The Researches of Landslide Stability Calculation in Earthquake Based on Time-histories Method

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Abstract. In this paper, the vibrative theory of variable cross-section shear beam in structure dynamics was used in the analysis of landslide stability. The displacement, velocity and acceleration of the landslide were calculated with Duhamel technique in which the earthquake curve was used. This method in our paper, realized the time-histories calculation of landslide stability. Undoubtedly, our analytical method was a kind of replenish and development to the calculation and analysis of landslide stability.

Introduction

This paper study the stability calculation of landslides during the earthquake time history method involves the soil dynamics, structural dynamics and nonlinear vibration theory, earthquake engineering, geotechnical and structural aseismic engineering, computational mechanics and computer programming technology, and many other disciplines, which is a multiple discipline study [1]. To now, the static stability analysis of landslide has been mature, but the seismic stability analysis of rock and soil landslide is related to many fields can be said a fledgling [2], so geotechnical earthquake landslide stability research importance and urgency, the current research methods mainly include analytical method, numerical simulation method, experimental method, etc. In this paper, the author uses the theory of structural dynamics to analyze seismic stability of landslide [3, 4, 6, 7, 8, 9], and to do a lot of supplementary work.

Slope Lateral Seismic Response Calculation

In this paper, the structure of the kinetic theory only considers the effect of shear deformation and bending deformation is negligible. Slope body generally belong to short and bold, to be calculated on shear wedge to be appropriate.

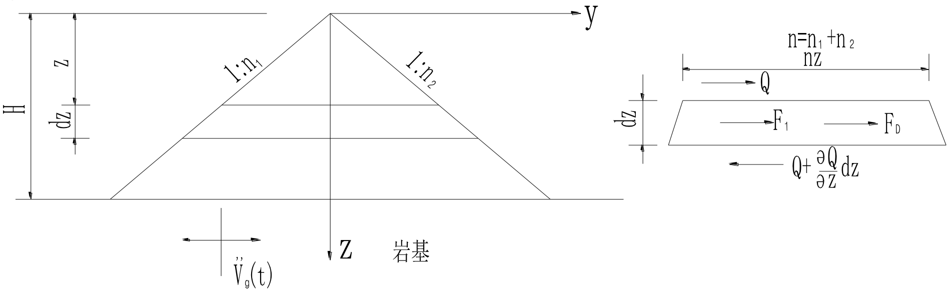


Fig. 1 The Calculation Figure of Vibration Theory

Shear wedge method to calculate the slope body transverse seismic response of the basic assumption that a total of four:

(1) The slope body for triangular cross-section (figure 1), longitudinal slope long take a unit thickness calculation;

(2) The slope body foundation for rigid foundation, the slope body underside of seismic time history input in each point is the same;

(3) Only considers the horizontal shear motion caused by earthquake, and any horizontal plane shear stress distribution;

(4) The shear modulus is constant or along the elevation changes according to certain rule.

As shown in figure 1, the establishment of motion differential equations, according to the section of horizontal force equilibrium condition of microstrip, as a one-dimensional problem.

Shear Wedge Method Formula is Derived

Set high slope body as shown in figure 1, left and right side slope gradient is 1:1 and 1:2, amounted to slope rate = 1 + 2, any height took out a small article on force analysis, horizontal shear displacement, shear strain, the height of the microstrip, width is, micro article by force.

At the top of the shear
$$Q = G\gamma nz = G\frac{\partial \upsilon}{\partial z}nz$$

At the bottom of the shear $Q + \frac{\partial Q}{\partial z}dz = G\frac{\partial \upsilon}{\partial z}nz + Gn(z\frac{\partial^2 \upsilon}{\partial z^2} + \frac{\partial \upsilon}{\partial z})dz$

Article on the inertia force of the earthquake $F_1 = \rho nzdz\left[\frac{\partial^2 \upsilon}{\partial t^2} + \ddot{\upsilon}_g(t)\right]$

Article on the damping force of earthquake $F_D = cnzdz\frac{\partial \upsilon}{\partial t}$

P, the density of the slope body;

C, damping coefficient, c=2 $\rho\lambda\omega$, here is not equal to $2m\lambda\omega$, because of damping force is multiplied by the volume $nzdz$;

G - shear modulus;

$\ddot{\upsilon}_g(t)$-slope bottom (rock) surface level to the input earthquake acceleration.

Based on force equilibrium condition, the equations of motion

$$\frac{\partial^2 \upsilon}{\partial t^2} + 2\lambda\omega\frac{\partial \upsilon}{\partial t} - \frac{G_0}{\rho H^{\frac{1}{2}}}\left(z^{\frac{1}{2}}\frac{\partial^2 \upsilon}{\partial z^2} + \frac{3}{2}z^{-\frac{1}{2}}\frac{\partial \upsilon}{\partial z}\right) = -\ddot{\upsilon}_g(t) \quad (1)$$

From the equation, the vibration of the slope body and has nothing to do. For when the slope body is constant, below the hill body vibration analytical solution is derived simple process.

Seismic Response Calculation

Using the modal superposition method for displacement response is as follows

$$\upsilon = \sum_1^{\infty} J_0\left(\beta_0\frac{z}{H}\right)\frac{-\eta}{\omega'}\int_0^t \ddot{\upsilon}_g(\tau)e^{-\lambda\omega(t-\tau)}\sin\omega'(t-\tau)d\tau \quad (2)$$

Among them

$$\eta = \frac{2}{\beta_0 J_1(\beta_0)}, \quad \omega = \frac{\beta_0}{H}\upsilon_s, \quad \omega' = \frac{\beta_0}{H}\upsilon_s\sqrt{1-\lambda^2}$$

Actual calculation, the type (24) just before 3 ~ 4 the sum, namely before 3 ~ 4 order vibration mode, carry on the linear superposition. Duhamel integral by the earthquake acceleration time history curve of numerical integral method.

Check Bessel function table will be the first class of first order Bessel function of zero root by literature [5] can get 9 zero root, as shown in table 3. 6 before the first kind of first-order Bessel function values are shown in table 4[5].

Response to the displacement of the partial derivatives with respect to time t to get reaction speed, as follows

$$\frac{\partial \upsilon}{\partial t}=\sum_{1}^{\infty} J_0\left(\beta_0 \frac{z}{H}\right)\left[-\eta\int_0^t \ddot{\upsilon}_g(\tau)e^{-\lambda\omega(t-\tau)}\cos\omega'(t-\tau)d\tau-\lambda\omega Y\right] \tag{3}$$

Response to displacement second order partial derivatives with respect to time t to get acceleration response, as follows

$$\frac{\partial^2 \upsilon}{\partial t^2}=-\ddot{\upsilon}_g(t)+\sum_{1}^{\infty} J_0\left(\beta_0 \frac{z}{H}\right)\eta\left[\frac{(1-2\lambda^2)\omega}{\sqrt{1-\lambda^2}}\int_0^t \ddot{\upsilon}_g(\tau)e^{-\lambda\omega(t-\tau)}\sin\omega'(t-\tau)d\tau+2\lambda\omega\int_0^t \ddot{\upsilon}_g(\tau)e^{-\lambda w(t-\tau)}\cos\omega'(t-\tau)d\tau\right] \tag{4}$$

Absolute acceleration response

$$\frac{\partial^2 \upsilon}{\partial t^2}+\ddot{\upsilon}_g(t)=\sum_{1}^{\infty} J_0\left(\beta_0 \frac{z}{H}\right)\eta\left[\frac{(1-2\lambda^2)\omega}{\sqrt{1-\lambda^2}}\int_0^t \ddot{\upsilon}_g(\tau)e^{-\lambda\omega(t-\tau)}\sin\omega'(t-\tau)d\tau\right.$$

$$\left.+2\lambda\omega\int_0^t \ddot{\upsilon}_g(\tau)e^{-\lambda w(t-\tau)}\cos\omega'(t-\tau)d\tau\right] \tag{5}$$

The displacement response of partial derivatives get shear strain response, as follows

$$\gamma=\frac{\partial \upsilon}{\partial z}=\frac{2}{H}\sum_{1}^{\infty}\frac{J_1\left(\beta_0 \frac{z}{H}\right)}{\omega' J_1(\beta_0)}\int_0^t \ddot{\upsilon}_g(\tau)e^{-\lambda\omega(t-\tau)}\sin\omega'(t-\tau)d\tau \tag{6}$$

Shear stress response

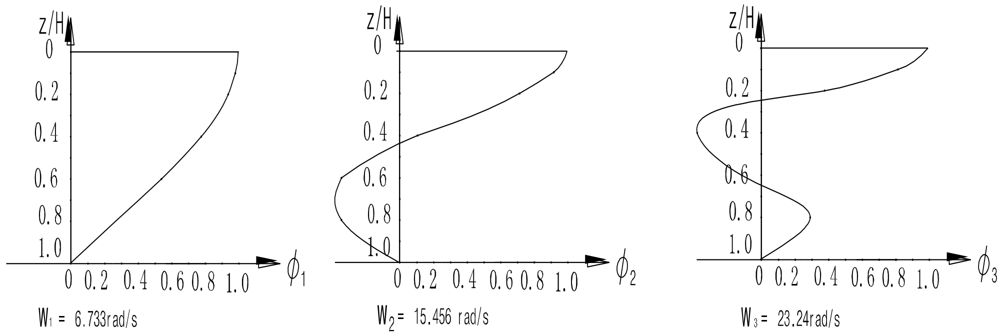
$$\tau=G\gamma \tag{7}$$

Above all, the general limited item mode (3 ~ 4).

Calculating Engineering Examples

One Slope Body (rock mass)H=150m, $z=H$, $V_S=420$m/s. Slope rock mass is assumed to be the uniform linear elastic. Quality of landslide is divided into five pieces, $m_1=m_2=m_3=m_4=m_5$, The focus of each piece of the distance from the top coordinates are $z_1=60m$, $z_2=57m$, $z_3=54m$, $z_4=51m$, $z_5=48m$, f=0.70. The minimum safety factor is for the vibration of the slope deformation and landslide.

$$K=\frac{\tan\phi}{\tan\alpha}=\frac{0.70}{0.577}=1.213$$



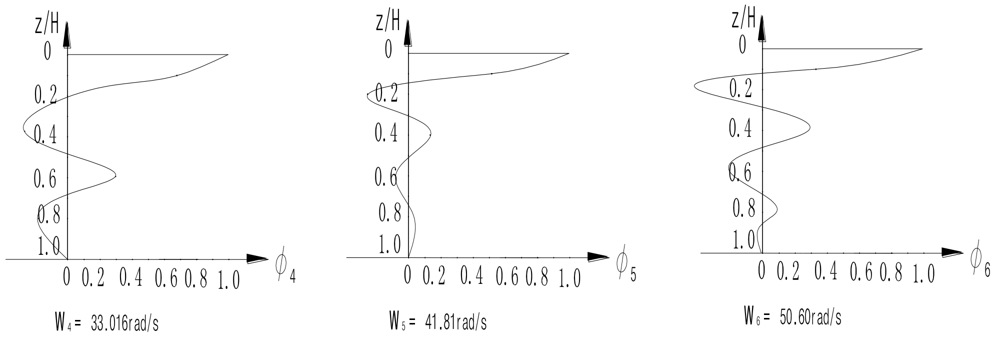


Fig. 2 The Vibration-mode Figure

Seismic Response Calculation

In the actual engineering calculation form [3], the vibration mode just need the before 3 ~ 4. Duhamel integral by the earthquake acceleration time history curve calculated using the numerical integral method. For instance, this paper before we take 6 order vibration modes to calculate.

(1)Integral Calculation of $S_1 \sim S_6$, for example:

$$S_1 = \int_0^t \ddot{\upsilon}_g(\tau)\frac{e^{0.33667\tau}}{e^{0.33667t}}(\sin 6.7334t\cos 6.7332\tau - \cos 6.7334t\sin 6.7334\tau)d\tau$$
$$= A(t)\sin\omega t - B(t)\cos\omega t$$

In the above formula:

$$A(t) = \int_0^t \ddot{\upsilon}_g(\tau)\frac{\exp(\lambda\omega_n\tau)}{\exp(\lambda\omega_n t)}\cos\omega_n\tau d\tau = \int_0^t \ddot{\upsilon}_g(\tau)\frac{e^{\lambda\omega_n\tau}}{e^{\lambda\omega_n t}}\cos\omega_n\tau d\tau$$

$$B(t) = \int_0^t \ddot{\upsilon}_g(\tau)\frac{\exp(\lambda\omega_n\tau)}{\exp(\lambda\omega_n t)}\sin\omega_n\tau d\tau = \int_0^t \ddot{\upsilon}_g(\tau)\frac{e^{\lambda\omega_n\tau}}{e^{\lambda\omega_n t}}\sin\omega_n\tau d\tau$$

(2)Acceleration Response Calculation of the Slope Body

This paper includes examples and practical projects, interested in the absolute acceleration $\ddot{\upsilon}(t) + \ddot{\upsilon}_g(t)$ of hillside body, which can be obtained directly from the solution type of hillside displacement.

Currently structure dynamic response analysis methods mainly include time domain analysis (Duhamel integral method) and the frequency domain analysis method (Fourier transform method) under arbitrary loading.

(3)Computed Result

By calculation, the safety factor of rock landslide is 0.93.

Conclusion

(1)In this paper, we combined the vibration of earth rockfill dam theory [3] with variable cross-section rod vibration theory of structural dynamics [4], which is used for slope dynamic time history analysis of the seismic reaction of the body, and calculated the minimum safety factor of rock landslide.

(2)As can be seen from the calculation process, when the relationship between the stress-strain of slope body (constitutive model) is a line of elastomer(E, μ are constant), the seismic time history response of slope body only related to the height of the slope body.When earthquake deformation is small, the results using the linear elastic theory should be reasonable, but on the contrary, the results obtained by the theory needing laboratory and field observation.

(3)The earthquake acceleration time history curve of this paper is taken from literature [9]. If we convert this acceleration curve data to velocity-time curve, as the inputs of the Domain Integral analysis, solution of the problem will become much simpler. If we transfrom the acceleration curve data into the displacement time history curve, as the seismic time history input of time domain integral analysis, solution of the problem will become much easier.

(4)Time domain analysis method according to the literature [3] instance, only 3 to 4 modal superposition can meet the requirements of engineering precision, and this paper has calculated six modes.

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