The research of behavior on stress and settlement based on finite element analysis of composite ground reinforced with GCP

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ABSTRACT: Gravel Compaction Pile(GCP) is actively used for soft foundation improvement, since this is able to increase bearing capacity of soft ground and reduce settlement. However, GCP in Korea is designed and constructed, based on empirical methods due to and absence of quantitative design methods. Therefore, many researchers are conducting studies on GCP design through field experiment, laboratory experiment and numerical analysis. This study aims to analyze stress and settlement behaviors depending on the ground strength and the replacement ratio by modeling the composite ground improved by GCP through a finite element analysis program, ABAQUS. The composite ground improved by GCP was numerically analyzed using the finite element method and when there were changes in ground strength and replacement ratio, the relation between stress-related coefficients and settlement reduction coefficients of the composite ground was analyzed. The analysis finding showed that the increased ground strength and replacement ratio led to the increased stress concentration ratio and the stress-related coefficients in the top rose equally, while the stress concentration ratio reduced. It is thought that designing the composite ground, based on the measurement in the upper level may cause a mistake, because the result differs from other values of individual depths. When the settlement reduction coefficients were analyzed and compared with the results of the existing settlement reduction coefficient equation through finite element analysis, also, the two values showed a similar tendency

Keywords: GCP method, vertical effective stress, Area replacement, Settlement reduction factor, Shear strength of soil

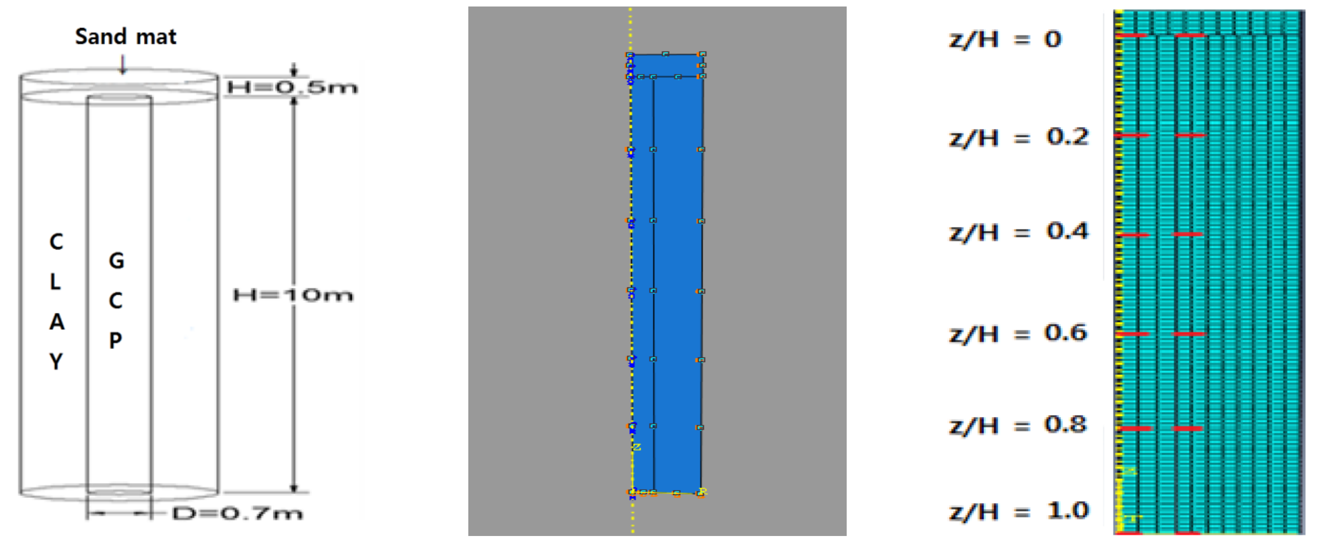
1 INTRODUCTION

Gravel Compaction Pile(GCP) is a ground improvement method to install a granular compaction pile by pressing sand and crushed stones in soft clay ground and soft sandy ground at a fixed relative density. On the clay ground, this forms a 10 to 40% substituted composite ground of the in-situ ground and gravel compaction piles and can improve engineering properties, including consolidation settlement reduction by enhancing ground bearing capacity and shearing strength and inhibiting lateral flow. This method is also applied to sandy soils for increasing density, preventing liquefaction and enhancing horizontal bearing capacity. GCP easily losses strength on the clay ground during construction because of ground disturbance and has some problems, such as uncertainty of construction and internal fracture. Besides, fracture cases, including clogging caused by expansion and fracture of the tip are rapidly increasing. In relation to the GCP method, however, no definite forms of fracture are defined and no fracture preventive measures are established and no clear causes for fracture are found. Also, construction and design are based on empirical methods due to an absence of design methods, which are appropriate for domestic circumstances. For such reason, shear fracture and local fracture frequently occur, but there is a lack of preventive measures for this. In addition, stress concentration ratio, settlement and bearing capacity differ from real measurements, because overseas methods are applied without consideration of differences in construction equipment and material characteristics. Accordingly, as a fundamental study for developing a rational and stable design GCP method, this study is focused on analyzing excess pore pressure, settlement and stress concentration ratio of the composite ground improved by GCP, using a finite element analysis program, ABAQUS.

2 NUMERICAL ANALYSIS AND DESIGN PARAMETERS FOR GCP COMPOSITE GROUND ANAYSIS

2.1 *Finite element analysis modeling*

As presented in Fig. 2(a), this study targeted a 2D-axisymmetric composite ground improved by a single GCP using ABAQUS. At different replacement ratios(10, 20, 30 and 40%), the diameter of the GCP was fixed at 0.7m and the size of the ground was changed depending on the replacement ratio and the sand mat and the ground were 0.5m and 10m in height, respectively. Fig. 1-(c) indicates the location for measuring effective vertical stress, excess pore pressure and settlement during finite element analysis and the measurement location(z/H) is expressed in depth/overall length.



a) GCP composite ground (b) 2D-axisymmetric modeling (c) Measurement position

Fig. 1. Composite ground modeling for finite element analysis

2.2 *Design parameters for numerical analysis*

Table 1 and 2 display design parameters used for numerical analysis. Clay ground 1 used the value, which was applied when the SCP composite ground of Busan New Port was designed(Busan New Port Corp 1999) and clay ground 2, 3 and 4 used the value applied to the previous studies(Han Sang-Jae et al 2013, Seong Gyeong-Hwa 2009, Kim In-Gi 2003)

Table 1. Design parameter of GCP and sand mat for finite element analysis

Material	Model	Parameter	Value	Parameter	Value
GCP	Mohr-Coulomb Model	E_0(kPa)	23200	∅	50.9
		ν	0.3	$\gamma(\mathrm{kN}/m^3)$	19
		c	0.1	k(m/day)	86.4
Sand mat	Elastic	E_0(kPa)	14000	$\gamma(\mathrm{kN}/m^3)$	20
		ν	0.2	$\gamma(\mathrm{kN}/m^3)$	0.864

Table 2. Design parameter of clay for finite element analysis

Material and Model	Parameter	Value			
		Ground 1	Ground 2	Ground 3	Ground 4
Clay and Modified Cam-Clay Model	κ	0.04	0.0521	0.07	0.05
	λ	0.265	0.356	0.34	0.4
	a_0(kPa)	25, 50, 75			
	e_0	1.6	2.801	2.798	2.749
	M	1.02	0.772	0.9	1.1
	ν	0.2	0.33	0	0.3
	γ(kN/m^3)	17	15.29	14.57	17.57
	$k_x(kN/day)$	6.26e-5	2.11e-4	5.69e-4	1.037e-3
	$k_y(kN/day)$	2.72e-5	8.10e-4	5.69e-4	1.037e-3

3 ANALYSIS OF GCP COMPOSITE GROUND

3.1 *Vertical effective stress analysis of GCP compostie ground*

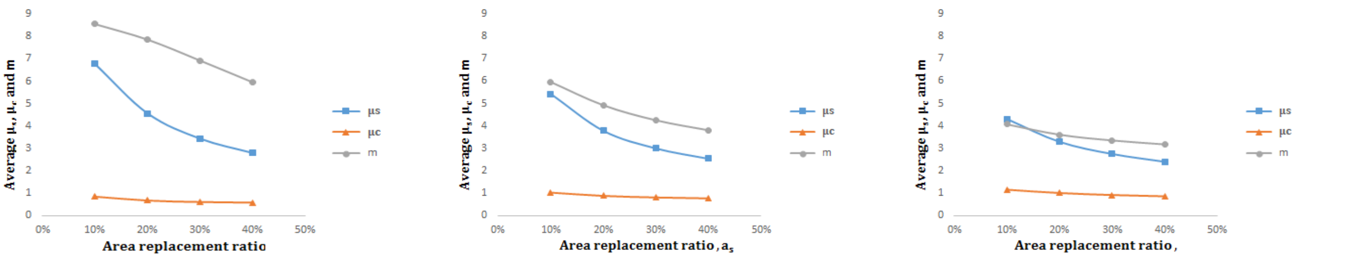
Total stress increases when the surcharge load is applied to the composite ground improved by GCP. Due to the increased total stress, the composite ground has an excess pore pressure and ov er time, it dissipates gradually. Before the surcharge load is applied, initial effective stress increa ses depending on the depth and after it is applied, stress increases in the top of GCP due to the increased vertical load and ground's effective strength increases, too due to dissipation of excess pore pressure. Also, excess pore pressure is not made and transferred into effective stress immedi ately due to big permeability coefficients in GCP. Table 3 shows vertical effective stress dependi ng over time at a ground strength of 25kPa and at different replacement ratios. As the result of analyzing, GCP's vertical effective stress was relatively bigger than the clay ground's vertical eff ective stress because of the difference in ground stiffness.

Table 3. Vertical effective stress with a_s

Shear strength (kPa)	Area replacement ratio (%)	Vertical effective stress	
		GCP (kPa)	Clay (kPa)
25	10	1610.76	188.46
	20	1123.58	133.68
	30	837.76	114.73
	40	662.49	107.70

3.2 *The relation among replacement ratio, ground strengt and stress-related coefficients*

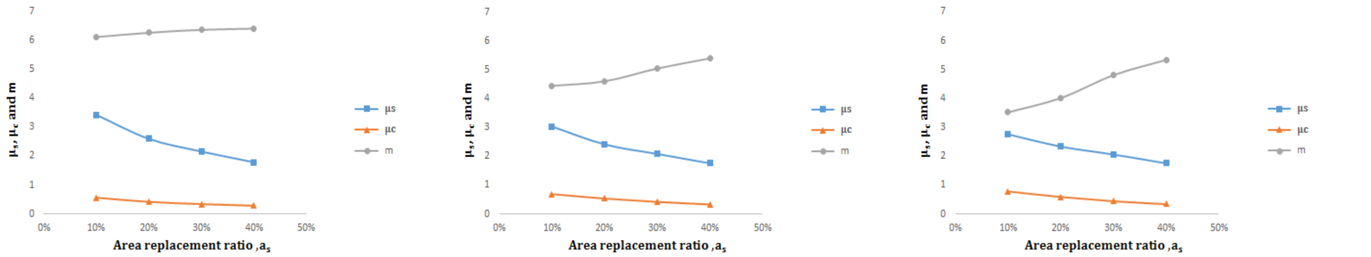
The relation between replacement ratio(a_s) and ground strength that are design parameters of the GCP method and the relation among stress concentration coefficient(μ_s), stress reduction coefficient(μ_c) and stress concentration ratio(m) that are stress-related coefficients, were analyzed. When stress-related coefficients depending on the replacement ratio and the ground strength were analyzed, the increase in replacement ratio and ground strength led to the decrease in averaged stress-related coefficients of individual depths and stress reduction coefficient and stress increase coefficient in the upper level reduced similarly. On the contrary, the stress concentration ratio rose, because the two values had different widths of decrease. Fig. 2 shows the average of coefficients of individual depths depending on the increase in replacement ratio on the clay ground and the change in the upper level. The increase in replacement ratio led to the bigger decrease in stress concentration coefficient(μ_s) of GCP than the decrease in stress reduction coefficient (μ_c) of the clay ground and thus the stress concentration ratio (m) fell. Unlike the average of coefficients of individual depths of the composite ground, the stress concentration ratio increased in the upper level. It is supposed that this is because of the different widths of decrease between the two values, although stress-related coefficients reduced, as the replacement ratio rose.



(a) Shear strength=25kPa, Average by depth

(b) Shear strength=50kPa, Average by depth

(c) Shear strength=75kPa, Average by depth



(d) Shear strength=25kPa, Upper layer

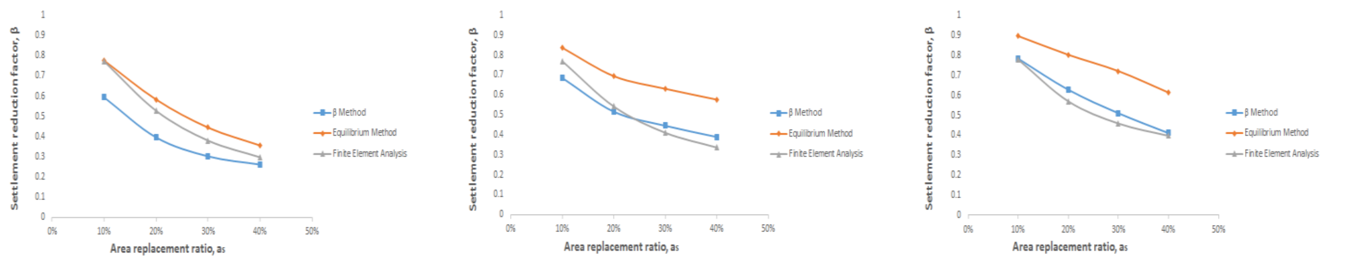
(e) Shear strength=50kPa, Upper layer

(f) Shear strength=75kPa, Upper layer

Fig. 2. Average μ_s, μ_c, m with shear strength and depth

3.3 *The relation among replacement ratio, ground strength and settlement reduction coefficient*

As the replacement ratio of GCP increases, settlement highly reduces and this settlement reduction effect can be expressed in a settlement reduction coefficient(β), which is calculated, based on the settlement ratio on the composite ground improved by GCP to the settlement of the in-situ ground. Fig. 3 shows the comparison between the values of the existing settlement reduction coefficient equation and finite element analysis depending on the replacement ratio and the ground strength. The settlement reduction coefficient calculated using finite element analysis had a small ground strength and when the replacement ratio was small, it was close to the value of equilibrium method. But when the replacement ratio and the ground strength were big, it was similar to the value of β method. This means that for the soft ground, the value of equilibrium method is overestimated and the value of β method is little underestimated, compared to the result of finite element analysis and the settlement reduction effect of the composite ground is influenced by the replacement ratio, the ground strength and the surcharge load of the composite ground.



(a) Shear strength=25kPa

(b) Shear strength=50kPa

(c) Shear strength=75kPa

Fig. 3. Comparison of settlement reduction factor

4 RESULT AND CONSIDERATION

This study analyzed the replacement ratio during filling and stress and settlement behaviors depending on the changes in ground strength using finite element analysis, as a basic stage of developing a rational and safe design method for GCP. When the replacement ratio and the ground strength increased, vertical effective stress rose in GCP, but it decreased on the clay ground. Also, the averaged stress-related coefficients of individual depths reduced when the replacement ratio and the ground strength rose, but the stress concentration ratio decreased in the upper level. It is supposed that due to the different widths of decrease between the two values, the stress concentration ratio increases. Therefore, a careful consideration is needed when designing the composite ground, since estimating the stress concentration ratio of the entire composite ground, based on the measurement in the upper level may cause an error. The settlement reduction coefficients of finite element analysis were analyzed and compared with the replacement ratio and the results of equilibrium method and β method. As the result, it was similar to the result of equilibrium method at a low replacement ratio and at a low ground strength, but it was similar to the result of β method when they were high. It is considered that subdividing various clay grounds and verifying settlement prediction through field test and construction would be more helpful in developing a rational and safe design method in future.

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