MPS-CAE ANALYSIS ON MIDDLE-PRESSURE JET GROUTING GROUND IMPROVEMENT METHODS

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INTRODUCTION

The middle-pressure jet grouting method is the practically used technology that sprays cement slurry at 20MPa or less and adopts mechanical agitation and mixing to develop a higher quality columnar soil-improved body (Komaki et al. 2018a and 2018b). This combination of cement slurry jets and rotation complicates the development mechanism of the columnar soil-improved body and the major barrier of the design and performance evaluation methods of the ground-improvement method itself also exists. Since it is conducted in an in-situ ground, is not possible to visually confirm the construction status or the validity of the design; it's design and construction must rely mainly on empirical rules. This study focuses on the application of MPS (moving particle semi-implicit) - CAE (computer-aided engineering) method to simulate from the planning and design stages in an attempt to visualize and evaluate the development situation.

OVERVIEW OF CAE-MPS METHOD

CAE is a computer simulation technology that simulates and analyzes prototypes considering the site conditions. MPS method is applied to analyze the behavior of fluid particles according to the equation of motion for fluids. The governing equations for the incompressible flow used in the analysis are the mass conservation law of Eq. (1) and the Navier's Stroke law of Eq. (2) considering surface tension.

$$\frac{D\rho}{Dt} = 0 \qquad (1)$$

$$\frac{D\boldsymbol{u}}{Dt} = -\frac{1}{\rho}\nabla P + \nu\nabla^2\boldsymbol{u} + \boldsymbol{g} + \frac{1}{\rho}\sigma\kappa\delta\boldsymbol{n} \qquad (2)$$

where ρ is the density of the fluid, u is the velocity vector, P is the pressure, ν is the kinematic viscosity coefficient, g is the gravity vector, σ is the surface tension coefficient, κ is the curvature, δ is the delta function for the surface tension to act on the surface, and n is the unit vector in the direction perpendicular to the surface.

Each differential operator (slope, divergence, and Laplacian) of the governing equation, as shown in Eq. (2), is discretized by a weighting function (Shakibaeini and Jin 2012). The weighting function depends on the interparticle distance and the influence radius (2.1 to 4.1 times the interparticle distance) in each particle interaction model.

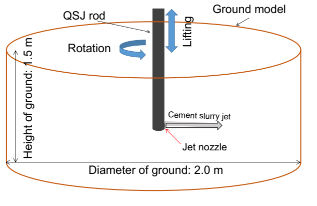

Fig. 1 Analytical model of jet grouting method

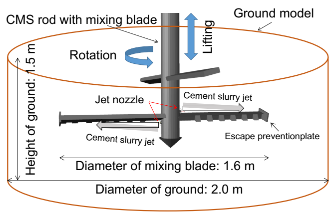

Fig. 2 Analytical model of jet grouting with mechanical agitation and mixing method

ANALYSIS CONDITION FOR MPS-CAE

Modeling the Analysis Target

Figures 1 and 2 shows the model for the jet grouting method (QSJ system) and the jet grouting with mechanical agitation and mixing method (CMS system) respectively. It shows the cylindrical ground of 2m dia. and 1.5m height. For QSJ system, a jet is sprayed in one horizontal direction from nozzle and for CMS system, a 1.6m mixing blade is rotated up and down while jet spraying from two nozzles installed above and below the lower blade. Plus, an escape prevention plate is attached at the end of mixing blade such that sprayed slurry collide it at an angle (Komaki et al. 2018b).

Table 1 shows the construction specifications for each case of analysis. Cases 1 to 4 are analysis cases that reproduce the jet grouting method (QSJ system). Case 5 is a reproduction of the jet grouting method (QSJ system), with water cutting during the penetration and slurry spraying from the jets during the pulling up of the rod. Cases 6 and 7 are models of the CMS system focusing in jet pressure difference; 15.0 MPa and 0.01 MPa respectively, while other conditions being the same. After reproducing the jet amount and jet speed, the initial particle distance was set to 0.03 m to reduce the calculation load, and the cement slurry particles were jetted intermittently from the jet nozzle.

Table 1 Construction specifications

Case of analysis	Case 1	Case 2	Case 3	Case 4	Case 5		Case 6	Case 7
Method of construction	QSJ	QSJ	QSJ	QSJ	QSJ		CMS	CMS
Range of target	Water	Water	Ground	Ground	Ground		Ground	Ground
Material of jet	Water	Cement slurry	Water	Cement slurry	Water*1	Cement slurry*2	Cement slurry	Cement slurry
Length of penetration while blanking (m)	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Length of penetration while improving soil (m)	-	-	-	-	0.5	0.5	0.5	0.5
Amount of jet (L/min)	80	90	80	90	80	90	80×2	80×2
Pressure of jet (MPa)	9.4	18.0	9.4	18.0	9.4	18.0	15.0	0.01
Velocity of jet (m/s)	137.5	155.0	137.5	155.0	137.5	155.0	141.5	4.2
Velocity of penetration while blanking (m/min)	-	-	-	-	6.0	-	10.0	10.0
Velocity of penetration while improving soil (m/min)	-	-	-	-	6.0	-	0.67	0.67
Velocity of lifting while improving soil (m/min)	-	-	-	-	-	0.33	1.0	1.0
Velocity of rotation (rpm)	-	-	-	-	80	20	20	20

*1 while penetrating *2 while pulling up

Material Parameters

Table 2 shows the material parameters of the water, cement slurry, and ground particles that comprised the target materials of the analysis. The water particles used the general value of a

Table 2 Material parameters

Range of target	Density (kg/m^3)	W/C (-)	Yield value (Pa)	Plastic viscosity (Pa·s)	Yield point (-)	Surface tension (N/m)	Fluid model
Water	1000	-	-	-	-	0.10	Newtonian fluid
Cement slurry	1500	1.0	10	0.28	0.0001	0.10	Bingham fluid
Ground	1600	-	1000000	1000	0.0001	0.002	Bingham fluid

Middle-pressure jet grouting method; MPS-CAE; Simulation
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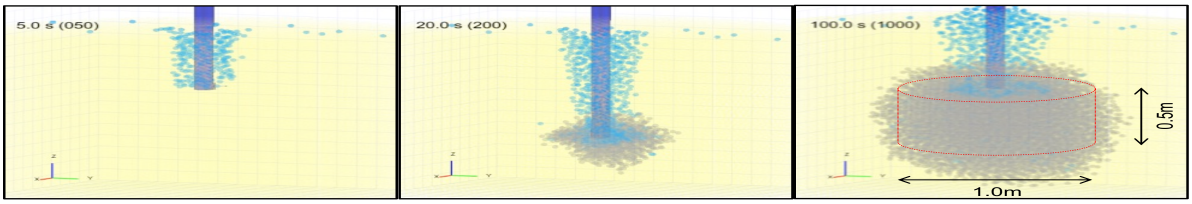

Fig. 3 Conditions of development of columnar soil-improved body by jet grouting method

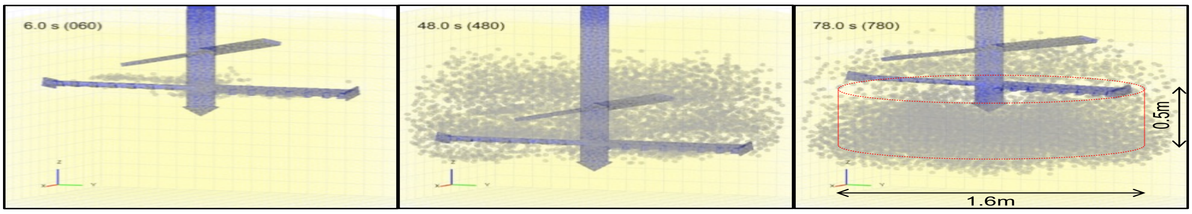

Fig. 4 Conditions of development of columnar soil improved body by jet grouting with mechanical agitation and mixing method (jet pressure: 15 MPa)

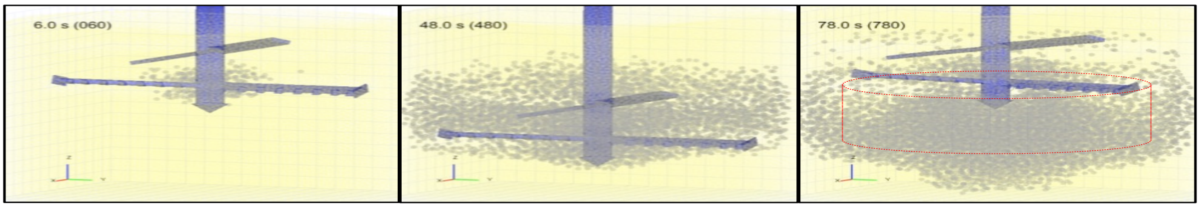

Fig. 5 Conditions of development of columnar soil improved body by jet grouting with mechanical agitation and mixing method (jet pressure: 0.01 MPa)

Newtonian fluid, and the cement slurry particles used the value of a Bingham fluid with the plastic viscosity being measured by a B-type viscometer. For the ground particles, the material parameters were set using the value of a Bingham fluid by a reproducible analysis of an unconfined compression test.

CAE ANALYSIS RESULTS AND DISCUSSIONS

Figure 3 shows the time-series changes in the development status of the columnar soil-improved body by Case 5. Ground particles are shown in semi-transparent yellow, water particles in light blue, and slurry particles in gray. After 1m depth penetration within 10s of construction start, cement slurry is sprayed for 90s while rod is pulled 0.5m upward slowly resulting in 1.0 m dia. cylindrical improved body.

Figures 4 and 5 shows the development conditions for Case 6 and Case 7 respectively. Cement slurry is sprayed after 6s when injection nozzle reached the top of the planned columnar soil-improved body. It took total 48s to reach maximum depth and 78s to complete the construction. The cement slurry jet reached the escape prevention plate after six seconds for case 6 but not for case 7. A densely packed result was seen at max. depth and outer periphery for case 6 while it was concentrated in the center of mixing blade for case 7.

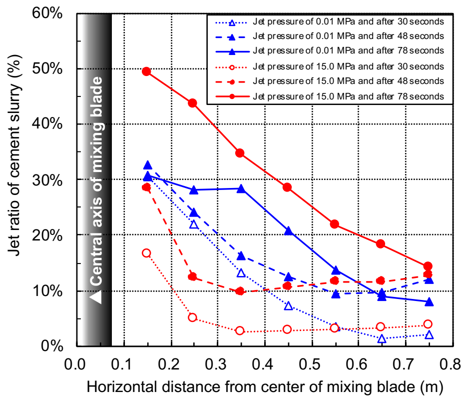

Fig. 6 Horizontal distribution of cement slurry jet ratio

Figure 6 shows the horizontal distribution of cement slurry jet ratio measured at the central depth of 0.1m in a radial direction from the central axis of the columnar soil-improved body. The number of particles in ground and cement slurry was measured and then cement slurry jet ratio was calculated from the volume fraction of particles. Middle-pressure jet (case 6) had a higher cement slurry jet ratio near the outer periphery of the mixing blade and the improvement range was throughout higher compared to the low-pressure jet (case 7).

CONCLUSIONS

This study was carried out with the objective of establishing CAE as a simulation tool for ground improvement method by middle pressure jet grouting from planning/design stages. As a result, it is found that compared to the low jet pressure (0.01MPa) the distribution of cement slurry is more homogeneous even at the outer periphery of the mixing blade in case of the jet pressure 15 MPa. With the application of CAE, it is possible to visualize the actual ground conditions and is also compatible with the variation in construction specifications so it will surely contribute greatly in the future research of the ground improvement methods.

REFERRENCE

Komaki, T. et al. (2018b): Efficient of Mechanical mixing method with middle pressure injection by High performance fluidizing agent, Proceedings of the 13th National Symposium on Ground Improvement, pp. 375-378.

Komaki, T. et al. (2018a): Demonstration experiment of evolution technology by combination mixing slurry of middle pressure injection total system, Proceedings of the 53th Japan National Conference on Geotechnical Engineering, pp. 835-836.

Shakibaeini, A. and Jin, Y.C. (2012): MPS mesh-free particle method for multiphase flows, Computer Methods in Applied Mechanics and Engineering, Vol. 229-232, pp. 13-26.