a very short time. Geogrid reinforced mechanical fill laid over mini jetgrout columns is thought to be the most suitable solution. As compaction problems occurred on the clay layer, lime stabilization was also applied at the excavation base. After finishing the soil improvement the RC foundation was reconstructed and the machines were reassembled by the end of year 2011. Both the structural and geotechnical design engineers have signed and stamped a "zero settlement commitment" after finishing the works, stating that "no settlement will occur" under the machine working loads. Both of the machines are still in operation as of the preparation date of this paper. Until March 2018, no further settlement has been reported by the owner of the factory. Also, the owner of the factory contacted GEOCON in year 2016, and asked to apply the same soil improvement work for a similar machine foundation within the same factory building.

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