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Seismic passive earth pressure on an inclined cantilever retaining wall using method of stress characteristics – A new approach

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ABSTRACT

This paper depicts the computation of passive earth pressure on an inclined retaining wall supporting a cohesionless backfill subjected to earthquake loading condition. The method of characteristics in association with the pseudo-dynamic approach has been adopted for the intended purpose. Unlike the previous studies considering the limit equilibrium or limit analysis method, a priori failure mechanism is not assumed in this analysis. The effect of various parameters such as angle of internal friction of the backfill soil, inclination and roughness of the wall, and phase difference of the seismic waves is discussed in detail. While comparing with the available literature, the present values of seismic passive earth pressure coefficient are mostly found to be lesser than the values reported by earlier pseudo-dynamic analyses assuming the linear failure surface.

1. Introduction

Determination of earth pressure has always been a fascinating task in the field of geotechnical engineering as it is found to be the key concept associated with the design of different geotechnical structures such as retaining walls, anchors and footings. Under the seismic condition, several researchers [1–11] reported various theories to determine the seismic passive earth pressure on the retaining wall considering the pseudo-static as well as the pseudo-dynamic approach. However, almost all the studies considered some predefined linear or composite failure surface in the analysis. The assumption of the preconceived failure surface might lead to a serious limitation in the analysis especially under the seismic condition. Therefore, a need is felt to define a new methodology for obtaining the seismic passive earth pressure considering more appealing pseudo-dynamic approach but without assuming any set failure mechanism. Hence, in this study, a rigorous but more exact solution technique is evolved to determine the passive earth pressure on a non-vertical cantilever retaining wall considering the method of stress characteristics [12] in association with the pseudo-dynamic approach, where the phase difference in the seismic waves is suitably considered without presuming any predetermined failure surface. A rigid, inclined, cantilever retaining wall of height H is placed to support dry, cohesionless, horizontal backfill as shown in Fig. 1. The wall face (OA) on the backfill side is inclined at an angle β with the vertical axis (x) and exhibits a wall friction angle δ.

2. Analysis

2.1. Seismic accelerations

The present analysis considers both shear (V_s) and primary (V_p) wave velocities acting within the backfill during an earthquake in the direction as shown in Fig. 1. For a sinusoidal base shaking subjected to both horizontal and vertical seismic accelerations, the accelerations at any depth x below the ground surface and time t can be expressed as, [9,10]

$$\alpha_h(x, t) = \left[1 + \frac{(H-x)}{H}(f_a - 1)\right] k_h g \sin 2\pi\left(\frac{t}{T} - \frac{H-x}{\lambda}\right) \tag{1a}$$

$$\alpha_v(x, t) = \left[1 + \frac{(H-x)}{H}(f_a - 1)\right] k_v g \sin 2\pi\left(\frac{t}{T} - \frac{H-x}{\eta}\right) \tag{1b}$$

2.2. The method of characteristics

Following Sokolovski [12] and the Mohr-Coulomb failure criterion for a cohesionless soil deposit, and considering the boundary conditions applicable along the ground surface as well as along the wall, the magnitude of θ at the ground surface (θ_g) and at the wall (θ_w) can be derived as

$$\theta_g = \frac{1}{2}\left(\pi + \kappa - \sin^{-1}\left(\frac{\sin\kappa}{\sin\phi}\right)\right);\ \text{where } \kappa = \tan^{-1}\left(\frac{\alpha_h}{1-\alpha_v}\right) \tag{2}$$

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Notations

f_a	amplification factor for seismic waves
g	acceleration due to gravity
H	height of wall
k_h	horizontal earthquake acceleration coefficient
k_v	vertical earthquake acceleration coefficient
K_{pq}	passive earth pressure coefficient due to surcharge
$K_{p\gamma}$	passive earth pressure coefficient due to unit weight of soil
P_{pe}	seismic passive thrust
q	uniformly distributed surcharge
t	time
T	period of lateral shaking
V_p	velocity of primary wave
V_s	velocity of shear wave
x, y	axes in two dimensional Cartesian co-ordinate system
α_h, α_v	horizontal and vertical earthquake acceleration
β	wall inclination
δ	wall roughness
ϕ	angle of internal friction of soil
γ	unit weight of soil
η	wavelength of primary wave
λ	wavelength of shear wave
σ	distance on the Mohr-stress diagram, between the centre of the Mohr circle and the point where the Coulomb's linear failure envelope joins with σ-axis
θ	angle made by σ_1 in a counter-clockwise sense with the positive x-axis
θ_g	magnitude of θ along the ground surface
θ_w	magnitude of θ along the wall

and

$$\theta_w = \frac{1}{2}\left(\pi - \delta - \sin^{-1}\left(\frac{\sin\delta}{\sin\phi}\right) + 2\beta\right) \tag{3}$$

On account of difference in the magnitude of θ along the ground surface (OG) from that along the wall backface (OA), the top of the wall (O) becomes a singular point. Based on the magnitude of θ_g and θ_w, different types of stress fields (continuous and discontinuous) appear behind the wall [5,13]. Starting from the known boundary stresses along the ground surface, all the $(\theta+\mu)$ characteristics converge about the point O and then extend towards the plane OA (Fig. 1), where, $\mu = \left(\frac{\pi}{4} - \frac{\phi}{2}\right)$. From the known boundary conditions along the ground surface, by using the equations applicable along two different families of characteristics ($(\theta+\mu)$ and $(\theta-\mu)$), the solution can be numerically established gradually towards the backface of the wall. The computations have been performed using the finite difference procedure framed by Sokolovski [12].

2.3. Determination of $K_{p\gamma}$

For computing the unit weight component of the passive thrust, a certain minimum value of q is always needed to avoid the floating error. However, its contribution can be deducted if the passive earth pressure coefficient (K_{pq}) due to the surcharge component is separately known [5]. After establishing the value of K_{pq}, the magnitude of passive earth pressure coefficient ($K_{p\gamma}$) due to the unit weight component is determined using the following expression:

$$K_{p\gamma} = \frac{(P_{pe} - K_{pq}qH)}{0.5\gamma H^2} \tag{4}$$

3. Results and discussion

3.1. Seismic passive earth pressure coefficient ($K_{p\gamma}$)

The variation of $K_{p\gamma}$ with k_h for different values of ϕ and β with $k_v = 0.5k_h$, $f_a = 1.0$, $H/\lambda = 0.30$ and $H/\eta = 0.16$ is presented in Fig. 2. It can be observed that the magnitude of $K_{p\gamma}$ decreases with the increase in k_h and β, but increases with the increase in ϕ and δ. It is worth noting here that β becomes positive or negative respectively, when the wall backface rotates in the counter-clockwise or clockwise direction from the positive x-axis.

3.2. Distribution of σ on the wall backface

The distribution of normalized σ along the height of the wall is presented in Fig. 3 for different input parameters. The magnitude of σ generally decreases non-linearly with an increase in the magnitude of input parameters k_h, k_v, f_a and β. The contours of normalized stress (σ/q) developed in the influence domain under different values of seismic accelerations are shown in Fig. 4.

3.3. Failure pattern

In Fig. 5, the failure patterns corresponding to the minimum value of $K_{p\gamma}$ are drawn for different values of wall inclination. It can be

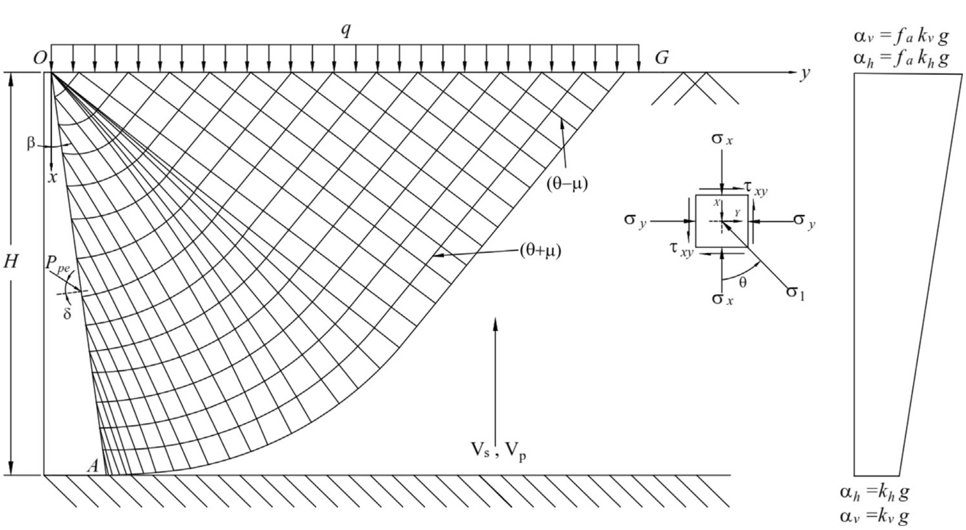

Fig. 1. Failure mechanism and associated forces.