Applied Ocean Research 47 (2014) 174–182

Contents lists available at ScienceDirect

Applied Ocean Research

journal homepage: www.elsevier.com/locate/apor

Sliding stability of non-vertical waterfront retaining wall supporting inclined backfill subjected to pseudo-dynamic earthquake forces

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ARTICLE INFO

Article history:
Received 21 December 2013
Received in revised form 9 May 2014
Accepted 10 May 2014
Available online 9 June 2014

Keywords:
Non-vertical waterfront retaining wall
Inclined backfill
Hydrodynamic pressure
Hydrostatic pressure
Stability
Factor of safety

ABSTRACT

The stability analysis has been performed for a generalized non-vertical waterfront retaining wall supporting an inclined backfill and subjected to the seismic forces. The limit equilibrium method has been used to obtain the factor of safety against sliding mode of failure. The advanced pseudo-dynamic approach has been implemented for the determination of the seismic active earth pressure and the wall inertia force. In the stability analysis, along with the hydrostatic pressures the hydrodynamic pressures have also been taken into consideration. The results clearly indicate about the adverse effect of earthquake on the sliding stability of waterfront retaining wall. It has been found that the parameters like seismic accelerations in both horizontal and vertical directions, soil and wall friction angles, time period, pore pressure ratio, wall batter and ground inclination have considerable effect on the stability of the non-vertical waterfront retaining wall when it is subjected to an earthquake. Comparison of results with the available results in literature for an ideal case of perfectly vertical waterfront retaining wall supporting horizontal backfill has shown nice agreement. It is expected that the proposed design charts and tables presented in this paper would be helpful for the engineers to design the waterfront retaining wall in an earthquake prone area.

1. Introduction

The importance of the waterfront retaining wall is enormous and the design of these retaining structures is an important research topic for the engineers. During an earthquake, the stability of a waterfront retaining wall may get affected severely. The evidence of the colossal damage of the waterfront retaining walls and breakwaters can be found from the recent South Asian earthquake of 2004 and Japan earthquake of 2011. At the time of earthquake a typical waterfront retaining wall can be subjected to a number of forces/pressures such as (i) the seismic forces, (ii) the hydrostatic pressures, and (iii) hydrodynamic pressures. Therefore, quite obviously for a safe design of a waterfront retaining wall, all these forces/pressures need to be considered. Except the research works reported by Ebeling and Morrison [1] and Choudhury and Ahmad [2,3], all other works available in literature considered either only one force/pressure or just a combination of a few of these forces/pressures at a time. For instance, Chakrabarti et al. [4] studied the effect of the hydrodynamic pressure on cellular type cofferdams. Kirkgoz and Mengi [5] and Kirkgoz [6–8] investigated the effect of wave action on caisson, vertical and sloping walls and other coastal structures. Muller and Whittaker [9,10] studied the effect of wave impact on the sloping walls. Ramsden [11] performed experiments for assessing the behavior of the vertical wall subjected to long waves. On the other hand, the active earth pressure acting on the rigid retaining wall with dry backfill soil under the seismic loading conditions were found out by using different methodology like the limit equilibrium technique [12–15], shear beam model [16,17], finite element method [18,19]. It should be mentioned here that, none of these solutions [12–19] considered the effect of hydrodynamic pressure. However, Ebeling and Morrison [1] and Choudhury and Ahmad [2] considered all the significant forces/pressures, but the seismic earth pressure was calculated by using the conventional pseudo-static approach. Whereas, Choudhury and Ahmad [3] also considered all these forces/pressures, but the seismic earth pressure was calculated by using more realistic pseudo-dynamic approach. It should be mentioned here that for the pseudo-dynamic approach in addition to the seismic accelerations, body waves traveling during earthquake, frequency of earthquake, duration were also taken into consideration, which ultimately provide a higher safety factor as compared to the conventional pseudo-static approach [20–22]. Note that, Ebeling and Morrison [1] and Choudhury and Ahmad [2,3] have considered only an ideal case of perfectly vertical wall with perfectly horizontal backfill, which is the main limitation of these three available research works. Therefore, till now, the complete

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http://dx.doi.org/10.1016/j.apor.2014.05.004

Notations

a_{hw} amplitude of seismic acceleration of the wall in the horizontal direction
a_{vw} amplitude of seismic acceleration of the wall in the vertical direction
$a_{hw}(z,t)$ wall acceleration in the horizontal direction at depth z and time t
$a_{vw}(z,t)$ wall acceleration in the vertical direction at depth z and time t
b width of the wall at the top
F resultant of all the forces acting on the failure wedge
F_{dR} total driving force by considering the restrained water case
F_{dF} total driving force by considering the free water case
F_{rR} total resisting force by considering the restrained water case
F_{rF} total resisting force by considering the free water case
FS_R factor of safety in sliding mode of failure of the wall by considering the restrained water case
FS_F factor of safety in sliding mode of failure of the wall by considering the free water case
g acceleration due to gravity
H height of the wall
h_u height of the water on the upstream side of the wall
h_d height of the water on the downstream side of the wall
k hydraulic conductivity of soil
k_h seismic acceleration coefficients in the horizontal direction
k_v seismic acceleration coefficients in the vertical direction
$K_{ae}(t)$ seismic active earth pressure coefficient
$m_w(z)$ mass of the thin shaded zone of the wall having thickness dz, and located at a depth z below the top of the wall
P_{dynu} hydrodynamic pressure in the upstream side
P_{dynd} hydrodynamic pressure in the downstream side
$P_{ae}(t)$ total seismic active earth pressure
P_{std} hydrostatic pressure on the downstream side of the wall
P_{stu} hydrostatic pressure on the upstream side of the wall
$Q_h(t)$ seismic inertia force on the backfill soil in the horizontal direction
$Q_v(t)$ seismic inertia force on the backfill soil in the vertical direction
$Q_{hw}(t)$ seismic inertia force on the wall in the horizontal direction
$Q_{vw}(t)$ seismic inertia force on the wall in the vertical direction
r_u pore pressure ratio
SWL sea water level
t time
T period of lateral shaking
V_p the velocity of the primary wave propagating through the soil
V_s the velocity of the shear wave propagating through the soil
V_{pw} the velocity of the primary wave propagating through the wall
V_{sw} the velocity of the shear wave propagating through the wall
W_w weight of the wall
α angle of inclination of the inclined backfill
β angle which the failure wedge plane makes with the horizontal at the base of the wall
β_c β for the critical collapse mechanism
δ wall friction angle
ϕ soil friction angle
γ_c unit weight of concrete
γ_d dry unit weight of the soil
γ_s unit weight of soil
γ_{sat} saturated unit weight of the soil
γ_w unit weight of water
γ_{we} the equivalent unit weights of water, modified due to submergence of the backfill
$\overline{\gamma}$ the equivalent unit weights of the soil, modified due to submergence of the backfill
μ coefficient of base friction
ν Poisson's ratio
θ inclination of wall with vertical
ω angular frequency = $2\pi/T$

solution for the combined effect of seismic active earth pressure and hydrodynamic pressure on a generalized non-vertical waterfront retaining wall supporting inclined backfill with the consideration of wall inertia is scarce. Thus in the present study, an attempt has been made to propose a methodology to study the sliding stability aspect of a generalized non-vertical waterfront retaining wall supporting inclined backfill, subjected to the earthquake, including the hydrostatic and hydrodynamic pressures with wall inertia forces, by using the limit equilibrium method in combination with the pseudo-dynamic approach. It is expected that the present study can be quite useful for the design of the waterfront retaining wall under seismic condition. The study presented in this paper has been divided into different sections. In the following section, the detail methodology has been presented. Subsequently the results and discussions, comparisons, remarks and finally the conclusions which can be drawn from the present study have been summarized.

2. Methodology

A typical non-vertical face rigid waterfront retaining wall supporting an inclined backfill is shown in Fig. 1. The height of the wall is H and the top width is b. The inclination of wall with vertical is θ and the inclination of the inclined backfill is α. The inclined backfill is submerged with water to a height h_d. The upstream water height is h_u. The total pressure/force due to (i) the upstream side

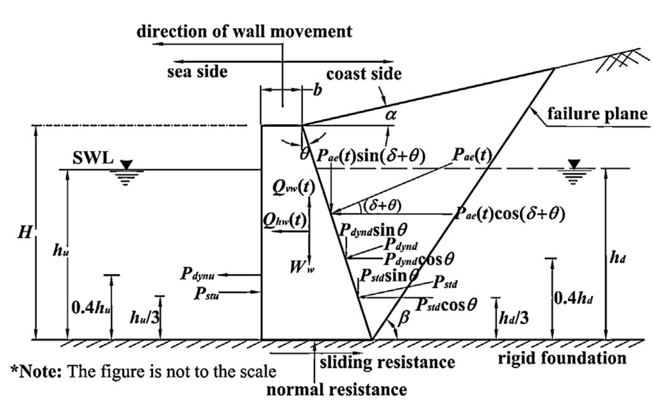

Fig. 1. A typical sketch of the waterfront retaining wall subjected to different forces during an earthquake under active condition.