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REASONABLE MANAGEMENT INDEX IN FILL LOADING WITH VACUUM CONSOLIDATION METHOD BASED ON FEM ANALYSES

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ABSTRACT: Vacuum consolidation method (VCM) is one of the recent methods being utilized for the improvement of soft ground. This method can forcibly drain pore water, and increase ground strength by loading with vacuum pressure. A fill loading with vacuum consolidation method (FLVCM) is reported to be able to control lateral displacement and upheaval of the surrounding area during rapid fill loading. However, the behavior of this combination of benefits on ground deformation is not fully clarified within FLVCM. Fill design and site management depends on experience with the technique. In this study, numerical simulation has been carried out by finite element method (FEM) for the quantitative evaluation of the deformation suppression effect of FLVCM on the soft grounds of Ariake clay in Japan. The utility of FLVCM was confirmed by comparison of observed and analytical ground deformation. In addition, numerical simulations have been carried out under various conditions of vacuum pre- and post-loading pressures and fill speeds. It looks as though a reasonable management index can be easily obtained by site measurement of deformation.

Keywords: FEM, lateral displacement, rational site management index, settlement, soft clay, vacuum consolidation method

INTRODUCTION

Japan is one of the primary soft ground countries in the world. Because of the limited usable land area in this country recently it has become necessary to construct infrastructure on soft ground. A variety of soft ground improvement methods have been developed. The vacuum consolidation method (VCM) is one of the more widely applied advanced methods.

Vacuum consolidation was first introduced by Kjellman (1952) to improve the strength of soft ground and it was also used in soft clay-like deposits. In recent years, many successful field applications have been reported using vacuum consolidation, including the use of vacuum preloading in a land reclamation project in China (Shang et al. 1998). The effectiveness of vacuum preloading consolidation was also demonstrated by eliminating excessive settlement under static and dynamic loads on an airport runway (Tang et al. 2000). Chu et al. (2000) presented a case study whereby vacuum preloading was used to improve the soil strength at an oil storage station. Terzaghi's consolidation theory was revisited by (Mohamedelhassan et al. 2002) in a study of combined vacuum and surcharge loading on soft ground. In this case vacuum consolidation of soft ground was promoted by applying vacuum pressure to generate pore water pressure along the horizontal drain of the soil surface and along the length of vertical drains installed in the soil. Water and air was exhausted from the ground and this increased soil strength and stability, thereby reducing the time for attaining the ultimate ground settlement (B.Indraratna et. al 2004). Vacuum consolidation generally induces inner lateral displacement and can cause cracks in the surrounding surface area due to inward movement of the ground induced by application of the vacuum pressure (Chai et al. 2005, 2006). The estimation technique and stability management index of pore water pressure for rapid fill construction that the filling combination with vacuum preloading enables rapid construction on soft ground. It aims at application to the business to pays attention to stability management flow and residual water pressure shows at the period of vacuum driving of setting flow (Matsumoto et al.2003). The expression by Matsuo et al.

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(1975) concerning embankment destruction is valid for construction management by predicting displacement and speed of the displacement on the soft ground.

Many researchers have worked only on a particular vacuum consolidation method (VCM) while actually in the field the quality and the type of surcharge loading varies with pressure speeds and pressure and fill speeds. A method to increase pore water drainage forcibly and ground strength involves increasing the vacuum pressure. Rapid fill construction and during the fill construction control of lateral movement along with reducing upheaval of the surrounding area has been accomplished with the vacuum consolidation method (FLVCM). Increased vacuum loading and VCM applied together produce ground improvement. Therefore, in some cases, the combination of vacuum pressure and fill speed may provide good overall ground improvement. However, the ground deformation behavior is not sufficiently clarified with FLVCM, and there is not a reasonable design method or good site management mechanism other than dependence on experience.

In this study, numerical simulation has been performed by finite element method (FEM) for general fill loading, VCM, and FLVCM on the soft grounds of Ariake clay, Japan. The utility of FLVCM was confirmed by comparison of the observed and the analytical ground deformation. In addition, the numerical simulation with the various vacuum pre- and post-loading pressures and fill speeds have been performed, and the authors propose a reasonable management index which can be easily obtained through site measurements of ground deformation.

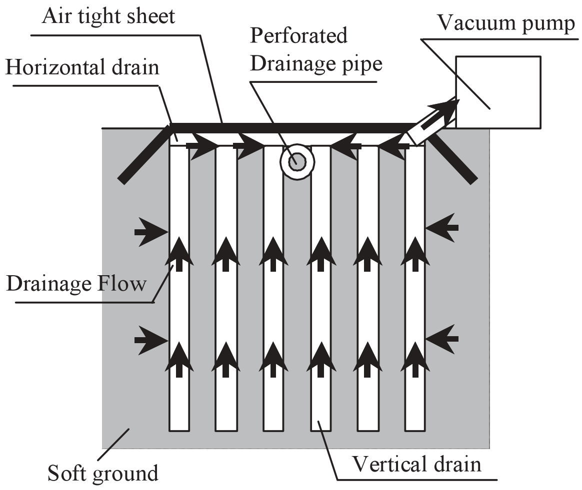

Fig.1 Conceptual diagram of vacuum consolidation method

VACUUM CONSOLIDATION METHOD

The conceptual model of VCM is shown in Fig. 1. VCM has been accomplished with many drainage routes through vertical drains placed at the surface of the soft ground and connected with horizontal drains and then to a perforated drainage pipe. This whole improvement area is covered by an airtight sheet. Afterwards, inside the drain decompressed by a vacuum pump, water and air drainage are forced. The ground strength is increased by loading the vacuum pressure at this comparatively early stage, and the consolidation process is advanced.

Table 1 Result of laboratory soil tests

Depth GL-m	Density ρ_s (g/cm^3)	Water content W (%)	Void ratio e	Degree of Saturation S_r (%)	Unconfined compressive strength q_u(kN/m^2)	Component (%)				Plasticity index I_p (%)	Classification of soil
						Gravel	Sand	Silt	Clay		
2.00~2.90	2.609	147.1	3.816	100	21.1	0	1.5	36.2	62.3	78.6	Clay
3.00~3.90	2.639	136.3	3.585	100	26.5	0	9.6	33.7	56.7	62.7	Silt
4.00~4.90	2.663	107.2	2.875	99.2	28.3	0.2	36.4	26.9	36.5	41.3	
5.00~5.90	Sand layer, coefficient of permeability k=1×10^{-4}cm/sec										Sand
6.00~6.90	2.627	119.2	3.132	100	45.1	0	5.7	40.8	53.5	55.9	
7.00~7.90	2.641	125.7	3.318	100	38.5	0	2.5	39.9	57.6	61.9	Silt
8.00~8.90	2.617	115.1	3.008	100	48.9	0	4.2	37.5	58.3	61.1	
9.00~9.90	2.656	116.5	3.008	100	44.1	0.1	1.9	35	63	63.8	Clay
10.00~10.90	2.684	90	2.444	98.9	64.7	0	10.3	37.5	52.5	44.2	Silt
11.00~11.90	2.647	67.4	1.782	100	60.7	0.2	11.2	32.8	55.8	40.9	

PHYSICAL PROPERTIES

The soil materials used in the present study were collected from Ariake (undisturbed) in Saga prefecture. The physical properties of the samples were identified by laboratory soil tests. Table 1 shows the result of laboratory soil tests such as particle density, water content, void ratio, degree of saturation, unconfined compressive strength and composition of grain degree for the various depth soil samples.

NUMERICAL ANALYSES

Soil Modeling

In this analysis, the Sekiguchi-Ohta model is applied as a constitutive model of soft clay behavior. Therefore, it is necessary to express the behavior of pore water pressure and consolidation. In this model, pore water and solid particle deformation behavior are produced by FEM analysis of the soil-water couple. Generally, any attempt to represent the behavior of soils as realistically as possible will make the model complex because of the need for many constitutive parameters. This makes for a practical procedure for determining the input soil parameters proposed to be used in solving the coupling problems by FEM based on the elasto-viscoplastic constitutive model proposed by Sekiguchi and Ohta (1977) for normally consolidated clays, which will be referred to as Sekiguchi-Ohta model. The finite element program used in this study was developed by Iizuka et al. (1987) and is named DACSAR (Deformation Analysis Considering Stress Anisotropy and Reorientation). In the present study, surcharge loading and VCM are reproduced by FEM analysis for express to the vacuum consolidation that the drainage boundary has been setting on the connected part of the vertical and horizontal drains.

Finite Element Modeling and Input Parameters

In this research, the plane strain condition was assumed by the FEM analysis. The general boundaries as well as the 2D finite element method of a half section of the single improvement area (area 17.6m×187m, depth about 12m) that had been the object of the previous research (Tanabashi Y. et. al 2005) in the field test constructed area shows the analytical model in Fig. 2. It is necessary to put the vertical drain up to - 11.0m in depth at horizontal intervals of 0.8m respectively. The shape of the fill is assumed to have width 8.8m in the bottom and 3.8m in the top with fill height 5.0m. Moreover, Table 2 shows the input analytical parameters determined by Ohta et al (2002) according to soil plasticity index parameters. Surface soil, clay, and silty clay layer are represented in the Sekiguchi-Ohta model and fill, sand mat and sandy silt layer are represented in the linear elastic model. The indoor soil test results (Table 1) of samples collected from the field test construction site are used for the parameter values and for determining the input soil parameters from the

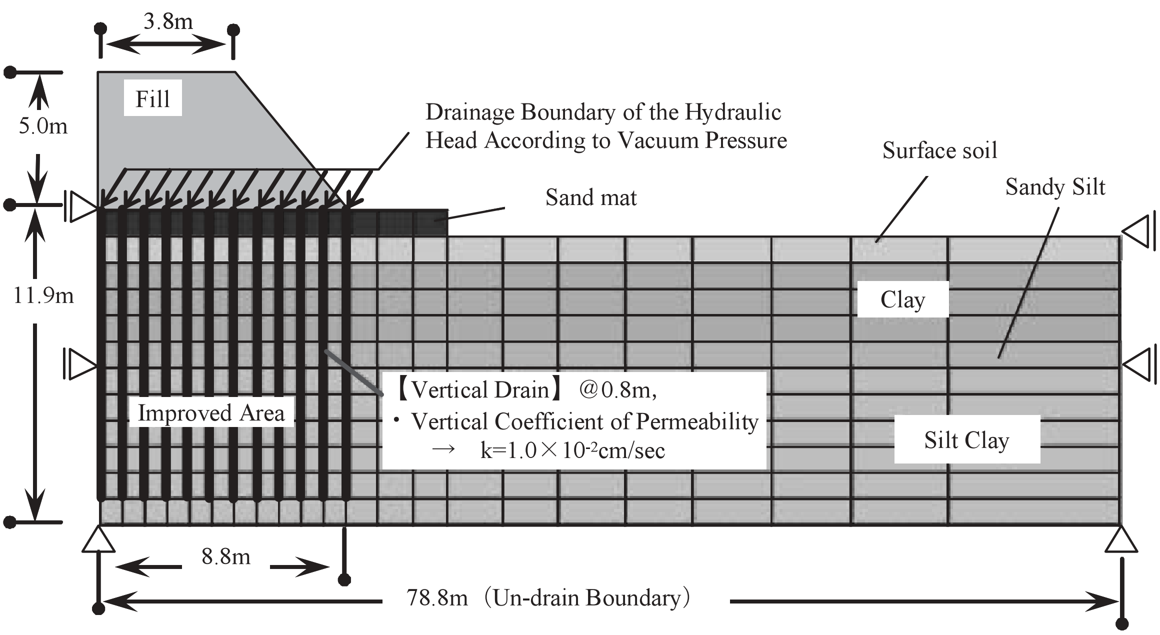

Fig. 2 Finite element modeling (Two-dimensional plane strain condition)

Table 2 Analytical model and input parameters

Name of layer		Depth (GL-m)	Model	E (kN/m^2)	ν	Đ	Λ	M	K_0	k(cm/sec)
Fill		-	L.E	2.69×10^4	0.300	-	-	-	-	1.0×10^{-2}
Sand Mat		0.0~1.0		4.5×10^4	0.300	-	-	-	-	1.0×10^{-3}
Surface Soil		1.0~2.0	S.O	-	0.387	0.093	0.481	0.842	0.631	3.1×10^{-7}
Clay	1	2.0~3.0		-	0.387	0.133	0.480	0.840	0.631	3.1×10^{-7}
	2	3.0~4.0		-	0.378	0.088	0.514	0.900	0.608	2.9×10^{-7}
	3	4.0~5.0		-	0.361	0.092	0.579	1.013	0.566	2.5×10^{-7}
Sandy Silt		5.0~5.5	L.E	3.30×10^4	0.300	-	-	-	-	1.0×10^{-3}
Silty Clay	1	5.5~7.0	S.O	-	0.374	0.092	0.532	0.931	0.596	1.3×10^{-7}
	2	7.0~8.0		-	0.378	0.116	0.516	0.903	0.607	2.6×10^{-7}
	3	8.0~9.0		-	0.377	0.096	0.518	0.907	0.605	2.0×10^{-7}
	4	9.0~10.0		-	0.379	0.120	0.512	0.895	0.610	4.4×10^{-7}
	5	10.0~11.0		-	0.364	0.139	0.568	0.995	0.573	2.0×10^{-7}
	6	11.0~11.9		-	0.361	0.107	0.581	1.016	0.565	8.7×10^{-8}

Note: L.E.: Linear Elasticity, S.O.: Sekiguchi Ohta, *E*: Coefficient of elasticity, *υ*: Effective poisson ratio, *Đ*: Coefficient of dilatancy, *Λ*: Inversibility ratio, *M*: Critical state parameter, K_0: Coefficient of earth pressure at rest, *k:* Coefficient of permeability

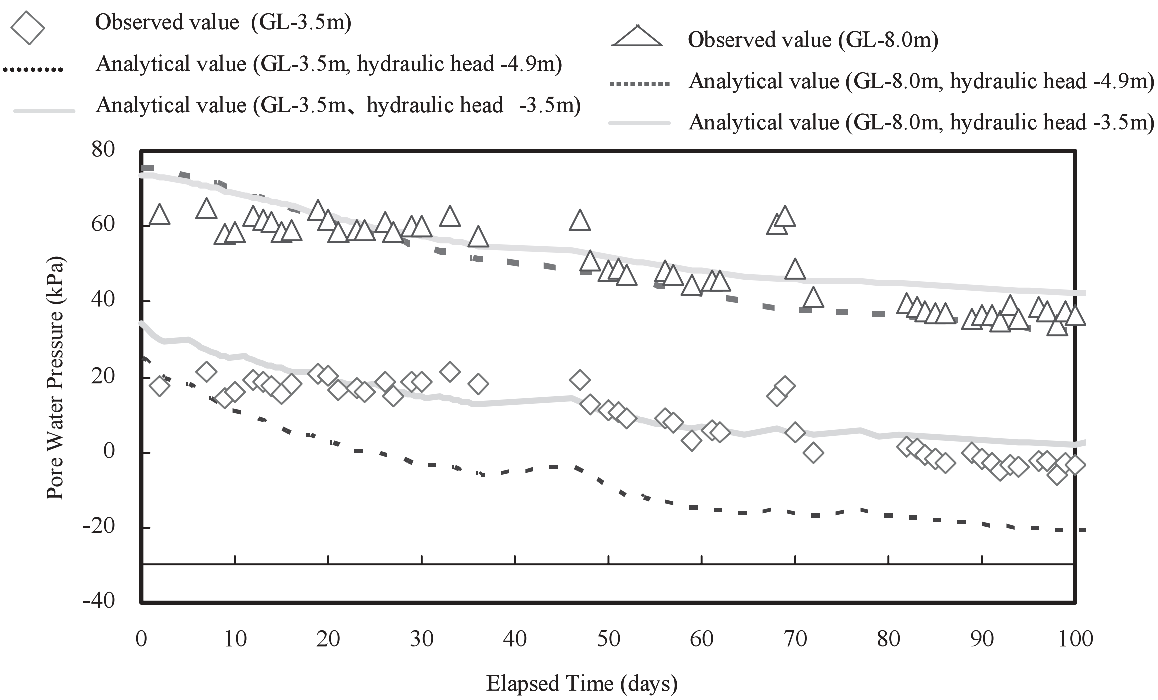

Fig. 3 Observed and analytical values of pore water pressure versus elapsed time

plasticity index. However, drainage boundary condition of hydraulic head is setting on the top of the vertical drain, then vacuum pump was operated, negative pressure was given pressurize top of the vertical drain and pore water pressure is decreased forcibly with increases the hydraulic head. It was tern off, than vertical drain was given undrained boundary condition. Therefore, hydraulic head is corresponded to the vacuum

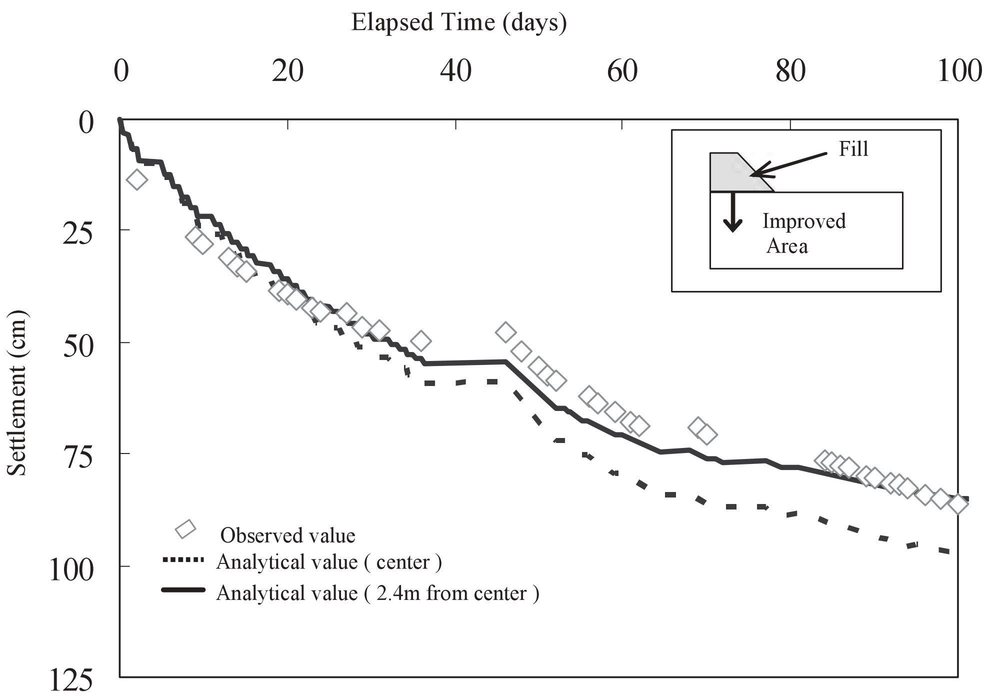

Fig. 4 Observed and analytical values of settlement and elapsed time

pressure in this modeling analysis. Moreover, boundary condition setting on the FEM analysis (Fig.2) as follows, surface of the improvement area is horizontally and vertically drained, center of the improvement area is horizontally undrained and vertically drained, edge of the improvement area is horizontally undrained and vertically drained, bottom of the improvement area is horizontally undrained and vertically undrained.

VERIFICATION OF ANALITICAL MODEL

Field measurement and numerical analysis of the field test construction are produced using the above-mentioned physical properties of each layer. In this paper, field and numerical analytical points are taken from a depth at GL-3.5m and GL-8.5m, respectively.

Figure 3 is a graph of pore water pressure versus elapsed time at various depths for the vacuum consolidation test. The data were recorded by model analyses according to -4.9m hydraulic head (Tanabashi et al 2008). There are roughly the same tendencies of the pore water pressure in this figure. The behavior of the pore water pressure can be determined from the figure by analysis as well as the mechanism of VCM in which the pore water pressure decreases because of action of the vacuum pressure. Moreover, result of making a change to hydraulic head who gives to drainage boundary that an analytical value of hydraulic head has -

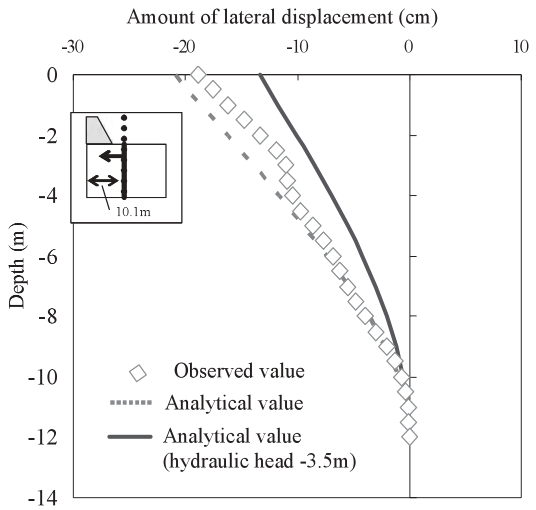

Fig. 5 Observed and analytical values of depth distribution of lateral displacement 10.1m away from center

3.5m given for the more similar to the actual field measurement value. Figure 4 shows the relationship between amount of surface settlement and elapsed time. Analytical value of the center from 2.4m is similar to actual field measurement value but center of simulation value is larger than 2.4m distant from the center of the field measurement value because maximum settlement is generated to the center according to the analytical result of the total improvement area. It is also thought by the authors that for an increased distance from center there is a decrease in the amount of surface settlement. Figure 5 shows the distribution depth of lateral displacement measured by field and model analysis. Lateral displacement is shown here at 10.1m from center of the improvement area. This result is shown after 98 days from starting of the fill construction. It has increased with decreasing hydraulic head for drainage boundaries from -4.9m to -3.5m. In this analysis the difference with the field data extends to after and before changes in the hydraulic head but it is thought the lateral shrinkage in the improvement area because of the influence of vacuum consolidation is roughly expressed by the model analysis.

Figures 3, 4 and 5 compare field and model analysis with both showing similar tendency changes behavior. It is determined that assuming the model and soil parameters used are appropriate. In this analysis, numerical simulation is discussed focus in terms relation of the model analysis to the settlement and lateral displacement, and is indicated to be the overall index management accounting for the fill construction.

EVALUATION OF SLM, VCM AND FLVCM

Analytical Cases

Table 3 shows the analytical cases. There are three methods that compare the deformation behavior of the ground such as surcharge loading method (SLM), VCM and FLVCM respectively. SLM and FLVCM have been

Table 3 Analytical cases

Method	Fill Speed (cm/day)	Fill height (m)	Vacuum pressure (kPa)	Period of vacuum pressure (day)
SLM	20	5	0	0
	50	5	0	0
FLVCM	20	5	-69	25
	50	5	-69	10
VCM	0	0	-69	25

SLM: Surcharge Loading Method, FLVCM: Fill Loading with Vacuum Consolidation Method, VCM: Vacuum Consolidation Method

assumed for each of the two cases according to fill speeds of 20 cm/day and 50 cm/day respectively. A total of five cases are reported in this analysis. When assumed the fill construction than fill height is setting 5m. Period of fill rest (period of vacuum pressure releases) is setting 360 days respectively. In all cases –69kPa of vacuum pressure has been used as measured by pore water pressure. There are two cases of the 20 cm/day fill speed such as SLM and FLVCM. The single other case is VCM without fill. These cases are compared with pore water pressure and deformation behavior for the period of fill loading. Therefore, fill speeds 50cm/day cases are used next section.

Figure 6 is a contour figure of pore water pressure. This figure shows the behavior of pore water pressure after 25 days elapsed time due to loading of vacuum pressure. The pore water pressure has decreased

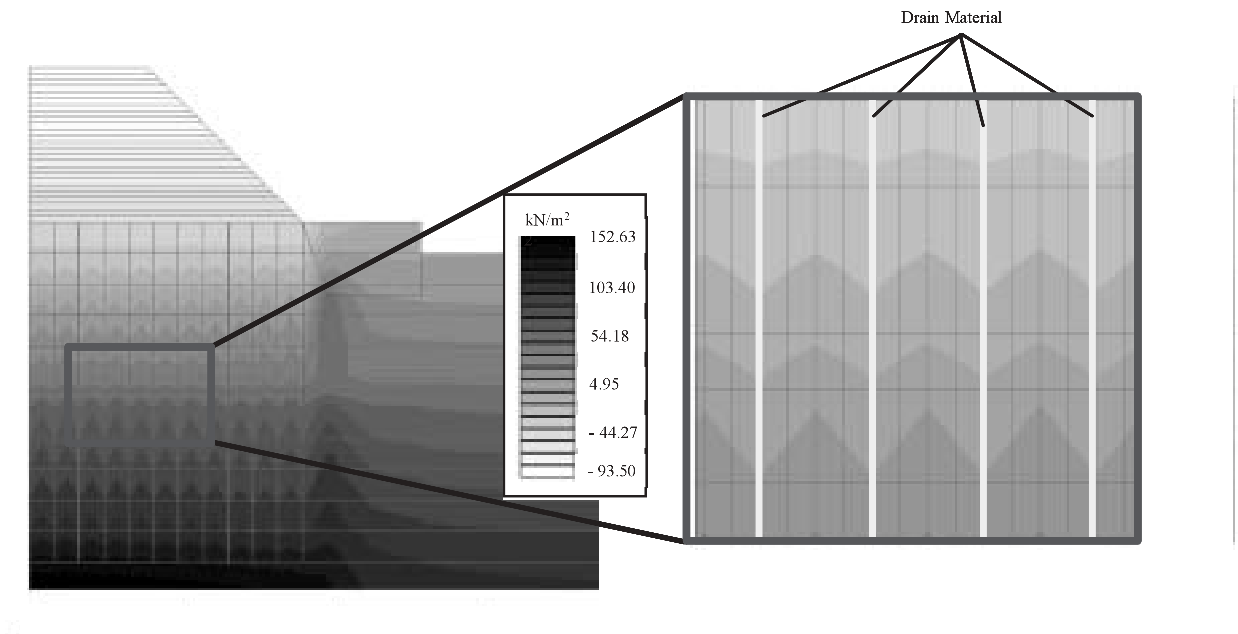

Fig. 6 Decreasing behavior of pore water pressure after 25 days due to vacuum preloading

dramatically around the drain material due to the distribution of irregular conditions as illustrated in the figure. Moreover, it also shows that the spread of the vacuum pressure has decreased in the portion of the soil between of the drains. Thus, this analysis confirms that decreasing pore water pressure is due to vacuum consolidation during the surcharge loading.

Figure 7 shows the depth distribution of the pore water pressure at the center of the improved area. The pore water pressure has been shown to distribution of initial stage and each case after 25 days (stage load) and 385 days (fill rest 360 days) elapsed from starting of the fill construction. SLM is generated excess pore water pressure about 50kPa after 25 days elapsed time from starting of the fill construction, oppositely decreasing the pore water pressure could seen about -30kPa~-20kPa into VCM respectively. At that time, FLVCM has been generated excess pore water pressure in the depth layer on the boundary of -5.0m at depth in this figure and compare with the SLM that FLVCM is become controlled in this analysis. Moreover, after 385 days elapsed time from starting the fill construction that only one case of the SLM is shown higher pore water pressure distribution than initial stage, dissipation of the excess pore water pressure is late, hydraulic pressure settles down to hydrostatic pressure over all depth after leaving of the fill construction.

Figure 8 shows the amount of settlement versus elapsed time at -4.0m depth at the center of the ground improvement area. FLVCM shows maximum settlement according to the period of fill loading. Because, it is thought that settlement behavior is excellent by the influence of both loading of vacuum pressure and fill construction. However, SLM shows maximum settlement in the period of fill rest, and VCM has been generated a rebound phenomenon after releases the vacuum pressure. It is thought that residual settlement and rebound behavior can be control by the combination of SLM with VCM during the fill construction.

Amount of Soil Settlement and Lateral Displacement

Figure 9 shows part of the deformation ground which is taken as definition of the amount of soil settlement and lateral displacement. The fill management index has been proposed to understand the deformation behavior of the ground. Deformation block area is assumed for definition ground of width 10.1m and length 11.9m respectively. The amount of soil settlement (V_S) and amount of lateral displacement (V_δ) is calculated according to the following equations

$$V_s = \Sigma\left\{\frac{1}{2}\times\left(S_i + S_{i-1}\right)\times\Delta\delta\right\} \quad \text{.................................(1)}$$

$$V_\delta = \Sigma\left\{\frac{1}{2}\times\left(\delta_i + \delta_{i-1}\right)\times\Delta S\right\} \quad \text{.................................(2)}$$

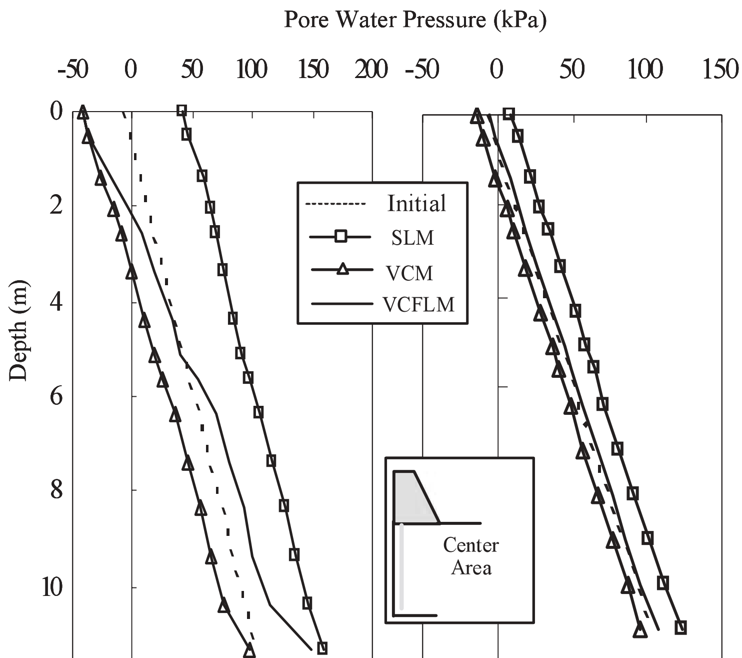

Fig. 7 Depth distribution of pore water pressure at the center of the improved area

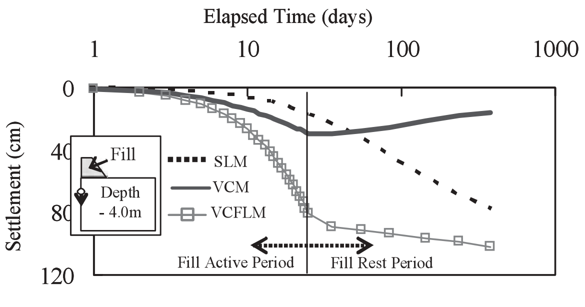

Fig. 8 Amount of settlement versus elapsed time at -4.0m depth at the center of the improved area

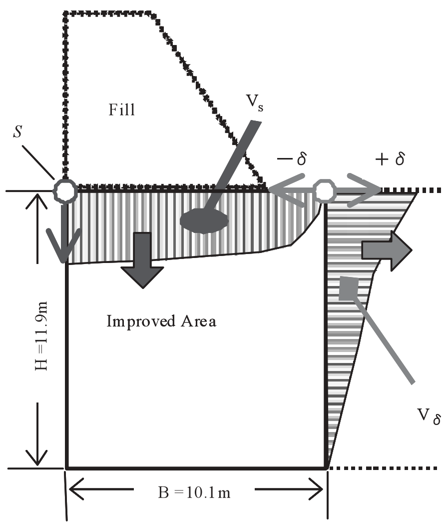

Fig. 9 Assumption for ground deformation amount of settlement and lateral displacement

where, V_s: amount of settlement, V_δ: amount of lateral displacement, S_i: amount of settlement in i node, δ_i: amount of lateral displacement in i node, ΔS: node distance in vertical direction, $\Delta\delta$: node distance in horizontal direction.

The amount of settlement (V_S) and amount of lateral displacement (V_δ) calculated using Eqns (1) and (2) are plotted in Fig. 10 along with SLM and FLVCM for fill speeds of 20 cm/day and 50 cm/day and without fill construction VCM (in Table 3). In this figure, dotted line is undrained response, where $V_S=V_\delta$ is satisfied to shows the ground deformation condition. The SLM cases are shows very close to the undrained response, and the case of 50cm/day is most unusual compared to the other cases and it is understood that SLM has been shown deformation behavior as like the neighborhood shearing deformation of an undrained response. After filling, both cases shows a strong rebound tendency with increased amount of settlement because there is no consolidation. Usually after filling soft ground tendency is become to initial stage without consolidation pressure. But as for the result of VCM is understood of the appearance that V_δ increased negative direction with increasing the settlement and relation of $V_s > -V_\delta$ is generated superior settlement with lateral shrinkage behavior of the ground deformation. However, FLVCM cases are tendency of $V_S>V_\delta$ relation stronger than SLM cases. It is also understood from figure that settlement behavior was shown more superior behavior in deformation mode. Moreover, it is estimated that the ground tendency has been shrunk rapidly according to the period of fill rest

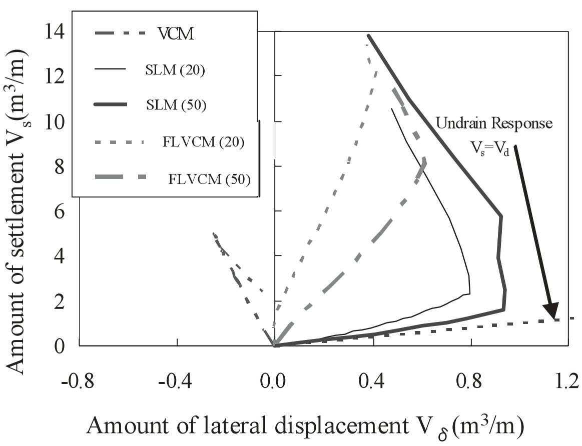

Fig. 10 Relationship between amount of settlement and lateral displacement according to the proposed assumption

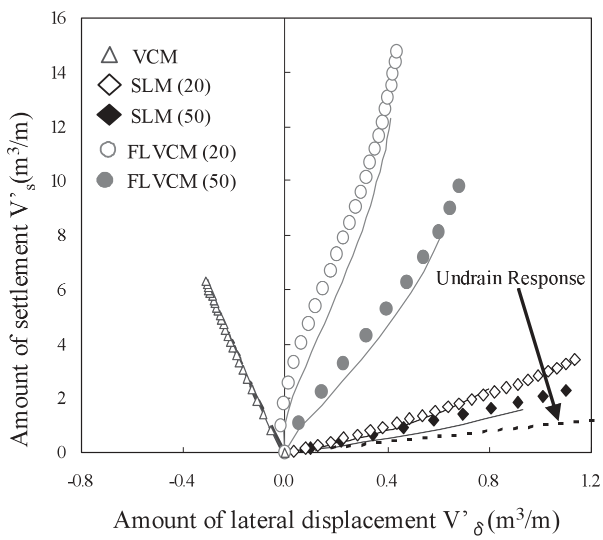

Fig. 11 Calculated and analytical values of amount of settlement versus lateral displacement

and fill construction is executed with 50cm/day, respectively.

The settlement record on the surface of the basement ground and measurement of the depth distribution of lateral displacement are become to needed according to the previous condition for the calculation of V_S and V_δ that described in the foregoing paragraph by Eqns (1) and (2). However, these types of various ground deformations measurement are very difficult on the site. Fig. 9 shows the assumed definition ground for amount of soil settlement and lateral displacement. Usually, the amount of settlement (S) is measured on the site of fill center surface of the ground, and the amount of horizontal displacement (δ) of the ground surface in the out of improvement area is calculated by according to the Fig. 9 and the authors tried to calculate the amount of deformation by the following equations

$$V_s' = S \times B \text{...(3)}$$

$$V_\delta' = \delta \times \frac{H}{2} \text{...(4)}$$

where, V_S': amount of settlement, V_δ': amount of lateral displacement, S: settlement in the center surface of ground, δ: lateral displacement on the ground surface, B: width of improvement area, H: thickness of improvement area.

Figure 11 shows the relation between amount of settlement (V_S') and amount of lateral displacement (V_δ') according to Eqns (3) and (4). The V_S versus V_δ relation (during the fill construction) is also shown with together. The figure shows the correspondence between V_S versus V_δ (during the fill construction) and V_S' versus V_δ' (Fig. 9) that calculated amount of soil deformation has been seen similar tendency and it is determined a strong tendency of ground deformation depends on settlement in center on the surface (S) and lateral displacement on the ground surface (δ). Therefore, it appears that deformation behavior may be able to managed by settlement in the center on the surface(S) and lateral displacement on the ground surface (δ) according to the FLVCM.

PROPOSAL OF CONSTRUCTION MANAGEMENT INDEX

Case Studies of FLVCM

Loading of vacuum pressure and fill speed are influences for discussion concerning the deforming behavior of soft ground. In this analysis, the authors used fill speeds of 20cm/day and 50cm/day and setting fill height 5.0m. The FLVCM has been modeling to changed by setting of vacuum pressures from -20kPa to -90kPa. Analytical cases are shown in Table 4. An analytical model and input parameters are same (Table2) as well as the above-mentioned as for this analysis.

Table 4 Case studies of FLVCM

Cases	Vacuum Pressure (kPa)	Fill Speed (cm/day)	Fill Height (m)	Period of Vacuum Pressure (day)
V-20(20)	-20	20	5	25
V-60(20)	-60			25
V-90(20)	-90			25
V-20(50)	-20	50		10
V-40(50)	-40			10
V-60(50)	-50			10
V-80(50)	-80			10
V-90(50)	-90			10

V: Fill Loading with Vacuum Consolidation Method

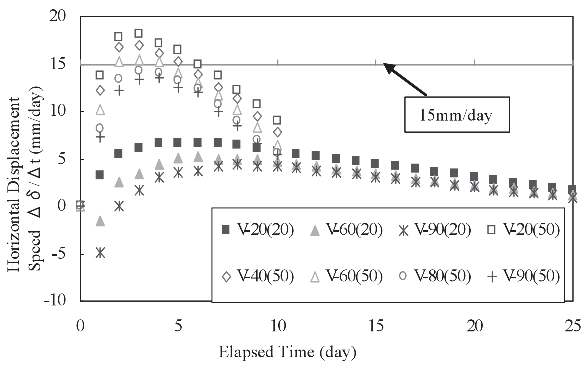

Fig. 12 Horizontal displacement speed versus elapsed time for case studies of FLVCM

RESULTS AND DISCUSSION

The ground behavior is evaluated by settlement (S) and lateral displacement (δ) as discus above. As a criterion, authors took the standard value ($\Delta\delta / \Delta t \leq$15~20mm/day) of horizontal displacement speed of the edge point of the fill slope according to VCM technological material (addition 2004). However, it is assumed the amount of lateral displacement of the ground surface at a point 1.3m away from the edge of the fill slope or 10.1m away from the center of the

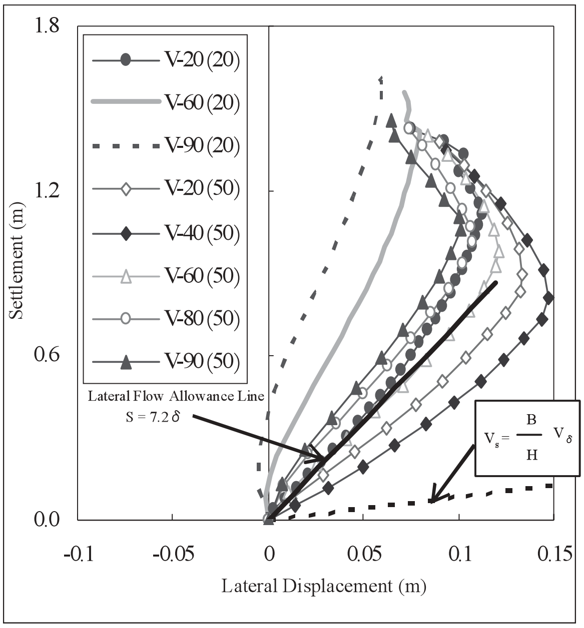

Fig. 13 Settlement versus lateral displacement for case studies of FLVCM

improvement area following Fig. 9. Figure 12 shows the relationship between horizontal displacement speed and elapsed time during fill construction for each case of FLVCM.

The cases V-20(50) and V-40(50) that correspond to fill speeds of 50cm/day and vacuum pressures of less than –60kPa exceed 15mm/day, this is the maximum horizontal displacement speed. Moreover, the maximum horizontal displacement speed is 15.4mm/day in case V-60(50).

This standard case has been satisfied the maximum horizontal displacement speed line or not in this analysis. Fill speed of 50cm/day and vacuum pressure less than –60kPa cases are exceeded the standard line, but fill speed of 20cm/day all cases are satisfied the standard line. So V-60(50) is a standard case that the approximation straight line is drawn that satisfies the standard during fill construction, and Fig. 13 is plotted for settlement (S) versus lateral displacement (δ).

In this figure, V-60(50) case is introduced an approximation line as a lateral displacement allowance line. It is understood that V-20(50) V-40(50) and V-60(50) cases are become in the deformation mode with especial superior lateral displacement behavior according to the S versus δ relation. Moreover, it can be determined that other cases shows a strong tendency to stable behavior of $S>\delta$.

Thus, it is proposed a stable management index for lateral displacement by introduced the critical line into the S-δ relation that controlled by fill speed and vacuum pressure.

CONCLUSIONS

Numerical simulation by FEM with SLM, VCM, and FLVCM applied to soft ground were performed. Authors have proposed a management index to examine the utility of FLVCM by comparison of actual deformation ground behavior to deformation behavior according to those analytical results. Moreover, numerical analysis to which was attention to carried out the loading of vacuum pressure in also during fill construction condition of FLVCM, deformation ground behavior was evaluated based on the proposed a construction management index, and considered to influence that loading of vacuum pressure was exerted. The authors have been able to clarify the following points in this research.

1) Average vacuum pressure -69kPa (hydraulic head had been given –3.5m to the drainage boundary) in the vacuum pump was expressed by the analyses, to great result of accuracy was able to be obtained to comparing the amount of settlement than hydraulic head given -4.9m respectively.
2) Numerical simulation of FLVCM was carried out of fill consideration and smaller element division made by analytical model. As a result, it was clarified that distribution in the ground of pore water pressure in vertical and horizontal direction by loading of vacuum pressure was expressible more in detail. Moreover, deformation ground behavior due to surcharge loading and VCM was compared during the fill construction, on that time clarified as an effect of using FLVCM as follows (a) Effect of controlling the ground deformation of circular slide as a center on fill edge point and great lateral shrinkage behavior. (b) Effect of rebound decrease that occurs after releasing vacuum consolidation pressure according to without fill construction. (c) Return to the initial stage of hydraulic pressure at fill rest period and controlling excess pore water pressure due to only on the general fill construction.
3) About the 3 kinds of numerical simulation result that relation is taken out of the amount of soil settlement and lateral displacement of the improvement area, undrained response became a standard, and could be decided to deformation mode during the fill construction of each method. Moreover, settlement of fill center on the surface versus maximum horizontal displacement on the out side of the improved area and relation between amount of settlement versus lateral displacement exhibit similar deformation mode.
4) Numerical simulation was carried out with attention

to loading of vacuum pressure on the condition of FLVCM that fill speed 50cm/day and vacuum pressure less than –60kPa cases are suggested unstable ground behavior from result of settlement and excess pore water pressure. However, it was clarified that the lateral displacement behavior especially exceeded the standard value than fill speed 50cm/day and vacuum pressure less than –60kPa, since the evaluated result of ground behavior was originally introduced a critical line that called lateral displacement allowance line. It is based on the standard value at the horizontal displacement speed during fill construction by the FLVCM standard specifications.

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