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EFFECT OF LIQUEFIED STABILIZED SOIL AS BACKFILLING MATERIAL ON THE BUILDING UNDER SEISMIC CONDITION

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ABSTRACT: In Japan, excavated soils generated from construction sites in urban areas are being disposed to landfill as industrial waste. With limited urban land in big cities, the landfill sites will be more and more scarce and overload state in the next few years. Therefore, the effective use of soil generated from construction is an urgent issue. Liquefied Stabilized Soil (LSS) is one of the effective methods of using excavated soil with construction works, has become popular in Japan. Numerous previous studies have shown the many advantages of LSS. However, no studies have evaluated the effect of LSS on the surrounding environment when an earthquake occurs. In this study, the effect of backfilling material on the building and ground under the earthquake is analyzed by using the finite element method (FEM). A three-dimensional model of the ground and a 10-story building with one basement was simulated in ABAQUS software. Three case studies with three types of backfilling material (backfilling soil, LSS, and LSS with fiber) were analyzed and compared. Based on the analysis results, it is shown that using LSS as a backfilling material can reduce the lateral displacement and inter-story drift of building slightly when an earthquake occurs. Besides, the acceleration and velocity of the ground around the building decreased, with the largest reduction rates up to 49.4 % and 24.5 %, respectively.

Keywords: Liquefied stabilized soil, Fiber material, FEM analysis, Earthquake

1. INTRODUCTION

A long time ago, in the big cities in Japan such as Tokyo, Nagoya, and Osaka, etc., when the subway lines, underground constructions, and high-rise buildings were built, millions of cubic meters of soil was excavated. The soil was carried by trucks from underground construction sites to disposal sites, which was the cause of environmental pollution. With limited urban land, landfill sites were more and more scarce and led to an overload state. The questions were where to put the excavated soil and how to develop sustainable infrastructure, which did not only reduce the cost of construction but also did not affect the natural environment. To solve these problems, one of the methods was recycling the excavated soil as backfilling soil. "Liquefied Stabilized Soil" (LSS), which was reported by Kuno [1], is one of the effective methods of using the excavated soil with construction works and has become popular in Japan. The LSS is a kind of cement-treated soil, which is prepared by mixing slurried soil and cement stabilizer. The LSS mixtures are not only created stabilized ground without compaction but also easy to fill space by pumping a long distance. However, the increase in cement content does not only increase the strength property, but also the brittleness increases. To improve the ductile performance of LSS, a reinforcement method has been created by mixing the newspaper as a fiber material into LSS. It was shown that the ductile property of LSS mixed with pulverized newspaper as a fiber material after the peak in the $q \sim \varepsilon_a$ curve was significantly improved by the reinforcement method [2-6]. There are many previous studies on the influence of various factors on LSS [7-11]. However, there is no research on the effect of using LSS as a backfilling material on the structure and the ground when the earthquake occurs.

In this study, the effect of backfilling material on the building under the earthquake is analyzed by using the FEM method. Based on the analysis results, the influences of LSS as backfilling material on the building and the ground were discussed.

2. NUMERICAL SIMULATION

2.1 Simulation of Study Cases

In this study, it was assumed that a 10-story building with a basement was constructed by the open-pit method. The pit was excavated to the bottom of the basement with the size as shown in Fig. 1. When the basement is completed, the excavation region will be filled by backfilling material. The backfilling content in each case would be Case 1: backfilling soil (sandy soil), Case 2: LSS and Case 3 was LSS mixed with fiber material. Subsequently, nonlinear time-domain dynamic analysis under the earthquake was conducted. From the results, the effect of backfilling material on the building under in each case was discussed. Acceleration and velocity of five points on the ground

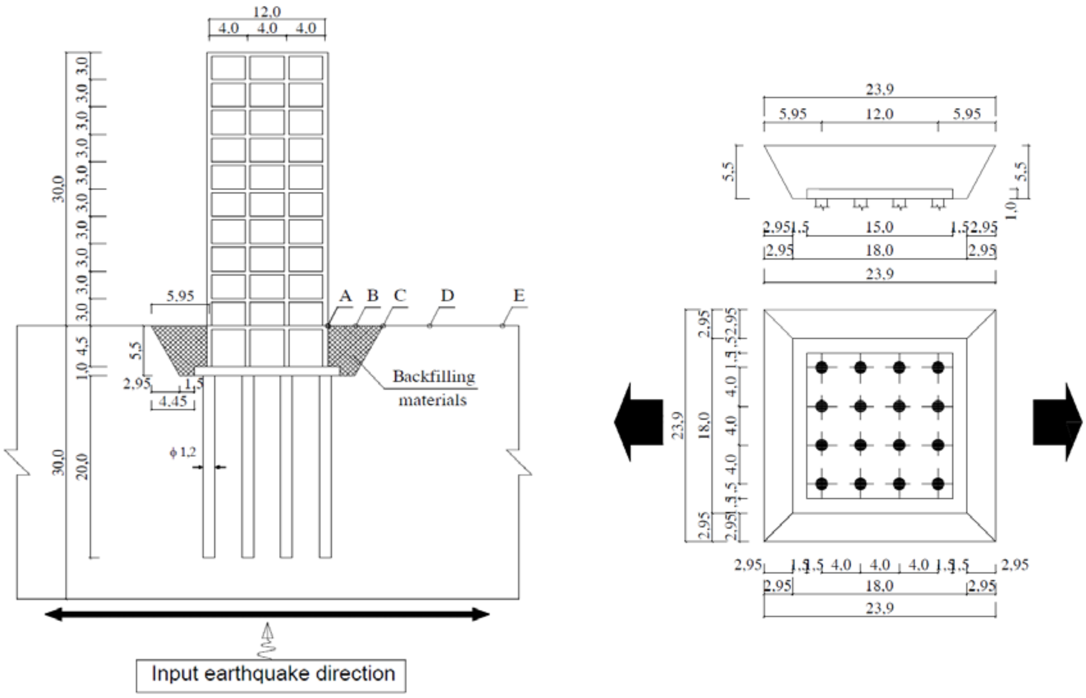

Fig. 1 Dimensions of the structure and excavation

surface A, B, C, D, E with distances of 0, 3, 5.95, 10.5, 18 m, respectively from the edge of the building were compared and investigated.

2.2 Numerical Modeling and Parameter

2.2.1 Structural modeling

In this study, a reinforced concrete ten-floor building frame, 30 m high and 12 m wide with 16 columns consisting of three spans of 4 m in each direction, and ten slabs and one basement was selected, as shown in Fig.1. The height of the floors was 3 m, and the basement floor was located at a depth of 4.5 m below the ground surface. The reinforced concrete foundation was 15x15 m square, and 1 m thick, and the reinforced concrete pile of 20 m depth and 1.2 m in diameter was selected to analyze in this study. The structural sections were specified after conducting a routine design procedure regulated in the relevant building codes [12]. SAP2000 v 22 software [13] was utilized for the structural analysis and design of the cross-sections of columns and slabs. The parameters of the columns, floor, foundation, and pile are shown in Tables 1 and 2, respectively.

The structural elements were modeled by using an elastic-viscoelastic constitutive equation. In the time domain, material damping needs to be converted to Rayleigh damping as follows [14].

$$[C] = \alpha\,[M] + \beta\,[K] \tag{1}$$

Where:

[C]: damping matrix
[M]: mass matrix
[K]: stiffness matrix
α: mass-proportional coefficient
β: stiffness-proportional coefficient

The mass-proportional (α) and stiffness-proportional (β) coefficients are calculated from selected natural frequencies and the damping ratio. The values of α and β are defined as follows [15]:

$$\boldsymbol{\alpha} = \xi\,\frac{2\omega_m\omega_n}{\omega_m+\omega_n} \tag{2}$$

$$\boldsymbol{\beta} = \xi\,\frac{2}{\omega_m+\omega_n} \tag{3}$$

Where:
$\boldsymbol{\xi}$: damping ratio
$\omega_m = 2\pi f_m$: angular frequency of corresponding mode m
$\omega_n = 2\pi f_n$: angular frequency of corresponding mode n

In this study, the natural frequencies of the building for the fixed base structure were simulated by SAP 2000 v22 program as shown in Fig. 2. Base on this simulation, the first and second natural frequencies are selected to determine the values of ω_1 = 7.96 (rad/s) and ω_2 = 22.32 (rad/s), respectively. From Eq. (2) and (3) with the material damping of 5 %, the mass-proportional and stiffness-proportional coefficients were obtained as α = 0.5868 and β= 0.0033, respectively.

Table 1 Characteristics of designed reinforced concrete column sections adopt in 3D FEM

Section Type	I_x (m^4)	I_y (m^4)	Area (m^2)	E (kN/m^2)	ν
Type I (levels 1-5 and basement)	3.64E-3	7.45E-3	0.25	2.86E7	0.2
Type II (levels 6-10)	1.50E-3	3.05E-3	0.16	2.86E7	0.2

Table 2 Characteristic of designed reinforced concrete floor slabs and foundations adopted in a 3D numerical model

Properties	Denote	Unit	Value
Floor slab thickness	h_s	m	0.25
Basement wall thickness	h_w	m	0.35
Foundation thickness	h_f	m	1
Density	ρ	kN/m^3	23.54
Young's modulus	E	kN/m^2	2.86E7
Poisson's ratio	ν	-	0.2

2.2.2 Soil modeling and characteristic of backfilling materials

The present building is constructed on 30 m deep soft clayey soil on the bedrock. From the previous research [16], this bedrock depth is reasonable because most of the amplification is in the first 30 m of the soil column. The properties of this soft soil were determined from actual in-situ and laboratory tests [17] with a density of 14.416 kN/m^3, a shear wave velocity of 150 m/s, and undrained shear strength of 50 kN/m^2. It was assumed that the groundwater level was equal to the level of the bedrock.

In this study, the properties of backfilling material, i.e., backfilling soil and LSS used for the analysis model were achieved from previous research [7,9,18,]. LSS slurry was made by the following procedure. New Snow Fine Clay (NSF-Clay) and water were put into a big bucket and mixed by hand mixer. The density of the mixture was adjusted to 12.562 kN/m^3 by measuring the mass of slurry filled into a stainless steel container of 400 cm^3 called "AE mortar container". After that, the cement content of 100 kg/m^3 was put into the mixture and mixed slowly and carefully by hand mixer. The flow test was controlled according to the JHS A313-Japan Highway Public Corporation Standard to measure the liquidity of LSS. The fiber material amount of 10 kg/m^3 were added with LSS slurry and mixed slowly and carefully by hand mixer. The damping ratio of LSS and LSS with fiber is assumed as 10 % [7, 9]. On the other hand, characteristics of backfilling soil are considered as follows. Because of not much investigation results on the stiffness of the backfilling soil, the investigation results on backfilling soil in Daikai station, which suffered from the Southern Hyogo prefecture earthquake in 1995, were used as the backfilling soil parameters. N value and unit weight, ρ was set at 10 and 17.0 kN/m^3, respectively. Shear modulus, G = 51.531 MN/m^2, was estimated from N value by Railway Design Standard [19]. The damping ratio of backfilling soil was assumed as 4 %. The physical properties of backfilling materials are shown in Table 3.

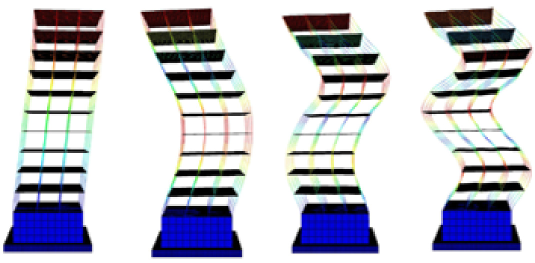

Fig. 2 The natural frequencies of the structure

The Rayleigh damping coefficients of the soil are obtained from Eq. (2) and (3). The first and second natural frequencies of the soil are selected to calculate the mass-proportional and stiffness-proportional coefficients. The values of natural frequencies of the ground are calculated as the following equation [20]:

$$f_n = \frac{V_s}{4H}(2n-1) \tag{4}$$

Where:

n: mode number

f_n: natural frequency of the corresponding mode n

V_s: shear wave velocity of the soil deposit

H: soil deposit thickness

For multi-layer ground, the average shear wave velocity $V_{s,30}$ should be computed by the following equation [12]:

$$V_{s,30} = \frac{30}{\sum_{i=1}^{N}\frac{h_i}{V_i}} \tag{5}$$

Where:

h_i: denote the thickness

$V_{s,30}$: average shear wave velocity (at a shear strain level of 10-5 or less) of the i-th formation or layer, in a total of N, existing in the top 30 m.

The Rayleigh damping coefficients of the soil are shown in Table 4.

Table 3 Parameters of backfilling materials

Material	E (kN/m^2)	ρ (kN/m^3)	V_s (m/s)	ξ (%)	ν
Backfilling soil	1.529E5	17	150	4	0.49
LSS	3.649E5	13.356	300	10	0.49
LSS with fiber	3.806E5	13.366	306	10	0.49

Table 4 Rayleigh damping coefficients of the soil

Case	Material	h(m)	V_s(m/s)	$V_{s,30}$(m/s)	f_1	f_2	α	β
Case 1	Backfilling soil	5.5	172	153.6	1.28	3.84	0.4825	0.0025
	Soft clay soil	24.5	150				0.6031	0.0031
Case 2	LSS	5.5	300	165.137	1.376	4.128	1.297	0.00578
	Soft clay soil	24.5	150				0.6484	0.00289
Case 3	LSS with fiber	5.5	306	165.465	1.379	4.136	1.299	0.00577
	Soft clay soil	24.5	150				0.6497	0.00288

Table 5 Characteristics of the adopted earthquake records

Earthquake	Country	Year	PGA (g)	M_w (R)	Duration (s)	Hypocentral distance (km)
Tokachi-Oki	Japan	1968	0.229	7.5	36	14.1

Note: PGA: peak ground acceleration; M_w: moment magnitude scale

2.2.3 Earthquake motions

In this study, the 1968 Tokachi-Oki earthquake in Hachinohe (Japan) was selected and utilized onto the finite element numerical model for conducting a time-history analysis. This earthquake has been chosen by the International Association for Structural Control and Monitoring for benchmark seismic studies [21]. The characteristics of the earthquake ground motions were indicated in Table 5, and the time histories of the earthquake were shown in Fig. 3. It was assumed that the earthquake ground motions are bedrock records.

2.2.4 Numerical modeling in the ABAQUS program

In this study, the effect of backfilling material on the building and the ground under the earthquake is analyzed by using ABAQUS 2020, a FEM analysis

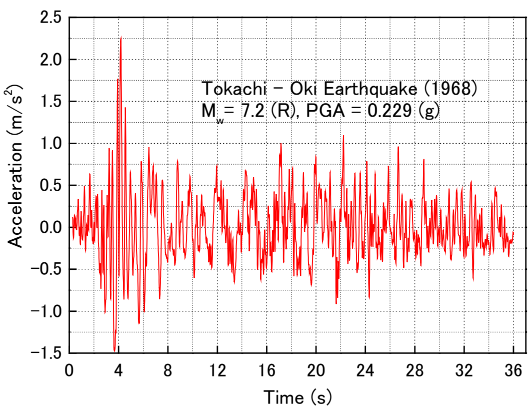

Fig. 3 The time histories of the 1968 Tokachi-Oki earthquake in Hachinohe city in Japan

program [22]. Both linear and nonlinear analyses are provided in ABAQUS to evaluate the interaction between the building and the ground.

Beam elements (B33: 2 - node linear beam element in space) in ABAQUS are used for simulation of the columns. The floor slabs and basement walls were simulated by the shell elements

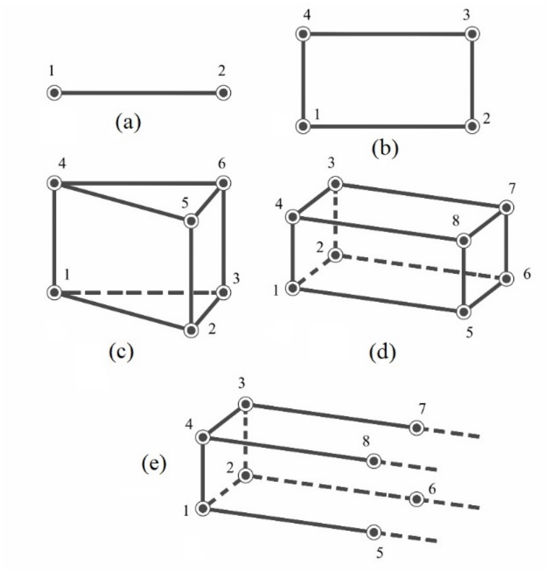

Fig. 4 Element types used in FEM: (a) 2-node linear beam element in space (B33); (b) 4-node, quadrilateral, stress/displacement shell element with reduced integration (S4R); (c) 3D, 6-node linear triangular prism elements (C3D6); (d) 3D, 8-node linear brick, reduced integration, hourglass control (C3D8R); (e) 3D, 8-node linear one-way infinite brick (CIN3D8)

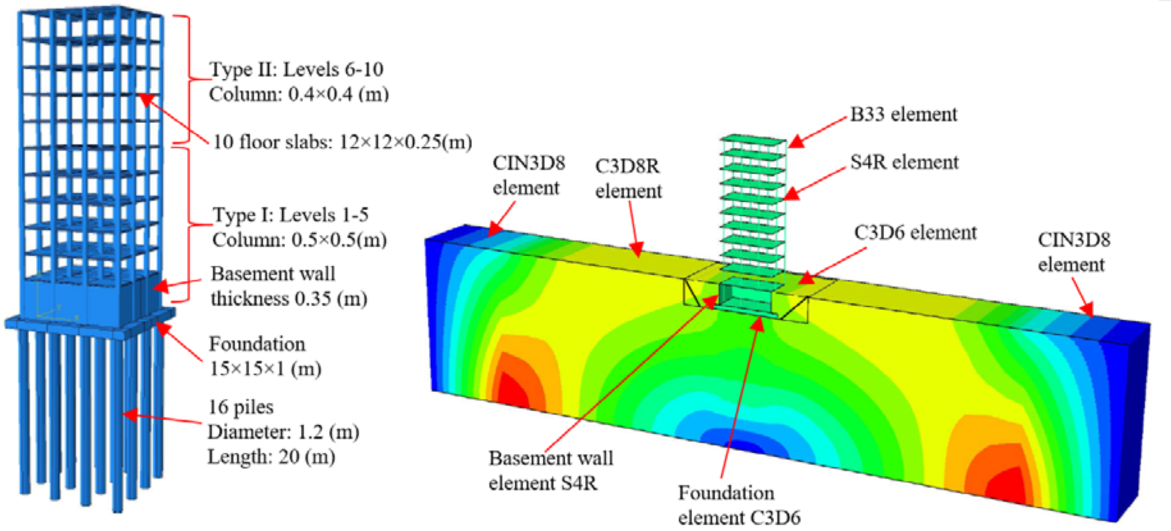

Fig. 5 The FEM of the structure and ground in the ABAQUS software program

(S4R: 4-node, quadrilateral, stress/displacement shell element with reduced integration), whereas the foundation and pile elements were modeled by solid elements (C3D6: 3D, 6-node linear triangular prism elements). Besides, the soil medium was modeled by using C3D8R elements (3D, 8- node linear brick, reduced integration, hourglass control elements), and C3D6 elements. The free-field soil columns were simulated by CIN3D8 elements with 3D, 8-node linear one-way infinite brick, but they have defined orientations, unlike the other numerical elements. A summary of all element types used in the FEM in this study is presented in Fig. 4. The FEM of the structure and soil medium is shown in Fig. 5.

3. RESULT AND DISCUSSION

3.1 Maximum Lateral Displacement and Inter-Story Drift

The maximum lateral displacement of the 10-story structure supported by the pile foundation under the 1968 Tokachi-Oki earthquake in each case as shown in Fig. 6. It is found that the maximum lateral displacement of the building in Case 2 (LSS) and Case 3 (LSS mixed with fiber) was smaller than Case 1 (Backfilling soil). On the other hand, there is no significant difference in displacement between Case 2 and Case 3. It is explained that this is due to the stiffness of LSS and LSS mixed with fiber are much larger than backfilling soil.

The maximum inter-story drifts of the building were calculated by the following equation [23], and the results were indicated in Fig. 7:

$$D_{rift} = (d_{i+1} - d_i)/h \tag{6}$$

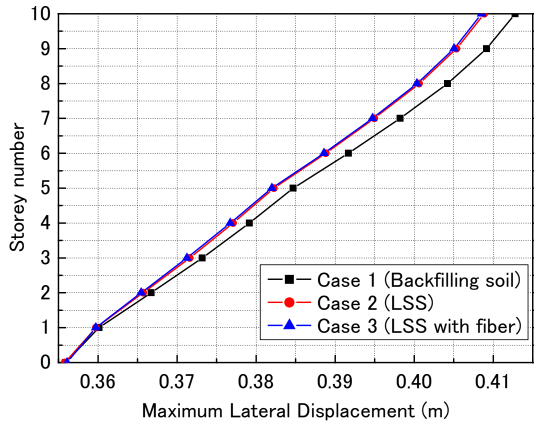

Fig. 6 Maximum lateral displacement of the 10-story structure supported by pile foundation under the 1968 Tokachi- Oki earthquake

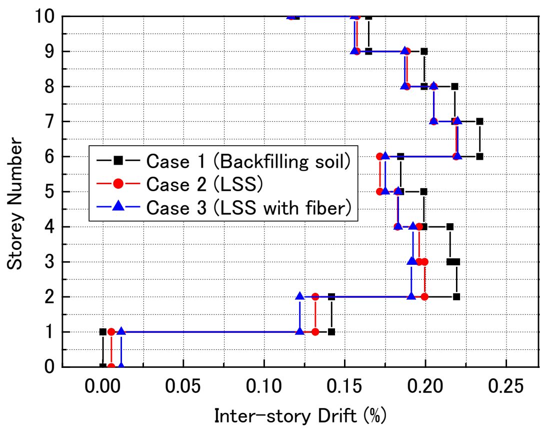

Fig. 7 The inter-story drift of the 10-story structure supported by pile foundation under the 1968 Tokachi – Oki earthquake

Where:
d_{i+1}: the deflection at the (i+1) level
d_i: the deflection at the (i) level
h: height of the story

Figure 7 shows that the inter-story drift of the building in Case 1 is the largest, followed by Case 2, and Case 3 is the smallest. It was found that when using LSS as a backfill material, the inter-story drift of the structure was reduced comparing to the backfilling soil. In particular, this figure also clearly shows the effect of fiber material, when mixed with LSS, will slightly reduce inter-story drift comparing with the case LSS without fiber.

Therefore, from the above results, it is seen that using LSS as a backfilling material will reduce the lateral displacement and inter-story drift of building under the earthquake. Moreover, in this study, LSS mixed with fiber has a little useful than LSS without fiber.

3.2 Relationship between Acceleration and Velocity with Distance

The maximum acceleration and velocity of 5 points A, B, C, D, and E in both the horizontal and vertical directions on the ground when affected by the earthquake are shown in Fig. 8 - 11, respectively. From the four figures above, we can see that the acceleration and velocity values at 5 points are almost the same for Case 2 and Case 3. It means that the benefits of fiber material, when mixed with LSS, are not made clear in this study. It is considered by the difference between the mechanical properties of LSS and LSS mixed with fiber material is very small compared to the case of a large load, especially as an earthquake, and happened in a very short time.

In contrast, there is a huge difference between Case 1 with Case 2 and Case 3. There is a significant decrease trend in acceleration and velocity when using LSS as a backfilling material compared to

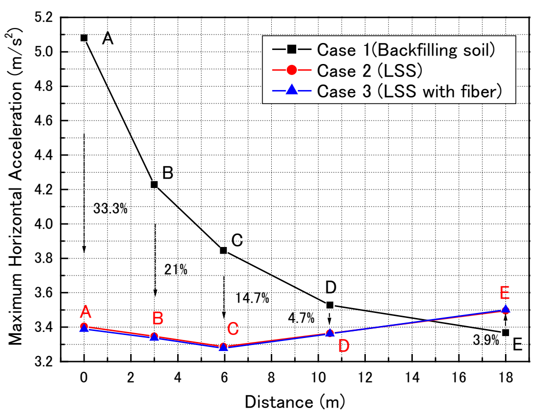

Fig. 8 Maximum horizontal acceleration at points A, B, C, D, and E

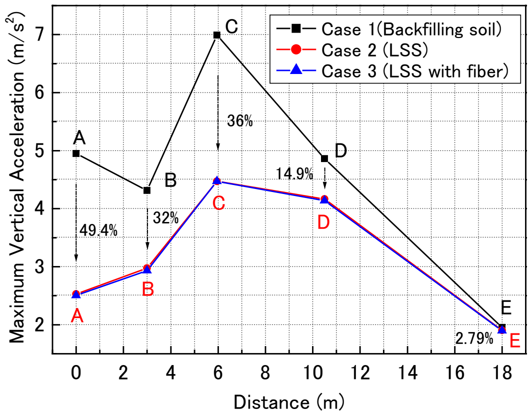

Fig.9 Maximum vertical acceleration at points A, B, C, D, and E

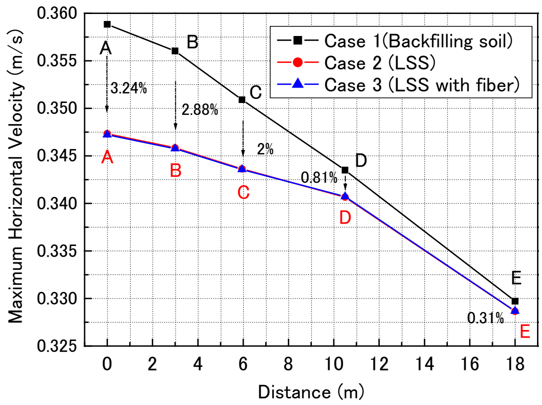

Fig. 10 Maximum horizontal velocity at points A, B, C, D, and E

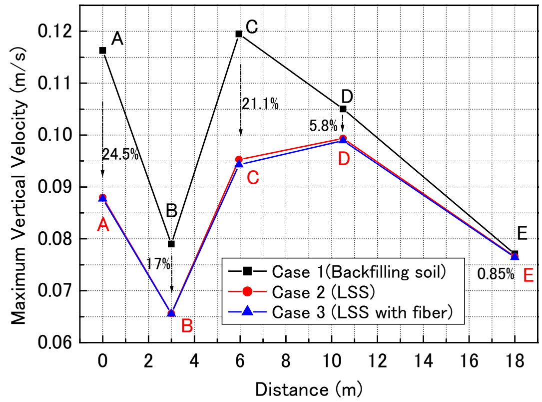

Fig. 11 Maximum vertical velocity at points A, B, C, D, and E

backfilling soil. Point A is the adjacent location to the construction, has the accelerating and speed with the highest reduction rate of 33.3 %, 49.4 %, 3.24 %, and 24.5 %, respectively. It is followed by points B, C, and D that have a decreasing rate of acceleration and velocity inversely proportional to distance. In particular, from Fig. 9 and Fig. 11, we can see that acceleration and velocity in the vertical direction at point B has a reduction ratio slightly lower than point C. It is explained that point C is a special point, where the junction between the two types of soil is LSS and soft clayey soil. Finally, the location has the 18 meters farthest distance from the building is the point E with almost no significant difference in the value of acceleration and velocity in the two cases of LSS and backfilling soil. It indicates that when using LSS as a backfill material will significantly reduce the acceleration and velocity of the ground around the building and the surrounding area when affected by the earthquake. It is considered by the fact that LSS has much higher stiffness and damping than backfilling soil.

Therefore, based on the above results, it is shown that the application of LSS as a backfill material will significantly reduce the acceleration and velocity of the ground around the building and adjacent areas.

4. CONCLUSION

To investigate the effect of using LSS as a backfilling material on the building and surrounding ground under an earthquake, the FEM of the structure and ground was simulated by the ABAQUS software program. After that, nonlinear time-domain dynamic analysis under the earthquake was conducted. The displacement and inter-story drift of the building and acceleration and velocity of the ground corresponding to each kind of backfilling material were compared. Based on the analysis results, the following conclusions were obtained.

1) Using LSS as a backfilling material will reduce the lateral displacement and inter-story drift of building under the impact of the earthquake.

2) The application of LSS as a backfill material will significantly reduce the acceleration and velocity of the ground around the building and adjacent areas.

3) The effect of fiber material, when mixed with LSS, was not noticeable in this study. LSS mixed with fiber has a little useful than LSS in comparing inter-story drift of building.

It is considered that the LSS has an effective potential to reduce the earthquakes on buildings and the surrounding soil environment. This property is a new advantage of LSS.

5. ACKNOWLEDGMENTS

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6. REFERENCES

[1] Kuno G., Liquefied stabilized soil method-Recycling technology of construction-generated soil and mud, Gihodo publication, 1997 (in Japanese).

[2] Kohata Y, Fujikawa T, Ichihara D, Kanda M and Murata, O., Strength and deformation properties of fibered material mixed in liquefied stabilized soil obtained from uniaxial compression test, Proc. of the 36th Japan National Conference on Geotechnical Engineering, 2002, pp.635-636 (in Japanese).

[3] Kohata Y and Tsushima H., Effect of fibered material mixing in liquefied stabilized soil on the triaxial shear characteristics, Proc. of the 39th Japan National Conference on Geotechnical Engineering, 2004, pp.721-722 (in Japanese).

[4] Kohata Y., The mechanical property of liquefied stabilized soil and future issues, Doboku Gakkai Ronbunshuu, F, 2006, Vol.62, No.4, pp.618-627 (in Japanese).

[5] Kohata Y, Ichikawa M, Nguyen C. G, and Kato Y., Study of damage characteristics of liquefied stabilized soil mixed with fibered material due to triaxial shearing, Geosynthetics Engineering Journal, 2007, Vol.22, pp.55-62 (in Japanese).

[6] Duong H. Q, Kohata Y, Omura S and Ozaki K., Strength and deformation characteristics of liquefied stabilized soil reinforced by fiber material prepared at laboratory and field, Geosynthetic Engineering Journal, 2014, Vol.29, pp.33-40.

[7] Duong H. Q, Kohata Y and Nguyen Q. D., Evaluation on Mitigation of Train-induced Vibration as Using LSS for Backfilling Ground of Cut and Cover Tunnel by FEM, the 50th Japan National Conference on Geotechnical Engineering, 2015, pp.2411-2412.

[8] Do T. A, Kohata, Y. and Sasaki, M., Effect of slurry density on triaxial compressive properties for liquefied stabilized soil reinforced with fiber material, Geosynthetics Engineering Journal, 2018, Vol.33, pp.15-22.

[9] Do T. A and Kohata Y., Reduction of vehicle-induced vibration using liquefied stabilized soil, International Journal of GEOMATE, 2019, Vol. 16, Issue 53, pp.44-46.

[10] Pham Q. V and Kohata Y., Various factors on the strength and deformation property of liquefied stabilized soil prepared at field, Lecture Notes in Civil Engineering, 2020, Vol. 62, pp.767-774.

[11] Cui Y, Kohata Y and Liu W., Influence of cement solidification agent and slurry density on mechanical property of liquefied stabilized soil, International Journal of GEOMATE, 2020, Vol. 19, Issue 73, pp.177-184.
[12] British standard., Eurocode 8: Design of structures for earthquake resistance, BS EN 1998-2004.
[13] SAP 2000 v22., Structural and earthquake engineering software, Computers and Structures, Inc, Berkley, CA.
[14] Ryan K. L and Polanco J., Problems with Rayleigh Damping in Base-Isolated Buildings. Journal of Structural Engineering, 2008, Vol. 134, Issue 11, pp.1780-1784.
[15] Chopra A. K., Dynamics of structures: Theory and applications to earthquake engineering, Fourth Edition, Prentice Hall, 2011, p.457.
[16] Rayhani M. H and Naggar M. H. EI., Numerical modeling of seismic response of rigid foundation on soft soil, International Journal of Geomechanics, 2008, Vol. 8, Issue 6, pp.336-346.
[17] Rahvar., Geotechnical investigation and foundation design report of Mahshahr train station, P. O. Rahvar Pty Ltd., Iran Railway Authority, Mahshar, Iran, 2006, pp.1-42.
[18] Kohata Y, Ito K, and Koyama Y., Effect of cement content on shear properties of liquid stabilized soil reinforced by fiber material, Geosynthetics Engineering Journal, 2011, Vol. 26, pp.95-100 (in Japanese).
[19] Railway Technical Research Institute., Explanation for railway structure and design standards, 1999.
[20] Kramer S. L., Geotechnical earthquake engineering, Prentice Hall, Upper Saddle River, NJ, 1996.
[21] Karamodin A.K. and Kazemi H. H., Semi-active control of structures using neuro-predictive algorithm for MR dampers, Structural Control and Health Monitoring, 2010, Vol. 17, Issue 3, pp.237-253.
[22] Abaqus 2020 [Computer software]. Dassault Systèmes SIMULIACorporation, Minneapolis.
[23] Standards Australia., Structural design actions-Part 4: Earthquake actions in Australia, AS1170.4, Sydney, Australia, 2007.