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REDUCTION OF VEHICLE-INDUCED VIBRATION USING LIQUEFIED STABILIZED SOIL

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ABSTRACT: Hanoi is the capital and second largest city in Vietnam. The process of urbanization poses numerous challenges to transportation systems such as traffic congestion and air pollution. The current situation calls for the development of comprehensive urban public transport systems. In addition, many urban areas and high-rise buildings have been constructed with high population density. On the other hand, the traffic-induced vibrations may cause structural damage and even failure and collapse of the structure. Therefore, the Liquefied Stabilized Soil (LSS) may be one of the effective methods to solve the problems.

In this study, a numerical investigation was performed to evaluate the reduction of the ground vibrations due to passing vehicles. Particularly, the finite element (FE) model of a two-dimensional soil-structure system is considered. The model includes the cross-section of a route, the foundation ground, the backfill material, a nearby building with eight floors and one basement. The analysis results show that the using of LSS as backfilling material can reduce the ground vibration caused by passing vehicles.

Keywords: Liquefied stabilized soil, Cyclic loading, FE analysis, Ground vibrations

1. INTRODUCTION

Vietnamese government had the plan that Hanoi's transport plan aims to increase the share of public transport from the current low figure of 9 % of trips to above 60 % by 2030, by which time Hanoi city is slated to have six new metro and three Bus Rapid Transit (BRT) lines. Vietnamese government hopes both traffic and environmental issues can be tackled. It is forecasted that a huge quantity of excavated soil will be discharged from the projects in Hanoi city over the next decade. Therefore, it will become more and more difficult to find reclamation sites for the soil to dump around the city from an environmental point of view. In Japan, LSS is an effective backfilling method for using excavated soil in construction work [1] and LSS has been popular as a recycling method for excavated soil. However, LSS indicates a brittle characteristic when the strength increments as increasing an amount of cement stabilizer. In order to improve the ductile performance of LSS, a reinforcement method has been created by mixing newspaper as a fiber material into LSS [2]-[6].

LSS was produced by adding and mixing cement stabilizer into the liquefied stabilized soil with a hand mixer. In the production process, the determination of the density was performed by measuring the mass of slurry filled into a stainless steel mold of 400 cm^3 called "AE mortar container". In order to determine the fluidity of LSS, the flow test was performed in accordance with JHS A313–Japan Highway Public Corporation Standard. Moreover, the fresh LSS is made to be removed air from inside specimen applying vacuum. However, an investigation of the reduction of vehicle-induced ground vibration by using LSS has not been performed.

In this study, the investigation focuses on the effect of using LSS for reduction of nearby building responses based on a parametric study directly in the time domain. Two cases (i.e. the use of backfilling soil and LSS) for backfill ground of building towards Giai Phong road, Dong Da district in Hanoi city were evaluated by using the numerical analyses procedure.

2. ANALYSIS PROCEDURE

2.1 Definition of Vibration Level

The vibration levels are estimated from three parameters as the displacement, the velocity, and the acceleration.

In Vietnam, vibration velocity is used to estimate the level as an applied standard. The abbreviation "VdB" is used for vibration decibels to reduce the potential for confusion with sound decibels [7]. Accordingly, the maximum vibration level is calculated as follows [8]:

$$L = \max(L_i) \le [L]\ [VdB] \quad (1)$$

Where:

$$L_i = 20\log_{10}\frac{v_i}{v_{ref}}\ [VdB] \quad (2)$$

$$v_i = \sqrt{\frac{1}{(t_2-t_1)f_{SP}}\sum_n v_n^2}\ \ [m/s] \quad (3)$$

$$v_n = \sqrt{v_{xn}^2 + v_{yn}^2}\ \ [m/s] \quad (4)$$

L: Maximum vibration level
L_i : Vibration level at interval time of i^{th} one-second
[L]: Criteria level acceptable level of vibration
v_i: Square root of mean vibration velocity at i^{th} one-second
v_{ref}: Reference vibration velocity
$v_{ref} = 5 * 10^{-8}$ m/s [8]
$t_2 - t_1 = 1s$ [7]-[9]
f_{SP} : Number of measured velocity within one-second
v_{xn}, v_{yn}, v_n : n^{th} Horizontal, vertical, and total vibration velocity at the measurement point

According to Russian standard being used in Vietnam at present, the vibration prediction for the building is assessed from the value of velocity at top of foundation [8]. Therefore, the velocity value at the ground surface is used to predict the vibration.

National Technical Regulation on Vibration has been popularized by Natural Resources and Environment in 2010 [10]. The regulation gives criteria for acceptable levels of ground-borne vibration from any source such as trains, buses on rough roads, and constructions activities, blasting, pile-driving and operating heavy earth-moving equipment for residence. The maximum permissible level of vibration is assigned to be 75 VdB. The value is also found in reports of Japan. It is reported on Japanese study that many people will find the vibration annoying at a vibration velocity level of 75 to 80 VdB [11].

2.2 Simulation of the Cyclic Load

In this paper, the investigation focuses on the effect of using LSS for the reduction of nearby building responses through a parametric study. The cyclic load by the vehicle on road pavement was directly considered in the mathematical modeling and analysis. Some details are given in references [12]-[17]. Therefore, as differences from others, the cyclic vehicle load is automatically taken into account and the effect of LSS is evaluated directly. Responses of the building and backfilling materials are given in terms of accelerations.

In this study, vertical vibrations can be produced during moving vehicles on the rough surface of the roads, thereby the transmitting of the inertial force is associated with the vibration through the suspension system and wheels into the pavement. This study was analyzed under 400 kN/m in moving load of vehicles and 10 Hz in frequency when the cyclic load is applied to the pavement on the truck with a speed of 60 km/h [12]-[17].

2.3 Numerical Model and Parameters

In this study, a reinforced concrete eight-floor building frame with one basement was selected and the model is shown in Fig.1.

2.3.1 Building, road and ground conditions

The building of 12 m in width and 24 m in height is located to the right-hand side of the road. The structure shown in Fig.1 is a part of the building that is formed by a series of parallel frames. The height of the floors is 3 m and the basement floor is located at a depth of 4.5 m below ground surface. The frame consists of three bays of 4 m of distance. The distance from the left end side of the building to the right end of the road was assumed to be 15.5 m. The pile foundation is selected to analyze in this study. The excavated area shown as “Backfilling material” in Fig.1 was set to 4.5 m in depth equal to the height of basement floor and 10 m in width, which is considered to be reduced a vehicle-induced building vibration from the previous study [18]. In this study, backfilling soils as Case 1 and LSS as Case 2 were selected as backfilling materials, and the reducing effect of vehicle-induced vibration is discussed. The ground profile of the construction area is schematically shown in Fig.2. The geotechnical properties of soil layers are shown in Table 1. The ground was composed of soft clay and loose sand from the surface to the depth of 30-40 m, and of dense sand or gravel below the depth of 30-40 m.

The damping ratio of soil layers, which is in the range of 3-8 %, is assumed to be 4 %. The vibration level of the ground is not significantly changed [19]. Also, most soil types in Hanoi city area have the damping ratio in a range of 3-5 % [20]. Poisson's ratio of all soil layers and the backfilling materials were assumed to be 0.49 [18]. The shear elastic wave velocity of ground was calculated from N-

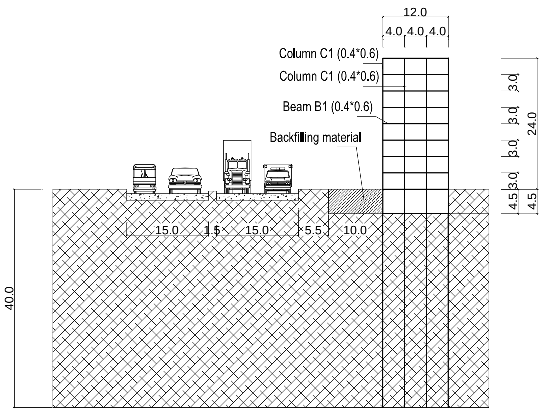

Fig.1 Numerical model of the considered soil structure system

Table 1 Geotechnical properties of soil layers

Depth (m)	Thickness (m)	Kind	Average N	ν	ρ (kN/m³)	G (MN/m²)	V_s (m/s)
2.2	2.2	Sand	9.3	0.49	17	48.921	168
9.5	7.3	Clay	9.3	0.49	15	67.447	210
14.1	4.6	Clay	4.5	0.49	15	41.72	165
25.8	11.7	Clay	9.5	0.49	15	68.656	212
37.8	12	Sand	40.7	0.49	19	146.735	275
50	12.2	Sand	98.3	0.49	20	278.103	369

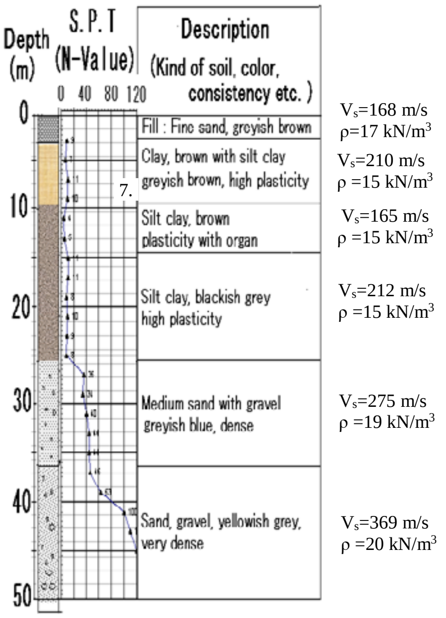

Fig.2 Ground profile

value, using the formula of Japanese railway standard [21]. The parameters of the building are shown in Table 2.

Fig. 3 shows a typical cross-section of Giai Phong road where the total thickness of the road embankment is 1.2 m. The thickness of subgrade soil is 0.4 m, sub-base layer is 0.4 m, the base layer is 0.3 m and asphalt concrete is 0.1 m, respectively. The total width of the road is 38 m, in which 30 m for traffic including two lanes and 8 m for the sidewalk. This road is one of the main roads in Hanoi city and it is the main connection road from Hanoi to the north-south highway of Vietnam. Material parameters and constitutive model are shown in Table 3.

2.3.2 Characteristics of backfilling materials

In this study, the properties of backfilling materials i.e. LSS and backfilling soil for the analysis model in Plaxis were adopted from the previous research [18].

The preparation and properties of LSS are as follows.

The original material was Vinhphuc clay taken

Table 2 Parameters of building

Components	ρ (kN/m³)	Elastic modulus (MN/m²)	ν
Piles	25	3500	0.15
Basement	25	3500	0.15
Columns and beams	25	2500	0.2

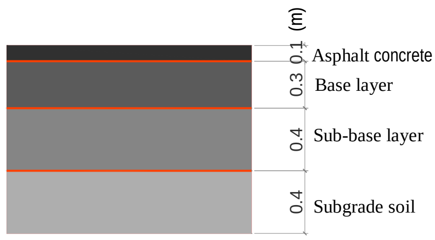

Fig.3 Typical cross section of Giai Phong road

from a construction site in Hanoi city. The soil is classified into low liquid limit clay [18]. Geoset 10 made by Taiheiyo Cement Co. was used as cement stabilizer.

Based on results of flow and bleeding tests and unconfined compression tests on samples with curing at 28 days, the content of cement stabilizer was assigned to be 200 kg/m³ and the target slurry density of LSS was 1.350 g/cm³.

The initial Young's modulus of LSS, E_0 = 58.8 MN/m² in case of confining pressure of 49 kPa, unit weight, ρ = 14.0 kN/m³ and shear modulus, G = 197.2 MN/m² were set as the basic properties of LSS. The damping ratio of LSS is assumed as 10 % [18].

On the other hand, Properties of backfilling soil is considered as follows.

As there are not much investigation results on the stiffness of the backfilling soil, the investigation results on backfilling soil (decomposed granite soil, which is "Masado") in Daikai station, which suffered from the Southern Hyogo prefecture earthquake in 1995, were used as the soil parameters. N value and unit weight, ρ was set at 10 and 17.0 kN/m³, respectively. Shear modulus, G = 51.531 MN/m² was estimated from N value in

Table 3 Material properties of road

Material	Unit	Asphalt concrete	Base (Crushed stone)	Sub-base (Crushed stone)	Sub-grade (Sand)
Constitutive model		Linear elastic	Mohr-Coulomb	Mohr-Coulomb	Mohr-Coulomb
Thickness	m	0.1	0.3	0.4	0.4
Young's modulus	MN/m^2	$2.1x10^3$	$1.2x10^2$	49	24
Poisson' ratio	-	0.45	0.35	0.3	0.3
Dry density	kN/m^3	20	20	18	17
Saturated density	kN/m^3		22	20	18
Cohesion	kN/m^2		30	20	0
Friction angle	Degree		43	40	35
Dilatation angle	Degree		13	14	5
Coefficient of Horizontal permeability	-		1	1	1
Coefficient of Vertical permeability	-		1	1	1

accordance with Railway Design Standard [21].The damping ratio of this material was assumed as 4 %. The physical properties of two backfilling materials are shown in Table 4.

2.3.3 Finite element model

The finite element model (FEM) is plotted in Fig.4. The FEM is divided into two parts. The first part is a domain including the source of the wave, i.e., road and soil layers. The second part consists of the building frame elements [22].

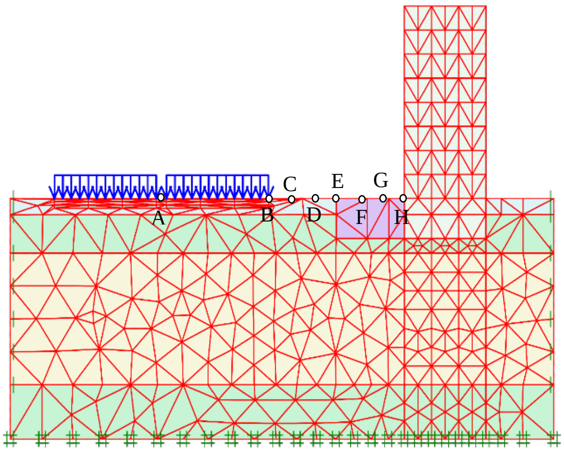

Fig.4 Finite element model in Plaxis

Table 4 Physical properties of backfilling materials

Backfilling material	V_s (m/s)	ρ (kN/m^3)	h (%)	ν
Case 1: backfilling soil	172	17	4	0.49
Case 2: LSS	370	14	10	0.49

Eight analyzed points on the ground surface A, B, C, D, E, F, G, H with distances of 0, 15, 17.583, 20.166, 22.749, 25.332, 27.914, 30.5m respectively from the origin of coordinate (center line of the road on the ground surface) are shown in Fig.4.

2.3.4 Numerical model in Plaxis program

In this study, a 2D model of the road, building, surrounding soil and cyclic loading of vehicles on the road with the use of Plaxis V8.6 finite element software is introduced in order to evaluate vibration propagation due to the passing of vehicles to the ground surface.

In the model, 15-node triangular elements were used infinite element mesh. For determining the optimum size of the element in order to get the reasonable precise result in a minimized time, four different meshing patterns were analyzed and the results of the analysis with very fine and fine meshing were very close to each other, therefore, fine meshing pattern was chosen as Fig.4.

The analysis is performed to determine responses of the backfilling area and the building due to applied vehicle loading. Therefore, the building frame is supported to be subjected to the static loading of the usual dwelling, which is no consideration in this analysis.

3. RESULTS AND DISCUSSION

3.1 Vibration acceleration in Case 1 and Case 2

In this study, vibration analysis using time domain methods was performed. The effect of LSS for reduction of vibration under cyclic loading of vehicles are evaluated. Therefore, the acceleration is described in points E and H to determine

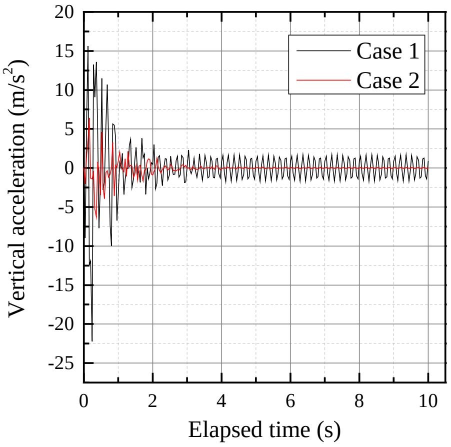

Fig.5 Vertical acceleration at point E for load amplitude =400 kN/m, f = 10 Hz

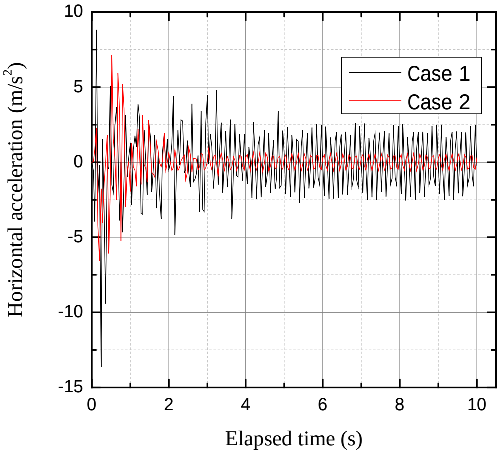

Fig.6 Horizontal acceleration at point E for load amplitude =400 kN/m, f = 10 Hz

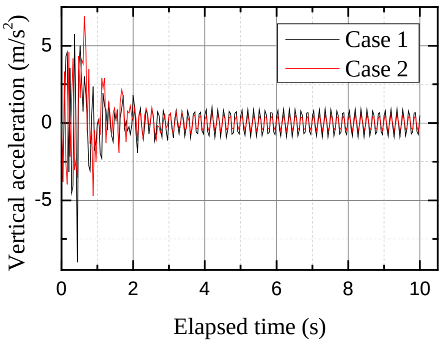

Fig.7 Vertical acceleration at point H for load amplitude =400 kN/m, f = 10 Hz

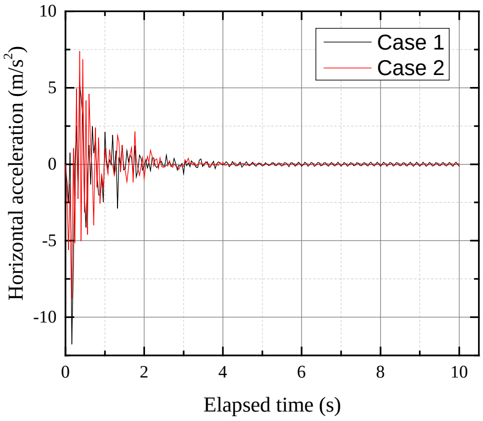

Fig.8 Horizontal acceleration at point H for load amplitude =400 kN/m, f = 10 Hz

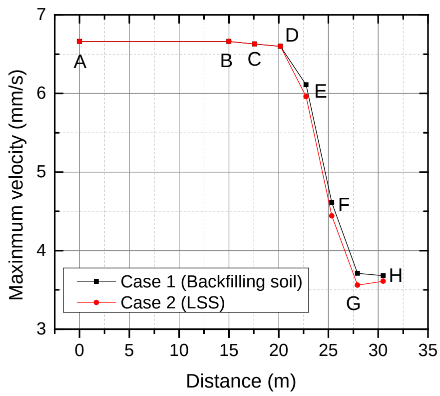

Fig.9 Distance and maximum velocity

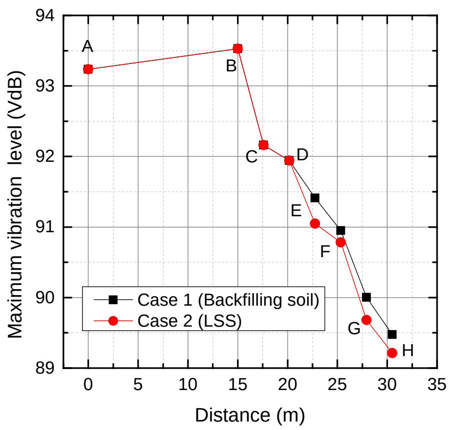

Fig.10 Distance and maximum vibration level

responses of backfilling materials due to cyclic loading.

Fig. 5 shows the graph of vertical vibration acceleration at point E for both cases using the backfilling material of backfilling soil (Case 1) and LSS (Case 2), respectively. It can be seen that the amplitude of the vertical vibration acceleration at point E in Case 2 is significantly lower than that in Case 1. One of the most important reasons for this difference in the amplitude between Case 1 and Case 2 is the stiffness of which LSS is much larger than backfilling soil. Moreover, it can be seen observed that vertical vibration acceleration in Case 2 is damped more quickly than that in Case 1.

The horizontal vibration time histories at point

E for Case 1 and Case 2 are shown in Fig.6. The figure indicates a considerable reduction in the acceleration amplitudes that achieve about 50 % for LSS.

In Fig.7, the time histories of the vertical acceleration at point H are described. Point H is the boundary point between the backfilling area and the building. Analysis of vibration at point H plays an important role not only for the backfilling area but also for the building. Therefore, the effects of reduction of backfilling materials are considered. In the figure, the reduction of the case of backfilling soil is compared with LSS. Although there is only a little difference in the vertical vibration accelerations in two cases, the results show the reduction of LSS more useful than backfilling soil.

Fig. 8 shows the horizontal acceleration time histories at point H. It can be noticed that the acceleration amplitudes in the case of LSS are larger than amplitudes in the case of backfilling soil.

3.2 Relationship between distance maximum vibration velocity and level

From eight analyzed points on the ground surface from A to H in Fig.4, it can be seen that ground conditions at points A~D are the same for Case1 and Case 2. Therefore, the level of vibration and velocity at these points are the same for both cases. In this study, the levels of vibration and velocity of points E-H are analyzed.

Fig. 9 shows the relationship between distance and maximum vibration velocity with the vehicle speed of 60 km/h. Although the amplitude of the vibration velocity in two cases is a notable difference, the amplitude of the vibration velocity in Case 1 is slightly larger than that in Case 2.

The relationship between distance and maximum vibration level is shown in Fig.10. It can be seen that the level of vibration rapidly decreases with distance from the center of the road for both cases. Moreover, in the backfilling area, at each point, the level of vibration in Case 2 is lower than that in Case 1. According to the figures, the effect of LSS on vibration reduction can be observed apparently.

4. CONCLUSIONS

This study focused on the utilization of backfilling soil and LSS as backfilling material, the reducing effect of ground vibration was discussed. The ground vibration properties were investigated by using the numerical analysis. The model of the vehicle body has been improved which is modeled as a system of two degrees of freedoms (2-DOFs) with consideration of primary and secondary suspension elements established in the previous study. The results of the model in term of the load time history can be input data for the numerical model in the solution of the road-soil interaction problem and then prediction of vehicle-induced ground vibration. Based on the analysis results, the conclusions were obtained as follows:

1) The LSS indicated significantly better reducing the effect of ground vibration induced by cyclic loading of vehicles on road due to its larger stiffness compared with the backfilling soil.
2) The vibration level of the LSS is lower than that of the backfilling soil at the points (E~H).
3) The vibration level is strongest affected by the vehicle-induced vibration at the points (A and B) near the center of the road on the ground surface independent of the backfilling material.

It is considered that LSS has an effective potential as the countermeasure against vehicle-induced vibration on the road. This property was pointed out as a new advantage of LSS.

5. ACKNOWLEDGMENTS

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