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The Vibration Impact to Slope Deformation on Soils Potentially Liquefactions

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Abstract. In an area that has potential for earthquake has possibility of losing soil stability and causing physical soil damage, one of them is liquefaction. This research was conducted to determine the magnitude of deformation on slopes with potentially liquefaction. The soil slope samples were tested using shaking table with various slope and frequency was set. Research began with soil physical properties had unit weight of density 1.81 gr/cm^3, moisture content 2.31%, specific gravity 2.72, sand properties with Cu is 2.1, Cc is 0.98 and φ is 23.962°. By giving certain earthquake acceleration in the soil slope sample that was tested by shaking table, it was liquefaction occurred. Results of research, the greater slope and frequency given, so the lateral and axial deformation will increase. Minimum lateral deformation occurs at frequency 6.6 Hz with a slope 6° and maximum lateral deformation is 17 cm at frequency 9.5 Hz with slope 24°, while minimum axial deformation is 0.5 cm at frequency 8 Hz with slope 6° and maximum axial deformation is 5 cm at frequency 9.5 Hz with a slope 24°, but 12-degree slope can consider as a safe slope for slope which holding vibration.

Keywords: deformation, frequency, liquefaction, slope

1. Introduction

Liquefaction can cause underground pipes due to buoyant forces to come to the surface (lifeline damage) and heavy structures to sink into the soil. The Great East Japan Earthquake caused liquefaction over a wide area from Tohoku to Kanto, where Tokyo is located, and when the earthquake stopped underground water burst up over the ground with soil grains, a phenomenon called jetted sand. Jetted sand caused serious damage to houses, underground pipes, roads, and river levees. Liquefaction-caused damage was larger in Kanto than in Tohoku. We need to apply the lessons about liquefaction from the Great East Japan Earthquake to prevent serious damage in future earthquakes [1]. Liquefaction is a process of changing the condition of the saturated sand soil to liquid, caused by a cyclic load at the time of the earthquake so that the moisture pressure increased close to even throw effective stress of the soil. The risks that can be inflicted by the liquidation in the event of an earthquake is a loss of bearing capacity

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and settlement. In the event of soil liquefaction phenomenon, it can be deformation due to shock. Lateral movements of the ground surface or slope of embankment can be damage to other infrastructure.

Previous studies mention that Earthquake-induced landslides are among the most destructive slope movements, not only because of their size and magnitude, but also because of the synergistic action with the earthquake the consequences are higher, due to the earthquake shaking and the landslide effect. Studies on landslides triggered by seismic activities are not as extensive as rainfall-induced landslides. In this study, a quantitative risk analysis approach was used to calculate the risk for people exposed to the threat of earthquake-induced landslide in Emamzadeh Ali, north of Iran [2].

Recent experiments show that clean sands do not behave similarly to silty sands. Tests on loose, silty sand indicate a ''reverse'' behaviour with respect to confining pressure and this violates the basic assumption that loose, silty sands behave similarly to loose, clean sands. Strong correlations between fines content, compressibility, and liquefaction potential are often found for these soils. A procedure for the analysis and evaluation of static liquefaction of slopes of fine sand and silt, such as submarine slopes, mine tailings, and spoil heaps, is presented [3].

The research became important to know, because many of the phenomena of structural failures on the granular soil that occurred during earthquakes, as had been occurred some areas in Indonesia. This research was conducted to determine the magnitude of deformation on slopes with potentially liquefaction soils.

2. Material and Methods

The soil samples in this study were taken at Bandulu Beach, Cinangka Banten Provence at 2018 as seen on Figure 1. The soils sample is disturbed sample (soils sample taken freely without protecting its original nature from the location that used to be a study place), and then tested in the laboratory include of soil physical properties which had unit weight of density, moisture content, specific gravity, coefficient of uniform, coefficient curvature obtained through a sieve analysis test and angle of repose obtained through Triaxial test.

The research methods used are experimental research, which goal is to know the consequences of a treatment given intentionally by researcher. In general, the methodology is used starting from determining the location of research; Data collection through experiment in laboratory and literary studies; and data analysis.

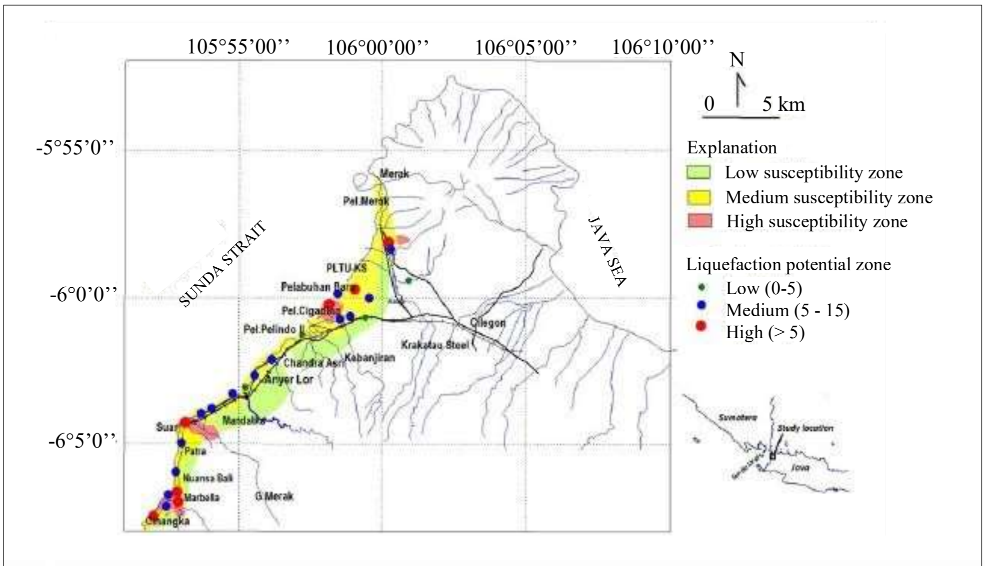

Figure 1. Map of Micro Zonation for liquidity vulnerability of Merak – Anyer
Source: Eko Soebowo, LIPI, 2016 [4]

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Based on the Figure 1. it can be seen that on beach Bandulu-Cinangka is located in a moderate vulnerability zone which allows for liquefaction and also indicated by high value of Liquefaction Potential Index (LPI), in the laboratory carried out soil physical testing and shaking table test with frequency to slope as variable. Soil sample testing consists of physical properties which include specific gravity, water contents, bulk density, sieve analysis and angle of repose as the size of the parameters to be used in the analysis. On the Table 1. below result of soil properties.

Table 1. Soil properties

Soil Properties	Symbol	Value	Unity
Bulk density	γ	1.81	gr/cm^3
Water content	W	2.31	%
Dry density	γ_d	1.77	gr/cm^3
Saturated density	γ_{sat}	1.98	gr/cm^3
Specific gravity	G	2.72	
Size particles:			
D_{10}		0.09	mm
D_{30}		0.13	mm
D_{60}		0.19	mm
Coefficient of Uniform	Cu	2.10	
Coefficient of Curvature	Cc	0.98	
Angle of repose	φ	23.96	degree

2.1. Regulation of Land Acquisition for Development of Public Interest

The earthquake was a great shock that spread to the surface of the earth caused by disruption in the lithosphere. This disorder occurs because inside the layer of the Earth's skin with a thickness of 100 km. The energy accumulation occurs due to the shifting of the skin of the Earth itself [5].

2.2. Total Normal Pressure

The normal pressure total is a multiplication of the weight of soils volume with the depth of the point being tested. By not taking into account the influence of water, the equations are as follows:[6].

$$\sigma = \gamma_t Z \tag{1}$$

Where,

σ = normal pressure (gram/cm^2)
γ_t = bulk density of soils (gram/cm^3)
Z = depth (cm)

2.3. Effective Stress

Effective stress is the stress in the soil that is influenced by the forces of the water contained in the soil. Applied to the soil that is saturated and associated with two stresses, namely the normal total stress (σ) and water pressure pore (u). The equations are as follows:[6].

$$\sigma' = \sigma - u$$
$$\sigma' = \gamma_{sat} z - \gamma_w H_w \tag{2}$$

Where,

σ' = effective pressure (gram/cm^2)
γ_w = bulk density of water (gram/cm^3)
γ_{sat} = bulk density of saturate (gram/cm^3)
Z = depth (cm)
H_w = depth of the point being reviewed to the groundwater (cm)

2.4. Angle of Repose

Karl Terzaghi defines that the angle of repose as an inner sliding angle obtained from extreme conditions (loose/looser state). In addition, it can be defined as the maximum slope angle where the soils are almost unstable. According to the Coulomb theory the angle of repose is brought to a close as the arctan of the maximum static friction coefficient [7].

2.5. Liquefaction

According to Marcuson [8] the liquefaction is defined as a granular material transformation from solid to liquid form as a result of rising pore water pressure and effective stress loss. Rising water pressure of pores is caused by the tendency of granular material to become dense due to cyclic shear deformations.

According to Seed et. al states that the liquidation is the process of changing the condition of a water saturated sand to liquid due to the increasing water pressure of the pore which is the same value as the total pressure by the cause of dynamic load, so that the effective stress of the soil to zero [9].

2.6. Mechanism of Liquefaction

The soil is essentially a collection of many soil particles or soil grains that have interconnection details. The cohesion is generated from the weight of the particles that are above the other grains that hold each particle to remain in position and provide strength to the ground. As a result of the cyclic load such as the earthquake, the soil structure on the saturated and loose sand will be destroyed and the sand's constituent particles will move and tend to form a denser configuration.

However, the water on the pores of the soil does not drain out and get trapped. As a result, the soils particles cannot move and close to form a denser configuration. Thus, the increase in pore water pressure will reduce the cohesion between soil particles causing the soil to lose strength [10].The change of solid nature to the liquid properties that occur in saturated sand is caused by increased pore water pressure and effective stress reduction. Effective stress equation [11].

$$\sigma_{eff} = \sigma_{tot} - u \tag{3}$$

where,

σ_{eff} = actual stress working on the soil grain (kg/cm^2);

σ_{tot} = stress due to the loading (kg/cm^2); and

u = porewater pressure (kg/cm^2).

2.7. Geotechnical Modelling

Modeling is a necessity in geotechnical engineering. Modeling is useful for conducting research in laboratories where we can model the original scale into scale model so that we do not need to make models according to natural existing conditions. In this modeling can use the same material as the location of the field. The scale (n) is the ratio or comparison between the values of each parameter that is in the model with the one in the field [12].

$$n = \frac{value\ in\ the\ field}{value\ in\ the\ model} \tag{4}$$

Table 2. Scale rule for dynamic models

Parameter	Model/Prototype
Length	1/N
Area	$1/N^2$
Volume	$1/N^3$
Stress	1
Strain	1
Mass	$1/N^3$

Note: N = scale factor [13].

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2.8. Deformation

According to Kuang deformation is a change in form, position and dimension of an object. Based on that definition the deformation can be interpreted as a change of position or movement of a point on one object [11].

2.9. Shaking Table

Shaking table research has provided valuable insight into the liquefaction, post-earthquake settlements and lateral soil pressure issues. For models used in shaking tables, the soil can be placed, compacted and instrumented relatively easily [15].

The concept of testing using a shaking table is to analyze the movement of one of the earthquake waves, shear waves [16].

$$A_{(max)} = (2\,\pi\, f)^2\, r \tag{4}$$

$$f = \sqrt{\frac{A_{max}}{(2\,\pi)^2\, r}} \tag{5}$$

3. Result and Discussion

Soil sample testing consists of physical properties which include specific gravity, water content, bulk density, sieve analysis and angle of repose as the size of the parameters to be used in the analysis.

3.1. Test Result with α = 24° and Frequency 9.5 Hz (0.7g)

The Shaking table test was done for 32 seconds. Water pore pressure experienced a significant increase after the earthquake load was administered. In the 1st Piezometer tool, there is no reading because it is enclosed by ground slope. In the 1st minute pore water pressure increased by 1.10 gr/cm^2, then the water pressure of the pore in each of the tools in the 19th second had an increase of 3.00 gr/cm^2. The 10th second to 32th seconds is the time span or range when soils liquefaction occurs.

Based on the analysis shown in Figure 2. in the 10th seconds the water pores pressure on the 2nd and 3rd Piezometer tools reach 2.00 gr/cm^2 and the effective stress reaches 0 gr/cm^2. Effective stress that has reached 0 gr/cm^2 (or minus) is an indication of the occurrence of the liquefaction. But at piezometer #1 is unreadable because it is obstructed by slopes, meaning the pore pressure is still small. In the Figure 2. show the dash red line as indication of limit between safe zone and liquefaction zone, under red line is liquefaction zone. This shows that the occurrence of liquefaction is only a few seconds after the vibration, the experiment's value show that is around 10 seconds.

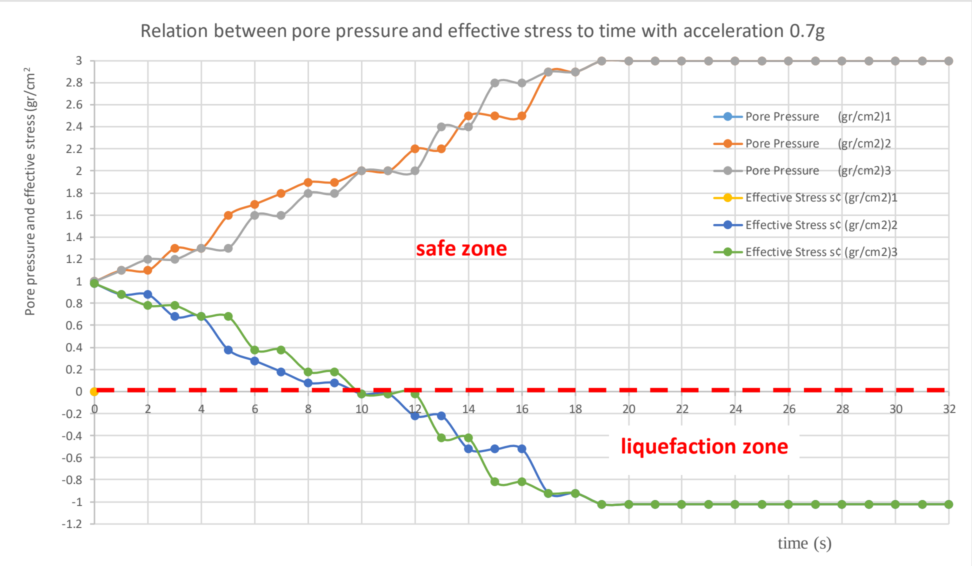
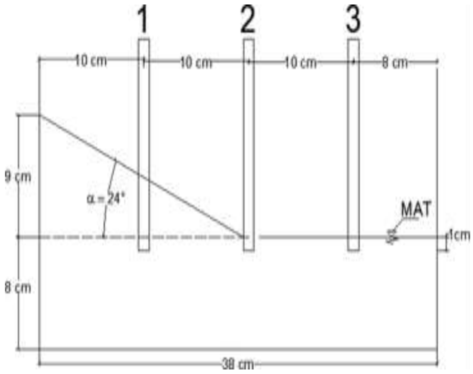
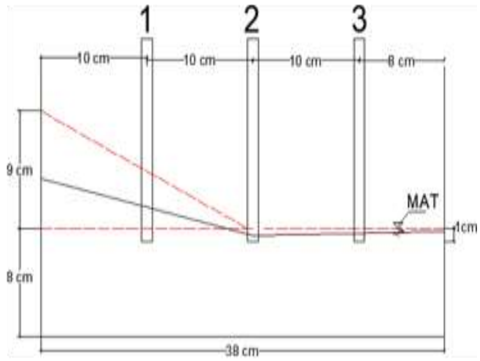


Figure 2. Water pressure pore and effective stress in time with acceleration 0.7 g



(a)



(b)

Figure 3. Installation piezometer and Shaking Table (a) before and (b) after testing

The Figure 3. the model before and after testing with soil before it was given an earthquake load could withstand the above slope. Then after given the earthquake load the slope occurs a settlement of 5 cm on the 1st piezometer area, 0.50 cm on the 2nd piezometer and 0.20 cm on the 3rd piezometer. In addition to the settlement, the ground slope on the model also occurs an avalanche of 17.00 cm due to the soil that is under the slope occurs liquefaction.

3.2. Relation between soil slope (α) with Effective Stress (σ')

The Figure 4. is a graph of the slope relationship to effective stress that is averaged and is taken most on every frequency and then plotted on the chart of the shaking table test result.

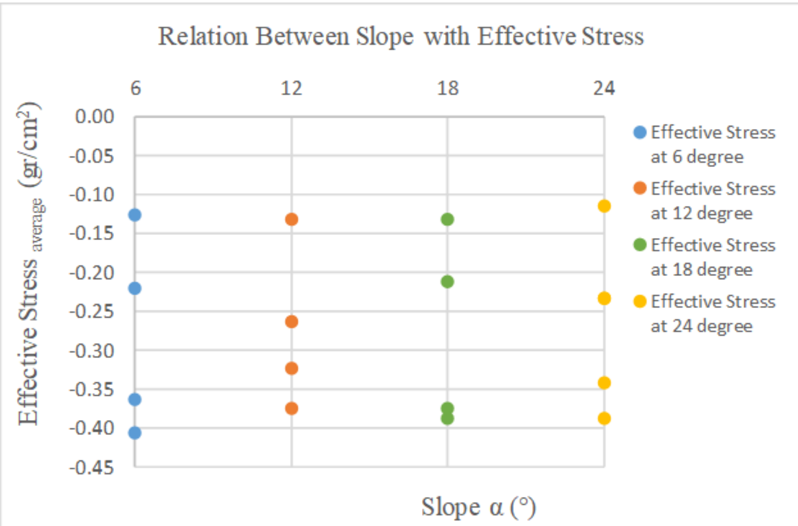


Figure 4. Relation slope with effective stress

Figure 4. provides that information on each slope has different effective stress, due to the influence of pore water pressure and frequency on the model. The greater frequency given the greater water pressure of the pores occurring, resulting in a smaller effective stress. While the slope has no effect on the liquefaction, because the liquefaction that occurs under the slope.

3.3. Relationship frequency and earthquake acceleration to deformation

On the chart of the frequency relations and the acceleration of the earthquake to the deformation obtained from the shaking table with a tilt of 6°, 12°, 18° and 24° then given earthquake acceleration 0, 4g; 0.5g; 0.6g and 0.7g with a frequency of 6.60 Hz; 7.40 Hz; 8.00 Hz and 9.50 Hz.

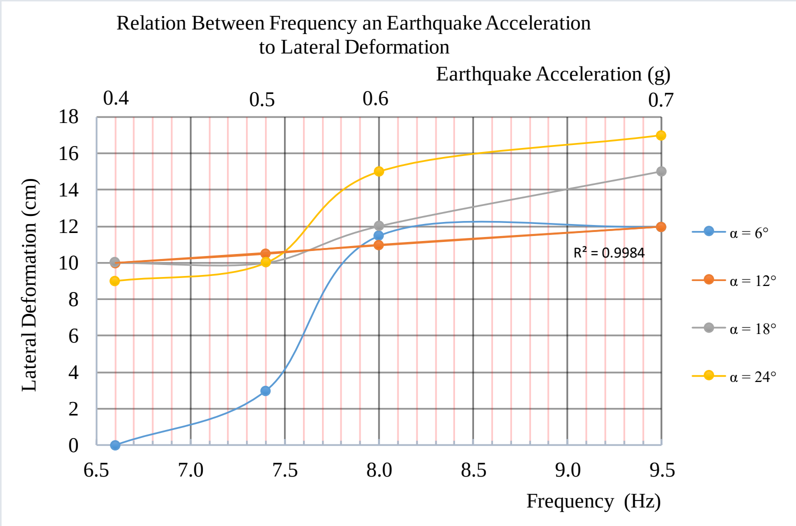


Figure 5. Frequency relations and earthquake acceleration against lateral deformation

Based on the Figure 5. at each given frequency produces different lateral deformations. At a slope of 6° when frequency 6.6 Hz does not occur lateral deformation, but when increased its frequency to 7.4 Hz, 8.0 Hz and 9.5 Hz There is a lateral deformation of 3.0 cm, 11.5 cm and 12.0 cm. After that at a slope of 12° with a frequency of 6.6 Hz of lateral deformation that occurs by 10.00 cm, frequency 7.4 Hz, 8 Hz and 9.5 Hz lateral deformation that occurs at 10.5 cm, 11.0 cm and 12.0 cm. Further testing is done with a slope of 8°, the frequency given is 6.6 Hz, 7.4 Hz, 8 Hz and 9.5 The lateral deformation is 10.0 cm, 10.0 cm, 12.0 cm, and 15.0 cm. Then at a slope of 24° with the same frequency of lateral deformations that occur that is 9.0 cm, 10.0 cm, 15.0 cm and 17.0 cm. At a slope inclination 12° lateral deformation tends to be linier with changes frequency, meaning that the safe slope of lateral deformation on the slope is about 12 degrees.

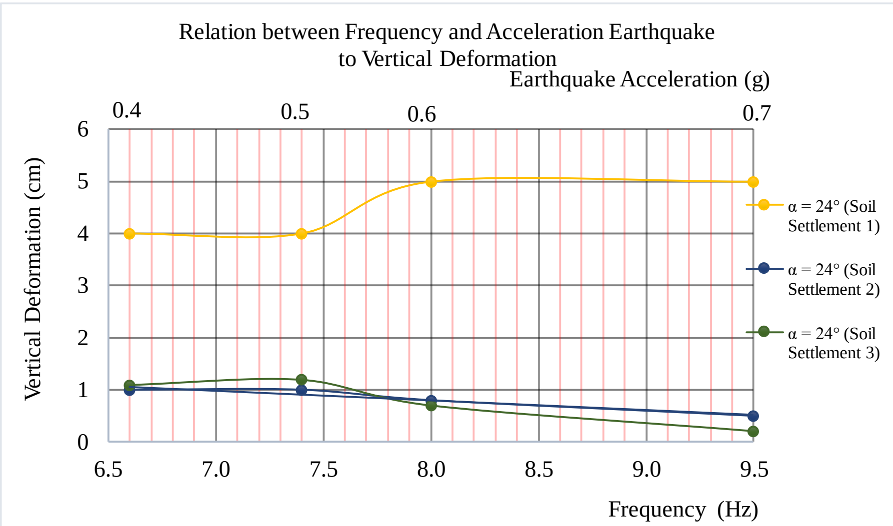


Figure 6. Frequency relations and earthquake acceleration of axial deformation at α = 24°

From the figure 6. Show that the frequency and acceleration of the earthquake to axial deformation, it can give an information on slope α = 24° with various frequency of 6.60 Hz, 7.40 Hz, 8.00 Hz, and 9.50 Hz the axial deformation of 1st occurs at 4.00 cm, 4.00 cm, 5.00 cm, and 5.00 cm respectively.

Further in the axial deformation 2nd occurs by 1.00 cm, 1.00 cm, 0.80 cm, and 0.50 cm. Then the axial deformation 3rd occurs by 1.10 cm, 1.20 cm, 0.70 cm, and 0.20 cm. This deformation occurs because the slope is under the soil that is undergoing liquefaction, resulting in axial deformation.

Table 3. Resume of deformation to frequency

Frequency	Slope	Slope Deformation	Axial Deformation[1]	Axial Deformation[2]	Axial Deformation[3]
Hz	°	cm	cm	cm	cm
6.6	6	0	2	0.6	0.5
7.4		3	2	0	0
8		11.5	0.5	0.4	1
9.5		12	1.2	0.4	1.2
6.6	12	10	2	1	1
7.4		10.5	2.2	0.5	1
8		11	2.4	0.2	0
9.5		12	2.5	0.3	1
6.6	18	10	1.7	0.2	1.1
7.4		10	1.8	0.1	1
8		12	2.6	0.4	0.7
9.5		15	4	0.5	0.5
6.6	24	9	4	1	1.1
7.4		10	4	1	1.2
8		15	5	0.8	0.7
9.5		17	5	0.5	0.2

4. Conclusions

Modelling vibration frequency influences on deformation on potentially liquid slopes can be concluded as follows:

a. With the characteristics of the sand $Cu < 6$ and $Cc < 1$ categorized as poor graded sand and also if the sand is at the most volatile limit then the condition of the soil can be potentially liquefaction.
b. Earthquake acceleration of 0.40g; 0.50g; 0.60g and 0.70g are shown to cause liquefaction when tested with shaking table.
c. The larger of the slope and the given frequency the greater the lateral and axial deformation that occurs. The maximum lateral deformation is 17.00 cm at a frequency of 9.50 Hz with a tilt of 24° while the axial deformation occurs at 5.00 cm at 9.50 Hz frequency with a tilt of 24°. But it is found that the ideal slope to withstand the vibration of the earthquake at 12-degree slope.

As an implication in the field of engineering, the application in the planning of slopes on potentially liquefaction soils should attention to the slope maximum of 20 degrees. For warning at the time while of the earthquake, that liquefaction occur very quickly on granular soils or cohesionless soils that is about 10 seconds.

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