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Study of Seismic Behavior of Retaining Walls - A Review

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Abstract-Safe and efficient design of retaining wall requires knowledge of active and passive earth pressure. For the earthquake effects the proper attention to reduce the destruction. The pseudo-static analysis for retaining wall provides an approximate result. Pseudo-dynamic method provides a better picture for the design. This method considers the dynamic effect with time and phase difference including the seismic wave velocities. This study compares both the method for design of retaining wall.
Keywords- Pseudo dynamic, Phase difference, Mononobe okabe method, Retaining wall, Earth pressure.

I. INTRODUCTION

Various structure are used to retain the soil such as rigid masonry wall, flexible retaining wall cantilever sheet piles etc. Such structure are subjected to the static as well as dynamic lateral earth pressures. Calculation of seismic earth pressure is necessary for the safe design of the retaining wall in the earthquake zones. Pseudo-static method for the estimation of seismic earth pressure on retaining wall was firstly performed by Okabe(1926) and Mononobe and Matsuo(1929) known as Mononobe-Okabe method. This method provides an linear earth pressure distribution in an approximate manner. Pseudo-dynamic method includes the effects of phase difference on the wall. This method is a time dependent method. Zeng and Steedman shown the result of centrifuge modeling which was in agreement with the pseudo-dynamic method analysis.

Dewikar and Halkude (2002) provided pseudo-static numerical analysis for seismic and passive thrust on retaining wall with the help of Kotters equation.

Kumar & Chitikela (2002) proposed the seismic passive earth pressure coefficients with the help of method of characteristics. Madhav & Kameswara Rao (1969); Choudhury & Nimbalkar (2002); Choudhury (2004); Subba Rao & Choudhury (2005) with the help of limit equilibrium approach determined individually the seismic passive earth pressure coefficients corresponding to unit weight, surcharge and cohesion components. Chaudhary and Nimbalkar (2006) developed an equation considering both horizontal and vertical seismic acceleration, which showed the effect of acceleration on seismic earth pressure on retaining wall. The parameters such like wall friction angle (δ), soil friction angle (ϕ), shear wave velocity (V_s), primary wave velocity (V_p) and both the horizontal and vertical seismic coefficients (k_h and k_v) effect on the seismic active earth pressure are also studied. Vertically propagating primary and shear waves in backfill produces vibrations in vertical as well as horizontal directions. These vibrations correspond to time dependent seismic inertia forces.

Greco (2010) computed seismic active earth pressure coefficient. Greco (2010) represented two mathematical equation for the system ,one of which the first cubic and the second quadratic, where solution converges quickly.

This method has not included the effect of the raylaigh waves on the seismic behavior of the retaining wall. Rayleigh wave , it constitutes about 67 % of the total seismic energy. Deepankar Choudhury , Amey Deepak Katdare , Anindya Pain (2013) incorporated the effect of raylaigh waves on the seismic behavior of the retaining wall.

II. MONONOBE OKABE METHOD

First method for the determination of the combined static and dynamic earth pressure on retaining wall was proposed by Okabe (1926) and Mononobe and Matsuo(1929). Method is based on the plasticity theory and this method is extended version of Coulomb sliding wedge theory in which earthquake forces are represented by equivalent static force. The method was developed for the dry cohesionless soil.

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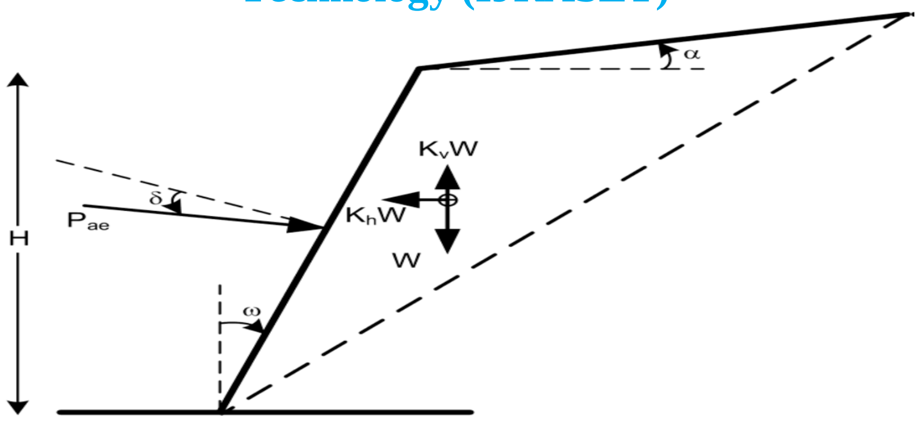

III. ASSUMPTIONS

Wall yields adequately so that a triangular soil wedge behind the wall is formed at the position of failure ,along the maximum shear strength mobilized along the sliding surface.

Wall and soil should act as rigid body with shear wave travelling at an infinite speed so that acceleration effectively becomes uniform throughout the soil wedge mass.

The active force on wedge is expressed as

$$P_{AE} = \frac{1}{2}\gamma H^2(1-k_V)K_{AE} \qquad \text{(i)}$$

Where K_{AE} is active earth pressure coefficient with earthquake effect

$$K_{AE} = \frac{cos^2(\phi-\theta-\beta)}{cos\theta cos^2\beta\cos(\delta+\beta+\theta)[1+\sqrt{\frac{\sin(\phi+\delta)\sin(\phi-\theta-i)}{\cos(\delta+\beta+\theta)\cos(i-\beta)}}]^2} \qquad \text{(ii)}$$

$$\theta=\tan^{-1}(\frac{k_h}{1-kv}) \qquad \text{(iii)}$$

equation (i) is known as Mononobe-Okabe active earth pressure equation.

The passive force P_{PE} is derived as

$$P_{PE} = \frac{1}{2}\gamma H^2(1-k_V)K_{PE} \qquad \text{(iv)}$$

$$K_{PE} = \frac{cos^2(\phi-\theta+\beta)}{cos\theta cos^2\beta\cos(\delta-\beta+\theta)[1-\sqrt{\frac{\sin(\phi+\delta)\sin(\phi+\theta-i)}{\cos(\delta-\beta+\theta)\cos(i-\beta)}}]^2} \qquad \text{(v)}$$

where

$$\theta=\tan^{-1}(\frac{k_h}{1-kv})$$

P_{AE} =active force per unit length of wall
P_{Pe}=passive force per unit length of wall
Y=unit weight of soil
H=height of retaining wall
K_{AE}=active earth pressure coefficient
Φ=soil friction angle
δ=angle of friction between wall and soil
β=slope of back of the wall with respect to vertical
i=slope of backfill with respect to horizontal

IV. PSEUDO-DYNAMIC METHOD

This method considers finite shear and constrained modulas of backfill ,that leads to the finite shear and primary wave velocity. An fixed vertical cantilever retaining wall holding mass of height H, supporting a cohesionless refill material with level ground is considered in analysis. Shear wave velocity V_S and primary wave velocity V_P act to soil medium at the time of earthquake loading

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.Lateral shaking period $T=\frac{2\pi}{\omega}$ and ω is angular frequency.Base of the wall is subjected to harmonic horizontal seismic acceleration, ah (= k_hg) and harmonic vertical seismic acceleration a_v(= K_VG) . Acceleration at any depth zand time t below the top of wall is expressed as

$$a_h(z,t)= a_h \sin \omega\, [t-\frac{H-z}{Vs}] \qquad (vi)$$

$$a_v(z,t)=a_v \sin\omega[t-\frac{H-z}{vp}] \qquad (vii)$$

Horizontal and vertical seismic acceleration are dependent on time and phase difference in the primary and shear waves propogating vertically through the backfill.

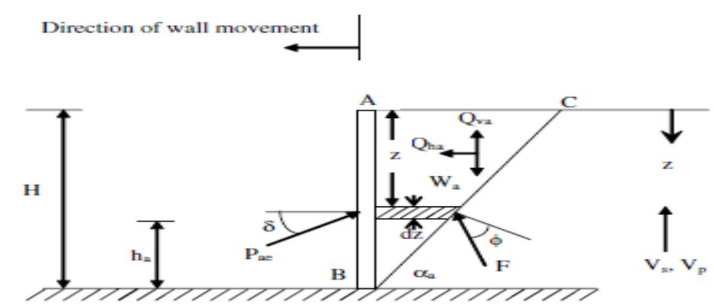

Figure 1. Model retaining wall considered for computation of pseudo-dynamic active earth pressure (Choudhury & Nimbalkar 2006).

V. SEISMIC ACTIVE EARTH PRESSURE

A planar failure surface BC at an inclination of α_a with respect to horizontal is considered in the analysis.
W_a is the weight of the failure wedge,
Q_{ha} and Q_{va} are the horizontal and vertical seismic inertia force components,
The mass of a thin element of wedge at depth z is

$$m_a(z) = \frac{\gamma H-z}{g \tan \alpha} dz \qquad (viii)$$

where, γ is the unit weight of the backfill.
The weight of the wedge is,

$$W_a = \frac{1}{2}\frac{\gamma H^2}{\tan\alpha_a} \qquad (ix)$$

The total horizontal inertia force on the wall

$$Q_{ha}(t) = \int_0^H m_a(z).\, a_h(z,t)dz = \frac{\lambda\gamma a_h}{4\pi^2 g \tan\alpha_a}[2\pi H \cos\omega\zeta + \lambda\, (\sin\omega\zeta - \sin \omega t)] \qquad (x)$$

total vertical inertia force acting on the wall can be expressed as

$$Q_{va}(t) = \int_0^H m_a(z).\, a_v(z,t)dz = \frac{\eta\gamma a_v}{4\pi^2 g \tan\alpha_a}[2\pi H \cos\omega\psi + \lambda\, (\sin\omega\psi - \sin \omega t)] \qquad (xi)$$

$\lambda = TV_s$ is the wavelength of the vertically propagating shear wave
$\eta = TV_p$, is the Wave length of the vertically propagating primary wave
$\zeta = t - H/V_s$
$\psi = t - H/V_p$.

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As the horizontal acceleration is acting from left to right and vice-versa and the vertical acceleration is acting from top to bottom and vice-versa, only the critical directions of $Q_{hs}(t)$ and $Q_{vs}(t)$ are considered to result the maximum seismic active earth pressure. The total (static + seismic) active thrust, P_{ae} can be obtained by resolving the forces on the wedge and considering the equilibrium of the forces and hence P_{ae} can be expressed as follows,

$$P_{ae} = \frac{W_a \sin(\alpha_a - \phi) + Q_{ha}\cos(\alpha_a - \phi) + Q_{va}\sin(\alpha_a - \phi)}{\cos(\delta + \phi - \alpha_a)} \qquad \text{(xii)}$$

where, W_a = Weight of the failure wedge in active case α_a = Angle of inclination of the failure surface with the horizontal in active case Q_{ha} = horizontal inertia force due to seismic accelerations respectively in active case Q_{va} = vertical inertia force due to seismic accelerations respectively in active case P_{ae} is maximized with respect to trial inclination angle of failure surface, α_a and then the seismic active earth pressure distribution, p_{ae} can be obtained by differentiating P_{ae} with respect to depth, z and can be expressed as follows,

$$P_{ae} = \frac{\gamma z}{\tan\alpha_a}\frac{\sin(\alpha_a-\phi)}{\cos(\delta+\phi-\alpha_a)}\frac{k_h\gamma z}{\tan\alpha_a}\frac{\cos(\alpha_a-\phi)}{\cos(\delta+\phi-\alpha_a)}\sin\left[w\left(t-\frac{z}{V_s}\right)\right] + \frac{k_v\gamma z}{\tan\alpha_a}\frac{\sin(\alpha_a-\phi)}{\cos(\delta+\phi-\alpha_a)}\sin\left[w\left(t-\frac{z}{V_p}\right)\right] \qquad \text{(xiii)}$$

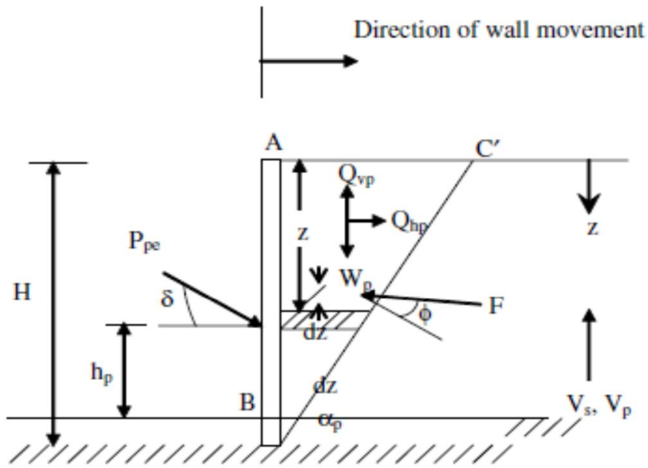

Figure 2. Model retaining wall considered for computation of pseudo-dynamic passive earth pressure (Choudhury & Nimbalkar 2005).

VI. SEISMIC PASSIVE EARTH PRESSURE

Fig.2 shows the passive state of earth pressure/ resistance on the rigid retaining wall. Again, a planar failure surface BC¢ at an inclination of α_p with respect to horizontal is considered in the analysis. In Fig. 2, W_p is the weight of the failure wedge, Q_{hp} and Q_{vp} are the horizontal and vertical seismic inertia force components, F is the soil reaction acting at an angle of ϕ (soil friction angle) to the normal to the inclined failure wedge, P_{pe} is the total passive resistance acting at height h_p from the base of the wall at an inclination of δ (wall friction angle) to the normal to the wall. For the thin element of thickness dz at depth z as shown in Fig. 2, mass is given by,

$$m_p(z) = \frac{\gamma}{g}\frac{H-z}{\tan\alpha_p}dz \qquad \text{(xiv)}$$

The weight of the whole wedge is,

$$W_p = \frac{1}{2}\frac{\gamma H^2}{\tan\alpha_p} \qquad \text{(xv)}$$

The total horizontal inertia force acting on the wall can be expressed as

$$Q_{hp}(t) = \int_0^H m_p(z).a_h(z,t)dz = \frac{\eta\gamma a_h}{4\pi^2 g\tan\alpha_p}[2\pi H\cos\omega\zeta + \lambda(\sin\omega\zeta - \sin\omega t)] \qquad \text{(xvi)}$$

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Total vertical inertia force acting on the wall can be expressed as

$$Q_{vp}(t) = \int_0^H m_p(z).\, a_v(z,t)dz = \frac{\eta\gamma a_v}{4\pi^2 g \tan\alpha_a}[2\pi H \cos\omega\psi + \lambda(\sin\omega\psi - \sin\omega t)] \qquad \text{(xvii)}$$

As the horizontal acceleration is acting from left to right and vice-versa and the vertical acceleration is acting from top to bottom and vice-versa, only the critical directions of $Q_{hs}(t)$ and $Q_{vs}(t)$ are considered to result the minimum seismic passive earth pressure. The total (static +seismic) passive resistance, P_{pe} can be obtained by resolving the forces on the wedge and considering the equilibrium of the forces and hence P_{pe} can be expressed as follows,

$$P_{pe} = \frac{W_p \sin(\alpha_p+\phi) - Q_{hp}\cos(\alpha_p+\phi) - Q_{vp}\sin(\alpha_p+\phi)}{\cos(\delta+\phi-\alpha_p)} \qquad \text{(xviii)}$$

where, W_p = Weight of the failure wedge in passive case
α_p = Angle of inclination of the failure surface with the horizontal in passive case
Q_{hp} = horizontal inertia force due to seismic accelerations respectively in passive case
Q_{vp} = vertical inertia force due to seismic accelerations respectively in passive case
P_{pe} is minimized with respect to trial inclination angle of failure surface, ap and then the seismic passive earth pressure distribution, p_{pe} can be obtained by differentiating P_{pe} with respect to depth, z and can be expressed as follows,

$$P_{ae} = \frac{\gamma z}{\tan\alpha_p}\frac{\sin(\alpha_p+\phi)}{\cos(\delta+\phi+\alpha_p)}\frac{k_h\gamma z}{\tan\alpha_p}\frac{\cos(\alpha_p+\phi)}{\cos(\delta+\phi+\alpha_p)}\sin\left[w\left(t-\frac{z}{V_s}\right)\right] - \frac{k_v\gamma z}{\tan\alpha_p}\frac{\sin(\alpha_p+\phi)}{\cos(\delta+\phi+\alpha_p)}\sin\left[w\left(t-\frac{z}{V_p}\right)\right] \qquad \text{(xix)}$$

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