A case study on the plan for soil reinforcement by TCS in south korea

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Abstract. Compaction grouting was developed in the 1950s as a remedial measure for the correction of building settlement, and used almost exclusively for that purpose for many years. Over the past 25 years, however, compaction grouting technology has evolved to treat a wide range of subsurface conditions for new and remedial construction. Compaction grouting is used foundation rehabilitation, ground improvement, railroad subgrade stabilization, seismic/liquefaction mitigation, sinkhole remediation, tunneling stabilization, void filling. It also has merit that makes possible to construct structures having narrow working spaces. But the effects of ground improvement depending on the type of soil must be studied in order to adopt in various soil(granular soil and cohesive soil). In this paper, field and laboratory tests were performed to understand effects of ground improvement for soft ground and seismic mitigation. To know the characteristics of bearing capacity in adjacent ground, plate loading test for behind the improving ground. Strength characteristics of TCS were indicated by uniaxial compression test. Ground improvement effect by TCS together strength increment effect by TCS itself was proved that TCS can be used for soil improvement method using bearing capacity increment.

1. Introduction
The TCS(Total Compaction Grouting System) method is a low-mobility mortar with 2 inch(50 mm) or less slump value, whose grouting material is composed of fine soil to secure plasticity and coarse soil to increase internal friction force, whose basic material is soil cement. The grouting material is an improvement method to compactify the ground by reducing pores between soil particles through consolidation of soil via applying a radial pressure to the ground in a solid type, not permeating into the pores in the surrounding ground([1]). This is a completely different non-discharge replacement grouting method from the discharge replacement in the venation concretion of cement, the permeation concretion of liquid and the high-pressure injection.
This exerts an excellent effect for securing a structural stability by reinforcing the soft ground and the sand, stone and gravel stratum. Therefore, this is widely used for the reinforcement of land/marine soft ground, the seismic and liquefaction measure of sand ground, the reinforcement of lighters wharf and quay wall structure, the seismic reinforcement of shore, the side-movement blocking of piers and bank bodies, the reinforcement and restoration of differential settlement, the reinforcement of pores, and the refilling of sand, stones and gravels([2-4]).
The TCS method can freely form an improvement range and concrete shape with almost no damage to the surrounding areas at a low noise and low vibration. In addition, the equipment is miniature to
enable construction at a narrow space (town, residential area, apartment, etc.) to have a high applicability and to be eco-friendly without slime.
This paper aims to take a look at the ground improvement characteristics appearing via an application of the TCS method, and to grasp the settlement suppression effect and bearing capacity improvement according to the reinforcement method during ground improvement, the countermeasure method for the section with liquefaction and the ground reinforcement effect through a quality verification after reinforcement through construction cases

2. Mechanism
The TCS method is a method to increase ground density by compressing and reinforcing the surrounding ground via forming a cylindrical homogeneous concrete through compaction of low-mobility mortar grouting materials in the ground. To emphasize this low mobility of grouting materials, the Michael Byler argued that it is necessary to change “Compaction grouting” to “Low Mobility Grouting” in 1997([5]). The TCS methods are divided into a mortar compaction grouting method and a mortar non-compaction grouting method. The mortar compaction grouting method is a method having both concepts of soft ground plus difference reinforcement and seismic reinforcement through the grouting to improve soft ground and the grouting to fill the pores with sand and stones at a grouting rate of 0.06 m³/min or less([6]). The mortar non-compaction grouting method performs grouting such as filling of large cavities and filling of large differences at a grouting rate of 0.06 m³/min or more regardless of dissipation of pore pressure.
The mortar compaction grouting method is classified into constant-pressure grouting and constant-rate grouting are shown in Fig.1. The constant-pressure grouting keeps the bearing capacity of the ground constant to form a cylindrical non-reinforced concrete column in the ground, increase the density of the surrounding ground according to the compressed reinforcement of the soil around it to four directions, and form a complex ground, securing a stability against bearing capacity and settlement. The constant-rate grouting forms a constant-root pile to get an effect of consolidating the surrounding soft ground by establishing a pile while forming an improvement via compression of soft ground through discharging a proper amount of grouting material in the ground considering the soil proper of the site and an effect of improving the ground by making the consolidated surrounding soft ground strong.

3. Construction cases of the TCS method
3.1. Seismic ground reinforcement
The seismic performance reinforcement methods can be largely divided into the method of increasing stiffness of the ground by executing grouting, the method of integrating the structure and the
foundation ground by constructing a micro-pile, the method of reducing the back soil pressure by installing a new wall structure and the method of reducing the back soil pressure by replacing the back of quay walls using a light material.

In application of methods, we selected and applied the TCS method that can minimize interference in operation of the wharf, is excellent in securing stability of structures, has abundant cases of similar construction, and is excellent in environmental efficiency and economic efficiency, as the optimal reinforcement method.

Because eccentric bearing capacity was insufficient as a result of seismic analysis on the foundation sand and stones in the quay wall, compaction grouting was applied to the sand and stone stratum and it was reinforced with 2 rows of Ø1,800 mm, center to center 1.6 m pier-type wall to secure stability of bearing capacity are shown in Fig.2.

After completion of construction, confirmation boring was performed to check the diffusion range of the improved object and conduct a compressive strength test are shown in Fig.3. The confirmation boring positions were 1 bore at the central part and 2 pores at the surrounding part, and the survey result showed a core recovery rate of 70.8 % and a compressive strength of 11.44 MPa, which met the design criterion of 4.8 MPa are shown in Fig.4.
To confirm the result of seismic reinforcement, boreholes were drilled and gamma-gamma (density verification) was conducted before and after the execution of TCS methods at the ○○1 port and the ○○2 port. Count rates were measured and density values were calculated by depth, which were compared and analyzed. The analysis result showed that density increased at the section to which the TCS method was applied. The results of density measurement by depth are shown in Fig. 5.

For the ○○1 port, the densities of the buried layer into which grouting was conducted were 1.771 before grouting and 2.094 after grouting, an about 18.2 % increase. For the ○○2 port, the densities of the buried layer were 1.827 to 2.171, an about 18.8 % increase. This is because the grouting materials filled the vacant spaces and crack gaps between the sands and stones of the buried layer to increase the unit weight.

3.2. Soft ground reinforcement case
The shore ground of the dredging soil reclamation site at the Tando port is a very soft marine clay stratum with a N value of 2 and a depth of 16.5 m, which is very deep to need an application of suitable ground improvement method for safe construction of shore. To protect the soft ground and prevent sinking of shore, the TCS method was applied to the cross-section of the breakwater to secure stability.

For this site, both land work and marine work were conducted simultaneously, and boring equipment was installed on the work stand for smooth marine work to conduct grouting work on a barge on which a barge plant was installed.

A total of 4,675 boreholes were drilled in center to center 2.1 × 2.1 m up to a depth of N>20 from the soft ground reinforcement position, and the replacement rate of TCS(Ø1,000 mm) is about 17.8 % of the object ground volume are shown in Fig.6. When grouting materials were mixed during construction at this site, specimens were always made for tests by us and national authorized institutions for quality control, and the result of strength tests met the design strength enough.
3.3. Structure reinforcement and restoration

For the MY-TV parking tower at Deungchon-dong, differential settlement happened due to digging work during construction of a neighboring building. Before reinforcement, the structure of the parking tower was inclined 13 cm, and its depth of 3 m was composed of mud to cause settlement continuously. The construction site of the neighboring building was balanced in a LW method, so its ground was improved to some degree. The ground was composed of buried layers, accumulated layers, residual soil layers and weathered rock layers from the top, and the buried layer was composed of fine soil or sand containing gravels and silts, and the ground was very loose. To restore the inclined building, the A row was grouted up to 2~2.5 m depth in a top-down type and the A, B, C, D rows were grouted up to 6.0~8.0 m depth in a bottom-up type are shown in Fig. 7.

For the settlement having happened at a house in Gangwon-do, reinforcement work was conducted using the TCS method to suppress the additional settlement expected in the future, restore the vulnerable part to a possible range, and solve stability in beauty and uncomfort in use. For this house, maximum 30.0 cm settlement happened in the diagonal direction on the road side due to heavy rains because of storms. By applying both the top-down method and the bottom-up method of
this method, the building was successfully restored to recover its original structural functions are shown in Fig.8.

Table 1. Change of heights before and after construction.

| Measured point | Before construction(m) | After construction(m) | Increase/decrease(cm) |
|----------------|------------------------|-----------------------|------------------------|
| No.1           | +11.995                | +12.024               | ▲2.9                  |
| No.2           | +11.930                | +11.989               | ▲5.9                  |
| No.3           | +11.870                | +11.965               | ▲9.5                  |
| No.4           | +11.999                | +12.062               | ▲6.3                  |
| No.5           | +12.140                | +12.162               | ▲2.2                  |
| No.6           | +12.204                | +12.215               | ▲1.1                  |
| No.7           | +12.259                | +12.258               | ▲0.1                  |
| No.8           | +12.137                | +12.150               | ▲1.3                  |

Because a result of safety diagnosis for the ○○ station building showed that its major members were cracked by friction forces in the piles according to the consolidated settlement of the surrounding ground, the building was reinforced using the TCS method to prevent cracks. Grouting was conducted for a total of 174 boreholes to a depth of 50 m beside the existing piles with respect to the mat of the building foundation, in a bottom-up type up to GL-2.0 m and in a top-down type up to the remaining 2 m section are shown in Fig.9.

As a result of conducting a static loading test to check the construction quality of the formed piles and obtain engineering data such as allowable bearing capacity and settlement quantity, the minimum allowable bearing capacity was 43.4 tons/ea or higher, which is higher than the design strength of 42.0 tons/ea without displacement of the existing structure are shown in Fig.10.
At the apartment complex in Gangreung city, ground settlement happened (10-69 cm). The structure-installed area caused almost no settlement due to its pile foundation, but the road, above-ground parking lot and flower garden using a soft ground treatment method by sand trains caused consolidated settlement in general. This site obtained a composite ground improvement effect of piles plus ground reinforcement by grouting 1,988 boreholes of 800 mm diameter and 354 boreholes of 600 mm diameter to improve the soft ground, and as a result of grasping the soft ground improvement effect due to a change in physical and mechanical property, the generated settlement quantity was reduced to an allowable settlement quantity of 25 mm or less. In addition, the structure and road having lost its existing function were repaired and improved to a pleasant residential environment.

For the mechanical properties of ground improvement after construction, the result of standard penetration test showed a generally increasing (1-6) trend of N value after improvement, and the result of piezo-cone penetration test showed an increase in ground properties such as cone resistance, over-compaction ratio and undrained strength compared to before improvement are shown in Fig.11. The result of site vane test showed the shear strength by region increased by about 43~79%. For the physical properties according to the room soil test, the natural water content ratio decreased 25%, the plasticity index decreased 7%, the initial spacing ratio decreased 0.07, the moisture density increased 0.05 ton/㎥, and the cohesion increased 0.06 ton/m² compared to before improvement to confirm that the strength characteristics of the original were improved. The leading compaction load increased 0.24 and the compression index decreased a little.

4. Conclusion
This study grasped the ground improvement effect via a case study for applications of the TCS method, and derived the following conclusions.
1. The grouting quality could be confirmed through a site loading test, a standard penetration test and a room uniaxial compressive strength test after construction of the TCS method as a measure of seismic reinforcement and soft ground reinforcement.

2. It could be confirmed that applying the TCS method to a soft ground showed a structure bearing capacity effect and a settlement suppression effect as well as a strength improvement effect of the ground around the improved object before and after application of the method.

3. It can be seen that this method has a good applicability to the soft ground reinforcement, liquefaction measure, structure restoration and reinforcement method through various construction cases.

Acknowledgments
This research was supported by the Korea Agency for Infrastructure Technology Advancement under the Ministry of Land, Infrastructure and Transport of the Korean government(Project Number: 19SCIP-B130947-05-00000).

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