On Slope Slide Failure Induced Earthquake Waves

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Abstrsact

Sudden ground movements during an earthquake can induce significant inertia forces in a slope. The induced inertia forces alternate in direction and magnitude numerous times. Thus, the factor of safety of a slope may drop unity several times during an eartquake. As a result, some movements of faild section may be induced. Thus, the overall effect of an earthquake on a slope is the possible accumulation of displacements at the failed section. If the accumulated displacements exceed a certain limit, the slope may be considerd to have failed. Some results of model test are compared with the analytical solutions i this paper.

In a conventional engineering analysis of a slope failure against earthquake foces, the slope is usually analyzed with the calculation of factor of safety under a pseudo−static inertia force, presumably generated by an earthquake ground motion(1,3,4).If the factor of safety is less than unity,then the slope is considered unsafe.This is certainly true under static gravity loading conditions. However,under an earthquake loading,the reduction in factor of safety only exist for a very short period of time for which large inertia forces are induced.Further,during an earthquake,the induced inertia forces will also alternate in direction and magnitude numeros times, only those forces that exceed the failure limit of the slope will induce further displacements.All these driving forces will be rapidly removed at the end of an earthquke.The overall effect of an earthquake on the slope is therefore the accumulation of displacement at the failed section(7,9).If these accumulated displacements are sufficiently large,the slope maybe considered to have failed(9).To apply Newmark's concept,a failure mechanism and its corresponding yield acceleration must be determined first from which the ovrall displacements of a faied slope under a given earthquake can be assessed(6).The calculations of displacement under a given earthquake can best be achieved by the following steps:

1). Calculated the yield acceleration at which the slippage is just to occur.
2). Apply various values of pseude−static force to the slope. These values are obtained from a discretized accelerogram of an actual or simulated earthquake.
3). Once the yield acceleration and accelerogram of an earthquake are known, it is a simple matter to calculate the time history of velocity of the sliding soil mass of a given slope. The magnitude of the displacements can be evaluated by integrating all the positive velocity.

The computation of the yield acceleration based on the upper bound technique of limit analysis of perfect plasticity has been reported elsewhere(2,5,7). Based on this yield acceler-

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ation and its associated failtre mechanism, the equation of motion for the estimation of displacements along the potential local log−spiral failure surface can be formulated.

1 YIELD ACCELERATION FACTOR:Kc

Herein, we shall determine the critical or yield horizontal inertia force that corresponds to the yield acceleration factor Kc, at which a condition of incipient slope movement is possible along the potential sliding surface(2,5,8). The computation of the yield acceleration for the log

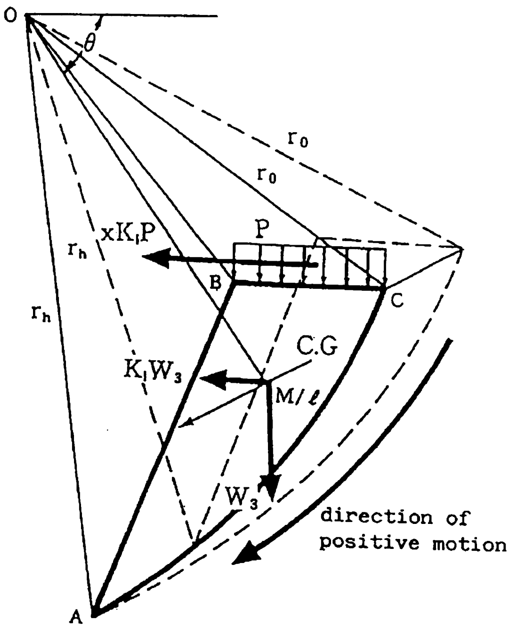


Fig. 1 Forces on a Sliding Block

−spiral failure mechanism shown in Fig. 1 is based on the following conditins :

1). Plain strain condition,
2). Upper bound technique of limit analysis of perfect plasticity,
3). Pseudo−static earthquake loading,
4). Uniform horizontal distribution of lateral acceleration,
5). The Morh−Coulomb failure criterion with constant cohesion c and internal fricetion angle ϕ, and
6). Homogeneous and isotropic slope.

2 EXAMPLE OF ACTUAL EARTHQUAKE

The inertia force, induced by the acceleration on the slope, tend to reduce the stability of a slope. Once the induced acceleration factor K reaches and exceeds the yield acceleration factor Kc, the slip the failure mechanism will occur.

The angular acceleration $\ddot{\theta}$, driving the sliding log−spiral failure mechanism, can be calculated. Referring to Fig. 1, for a given earthquake, we first find the positive angular acceleration $\ddot{\theta}$, and the angular velocity $\ddot{\theta}$, with which the downhill movement will begin at time t_i.

Based on this motion, angular accelerations and velocities between two time instants, e. g., t_i and t_{i+1}, the angular displacement of the failure section between t_i and t_{i+1}, thereby can be calculated as ;

$$\theta_{i+1}=\theta_i+\theta_i(t_{i-1}-t_i)+\frac{(2\ddot{\theta}_i+\ddot{\theta}_{i+1})(t_{i+1}-t_1)}{6}$$

Similar procedures can be performed to find the overall displacement until the end of a given earthquake. Details is shown (4, 5) clearly.

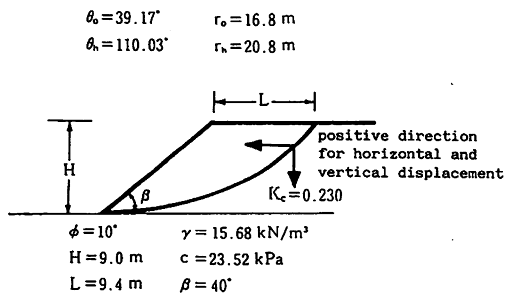


Fig. 2 Model of a Failure Mechanism

We select the earthquakes of Fig. 3 and 4 and determine the accelerationKG of the earthquake for the time of interest during the earthquake shaking, e. g., a constant of O. Olsec. may be chosen to designate the and subsequently estimate all the corresponding accelerations. Two diagrams of displacements versus time for the failure mechanism of Fig. 2 corresponding to the two actual earthquakes are given in Figs. 3 and 4.

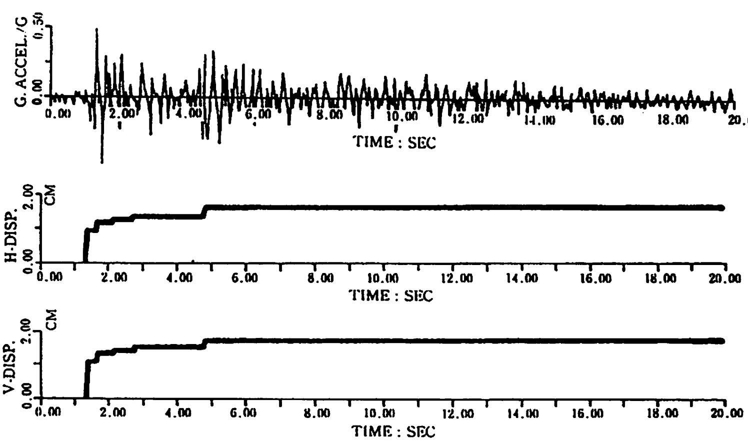


Fig. 3 Earthquake Waves – KAIHOKU BRIDGE LG.

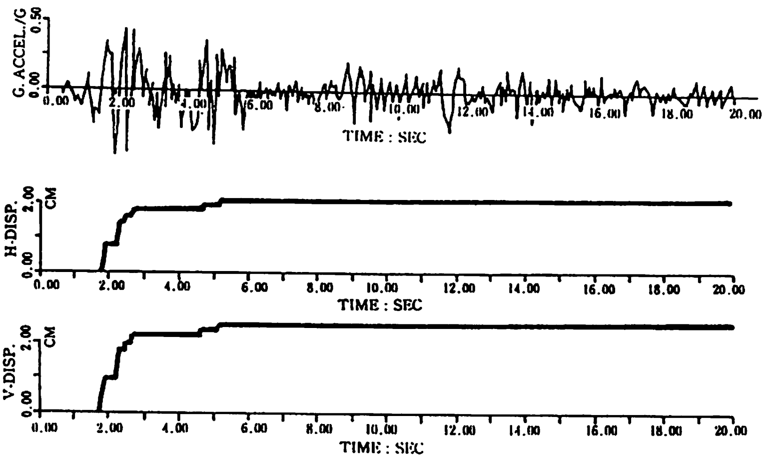


Fig. 4 Earthquake Waves－EL－CENTRO NS COMP.

As these two earthquakes have near area of power spectrum each other as shown in Figs. 5 and 6, also have near their periods (EL−CENTRO wave: 0.45 sec. KAIHOKE wave: 0.40 sec.) with their continuous time of main earthquake close to five seconds. Both accumulative displacements represent a nearly equal value.

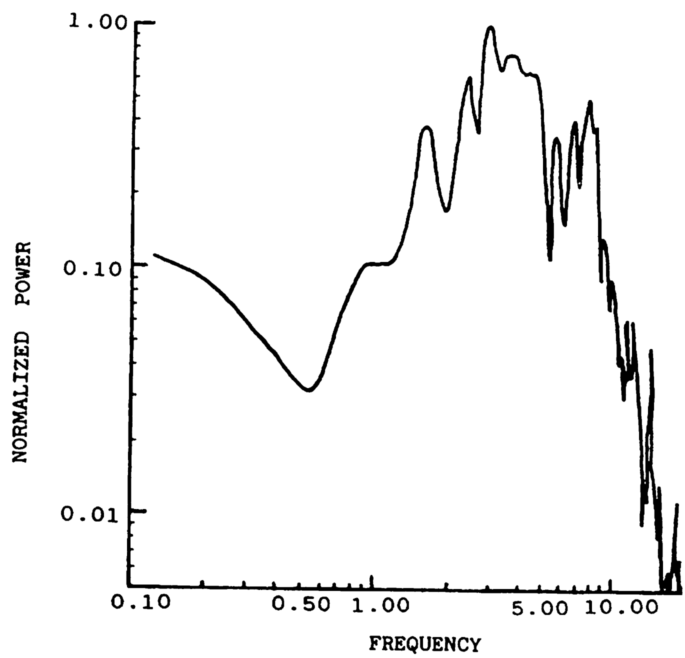


Fig. 5 Case of KAIHOKU BRIDGE LG.

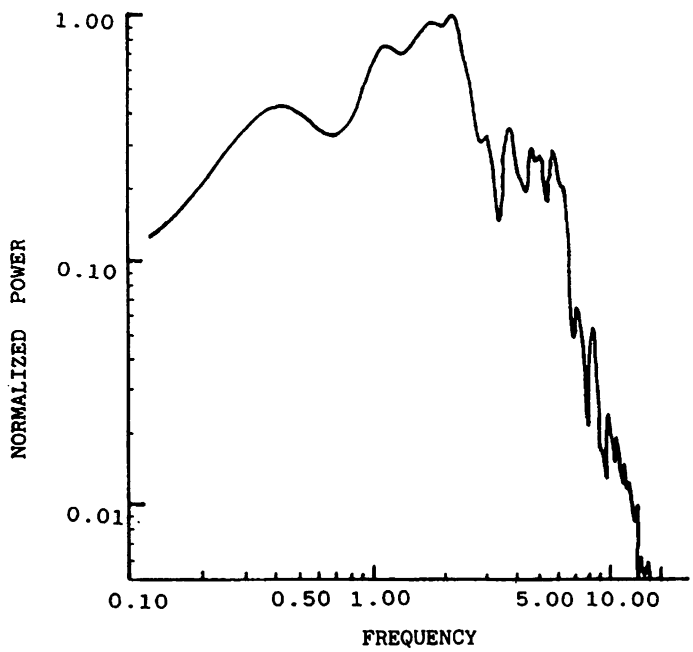


Fig. 6 Case of EL-CENTRO NS COMP.

3 MODEL EXPERIMENT

Herein, a model test of a collapsing slope induced by an earthquake isdescribed. This experiment is conducted to study the seismic yield acceleration factor, sliding displacement and velocity a sliding mass under a laboratory condition (Photo.1).

3 − 1 Material and instrumentation of the test

The material used in the test passed the sieve 2. 5mm, and mixed with a few silt and surface −dry condition. From the mono−face shearing test and specific gravity test, we determined internal friction angle $\phi = 36.03°$, choesion strength c=0. 055kg/cm² and specific gravity $\gamma = 2.64$ g/cm³. Using this material,we created the model slope in the box made from Acryl (40cm×40 cm×80cm). To see the behavior of seismic displacement and failure mechanism of the slope, we made stratums with line(about 5cm between the lines). (Photo.l) In this test, we equipped two sensors of acceleration.

One sensor is buried in the model slope and other is put in the acrylic−test box to measure the acceleration of external inertia force (Photo.1)

As for the earthquake waves, we use s nearly sine waves with 3 / 2 Hz period 0. 42G maximum acceleration. Thus, the signals are picked up by the sensors and measured through the dynamic strain meter.

We can therefore determine the yield acceleration of slope with records of ther data by a rapicorder. At the same time, we took the videotape of the seismic slope failure−experments. As a result, we are able to see the slipe displacement and slope failure mechanism with the videotape. In this way, real displacements can be calculated from posing replay pictures of video similar to the actual model.

Using video−replay−machine, we can calculate the enact displacements similar to that of posing pictures in the video tape, and find the interval times between scenes and the next scene by the machine, and measure the sliding velocity with these two factors.

By taking the photographs of each scene, we can clearly find failure mechanisms of the slope (Photo.2)

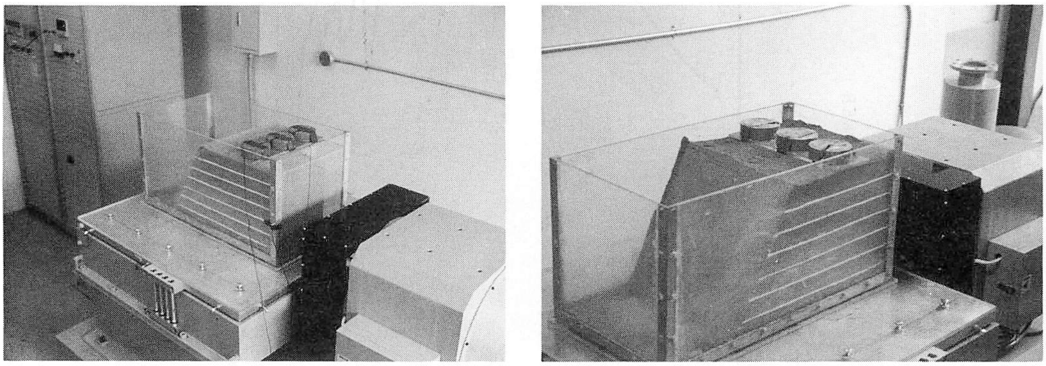
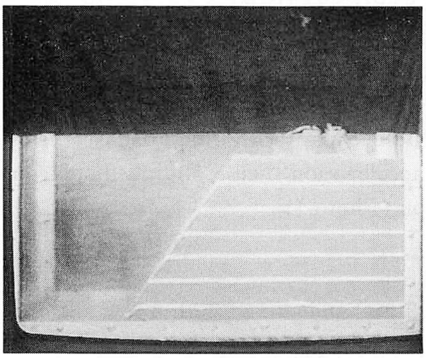


Photo 1 Model Test



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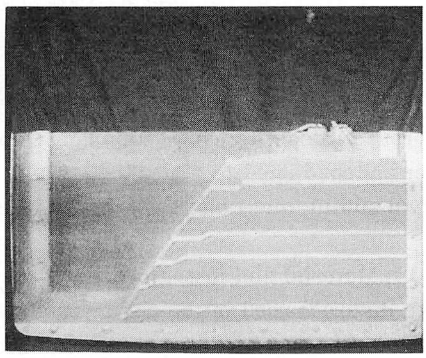
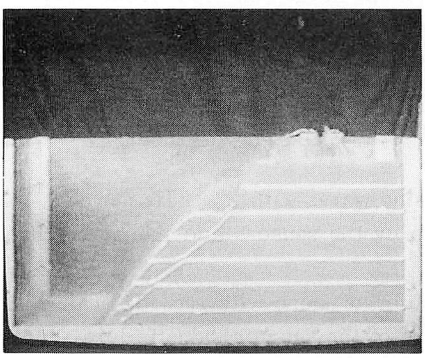


0. 1 second later



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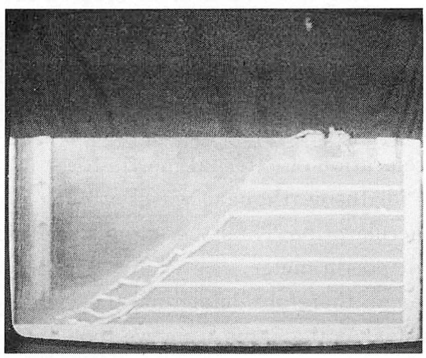

1.3 second later

Photo 2 An Example of Tasts.

3 − 2 Comparison of the test with numerical analysis

The tests (Table 2)and the numerical analysis (Table 1 and Fig.7)show a good agreement. Table 2 shows that accumulative displacement is about 13. 2cm after 1. 3sec. of collapse for the

Table 1 Comparing between Results of Model Test and Analytical Solution.

Time (sec)	Accumelation Displacement	
	Model Test	Analysis
0.10	3.5 cm	0.004 cm
0.50	10.6 cm	3.305 cm
1.00	12.2 cm	10.468 cm
1.30	12.9 cm	13.451 cm

case Kc=0. 204, β=60°, P= 6 kg and b=10cm. In Table 2, D_1 to D_4 or V_1 to V_4 are displacement s and velocities of each observing point of each line from the surcharge surface of the slope.

Table 2 Analytical Accumlation Slide Displacement.

KAIHOKU BRIDGE LG.Waves		EL- CENTRO NS.Waves	
H-Disp.	V-Disp.	H-Disp.	V-Disp.
1.98cm	1.89cm	2.08cm	2.11cm

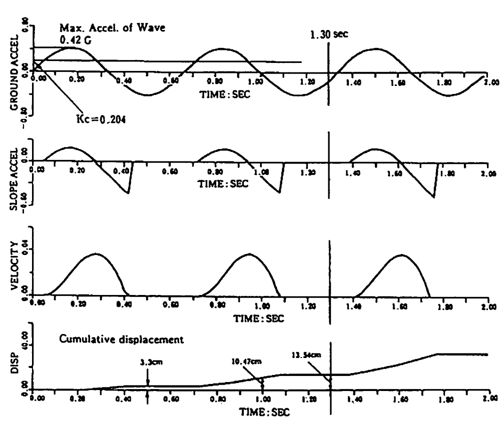

Fig. 7 Effect of Numerical Analysis.

Having almost the same displacement at each point,the slope reaches a collapse state after 1·3sec.from the start to the end.It is rather close to the theoretical analysis assuming a rigid body motion with a logarithmic spiral failure slide surface(Photo.2).Similarly,the numercal analysis by adding the displacements of two waves exceeding is also found to be 13·54cm (Table 1)·

Numercal results for the velocity have two peaks at the time of 0·24sec.and 0·92sec.when the rigid body starts to move(Fig.7). On the other hand,the test results have also two peaks(Table 2)·

Generally speaking,the experiments compare well with the present theoretical analysis.

4 SUMMARY AND CONCLUSIONS

The computational model developed in the present study is based is baded on a pseudo－static approach, not a dynamic analysis. However, the method doesinclude the actual timehistory of a earthquake tremor. In designing earth slope, one may either adopt a procedure in which the static resistance of the slope is always greater than the anticaipated maximud earthquake acceleration likely to occur, or one can estimate the slope stability in term of the accumulated displacements corresponding to a given earthquake computed by the method developed in (4, 5).

In some cases, it may be required to avoid permanent displacements altogether, that is, the yield acceleration must be well above the anticipated maximum earthquake accelration. This approach can be uneconomical for general use. Comparison of the model tests with the present numerical analysis give a good agreement.

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