Model Test of Yield Acceleration Factor $-K_c-$ of a Foundation Near Down-Hill Slope Induced Dynamic Waves

by

Tomoyuki SAWADA*, Sumio G. NOMACHI**, Takashi ONO***
and Wai F. CHEN****

(Received November 30, 1990)

Abstract

The finite element method is a powerful method to approximate the deformation of an element in a structure. Finite element analysis is also used to evaluate the safety of the structure. It is, however, far more difficult to model the progressive failure of soil structures. The conventional pseudo-static approach is used to simplify the computation of the upper limit of a slope under seismic load but does not yield information about the sliding displacement as such. In this paper, a technique based on the upper limit[1] is used to find the yield acceleration factor (K_c)[2] of a foundation near a down-hill slope. Some assumptions are made. First, a logarithmic spiral rapture is assumed to start at an edge of the loaded area far from the slope. A land slide is assumed to behave as a rigid body so that the inertia force acts at its center of gravity. A final assumption is that the rate of kinematic energy of the landslide together with the load should be equal to the disspation of the internal energy rate along the sliding line. Also in this paper, several effects of the model tests for slope collapses induced dynamic waves is described (Fig. 1). This experimental investigation is conducted to study seismic yield acceleration factor.

1. REVIEW OF THEORETICAL FORMULATION

By equating the rate of internal energy dissipation to the total rates of external work[1], we have

$$K=\frac{cF_c-\gamma r_0(F_1-F_2-F_3)-pF_p}{\gamma r_0(F_4-F_5-F_6)+xPF_q} \tag{1}$$

Herein,

$$F_1=\frac{1}{3(1+9\tan^2\phi)}\{\exp[3(\theta_h-\theta_0)\tan\phi](3\tan\phi\cos\theta_h+\sin\theta_h)$$
$$-3\tan\phi\cos\theta_0-\sin\theta_0\}$$

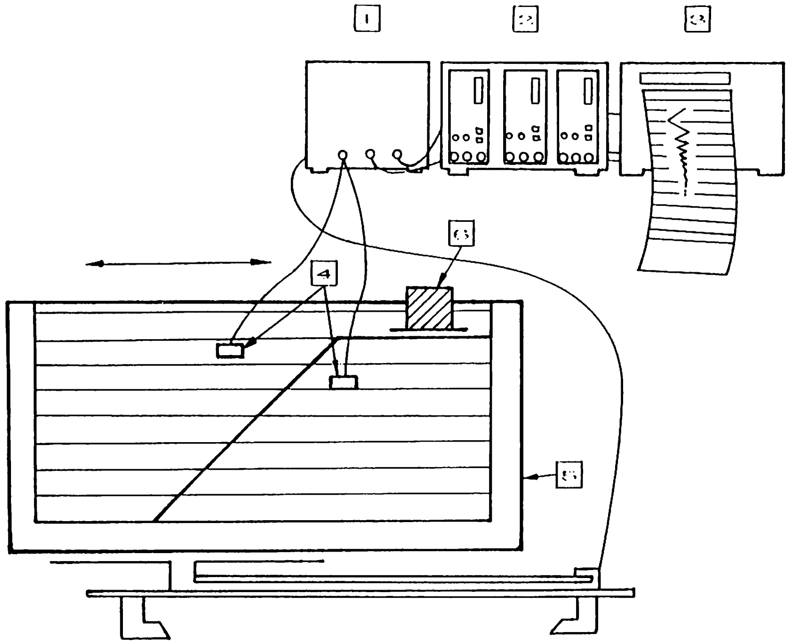
$$F_2=\frac{1}{6}\frac{L}{r_0}2\cos\theta_0\cdot\sin\theta_0$$

* Assoc. Professor, Dept. of Civil Engineering, Tomakomai National College of Technology, Hokkaido.

** Professor, Dept. of Civil Engineering, School of Industrial Technology Nihon University, Chiba.

*** research accociate, Dept. of Civil Engineering, Tomakomai National College of Technology, Hokkaido.

**** Professor & Head, Dept. of Civil Engineering, School of Civil Engineering, Purdue University, Indiana, USA.



1 Shaking Table

2 Dynamic Strain Meter (DPM—6BA)

3 Rapicorder(RMV—30A)

4 Accelerometer(SHINKOH BAL—50G)

5 Acrylic Box(40cm×40cm×80cm)

6 Surcharge Load

Fig. 1 Apparatuses of model test

$$F_3 = \frac{1}{6}\exp[(\theta_h-\theta_0)\tan\phi]\{\sin(\theta_h-\theta_0)-\frac{L}{r_0}\sin\theta_h\}\cdot\{\cos\theta_0+\cos\theta_h\exp[(\theta_h-\theta_0)\tan\phi]\}$$

$$F_4 = \frac{1}{3(1+9\tan^2\phi)}\{3\tan\phi\sin\theta_h-\cos\theta_h)\exp[3(\theta_h-\theta_0)\tan\phi] -3\tan\phi\sin\theta_0+\cos\theta_0\}$$

$$F_5 = \frac{1}{6}2\frac{L}{r_0}\sin^2\theta_0 \qquad F_p = \frac{L}{r_0}\cos\theta_0 \qquad F_q = \frac{L}{r_0}\sin\theta_0$$

$$F_6 = \frac{1}{6}\exp[(\theta_h-\theta_0)\tan\phi]\{\sin(\theta_h-\theta_0)-\frac{L}{r_0}\sin\theta_h\} \cdot\{\exp(\theta_h-\theta_0)\tan\phi\sin\theta_h+\sin\theta_0\}$$

The values of K as given in Eq.(1) are upper bound solutions for the yield acceleration factor corresponding to the log-spiral failure mechanism as shown in Fig. 2. Using the conditions

$$\frac{\partial F}{\partial\theta_0}=0 \quad \text{and} \quad \frac{\partial F}{\partial\theta_h}=0 \qquad (2)$$

Model Test of Yield Acceleration Factor $-K_c-$ of a Foundation 69

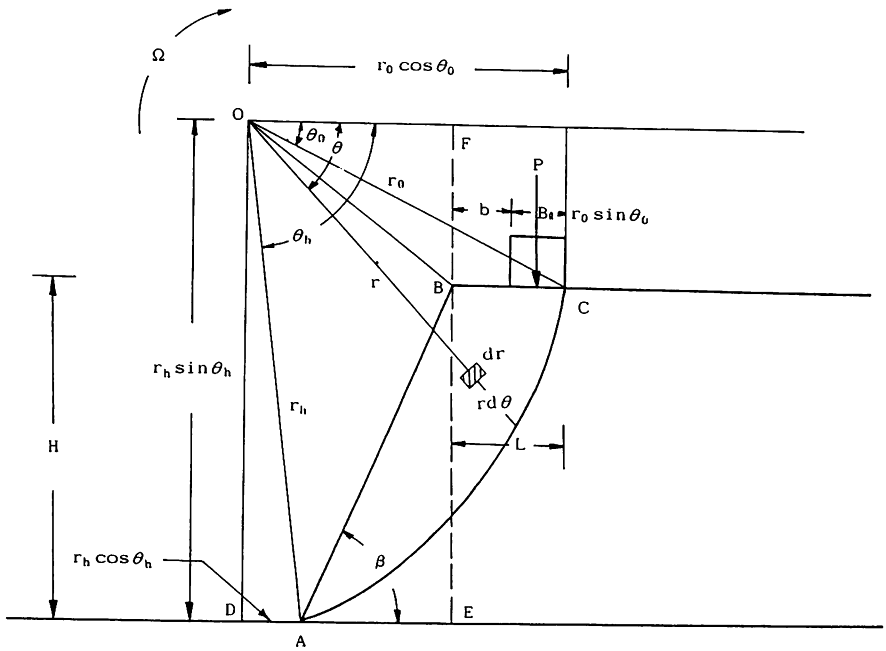


Fig. 2 Log-spiral failure mechanism

and solving Eq.(2), we obtain the critical values of θ_0 and θ_h which give the minimum value of K, or K_c as

$$K_c = \text{min. } F(\theta_0, \theta_h) \tag{3}$$

The flow chart of computer progrom is shown in Fig. 3.

Extensive numerical results have been obtained by this program. Some of the results are illustrated graphically in Fig. 4−6.

Fig. 4 ··· relation between K_c and slope angle(β)
Fig. 5 ··· relation between K_c and internal friction angke(ϕ)
Fig. 6 ··· relation between K_c and stability factor(N_s)

All results of log-failure mechanism less than the results of plane failure mechanism. So to speak, the log-spiral failure mechanism as shown in Fig. 2 should be taken as the local slope failure mode.

2. MODEL TEST

The soil as a material of the test is passed the sieve sized 25 mm, mixed a few silt and surface-dry condition. By mono-face shearing test and specific gravity test, we decided internal friction angle ϕ (36.03°), cohesion strength c (0.055 kg/cm^2) and specific gravity γ (2.64 g/cm^3). Using this material, we created the model slope in the box made from Acryl (40^{cm}×40^{cm}×80^{cm}). As our understanding the behavior of seismic displacement and failure mechanism of a slope, we composed some stratums with line (about 5 cm between among the lines). (Photo. 1)

And a sample of acceleration record is presented in Fig. 7～8.

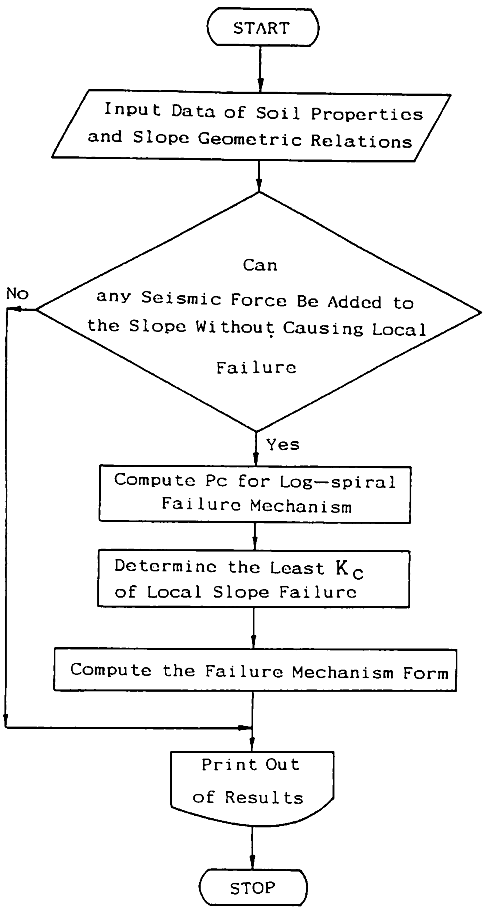


Fig. 3 Flow Chart of Computer Program

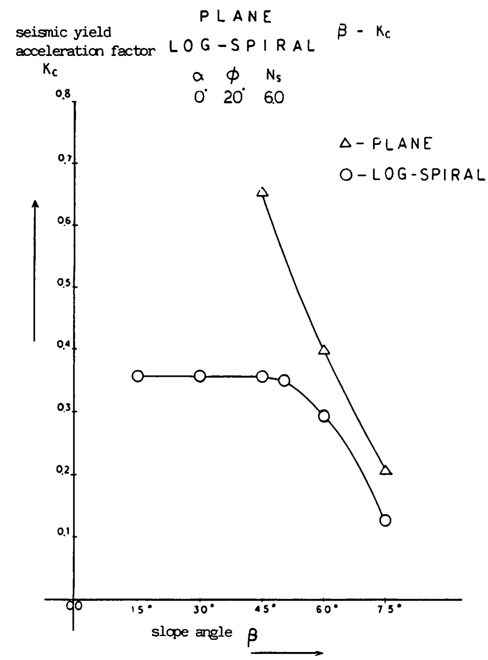


Fig. 4 Relation between K_c and Slope angle (β)

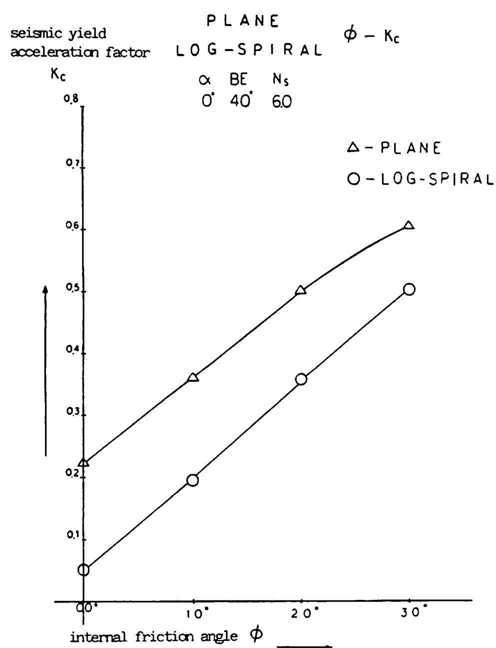


Fig. 5 Relation between K_c and internal friction angle (ϕ)

Model Test of Yield Acceleration Factor $-K_c-$ of a Foundation

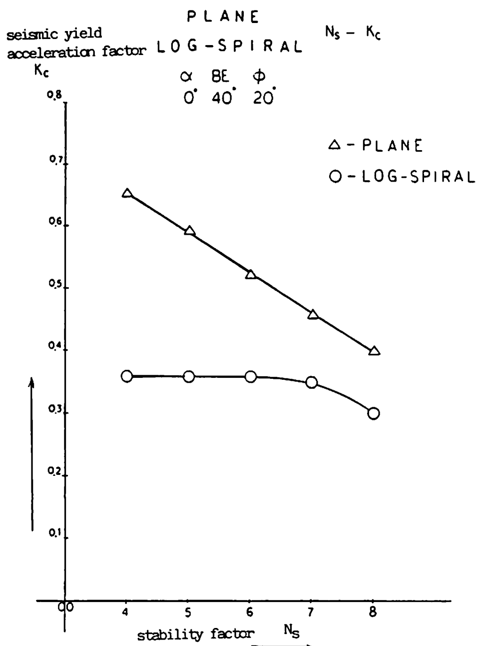


Fig. 6 Relation between K_c and Stability factor (N_s)

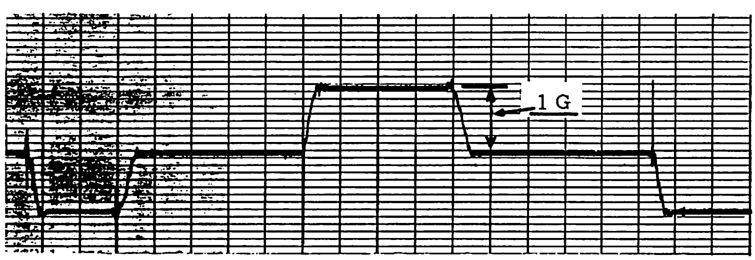


Fig. 7 Calibration

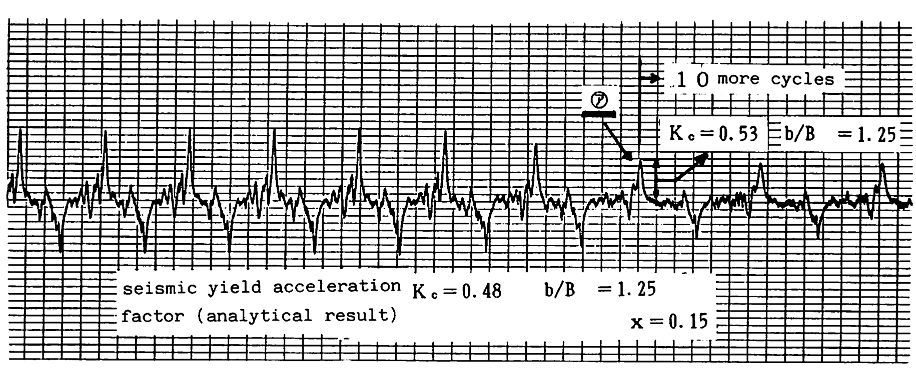


Fig. 8 Acceleration record $-$No. 1$-$ (continue to No. 2)

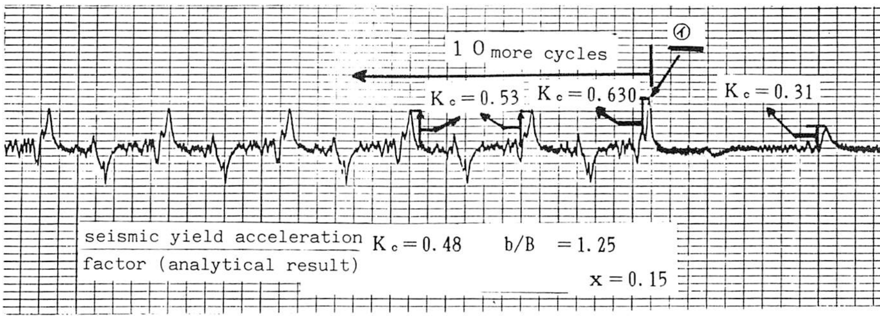
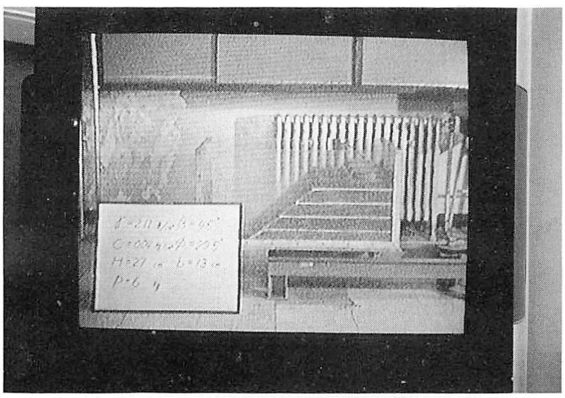
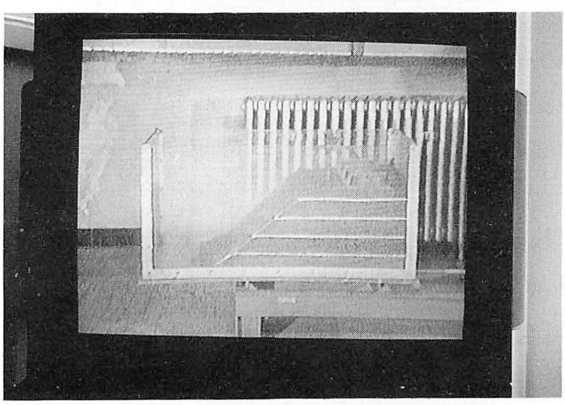


Fig. 8 Acceleration record －No. 2－

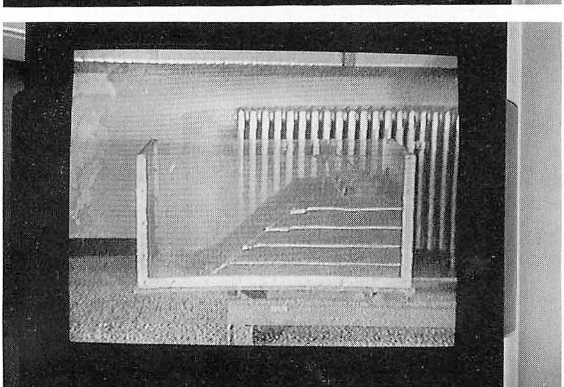
Photo. 1
Example 1 of Model Test



Express



Collapse
start just



Collapse start
right after

Model Test of Yield Acceleration Factor $-K_c-$ of a Foundation 73

3. EFFECTS OF MODEL TEST INDUCED DYNAMIC WAVES

Photo. 2 shows a example of slope collapese of a model test.

In Table 1～4, it is shown that yield acceleration factors of effects of fifty-five test examples. As a result, in each table, Increasing the slope angle (β) and the slope height (h), slope tends to reduce stability. Also Table 3～4 show that length between the crown of the slope and the front of surcharge

Photo. 2 A example of slope collapse of model tests

Effects of Model Experiments

tfble 1

β \ h	20 cm	25 cm	30 cm	35 cm	
35 deg	0.452G	0.416G	0.405G	0.400G	Surcharger Condition
45 deg	0.275G	0.250G	0.235G	0.214G	P = 0 kg
50 deg	0.240G	0.222G	0.213G	0.203G	b = 0 cm
60 deg	0.178G	0.176G	0.172G	0.099G	

table 2

β \ h	20 cm	25 cm	30 cm	35 cm	
35 deg	0.549G	no failure			Surchager Condition
45 deg	0.296G	0.292G	0.242G		P = 6 kg
50 deg	0.392G	0.236G	0.232G	0.208G	b=15 cm
60 deg	0.214G	0.210G	0.210G	0.202G	

Effects of Model Experiments

table 3

β \ h	20 cm	25 cm	30 cm	35 cm	
35 deg	no failure	no failure	0.497G		Surcharger Condition
45 deg	0.294G	0.291G	0.239G	0.232G	P = 6 kg
50 deg	0.282G	0.220G	0.208G		b =10 cm
60 deg	0.208G	0.202G	0.194G		

table 4

β \ h	20 cm	25 cm	30 cm	35 cm	
35 deg	no failure	no failure	0.492G	0.383G	Surcharger Condition
45 deg	0.240G	0.226G	0.199G	0.180G	P = 6 kg
50 deg	0.198G	0.160G	0.124		b =5cm
60 deg	0.128G	0.120G			

load (b) effects the seismic stability of slopes. In a word, As "b" decrease, slopes tend unsteady. The case of no surcharge load, being no compaction effect, the slope tends to reduce seismic stability rather than the case of surcharge condition. On the whole, these experiment-examples have almost good tendency.

ACKNOWLEDGMENTS

The authors wish to acknowledge Astushi OHONO, Tsutomu KUSHIDA and Yukio KUBOTA of the Tomakomai National College of Technology for the fabrication and testing of composite specimens.

Appendix NOTATIONS

The following symbols are used in this paper ;

g : Acceleration of gravity.

γ : Gravity of soil per unit volume.

r_0 : Radius of rotational failure mechanism. (in Fig. 2)

ϕ : Internal friction angle.

θ_0 : Angle of starting point of failure mechanism. (in Fig. 2)

θ_h : Angle of ending point of failure mechanism. (in Fig. 2)

c : Cohesion strength.

l : Arm length of failure mechanism.

K : Acceleration factor of earthquake.

xK: Acceleration factor corresponding to P relating to K of soil weight multiplied by coefficient x, which can be greater or less than unity.

Ω : Angular velocity relative to the materials below the failure, surface about the center of rotation center ; O. (in Fig. 2)

L : Length of failure mechanism.

B_l : Length on surcharge load P.

b : Length from the crown to the end of surcharge load. (in Fig. 2)

P : surcharge load.

REFERENCES

1) Chen, W. F. and Sawada, T. : "On Analysis of Seismic Stability of Slopes in Anisotropic Soils", Technical Report-CE-STR-82-25, Purdue University Structural Engineering, 1982, pp. 1−108.

2) Sawada, T., Nomachi, S. G. and Chen, W. F., "Seismic Stability of Nonhomogeneous, Anisotropic Slopes," Speciality Conference, ASCE, EMD, Vol. II, May, 1983, pp. 1009−1013.

3) Chen, W. F., "Limit Analysis and Soil Plasticity" Elsevier Scientific Publishing Co., Amsterdam, The Netherland, 1975.

4) Chen, W. F. and Sawada, T., "Earthquake-Induced Slope Failure in Nonhomogeneous, Anisotropic Soils", Soils and Foundations, The Japanese Society of Soil Mechanics and Foundations Fngineering, Vol. 23, No. 2, June, 1983, pp. 125−139.

5) Chen, W. F., "Limit Analysis of Stability of Slopes", Journal of the soil Mechanics and Foundation Division, ASCE, Vol. 97, No. SM1, January, 1971, pp. 19−26.

6) Sawada, T., Nomachi, S. G. and Chen, W. F., "Seismic Bearing Capacity of a Mounded Foundation Near a Down-Hill Slope by Pseudo-static Analysis", Technical Report-CE-STR-90-36, Purdue University Structural Engineering, 1990, pp. 1−44.