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Design of earth retaining structures and tailing dams under static and seismic conditions

S S. Nimbalkar
University of Wollongong, sanjayn@uow.edu.au

D Choudhury
Indian Institute Of Technology, dc@civil.iitb.ac.in

In this paper the seismic active earth pressure is determined by using pseudo-dynamic method. Mononobe-Okabe method by pseudo-static approach gives the linear distribution of seismic earth pressure behind retaining wall in an approximate way. A rigid vertical retaining wall supporting cohesionless backfill material with horizontal ground has been considered in the analysis with planar rupture surface. Results highlight the non-linearity of seismic earth pressures distribution. Applications of pseudo-dynamic method for stability assessment of gravity dams and tailing dams are presented. A new simplified method to include soil arching effect on determination of earth pressures is also proposed.

DESIGN OF EARTH RETAINING STRUCTURES AND TAILING DAMS UNDER STATIC AND SEISMIC CONDITIONS

S. S. Nimbalkar[1], D. Choudhury[2]

ABSTRACT

The estimation of static and seismic earth pressures is extremely important in geotechnical design. The conventional Coulomb's approach and Mononobe-Okabe's approach have been widely used in engineering practice. However the latter approach provides the linear distribution of seismic earth pressure behind retaining wall in an approximate way. Therefore, the pseudo-dynamic method can be used to compute the distribution of seismic active earth pressure in more realistic manner. Effect of both the wall and soil inertia must be considered for the design of retaining wall under seismic conditions. In this paper, by considering pseudo-dynamic seismic forces acting on the soil wedge and the wall, the required weight of the wall under seismic conditions is determined for the design purpose of the retaining wall under active earth pressure condition. The method proposed considers the movement of both shear and primary waves through the backfill and the retaining wall due to seismic excitation.

Seismic stability of tailings dams and embankments is an important topic which needs the special assessments by the researchers. The crude estimate of finding the approximate seismic acceleration makes the pseudo-static approach too conservative to adopt in the stability assessment. In this paper, pseudo-dynamic method of analysis is used to compute the seismic inertia forces acting on the sliding wedge of the tailings dam by considering the effects of time of seismic accelerations, phase differences in the propagating shear and primary waves in the soil during an earthquake, frequency of earthquake excitation etc. with the horizontal and vertical seismic accelerations.

The predictions of the active earth pressure using Coulomb theory are not consistent with the laboratory results, to the development of arching in the backfill soil. A new method is proposed to compute the active earth pressure acting on the backface of a rigid retaining wall undergoing horizontal translation. Effect of soil arching for cohesive backfill soil as well as friction mobilized along wall-soil interface is considered. The theoretical formulae for determining the distribution of active earth pressure and active thrust are derived. The predictions of the proposed method are verified against results of laboratory tests as well as the results from other methods proposed in the past. The results show that the proposed method yields satisfactory results (Figure 1).

[1]Research Fellow, Centre for Geomechanics and Railway Engineering, Centre for Geomechanics and Railway Engineering, Faculty of Engineering and Information Sciences, University of Wollongong, Wollongong, Australia, sanjayn@uow.edu.au

[2]Professor, Department of Civil Engineering, Indian Institute of Technology Bombay, IIT Bombay, Powai, Mumbai – 400 076, India. and, Adjunct Professor, Academy of Scientific and Innovative Research (AcSIR), CSIR – OSDD Unit, New Delhi, India and CSIR – Central Building Research Institute (CBRI), Roorkee, India, dc@civil.iitb.ac.in

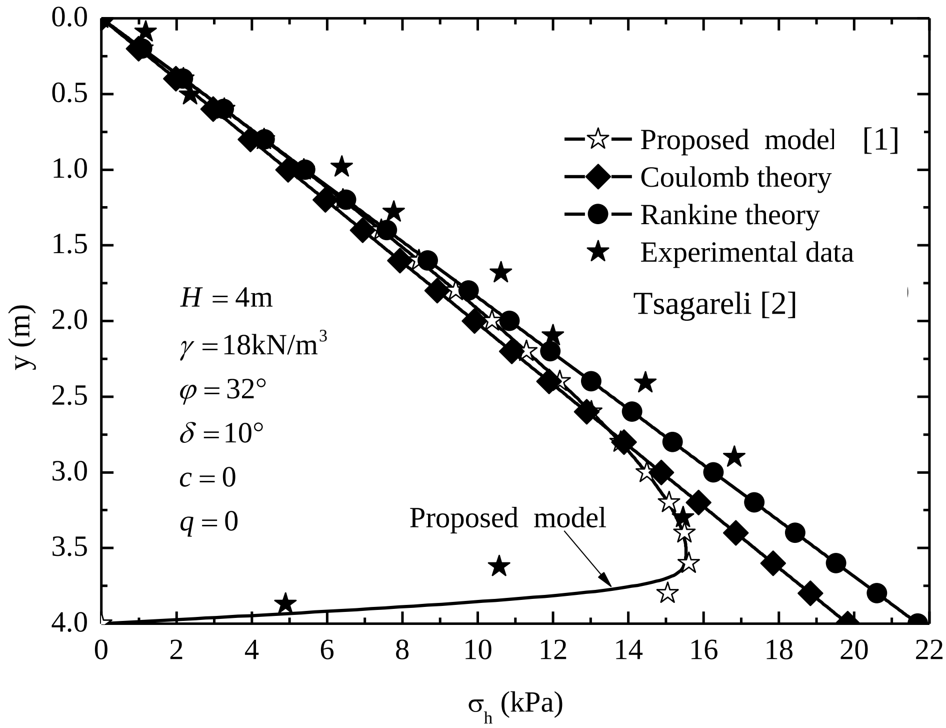

Figure 1. Comparison between predicted and experimental data ([1], With permission from ASCE)

In this paper, design approaches of earth retaining structures including dams and tailing dams are presented. Novel applications of the pseudo-dynamic method are discussed.

Keywords: Soil-structure interaction, Earth pressure, Seismic stability, Pseudo-dynamic method, Time dependence, Safety factors

References:

1. Rao, P., Chen, Q., Zhou, Y., Nimbalkar, S. and Chirao, G. (2015), Determination of active earth pressure on rigid retaining wall considering arching effect in cohesive backfill soil, *International Journal of Geomechanics, ASCE* doi: 10.1061/(ASCE)GM.1943-5622.0000589.
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DESIGN OF EARTH RETAINING STRUCTURES AND TAILING DAMS UNDER STATIC AND SEISMIC CONDITIONS

S. S. Nimbalkar, Research Fellow, University of Wollongong, Australia, email: sanjayn@uow.edu.au
D. Choudhury, Professor, Indian Institute of Technology Bombay, India, email: dc@civil.iitb.ac.in

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INTRODUCTION

Study of dynamic active earth pressure is essential for the safe design of retaining wall in the seismic zone. As pioneering work in this area, the theory of dynamic lateral earth pressure based on pseudo-static analysis was proposed, commonly known as Mononobe-Okabe method [1,2]. But this method using pseudo-static approach gives the seismic active earth pressure value in a very approximate way. To Rectify the shortcomings of the pseudo-static approach, a pseudo-dynamic method has been recently developed to address this problem [3-5]. Effects of both the horizontal and vertical seismic accelerations can be considered to provide more realistic results [6-9].

In one of pioneer studies [10], soil arching was also found to affecting the nonlinear distribution of the active earth pressure acting on the rigid walls in contrast to the assumption made by both Coulomb [11] and Rankine [12] theories. A method for calculating the active earth pressures assuming Coulomb slip was proposed [13]. The seismic active earth pressure acting on the retaining walls were evaluated using the pseudo static [14], more recent pseudodynamic [4,6,15-17] as well as modified pseudodynamic methods of analyses [18]. However, none of these studies considered the stress trajectory caused by soil arching effect, a common phenomenon in geotechnical engineering.

The design and behavior of retaining wall under seismic conditions is very complex and many researchers have discussed on this topic. A classical seismic design method by using Mononobe-Okabe method for the design of earth retaining structures [19]. Caltabiano et al. [20] determined the seismic stability of retaining wall with surchage using Mononobe-Okabe method along with the soil-wall inertia effect by considering pseudo-static seismic acceleration in horizontal direction. Although several researchers in the past highlighted the limitations and drawbacks of the pseudo-static approach, there are very limited studies being reported worldwide for the seismic stability assessment of dams and embankments.

Seismic stability of tailings dams and embankments is an important topic which needs the special treatment by researchers as it is mainly governed by the safety concerns. Many researchers in the past have attempted to investigate the seismic stability of dams and embankments by using pseudo-static method of analysis. Semi empirical stability charts [21] are often used to obtain a preliminary estimate of the permanent, earthquake induced deformation of earth dams and embankments.

In recent past, methods for determination of active earth pressure considering the soil arching effects have been proposed [22,23]. However, these methods were limited to non-cohesive soils. Considering this, a simplified method for calculating the active earth pressure acting on a rigid retaining wall undergoing translation is proposed.

PSEUDO-DYNAMIC METHOD

Consider the fixed base vertical cantilever wall of height H as shown in Fig. 1. The wall is supporting a cohesionless backfill material with horizontal ground. The shear wave and primary wave are assumed to act within the soil media due to earthquake loading. For most geological materials, $V_p/V_s = 1.87$ [24]. The period of lateral shaking, $T = 2\pi/\omega$, where ω is the angular frequency is considered in the analysis. Consider a planer rupture surface inclined at an angle, α with the horizontal.

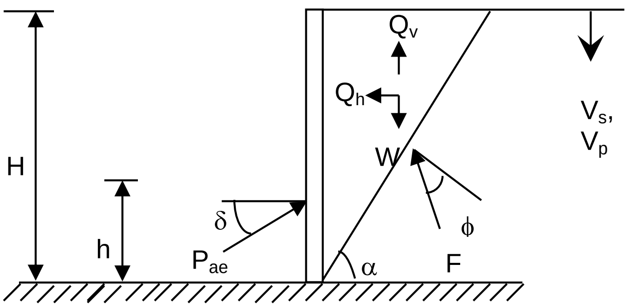

Fig. 1 Model retaining wall considered for computation of pseudo dynamic active earth pressure

Let us assume that the base of the wall is subjected to harmonic horizontal seismic acceleration of amplitude $a_h g$, and harmonic vertical seismic acceleration of amplitude $a_v g$, where g is the acceleration due to gravity.

The acceleration at any depth z and time t, below the top of the wall can be expressed as,

$$a_h(z,\ t) = \mathrm{a_h} \sin\left[t - \frac{H-z}{V_s}\right] \tag{1}$$

$$a_v(z,\ t) = \mathrm{a_v} \sin\left[t - \frac{H-z}{V_p}\right] \tag{2}$$

The mass of an elemental wedge at depth z is

$$m(z) = \frac{\gamma}{\mathrm{g}} \frac{H-z}{\tan\alpha} dz \tag{3}$$

where, γ is the unit weight of the backfill. The total horizontal inertial force acting within the failure zone can be expressed as,

$$Q_h(t) = \int_0^H \mathrm{m(z)a_h(z,\ t)dz}$$

$$= \frac{\lambda\ \gamma\ a_h}{4\pi^2 g \tan\alpha}\left[2\pi \mathrm{H}\cos w\zeta + \lambda(\sin w\zeta - \sin wt)\right] \tag{4}$$

where, $\lambda = TV_s$ is the wavelength of the vertically propagating shear wave and $\zeta = t - H/V_s$. And, total vertical inertial force acting within the failure zone can be expressed as,

$$Q_v(t) = \int_0^H \mathrm{m(z)a_v(z,\ t)dz}$$

$$= \frac{\eta\ \gamma\ a_v}{4\pi^2 g \tan\alpha}\left[2\pi \mathrm{H}\cos\omega\psi + \eta(\sin\omega\psi - \sin\omega t)\right] \tag{5}$$

where, $\eta = TV_p$, is the wavelength of the vertically propagating primary wave. And $\psi = t - H/V_p$. The total (static plus dynamic) active thrust can be obtained by resolving forces on the wedge and can be expressed as,

$$P_{ae}(t) = \frac{W\sin(\alpha-\phi) + Q_h(t)\cos(\alpha-\phi) - Q_v(t)\sin(\alpha-\phi)}{\cos(\delta+\phi-\alpha)} \tag{6}$$

The seismic active earth pressure distribution can be obtained by differentiating the total active thrust as,

$$p_{ae}(t) = \frac{\partial P_{ae}(t)}{\partial z} = \frac{\gamma\ \mathrm{z}}{\tan\alpha}\frac{\sin(\alpha-\phi)}{\cos(\delta+\phi-\alpha)} + \frac{k_h \gamma z}{\tan\alpha}\frac{\cos(\alpha-\phi)}{\cos(\delta+\phi-\alpha)}\sin\left[w\left(t-\frac{z}{V_s}\right)\right] - \frac{k_v \gamma z}{\tan\alpha}\frac{\sin(\alpha-\phi)}{\cos(\delta+\phi-\alpha)}\sin\left[w\left(t-\frac{z}{V_p}\right)\right] \tag{7}$$

Results and Discussion

In the case of cohesionless soils, to avoid the phenomenon of shear fluidization for the certain combinations of k_h and k_v [25] the values of ϕ considered in the analysis are to satisfy the relationship given by,

$$\phi \succ \tan^{-1}\left[\frac{k_h}{1-k_v}\right] \tag{8}$$

Fig. 2 shows the comparison of normalized pressure distribution behind rigid retaining wall obtained by the present study with that by Mononobe-Okabe method. It reveals nonlinear seismic active earth pressure distribution behind retaining wall in a more realistic manner compared to the pseudo-static method.

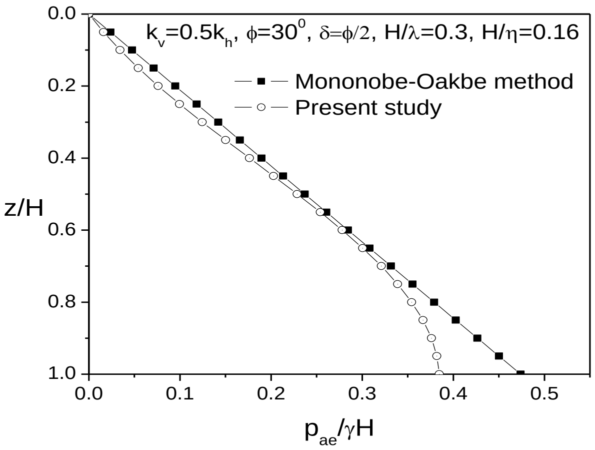

Fig. 2 Comparison of results for $k_v = 0.5k_h$, $\phi = 30^0$, $\delta = \phi/2$, $H/\lambda = 0.3$, $H/\eta = 0.16$

SEISMIC STABILITY OF DAMS

In this section, pseudo-dynamic method is applied for the seismic design of the retaining wall with respect to the stability of the wall against sliding, by considering both the soil and wall inertia effect due to both shear and primary waves propagating through both the backfill and the wall with time variation.

Consider the rigid vertical gravity wall of height H and width b_w, supporting horizontal cohesionless backfill. Using D'Alembert's principle [26] for inertial forces acting on the wall,

$$N_b = P_{ae}(t)\sin\delta + W_w(t) - Q_{vw}(t) \tag{9}$$

$$F_b = P_{ae}(t)\cos\delta + Q_{hw}(t) \tag{10}$$

where, N_b and F_b are the normal and tangential components of the reaction at the base of the wall respectively.

At sliding [27],

$$F_b = N_b \tan\phi_b \tag{11}$$

where, ϕ_b is the friction angle at the base of the wall. Thus,

$$\begin{aligned} &P_{ae}(t)\cos\delta + Q_{hw}(t) \\ &= \left[P_{ae}(t)\sin\delta + W_w(t) - Q_{vw}(t)\right]\tan\phi_b \end{aligned} \tag{12}$$

Weight of the wall is given by,

$$W_w(t) = P_{ae}(t) C_{IE}(t) \tag{13}$$

where, $C_{IE}(t)$ is the dynamic wall inertia factor given by,

$$\begin{aligned} C_{IE}(t) &= \frac{\cos\delta - \sin\delta\tan\phi_b}{\tan\phi_b} \\ &+ \frac{Q_{hw}(t) + Q_{vw}(t)\tan\phi_b}{P_{ae}(t)\tan\phi_b} \end{aligned} \tag{14}$$

The relative importance of the two dynamic effects (i.e., the increased seismic active thrust on the wall due to pseudo-dynamic soil inertia forces on the sliding wedge and the increase in driving force due to time dependent inertia of the wall itself) can be seen by normalizing them with regard to the static values. Thus defining soil thrust factor, F_T as

$$F_T = \frac{K_{ae}}{K_a} \tag{15}$$

and wall inertia factor, F_I as

$$F_I = \frac{C_{IE}(t)}{C_I} \tag{16}$$

where,

$$C_I = \frac{\cos\delta - \sin\delta\tan\phi_b}{\tan\phi_b}$$

Considering the product of the soil thrust and wall inertia factors as a safety factor applied to weight of the wall to consider both the effects of soil inertia and wall inertia, the combined dynamic factor, F_w proposed for the design of the wall is defined as,

$$F_w = F_T F_I = \frac{W_w(t)}{W_w} \tag{17}$$

where, W_w is the weight of the wall required for equilibrium against sliding under static condition.

Results and Discussions

Fig. 3 shows variation of combined dynamic factor, F_w with k_h for different values of vertical seismic acceleration coefficient (k_v). From the plot, it may be seen that the combined dynamic factor, F_w increases with the increase in vertical seismic acceleration. For k_h = 0.2, F_w increases by 15 % when k_v changes from 0 to 0.5k_h and 14 % when k_v changes from 0.5k_h to k_h. Though usually the effect of vertical seismic acceleration on stability of retaining wall is hardly considered in the analysis by many researchers, but the present study reveals the significant influence of vertical seismic acceleration on the stability of retaining wall.

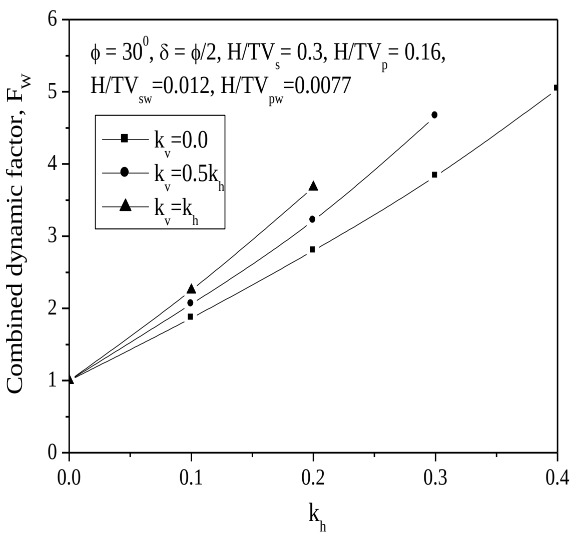

Fig. 3 Effect of vertical seismic acceleration coefficient (k_v) on combined dynamic factor, F_w

SEISMIC STABILITY OF TAILING DAMS

In this section, the seismic stability of the tailings dam by using horizontal slice method considering pseudo-dynamic inertia forces along with other seismic input parameters.

Proposed Analytical Model

The tailings dam, of height H, supporting the compacted tailings overlaid by tailings pond is shown in Fig. 4. The phase of both the horizontal and vertical seismic accelerations are varying along the depth of the dam.

The total horizontal inertia force $q_{hi}(t)$ acting on the ith slice can be expressed as,

$$q_{hi}(z,t) = m_i(z).a_h(z,t) \tag{18}$$

Again, the total vertical inertia force (q_{vi}) acting on the ith slice can be expressed as,

$$q_{vi}(z,t) = m_i(z).a_v(z,t) \tag{19}$$

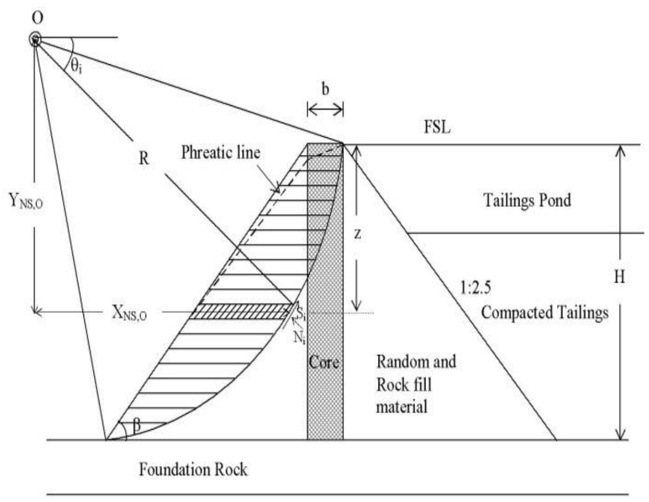

Fig. 4 Tailings dam section considered in the analysis

Detailed mathematical treatment of $q_{hi}(t)$ and $q_{vi}(t)$ can be found elsewhere [8,9]. Similar to the 2N+1 formulation [28], equilibrium equations can be written as

$\sum F_y = 0$ (for each slice) gives

$$V_{i+1} - V_i - W_i - q_{vi} + S_i \sin\alpha_i + N_i \cos\alpha_i = 0 \tag{20}$$

where, V_i and V_{i+1} are vertical inter-slice forces calculated by integration of overburden pressures on horizontal border of slice.

Again, $\tau_r = \frac{\tau_f}{FS}$ (for each slice) yields

$$S_i = \frac{1}{FS}\left(cb_i + N_i \tan\phi\right) \tag{21}$$

Substituting for S_i from equation (21) into equation (20),

$$N_i = \frac{V_i - V_{i+1} + W_i + q_{vi}(z,t) - \frac{cb_i}{FS}\sin\alpha_i}{\frac{\tan\phi}{FS}\sin\alpha_i + \cos\alpha_i} \qquad (22)$$

$\sum M_O = 0$ (for the whole wedge)

$$\sum_{i=1}^{m}\begin{bmatrix} q_{hi}(z,t)\left(Y_{G,O1} + R\sin\theta_i\right) \\ -\left(W_i + q_{vi}(z,t)\right)\left(X_{G,O1} + R\cos\theta_i - l_i\right) \\ -\left(S_i\sin\alpha_i + N_i\cos\alpha_i\right)\left(X_{NS,O}\right) \\ -\left(S_i\cos\alpha_i - N_i\sin\alpha_i\right)\left(Y_{NS,O}\right) \end{bmatrix} = 0 \qquad (23)$$

Here, the assumption is made that the normal (N_i) and shear (S_i) forces act at the mid-point of base of each slice and thus,

$$\left.\begin{aligned} X_{NS,O} &= R\cos\theta_i - \frac{h_i}{2\tan\alpha_i} \\ Y_{NS,O} &= R\sin\theta_i + \frac{h_i}{2} \end{aligned}\right\} \qquad (24)$$

Substitute S_i and N_i in equation (23) to obtain the factor of safety (FS). The slip circle is assumed as circular in this analysis for the sake of simplicity.

Results and Discussion

The values of factor of safety for tailings dam are reported for both the tailings pond empty and full water conditions.

Fig. 5 shows the effects of both horizontal and vertical seismic acceleration coefficients (k_h and k_v) on factor of safety (FS) for tailings dam empty and full water condition respectively. It is evident from Fig. 5 that, the required value of FS shows significant decrease with increase in horizontal and vertical seismic acceleration coefficients (k_h and k_v).

Referring to the tailings dam empty condition, for $k_v = 0.5k_h$, when k_h changes from 0 to 0.1, required factor of safety (FS) of decreases by about 22.6%. Also when k_h changes from 0.1 to 0.2, required factor of safety (FS) decreases by about 21.5%. Similarly when k_h changes from 0.2 to 0.3, required factor of safety (FS) decreases by about 21%. Also for $k_h = 0.2$, when k_v changes from 0 to $0.5k_h$, the required factor of safety (FS) decreases by about 6.2% and when k_v changes from $0.5k_h$ to $1.0k_h$, required factor of safety (FS) decreases by about 8%.

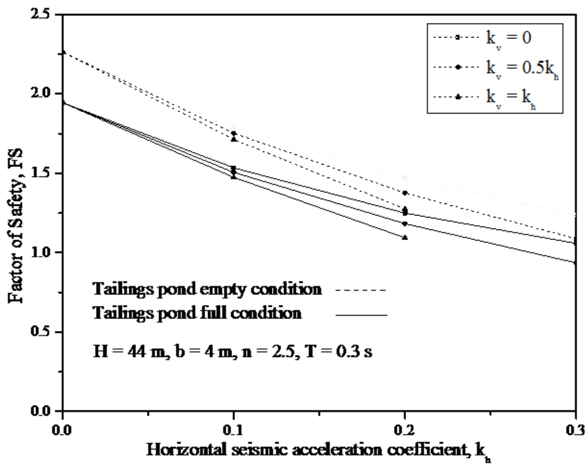

Fig. 5 Effect of horizontal and vertical seismic acceleration coefficients on factor of safety, FS

Similar trend is observed for the tailing dam full water condition. Thus, effects of both horizontal and vertical seismic acceleration coefficients (k_h and k_v) are significant in the computation of stability of the tailings dam. The results reported in the present paper are compared with the pseudo static based slope stability analysis of the tailings dam. Figure 6 shows such a comparison of the results of slope stability analysis using both of these methods of analysis for the case of tailings pond empty and full water condition respectively. It is evident that for the static case, both the methods report similar results.

For finite values of k_h and k_v, factor of safety (FS) computed by pseudo-dynamic method of analysis is more than that by pseudo-static method. The pseudo-static based approach seriously underestimates the stability of dam due to conservative use of constant seismic accelerations throughout the height of dam. Also as the seismic increases, the results computed by using pseudo-dynamic method of analysis deviates more from those of pseudo-static method of analysis.

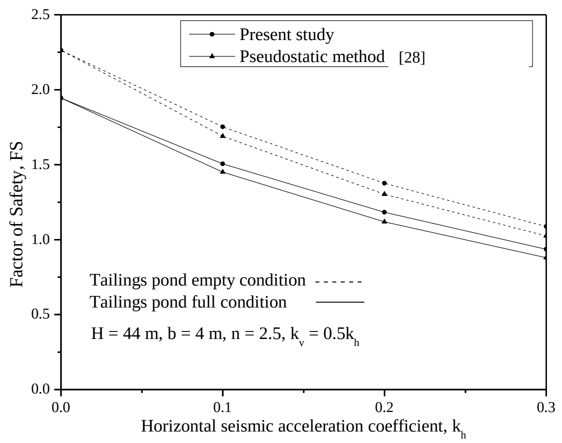

Fig. 6 Comparison of factor of safety (FS) obtained by pseudo-dynamic results with those by pseudo-static results [28] with $k_v = 0.5k_h$.

EFFECT OF SOIL ARCHING ON STABILITY OF RETAINING STRUCTURES

The retaining wall is considered to be rigid and the backfill soil is considered to be cohesive. A planer failure surface is considered in accordance with previous studies [29-34]. The analysis of lateral active earth pressure in cohesive soils is carried out using horizontal flat element method. In this method [35], the failure wedge is divided into a number of horizontal flat elements. Each flat element derives the wall-soil adhesion resistance along the vertical boundaries and the internal frictional resistance induced from the direction of the principal stresses acting on the horizontal boundaries (Fig. 7). For the sake of simplicity, similar to an earlier method reported [22], it is assumed that the trajectory of minor principal stresses takes the form of an arc of a circle.

Analytical Model

Considering the effects of soil arching and wall-soil friction, a new coefficient of lateral active earth pressure (K_{aw}) is defined as:

$$K_{aw} = \frac{1+\dfrac{1-\sin\phi}{1+\sin\phi}\cot^2\left(\dfrac{1}{2}\arcsin\left(\dfrac{\sin\delta}{\sin\phi}\right)-\dfrac{\delta}{2}\right)}{\csc^2\left(\dfrac{1}{2}\arcsin\left(\dfrac{\sin\delta}{\sin\phi}\right)-\dfrac{\delta}{2}\right)-\dfrac{2\sin\phi}{3(1+\sin\phi)}} \tag{25}$$

From Equation (1), it is established that when the wall surface is smooth (i.e. δ = 0), $K_{aw} = K_a = \tan^2(45° - \phi/2)$ which coincides with Rankine's active earth pressure coefficient. The lateral active earth pressure at the back of the wall can be calculated as:

$$\sigma_h = K_{aw}\left[\left(q+\frac{\gamma H}{1+\chi}+\frac{c}{\tan\phi}\right)\times\left(1-\frac{y}{H}\right)^{-\chi}-\gamma\left(\frac{H-y}{1+\chi}\right)\right]-\frac{c}{\tan\phi} \tag{26}$$

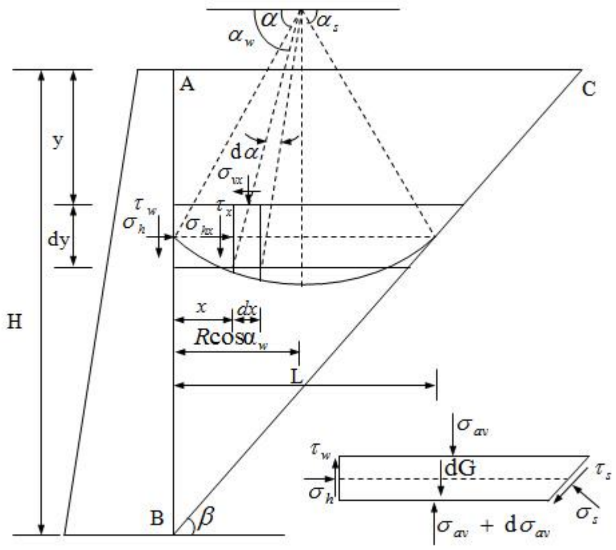

Fig. 7 Trajectory of principal stresses and forces of differential flat element ([35], With permission from ASCE)

If cracks do not appear in the backfill surface, integrating Equation (10) with respect to *y*, the active thrust can be obtained:

$$E_h = \int_0^H \sigma_h \mathrm{d}y = \xi\left(qH+\frac{\gamma H^2}{2}\right)-(1-\xi)\frac{cH}{\tan\phi} \tag{27}$$

where

$$\xi = \frac{\sin\left(\lambda-\dfrac{\phi+\delta}{2}\right)\cos\delta}{\cos\left(\lambda-\dfrac{\phi+3\delta}{2}\right)\tan\left(\lambda+\dfrac{\phi-\delta}{2}\right)} \tag{28}$$

From the analysis of Equations (27) and (28), it is observed that when the wall surface is smooth (i.e.

$\delta = 0$), $\xi = K_a = \tan^2(45° - \varphi/2)$ which coincides with the Rankine's active earth pressure coefficient, and the active thrust is equal to that computed by Rankine's theory [12].

If a crack papers at a given the depth (H_c) within the backfill surface, the lateral earth pressure within this depth is assumed to be as zero. By integrating Equation (26) with respect to y from h_c to H, the lateral active earth pressure force can be obtained as follows:

$$E_h = \int_{H_c}^{H} \sigma_h \mathrm{d}y$$
$$= \xi(H - H_c)\left[q\left(1 - \frac{H_c}{H}\right)^{-\chi} - \left(\frac{\eta_c c}{\tan\phi}\right) + \eta_r \gamma \left(\frac{H - H_c}{1+\chi}\right)\right] \quad (29)$$

where

$$\eta_c = \frac{1}{\xi} - \left(1 - \frac{H_c}{H}\right)^{-\chi}$$

$$\eta_r = \left(1 - \frac{H_c}{H}\right)^{-1-\chi} - \left(\frac{1-\chi}{2}\right)$$

Results and Discussion

Figure 8 shows the lateral active earth pressure distribution along the normalised height (y/H) of a translating rigid wall with cohesive backfill soil for various values of soil cohesion. It is evident that the lateral active earth pressure distribution along the rigid wall exhibited nonlinear shape for all the values of soil cohesion. With the increase of the soil cohesion c, the lateral active earth pressure decreases significantly, while it is interesting to note that the normalised height of the point of application of active thrust increased marginally. In addition, the depth of tension crack from the surface of the cohesive backfill soil is developed significantly, attributed to the increasing values of soil cohesion.

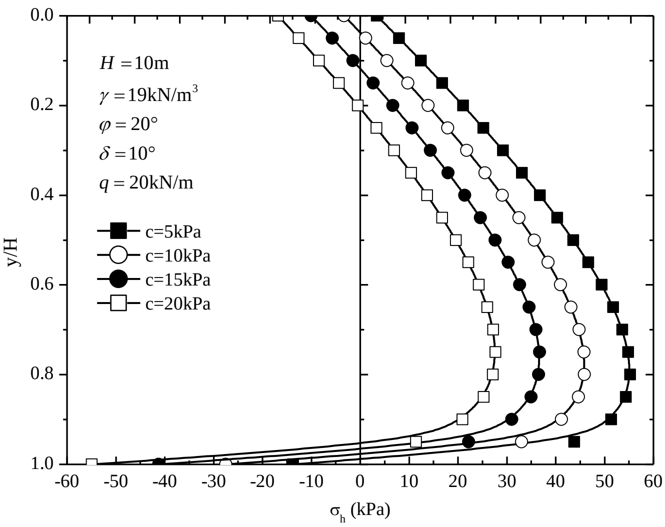

Fig. 8 Variation of active earth pressure distribution with the cohesion of backfill soil ([35], With permission from ASCE)

Figure 9 shows the lateral active earth pressure distribution along the normalised height (y/H) of a translating rigid wall with cohesive backfill soil for various friction angle (ϕ). It is apparent that the lateral active earth pressure decreases significantly with the increasing value of internal friction angle of cohesive soil, while the shape of the lateral active earth pressure distribution remained unchanged.

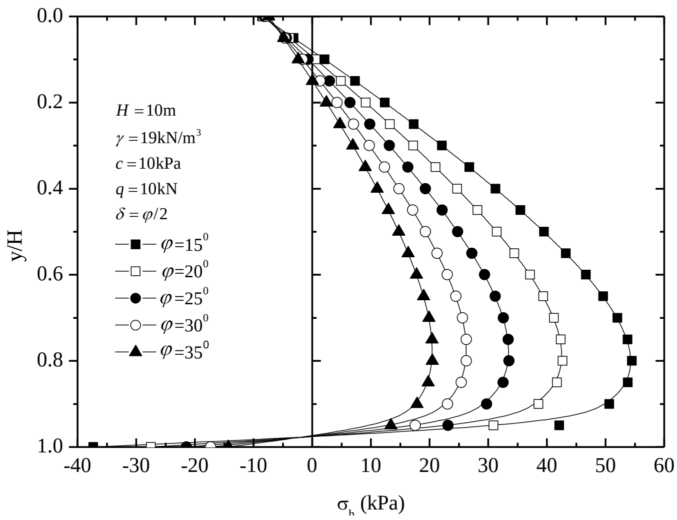

Fig. 9 Variation of active earth pressure distribution with soil friction angle ([35], With permission from ASCE)

The normalised height of the point of application of the active thrust from the base of the wall increased marginally. Moreover, as ϕ increases, the depth of tension crack from the surface of the cohesive soil increases significantly.

Comparison with Other Studies

In order to check the applicability of the proposed formulations, the predictions from the derived equation are compared with experimental results [36], where the distribution of the active earth pressures acting on the translating rigid retaining wall with the height of 4 m were measured. Figure 10 shows the comparison of the non-dimensional distributions of the active earth pressure with other studies [11,12,28].

It is evident that the results obtained using the proposed equation are in good agreement with the measured values, especially for capturing the salient feature of non-linear distribution of active earth pressures, which cannot be predicted by using the existing Coulomb's [11] and Rankine's theories [12].

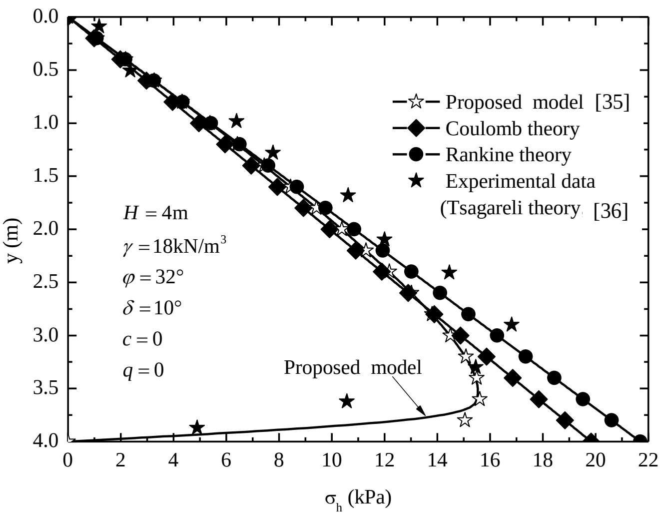

Fig. 10 Comparison between predicted and experimental data ([35], With permission from ASCE)

CONCLUSION

In pseudo-dynamic method by considering the phase change in shear and primary waves propagating in the backfill behind the rigid retaining wall, the seismic active earth pressure distribution as well as the total active thrust behind the retaining wall is altered from that by pseudo-static method. It gives more realistic non-linear seismic active earth pressure distribution behind the retaining wall as compared to the Mononobe-Okabe method.

Pseudo-dynamic method is adopted for the analysis of dam. Seismic stability of dam reduces with increase in the seismic accelerations and phase difference in body waves. Seismic inertia forces acting on the tailings dam are obtained using the pseudo-dynamic method. The results of this study also indicate that, the pseudo-static based procedures conventionally used may underestimate sometimes the stability of tailings dams and embankments under seismic conditions. By using the pseudo-dynamic method, a more rational approach can be adopted for the seismic stability assessment based on correct estimation of dynamic soil properties and accurate prediction of ground motion parameters.

A simplified method for determining the nonlinear distribution of the active earth pressure on rigid retaining walls under translation mode is proposed. The analysis of active cohesive earth pressure is carried out using horizontal flat element method, and analytical expressions for computing active earth pressure distribution, active thrust and its point of application. The general applicability of the proposed method is demonstrated by comparing its predictions with experimental results and other theoretical analyses.

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A significant portion of the contents reported here are described in more detail in a number of scholarly articles listed below. Kind permission has been obtained to reproduce some of these contents in this paper.

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