The shape of slide surface of gravity retaining walls construction on sand by small scale sinusoidal dynamic load tests

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Abstract

The shape of slide surface of retaining wall construction with the gravity-type on soil layer of sand with a sinusoidal dynamic loading is influenced by several dynamic parameters, including: (1) the frequency of vibration, (2) the density of sand soil, (3) deviation and (4) the dynamic acceleration. This research aims to explore the role of dynamic parameters to shape of landslide of retaining wall construction due to dynamic load sinusoidal by small-scale testing in the laboratory. The retaining wall was modeled in the glass box of 2 meters in length, 0.4 meter in width and 1 meter in height. This models used gravity types retaining wall which was made of concrete and was placed on dry sand. The model was examined using dry sand material of loose sand density ($\rho_d = 1.4184$ gr/cm$^3$), medium sand density ($\rho_d = 1.5816$ gr/cm$^3$) and dense sand density ($\rho_d = 1.6784$ gr/cm$^3$). The model was vibrated using shaking tables with a given variation on sinusoidal loads and was recorded using accelerometer. The displacement of granular soil in a particular point was also monitored during vibration. The results show that there is the difference in the maximum vibration acceleration response generated due to differences in the frequency of vibration. The differences in deviation lead to differences of shape of slide surface areas. The density of sand also affects the width of the slide surface.

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1. Introduction

Slope is the result of the formation of the contours of the land changed gradually due to geological activity over millions of years. In geotechnical, slope that formed to have a slope angle, soil parameters and stability are varied. Seismic activity continues throughout earth is still 'alive' makes the earthquake can hit at any time. Slopes are stable under conditions of no earthquake, it might be bothered by the presence of seismic wave propagation. In anticipation of a large loss, we need a strengthening / retaining slope that is able to stand on earthquake rocked conditions.

Many methods have been proposed by researchers to estimate the lateral pressure on the walls due to earthquake load. Ones of well-known methods are ones developed by Mononobe and Matsuo (1929) [1] and Okabe (1924) [2], by lowering the ground retaining wall (gravity wall). The method is a further development of Coloumb theory that follows the principle of equilibrium limit (limit equilibrium). Seismic lateral pressure distribution on the retaining wall is not linear; pattern collapse occurs depends on the magnitude of the applied load [3]. Distribution of dynamic lateral earth pressure of retaining wall on sandy soil has a certain pattern, not linear and depends on the friction angle between the surface of the wall to the soil [4]. Until recently there have been no research that explain the pattern of collapse that occurred in the construction of retaining wall by a given amount of dynamic load. The objectives of this study were to examine the shape of the surface of landslide of sand behind the construction of gravity retaining wall caused by the sinusoidal dynamic load by using a small scale test.

2. Literature review

Retaining walls are often classified in terms of their relative mass, flexibility, and anchor condition [5]. Gravity walls are the oldest and simplest type of retaining wall. Gravity walls are thick and stiff enough that they do not bend; their movement occurs essentially by rigid-body translation and/or rotation. The dynamic response of even the simplest of retaining wall is quite complex. Wall movement and pressures depend on the response of the soil underlying the wall, the response of backfill, the inertial and flexural response of the wall itself, and the nature of the input motion.

Soil and structures have not only received the static load of the building construction both inside and on the surface of the ground, but also the dynamic load. The dynamic load can be derived from natural or man-made that work on the soil that will cause movement of the supporting soil grains. As a result, the structure which is supported by the soil will experience instability. Laboratory modeling experiments can be conducted to study the movement of soil grains due to vibration (dynamic load) using the structure model that is supported by sand with given dynamic loads (sinusoidal) and vibration acceleration variations.

A vibrating body will form a path of repeated displacement within a certain time. Vibration generated the simplest harmonic vibrations that can be described by a sine or cosine function. One example of the simplest path to describe the vibration is sinusoidal function is written according to Eq. 1. [6,7].

\[ z = Z \sin(\omega t) \]  

where \( \omega \) is the angular velocity or angular frequency with units of radians/sec and \( t \) is time in seconds. The harmonic motion repeated every 2\( \pi \) radians with fixed angular velocity and maximum displacement is value of \( Z \), referred to as amplitude (Fig.1.a.). A cycle of motion is completed when the movement reached one full rotation as described in Eq. 2..

\[ \omega T = 2\pi \]  

So that, to do one round of motion takes the value shown by Eq. 3.

\[ T = \frac{2\pi}{\omega} \]  

where \( T \) is the period of vibration. While the frequency of vibration is the inverse of the time period and is calculated by Eq. 4.
where \( f \) is the frequency of vibration. In order to determine the velocity and acceleration of motion, we differentiate Eq. 1 to time, \( t \). The first derivative of displacement equation to time (\( t \)) is the velocity of motion equation which is described as Eq. 5.

\[
\text{Velocity} = \dot{z} = \omega Z \cos \omega t = \omega Z \sin (\omega t + \frac{\pi}{2})
\]  

where \( \dot{z} \) is the velocity of motion equation. Then, the velocity equation differentiated to time to be obtained the acceleration equation of motion and described in Eq. 6.

\[
\text{Acceleration} = \ddot{z} = -\omega^2 Z \sin \omega t = -\omega^2 Z \sin (\omega t + \pi)
\]

The acceleration equation of motion (Eq. 6.) can also be expressed in the equation of displacement as shown in Eq. 7.

\[
\text{Acceleration} = a = -\omega^2 z = -\omega^2 Z \sin \omega t
\]

where \( \ddot{z} \) is the acceleration equation of motion. The displacement path and acceleration of motion was described in Fig. 1.b.

3. Experimental procedure

A model of gravity retaining wall made of concrete with foundation width of 10 centimeters, height of 20 centimeters and width peak of 2 centimeters was used as test models. Model retaining wall is placed on dry sand material with a grain size through no. 4 of sieve and retained no. 100 with variations of loose density \( (\rho_d = 1.4184 \text{ g/cm}^3) \), medium density \( (\rho_d = 1.5816 \text{ g/cm}^3) \) and solid \( (\rho_d = 1.6784 \text{ g/cm}^3) \). The model is placed in a glass box with a width of 40 centimeters, a length of 2 meters and a height of 1 meter. The thickness of glass box was 10 millimeters. The model was placed on a shaking table which supported by four wheels driven horizontally by an electric motor with a variation of the amplitude and frequency of vibration. Shaking table was equipped with a recording apparatus to record the vibration acceleration of dynamic acceleration response of the models and an inverter was used to control the speed of vibration. During the test the movement of sand grains recorded by video camera which was placed on the shaking table. Fig. 2. shows the schematic drawings of the model equipment with shaking table.
4. The model test results and discussion

Small scale retaining wall model was tested by providing a variety of vibration frequency, amplitude and density of the sand. The accelerometer was activated to record dynamic acceleration responses that occur. Furthermore, the dynamic acceleration response idealized in the form of a sine equation using the Eq. 1 to Eq. 7. The results of the testing of models with variations in frequency and density of sand are presented in Fig. 3.

Fig. 3. The graph of the dynamic response acceleration with frequency and density variations

Fig. 3. shows that the sinusoidal dynamic acceleration response increases with increasing vibration frequency with the same amplitude at certain density of the sand. However, if the density of the sand is changed, the amplitude, frequency of vibration and the dynamic acceleration response are remained the same. So, the frequency of vibration has a strong influence on the dynamic acceleration response. Furthermore, the model test results with amplitude variations, vibration frequency and density of sand are presented in Fig. 4.
Fig. 4. The graph of the dynamic response acceleration with frequency and density variations

Fig. 4. shows that the sinusoidal dynamic acceleration response increases with increasing frequency of vibration and amplitude at certain density of the sand. If the test was run on the same sand density, with increasing amplitude and decreasing frequency of vibration then, the dynamic acceleration response was increasing. In this case the amplitude was more influential than the vibration frequency. If the sand density and vibration frequency increase, but the amplitude remains then the results shows increasing dynamic acceleration response. So the dynamic acceleration response is determined by the frequency of vibration.

Furthermore, the shape of landslide that occurs in a model test with the provision of sinusoidal dynamic load as shown in Fig. 3. and Fig. 4., is shown in Fig. 5. and Fig. 6.. Fig. 5. shows the shape of landslide that occurred in each of the model test with sinusoidal dynamic load as given Fig. 3., Fig. 6 displays the overall shape and landslide that occurs in each of the model test with the provision of sinusoidal dynamic load as given in Fig. 4.

Fig. 5. The graph of the shape of slide surface with frequency and density variations

From Fig. 5. it could be figured out that the model tests with a particular density of sand, a particular amplitude and an increased frequency of vibration will increase the area of landslide with the increase in the width and height of landslide. However, if the model test was conducted by an increased density of the sand, with a particular the amplitude and frequency of vibration, the area of landslide decreased which characterized by a decrease in the width and height of landslide.
Fig. 6. The graph of the shape of slide surface with frequency, amplitude and density variations

| No. of tests | Density [gr/cm^3]; amplitude [cm]; frequency [cps] | Acceleration (\(a\)) [g] | The function of landslide \([Y = \ldots]\) | Area of landslide [cm^2] | Landslide width to width of foundation \([x_B]\) | Landslide height to height of foundation \([x_H]\) |
|-------------|---------------------------------|-----------------|--------------------------|-----------------|-----------------|-----------------|
| 1           | 1.4184; 0.62; 0.65               | 0.10341         | 0.006x^2 – 0.307x + 121.1 | 107.0163        | 1.54945         | 0.4629          |
| 2           | 1.4184; 0.62; 0.8                | 0.14778         | 0.007x^2 – 0.413x + 108.1 | 127.0639        | 1.5495          | 0.5279          |
| 3           | 1.4184; 0.62; 0.95               | 0.22088         | 0.001x^2 + 0.234x + 32.68 | 346.6868        | 2.9538          | 0.8815          |
| 4           | 1.4184; 0.62; 1.05              | 0.26982         | 3E-09x^4 - 1E-06x^3 + 0.001x^2 – 0.102x + 27.2 | 646.5262        | 4.7099          | 0.9117          |
| 5           | 1.5816; 0.62; 1.0               | 0.2448          | 9E-09x^4 - 2E-06x^3 + 0.001x^2 + 0.064x + 74.75 | 264.7131        | 2.7781          | 0.654           |
| 6           | 1.5816; 0.62; 1.05              | 0.26923         | 2E-11x^3 - 1E-08x^4 + 3E-06x^3 + 0.404x + 36.42 | 286.6114        | 2.7651          | 0.8468          |
| 7           | 1.4184; 0.82; 0.5               | 0.08093         | 0.169x + 107.9            | 235.5111        | 4.316           | 0.3593          |
| 8           | 1.4184; 1.5; 0.6                | 0.21318         | 0.275x + 62.1             | 333.0475        | 4.2694          | 0.5828          |
| 9           | 1.5816; 1.5; 0.7                | 0.29015         | 0.008x^2 – 0.045x + 29.29 | 163.6943        | 1.4936          | 0.8872          |
| 10          | 1.6784; 1.5; 0.7                | 0.29015         | 1E-05x^3 - 2E-05x^2 + 0.350x + 52.2 | 171.5559        | 1.9075          | 0.7592          |
| 11          | 1.6784; 1.8; 0.65               | 0.30021         | 1E-05x^3 + 0.173x + 49.98 | 213.4285        | 2.3173          | 0.7644          |

Fig. 6. shows that the model tests with a particular density of sand, an increased amplitude and an increased frequency of vibration will result the increase in the area of landslide which characterized by the increase in width and height of landslide. Furthermore, the model tests with a particular density of sand, an increased amplitude and a decreased frequency of vibration will give increase of the area of landslide which indicated by the increase in width and height of landslide. However, if the model test was conducted by an increased density of the sand, a particular amplitude and an increased frequency of vibration, then the area of landslide decreased which identified by a decrease in width and height of landslide. The whole of model test results discussed in all figures above are also shown in table form where the calculation of landslide width to width of foundation and height of landslide against...
the height of foundation of model test are presented in Table 1.

5. Conclusion

The following conclusions could be made based on the experimental results obtained and discussed in this paper:

- The increase of the frequency of vibration causes the increase both of the angular frequency trajectory and the maximum vibration acceleration
- The increase of the frequency of vibration with a particular of the amplitude and the density of sands on the model tests causes the increases of the area of landslides
- The increase of the density of sands with a particular of the amplitude and the frequency of vibration on the model tests causes the declines of the area of landslides
- The increase of the amplitude and the frequency of vibration but with a particular of the density of sands on the model tests causes the increases of the area of landslides
- The increase of the amplitude but the decrease of the frequency of vibration with a particular of the density of sands on the model tests causes the increases of the area of landslides
- The increase both of the density of sands and the frequency of vibration with a particular of the amplitude on the model tests causes the declines of the area of landslides
- The increase of sinusoidal dynamic loads accelerates soil grain movement that expands the area of landslide

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