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Sliding stability and seismic design of retaining wall by pseudo-dynamic method for passive case

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Abstract

Knowledge of the influence of soil inertia and wall inertia on the design of a retaining wall is very important and more so under earthquake conditions. In this paper, by using the pseudo-dynamic seismic forces acting both on the soil and the wall, the design weight of the wall required under seismic conditions is determined under passive earth pressure conditions. The present pseudo-dynamic method considers time, phase difference and effect of amplification in shear and primary waves traveling through both the backfill and the retaining wall due to seismic excitation. A model rigid vertical retaining wall under passive earth pressure conditions with cohesionless backfill material has been considered in the present analysis. Results in graphical form show the non-linear variations of the soil passive resistance factor (F_T), wall inertia factor (F_I) and combined dynamic factor (F_w) with respect to the horizontal seismic acceleration coefficient (k_h), required for the design of the wall. The effects of parameters such as wall friction angle, soil friction angle, shear wave velocity, primary wave velocity, period of lateral shaking, horizontal and vertical seismic accelerations and amplification factor on the sliding stability of the retaining wall have been studied. With the increase of seismic accelerations both in horizontal and vertical directions, the sliding stability of the retaining wall decreases significantly.

Keywords: Earthquake; Retaining wall; Sliding; Time dependence; Soil–wall interaction; Design parameters

1. Introduction

Computation of the passive earth pressure is extremely important and it is the basic data required for the design of the geotechnical structures like the retaining walls moving towards the backfill, the foundations, the anchors etc. The level of importance of the passive earth pressure increases many fold under the earthquake conditions due to the devastating effects of the earthquake. Hence to design the retaining wall under passive condition for both under the static and seismic conditions, the basic theory is very complex and the several researchers have discussed on this topic. Initially Okabe [1] and Mononobe and Matsuo [2] had proposed the theory to compute the pseudo-static lateral earth pressure on the wall, which is commonly known as the Mononobe–Okabe method (see Kramer [3]). Again, by using an approximate method based on a modified shear beam model Wu and Finn [4] developed charts for seismic thrusts against rigid walls. A design method by considering the surcharge and using Mononobe–Okabe method, Caltabiano et al. [5] proposed a design method for retaining wall by considering the effect of pseudo-static seismic accelerations on both the soil and wall. Schnabel et al. [6] had developed a computer program 'SHAKE' for the earthquake response analysis of horizontally layered sites, based on the one dimensional site response method to incorporate the non-linear stress–strain effects. Nadim and Whitman [7] had further proposed a new seismic design method for the gravity retaining wall, based on the earthquake induced permanent displacement of the wall considering the effects of ground motion amplification. In recent past, Morrison and Ebeling [8], Soubra [9], Kumar [10], Choudhury and Subba Rao [11], Choudhury et al. [12], Subba Rao and Choudhury [13] and few others had proposed the seismic design of a retaining wall under the passive earth pressure condition. These

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Notations

$a(z, t)$ acceleration at depth z, time t
a_{hs}, a_{vs} amplitude of horizontal and vertical seismic acceleration acting on the soil wedge
a_{hw}, a_{vw} amplitude of horizontal and vertical seismic acceleration acting on retaining wall
G_s, G_w shear modulus of the soil and wall material
K_p, K_{pe} static and seismic passive earth pressure coefficient
k_{hs}, k_{vs} seismic acceleration coefficient in the horizontal and vertical direction for the soil.
k_{hw}, k_{vw} seismic acceleration coefficient in the horizontal and vertical direction for the wall.
$P_{pe}(t)$ pseudo-dynamic passive resistance
C_I, $C_{IE}(t)$ static and dynamic wall inertia factor
F_T, F_I, F_W soil passive resistance, wall inertia and combined dynamic factor
H, b_w height and width of the wall
W_w, $W_w(t)$ weight of the wall for static and seismic design
$Q_{hs}(t)$, $Q_{vs}(t)$ horizontal and vertical inertia force acting on the soil wedge
$Q_{hw}(t)$, $Q_{vw}(t)$ horizontal and vertical inertia force acting on the retaining wall.
N_b, F_b vertical and horizontal component of reaction on the base of the wall.
t time
T period of lateral shaking
f_s, f_w amplification factor for the backfill soil and wall
V_{ss}, V_{ps} velocity of shear and primary wave propagating through the backfill
V_{sw}, V_{pw} velocity of shear and primary wave propagating through the wall
α_f angle of inclination of the failure surface with the horizontal
γ_s, γ_w unit weight of the soil and wall material
ϕ, ϕ_b soil friction angle and wall base friction angle
δ wall friction angle

theories consider the pseudo-static method of analysis, i.e. without considering any time dependent behavior of the soil and the wall.

In most of the design methods proposed by the previous researchers, the effects of seismic accelerations were considered only on the soil wedge but not on the wall. But under the earthquake condition, it is obvious that both the soil and the wall will experience the seismic accelerations in both horizontal and vertical directions and the analysis should deal with the effect of the earthquake on both the soil and wall while analyzing the earth pressure problems. Rectifying this drawback, initially Richards and Elms [14] had suggested a new design method for the gravity retaining wall by considering the effect of pseudo-static seismic accelerations on both the soil and the wall under the active condition of earth pressure. From this work, it was clear that both the soil and the wall inertia effect must be considered for seismic design of a retaining wall. But the similar consideration of both the soil and the wall inertia effects for seismic design of a retaining wall under the passive condition of earth pressure is still scarce.

Recently, based on the pseudo-dynamic method proposed by Steedman and Zeng [15], Zeng and Steedman [16], Choudhury and Nimbalkar [17] for the active earth pressure condition, Choudhury and Nimbalkar [18,19] had proposed the theory to compute the seismic passive earth pressure by pseudo-dynamic method by considering both the shear and the primary waves propagating through the soil with a time variation. But the analysis did not consider the effect of the amplification and the wall inertia in the seismic design of the wall and hence leading to an incomplete analysis for design purpose of the wall. Again the recent research by Choudhury and Nimbalkar [20] shows the need of seismic design of retaining wall under passive earth pressure condition by considering the rotational stability of the wall. However, another important displacement-based sliding stability analysis for the design of retaining wall is still scarce. Hence in this paper, the sliding stability of a wall under the seismic passive earth pressure condition is studied by considering the dynamic effect of earthquake forces with the variation of time and both the shear and the primary wave velocities propagating through both the soil and the wall medium using the pseudo-dynamic approach. The effects of variation of different parameters such as soil friction angle (ϕ), wall friction angle (δ), period of lateral shaking (T), amplification factor (f), horizontal and vertical seismic acceleration coefficients for the soil (k_{hs}, k_{vs}) and for the wall (k_{hw}, k_{vw}), shear wave velocities in the soil (V_{ss}) and in the wall (V_{sw}), primary wave velocities in the soil (V_{ps}) and in the wall (V_{pw}) on the design of a retaining wall against sliding stability under seismic conditions are considered in the present analysis.

2. Method of analysis

Consider the rigid vertical gravity wall, ABKL of height H and width b_w, supporting horizontal cohesionless backfill as shown in Fig. 1. The shear wave velocity propagating through the backfill soil, $V_{ss} = (G_s/\rho_s)^{1/2}$, where, ρ_s is the density of the backfill material and the primary wave velocity, $V_{ps} = (G_s(2–2v_s)/\rho_s(1–2v_s))^{1/2}$, where v_s is the poisson's ratio of the backfill are assumed to act within the soil media due to the earthquake loading. Similarly, the shear wave velocity propagating through the wall, $V_{sw} = (G_w/\rho_w)^{1/2}$ where, ρ_w is the density of the wall