International Journal of Civil and Structural Engineering – IJCSE
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Volume 6 : Issue 1- [ISSN : 2372-3971] - Publication Date: 10 May, 2019

Numerical Modeling of the Casagrande Cup Test

with Newmark's Method

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Numerical modeling of Casagrande cup test can be conducted by applying Newmark's method in a finite element program. Casagrande is a test that applies acceleration as a load to mini-slope that is molded in a cup until the slope fails. Modeling of the test cannot be performed without scaling because finite element program must have its limit in mesh size. Thus, a series of scaling up and down needs to be carried out to match the parameter for obtaining a realistic result. The test is done in a series of water contents to gain information about the change in behavior of the slope, which is then validated by the result of a physical test, on which the input for the modeling data is gained. By doing so, the difference in real test and modeling result can be equally compared. This study aims to propose a method of modeling the Casagrande cup test, which includes the scaling procedure and the reduction in Young's modulus to obtain the desired result. In conclusion, reduction in Young's modulus of the base plate is necessary to ensure an accurate result of the model. Comparison of the result of numerical modeling and that of the real Casagrande test presents a small error, which is still acceptable because the Casagrande test has high repeatability between tests even with the same sample. A proper method of finding the exact value of other properties followed by proper scaling is important to obtain the desired soil behavior.

Casagrande cup test, modeling, Newmark's method, scaling law, Young's modulus.

I. Introduction

The Casagrande cup test is a method for determining liquid limit that is described as a mini-landslide occurring under a dynamic load. To model the Casagrande test in different sizes, an appropriate scaling and a slight modification of a prototype's parameters are necessary. This study proposes a method for modeling landslides by applying a particular scaling law and reducing reliable input parameters. The mineral bentonite is used as the proposed study object to generate a constant result.

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II. Methods

A. *Mechanics of the Casagrande Cup Test*

The Casagrande cup test is basically a stability test for a slope under a dynamic load that is moving due to the vertical acceleration applied to each bump (Wroth, 1979). Figure 1 shows an accelerogram calculated by Haigh (2012) during an experimental analysis of the mechanics of the Casagrande cup test. The accelerogram was then used as a load applied to the calculation. Notably, each blow may provide a different but nearly identical accelerograms. However, the difference is insignificant in displacement calculation due to the integration in the formula (Haigh, 2012).

Liquid limit is empirically described as a condition in which the soil sample closes the gap between its particles in exactly 25 blows. Theoretically, liquid limit is described as a condition in which the specific strength of the model reaches 0.97 m^2/s^2 (Haigh, 2012) and its undrained shear strength is approximately 2 kPa (Casagrande, 1932). Specific strength is the ratio of the energy of an object to its mass.

The standard developed by the ASTM International is used in the experimental modeling. The modeled slope is set as 8 mm high (Fig. 2). By assuming that the slope is perfectly modeled, its two sides can be considered identical. Hence, only one side of the slope should be analyzed.

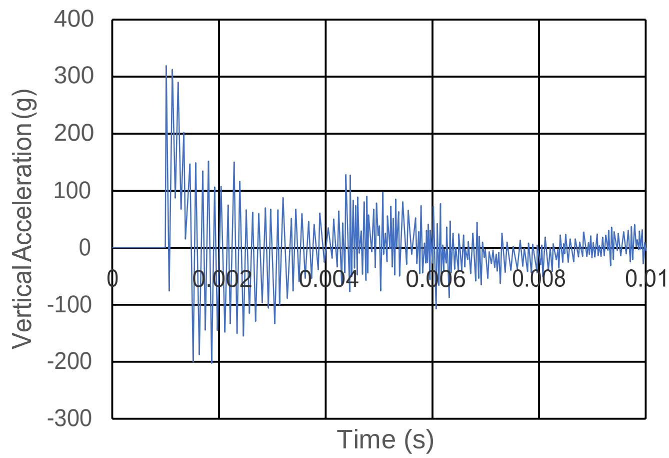

Figure 1. Casagrande's Dynamic Load Accelerogram (Haigh, 2012).

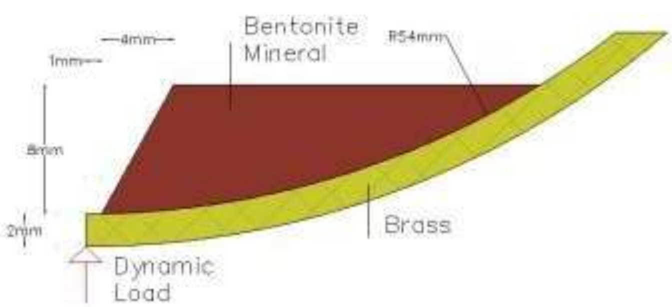

Figure 2. Illustration of Slope Modeling.

B. *Modeling*

Newmark's sliding block analysis is a method used to determine the displacement of an object that is sliding on a slope under a dynamic load. The application of Newmark analysis to the modeling process is combined with the finite element method to calculate small parts of the soil and determine the interaction between each part. Calculation is not performed manually but instead uses a finite element program to accelerate the required time and to increase the accuracy of the result.

A series of scaling is also performed by determining ρ (density) as a dominant factor. The scaling law shown in Table I is the same as the scaling law used in centrifugal modeling. Given that the principle of scaling is the same in both tests, the same scaling law can be applied to both tests. From the dimensional analysis, the scaling for Young's modulus (E) is determined as N^{-2}.

TABLE I. SCALING LAW (AZIZI, 2000).

Properties	**Scaled Properties**	
	Scaling Law	**Scaling Factor**
Acceleration	$a_m = N.\ a_p$	N^{-1}
Amplitude	$d_m = d_p/N$	N
Frequency	$f_m = N.\ f_p$	N^{-1}
Velocity	$V_m = V_p$	1
Density	$\rho_m = \rho_p$	1
Unit Weight	$\gamma_m = N.\ \gamma_p$	N^{-1}
Length	$L_m = L_p/N$	N
Strain	$\varepsilon_m = \varepsilon_p$	1
Stress	$\sigma_m = \sigma_p$	1
Temperature	$T_m = T_p$	1
Time (dynamic)	$t_m = t_p/N$	N
Time (static)	$t_m = t_p/N^2$	N^2

A 90% reduction in the Young's modulus of the brass base plate is applied as a unique modification technique to achieve an appropriate result of the numerical modeling output. The reduction amount is obtained by performing multiple empirical trial-and-error tests during the landslide modeling process.

Notably, this numerical modeling should be performed with the finite element method to determine the interaction between each particle. However, this process cannot be simply realized because the base plate of the Casagrande cup test is an arch. This problem can be solved by modeling the arch as a short line and connecting these lines to one another to form an arch-like shape. A more detailed approach with shorter lines produces a smoother result.

C. *Validation*

To validate the analysis, data obtained from a real test are compared with the output data obtained from the numerical calculation. The comparison of the displacement at the end of the test and the calculation can be performed visually. To achieve a real Casagrande cup test 2D deformation, a paper is used as the medium for recording the deformation at the center of the cup. For the numerical calculation, an appropriate finite element program can simply derive the true scale result. The difference between the real test and the output is visible when the results are overlaid on one another.

III. Result and Analysis

A. *Laboratory Result*

Preliminary tests are conducted to collect input data for the numerical modeling. From the result of the laboratory test, data are gained and plotted graphically. The relation between water content and unit weight is illustrated in Fig. 3.

Undrained cohesion (S_u) is obtained by conducting a fall cone penetrometer test using the following equation:

$$— \quad (1)$$

where K is the cone constant that can be determined using Table II, Q is the weight of the cone that is used in the test (80 g), and *h* is the depth of the cone penetration shown in Fig. 4 as a result of the fall cone test. The result of the calculation is presented in Fig. 5 as the relation between the penetration and undrained cohesion of a sample.

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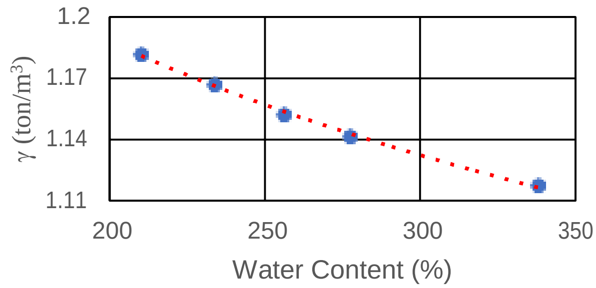

Figure 3. Correlation between Unit Weight and Water Content.

TABLE II. FALL CONE CONSTANT
(KOUMOTO AND HOULSBY, 2001).

β	30^0	45^0	60^0	75^0	90^0
Smooth	2.000	0.835	0.400	0.216	0.120
Semi-rough	1.330	0.580	0.305	0.171	0.097
Rough	1.030	0.495	0.250	0.152	0.090

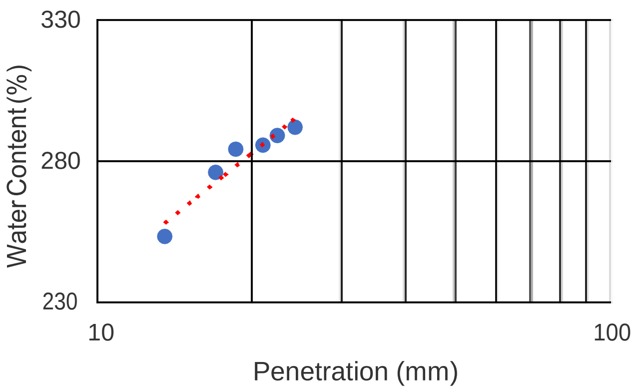

Figure 4. Result of the Fall Cone Penetrometer Test.

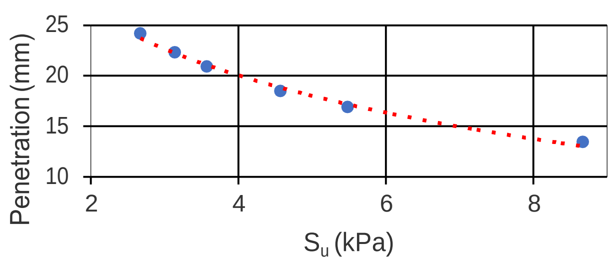

Figure 5. Calculation Result of Undrained Cohesion.

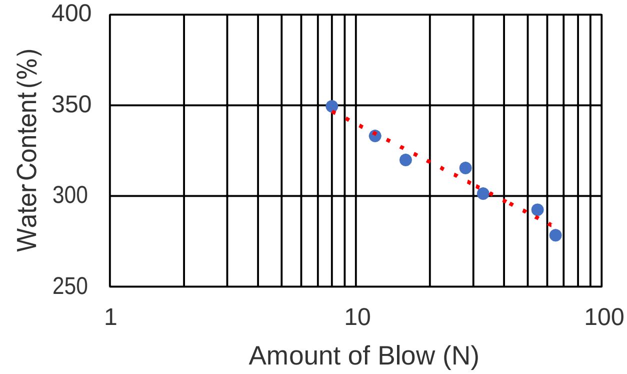

Figure 6. Casagrande Test Result.

Then, the Young's modulus of the modeled soil (E) can be approached using the chart in Fig. 7, assuming that the overconsolidated ratio is 1. The plasticity index (PI) is calculated with the following equation:

. (2)

LL as liquid limit and *PL* as plastic limit. The amounts of *LL* and *PL* can be obtained from Fig. 4 using data interpolation and extrapolation. The *LL* of bentonite is 282% and its *PL* is 145%. Thus, when (2) is used, the *PI* value is 137%. From Fig. 7, the ratio of E/S_u can be determined as 150.

The result of the Casagrande cup test is recorded using a piece of paper, as shown in Figs. 8, 9, and 10. The initial form is justified into a perfect model as described in Fig. 2.

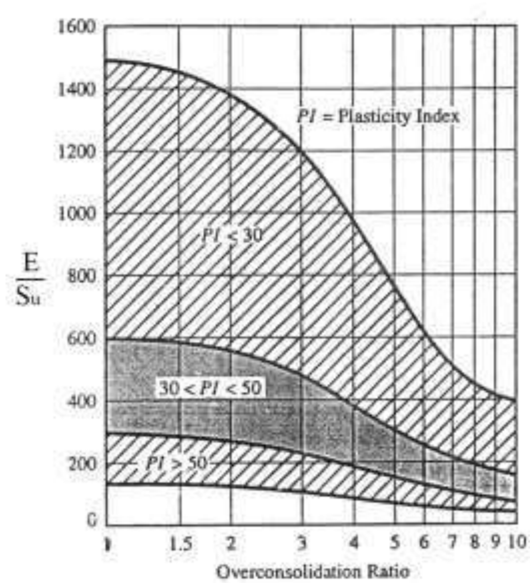

Figure 7. Correlation of S_u, E, and PI.
(Duncan and Buchignani, 1976).

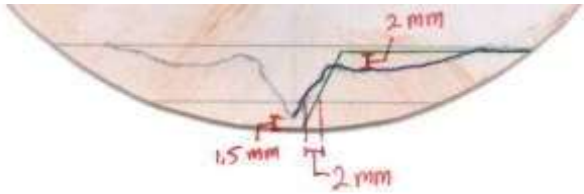

Figure 8. Real Casagrande Result (8 Blows).

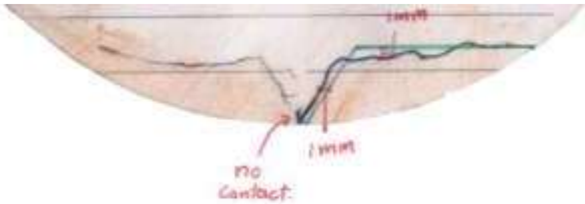

Figure 9. Real Casagrande Result (28 Blows).

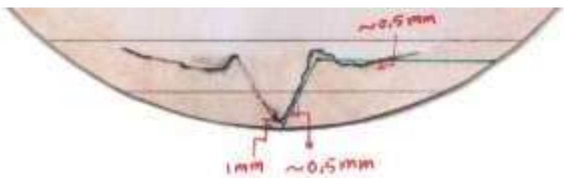

Figure 10. Real Casagrande Result (65 Blows).

B. *Numerical Modeling*

The real Casagrande cup test of is performed by following the criteria presented earlier. Table III provides the parameters of bentonite mineral, Table IV presents those of brass, and Table V lists the general modeling criteria used in the numerical calculation. The scale factor adopted in the modeling process is 1:100.

TABLE III. INPUT OF BENTONITE PARAMETERS.

Number of Blows	S_u (kPa)	Density (kN/m^3)		E (kPa)	
		Real	Input	Real	Input
65	5.96	10.69	0.1069	894	0.0894
28	1.79	12.75	0.1275	269	0.0269
8	0.30	16.24	0.1624	45	0.0045

TABLE IV. INPUT OF BRASS PARAMETERS.

Young's Modulus		Density (kN/m^3)	
Real	Input	Real	Input
9.0E+07	900	85.61	0.8561

TABLE V. MODELING CRITERIA.

Material	Type of Difference		
	ν\` (Poisson's ratio)	Material Model	Drainage Type
Bentonite	0.40	Mohr–Coulomb	Undrained (B)
Brass	0.33	Linear Elastic	Nonporous

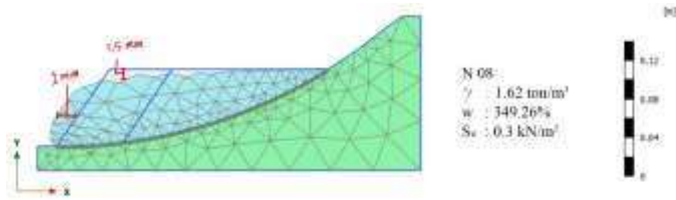

Figure 11. Numerical Output (8 Blows).

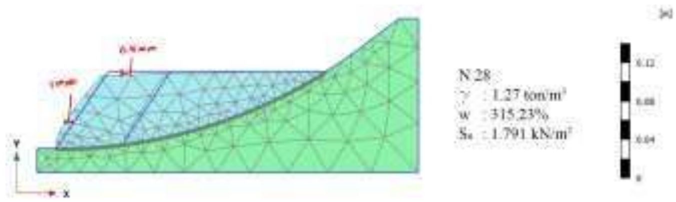

Figure 12. Numerical Output (28 Blows).

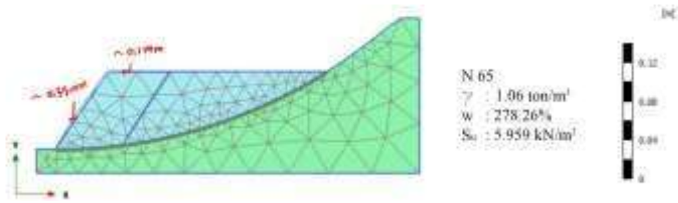

Figure 13. Numerical Output (65 Blows).

The output result of the numerical calculation is shown in Figs. 11, 12, and 13. Blue represents the bentonite mineral, whereas green represents the brass base plate. All the figures are shown in true scale.

C. *Overlay*

An overlay is basically an act of putting something on top of another to cover some of its sections. This method is used to compare the real Casagrande cup test result and the numerical output. Figures with the same number of blows are placed together and graphically edited to show the necessary section. Figs. 14, 15, and 16 present the overlaying results of the real Casagrande cup test and the numerical calculation conducted using a finite element program.

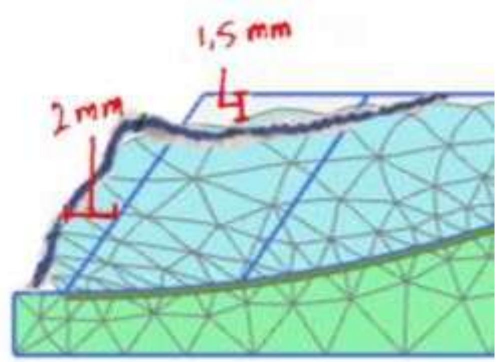

Figure 14. Overlay Result (8 Blows).

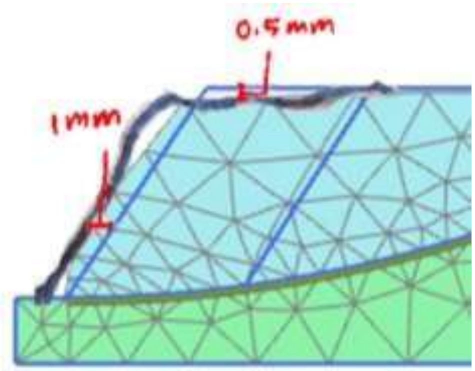

Figure 15. Overlay Result (28 Blows).

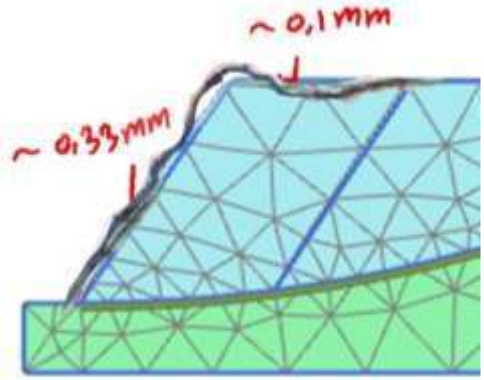

Figure 16. Overlay Result (65 Blows).

IV. Discussion

Overall, the size and pattern of the landslide is similar, thereby showing that the method applied to the modeling process fits the criteria. Newmark's method is clearly a good technique for modeling a slope under a dynamic load. A slight difference can be clearly seen in the overlay result. Such differences may occur due to the lack of accuracy while collecting the actual sample.

The dynamic load will be amplified because of the reduced Young's modulus. Without reducing the base plate's Young's modulus, the total displacement that occurs is not highly significant, such that the bentonite does not bother to move. By contrast, the over-reduction of Young's modulus may lead to a bouncy material, which is illogical.

Moreover, an appropriate scaling is crucial because soil behavior depends on the given parameters. A mistake on the scaling process may lead to program error or an illogical result. A false scale may cause too much displacement and/or a wrong output shape. Occasionally, the program simply does not run because the slope fails due to excessive burden compared with the required soil strength.

V. Conclusion

The numerical modeling of a Casagrande mini-slope under vertical acceleration can be performed by appropriately scaling the prototype with the assumption that density is a dominant factor. Displacement can be calculated using Newmark's method, and the finite element method is used as a tool to determine soil-to-soil interaction. In addition, a reduction in the base plate's Young's modulus is crucial to gaining an appropriate result.

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