INFLUENCE OF BACKFILL COHESION ON SEISMIC DISPLACEMENT OF GRAVITY RETAINING WALL

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ABSTRACT :

Backfill cohesion can significantly reduce active seismic earth pressure. The influence of this factor on earthquake-induced displacement of walls was discussed. Based on the Raffnsson, Wu and Prakash's framework and the theory on seismic earth pressure of cohesive backfill, a model was established to compute the cumulative displacement. A coupling movement mode of sliding and rocking of a wall was considered, and the dynamic nonlinearity of foundation soil and the cohesion of backfill were simulated. Permanent displacements of a sample wall were computed, considering 16 combined conditions of backfill cohesion and friction angle. The results show that the permanent displacement tends to decrease with the cohesion increasing. However, the decreasing range is negligibly small comparing with the decrease of active earth pressure. It is suggested that the effect of backfill cohesion on the permanent displacement should not be considered in the displacement-based seismic design of gravity retaining structures.

KEYWORDS: gravity retaining wall, seismic permanent displacement, backfill cohesion, seismic earth pressure

1. INTRODUCTION

Large permanent displacement of retaining walls has been observed in many historic seismic events and modeling tests (e.g., Liu, H.X. et al. 1986; China earthquake investigation group. 1995; Huang, C.C. et al. 2004; Huang, C.C. 2005; Zeng, X. 1998; Todorovski, L.I. 1999). It is necessary to investigate factors which have effects on the seismic permanent displacement of walls (Yang, M. et al. 2002; Chen, X.L. et al. 2006).

Since cohesionless soil has good permeability, it is a priority selection for constructing a backfill with cohesionless soil. However, in engineering practice there are many situations in which silt or clay have to be used as backfill soil. Some authors (e.g., Chen, X.L. et al. 2002; Chen, X.M. 2003) reported that the cohesion of this kind of backfill significantly reduces seismic active earth pressure. Since the displacement of walls depends on the dynamic earth pressure, the backfill cohesion might reduce the permanent displacement. Little research has been conducted on the effect of backfill cohesion on the seismic permanent displacement of retaining walls.

Chen, X.L. and Tao, X.X. (2002) suggested a general Mononobe-Okabe formula to calculate dynamic earth pressure considering the backfill cohesion effect. Rafnsson (1991) developed a model to compute seismic displacement of a rigid retaining wall. Wu and Prakash (2000) developed this model further, analyzing the displacement of rigid walls on submergence. In this paper, the incorporation of the model and the general M-O formula is presented to investigate the backfill cohesion effect on the displacement of retaining walls.

2. MODEL FOR EVALUATING DISPLACMENT OF GRAVITY RETAINING WALLS SUBJECTED TO EARTHQUAKES

2.1 Assumptions

The development mechanism of seismic displacement of walls during earthquake is considerably complicated. According to many laboratory tests (e.g., Zeng, X. 1998; Todorovski, L.I. 1999), walls experienced intermittent displacement relative to the ground away from backfill. After an earthquake, the final displacement was the summation of these intermittent displacements. In order to simplify this process, some assumptions are adopted:
1. The wall is rigid so that no deformation of walls is needed to be considered.
2. The wall is long enough so that the problem satisfies the plane strain assumption.
3. Both sliding and rotational movement of walls are considered, and the rotational center is the projection of the wall centroid on the bottom margin of the wall section (point O, as shown in Fig. 1).
4. The movement of the wall towards backfill is negligible small and will not be considered.
5. The inputted ground motion is horizontal, and the vertical earthquake is neglected.

2.2 Equation of Motion of Wall

The motion of a wall can be divided into sliding along the base and rotation at the point O, as shown in Fig. 1. Hence, the absolute displacement of centroid from the static equilibrium position is given by

$$x_c = x_g - x_{cr} = x_g - x - \theta h \tag{1}$$

where h = height of centroid; θ = rotation angle of wall, and the positive direction assumed is counterclockwise; x = sliding of point O relative the base; $x_{cr} = x + \theta h$ = relative displacement of centroid, with left being positive; and x_g = inputted earthquake ground motion, with right being positive, as shown in Fig. 1.

Fig. 2 shows the forces acting on a gravity retaining wall during vibration. Displacement of the wall is computed beginning with the static equilibrium position. Only the dynamic earth pressure increment, $\Delta P_{AE} = P_{AE} - P_A$, is used here acting on the wall back, where P_{AE} = active seismic earth pressure, and P_A = active static earth pressure. In this figure, R is the resultant force of subgrade reaction, which is assumed acting at the point O. The equilibrium of forces in the horizontal direction gives

$$k_s x + c_s \dot{x} - m\ddot{x}_c - \Delta P_{AE} \cos\left(\delta + \alpha\right) = 0 \tag{2}$$

in which m = mass of wall per unit length; k_s = stiffness in sliding of foundation soil; c_s = damping in sliding of foundation soil; δ = friction angle between backfill soil and wall; and α = slope angle of wall back.
Substituting (1) into (2) gives

$$m\ddot{x} + mh\ddot{\theta} + c_s\dot{x} + k_s x = m\ddot{x}_g + \Delta P_{AE} \cos\left(\delta + \alpha\right) \tag{3}$$

Summing the moments of forces and inertia effects equal to zero about an axis through point O,

$$\sum M_O = I\ddot{\theta} + k_\phi \theta + c_\phi \dot{\theta} + \Delta P_{AE} \sin\left(\delta + \alpha\right) \cdot e - m\ddot{x}_c h - \Delta P_{AE} \cos\left(\delta + \alpha\right) \cdot h_s = 0 \tag{4}$$

where I = mass moment of inertia; k_ϕ = stiffness in rocking of the foundation soil; c_ϕ = damping in rocking of the foundation soil; e = horizontal distance between heel and centriod; and h_s = height of action point of ΔP_{AE}. Substituting (1) into (4) and calculating $\sum M_O$ gives

$$mh\ddot{x}+(I+mh^2)\ddot{\theta}+c_\phi\dot{\theta}+k_\phi\theta=mh\ddot{x}_g+\left[h_s\cos(\delta+\alpha)-e\sin(\delta+\alpha)\right]\Delta P_{AE} \tag{5}$$

Eqn. (3) and (5) are equations of motion of the wall, and appear in matrix form as

$$\begin{bmatrix} m & mh \\ mh & I+mh^2 \end{bmatrix}\begin{Bmatrix}\ddot{x}\\ \ddot{\theta}\end{Bmatrix}+\begin{bmatrix} c_s & 0 \\ 0 & c_\phi \end{bmatrix}\begin{Bmatrix}\dot{x}\\ \dot{\theta}\end{Bmatrix}+\begin{bmatrix} k_s & 0 \\ 0 & k_\phi \end{bmatrix}\begin{Bmatrix}x\\ \theta\end{Bmatrix}=\begin{Bmatrix} m\ddot{x}_g+\Delta P_{AE}\cos(\delta+\alpha) \\ mh\ddot{x}_g+\left[h_s\cos(\delta+\alpha)-e\sin(\delta+\alpha)\right]\Delta P_{AE}\end{Bmatrix} \tag{6}$$

or

$$[M]\{\ddot{u}\}+[c]\{\dot{u}\}+[K]\{u\}=\{p\} \tag{7}$$

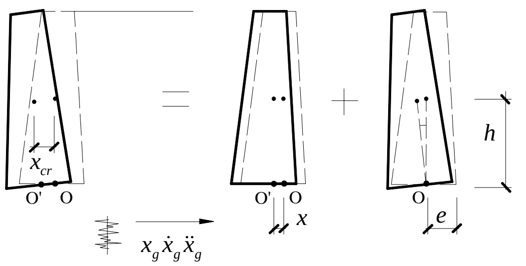

Figure 1 Motion of wall subjected to earthquake

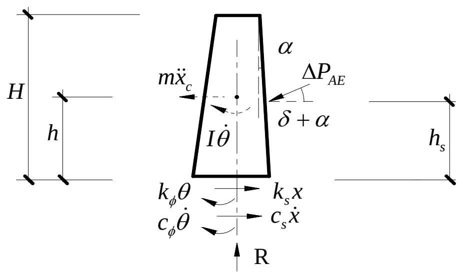

Figure 2 Forces on wall

2.3 Model Parameters

The stiffness and damping coefficients, k_s, k_ϕ, c_s and c_ϕ, have been presented in Wu (2000). According to Eurocode-8 Ch. 7, $h_s = 0.5H$, in which H = total height of wall. The dynamic and static earth pressure, P_{AE} and P_A, are computed using Chen, X.L. and Tao, X.X. (2002) expression.

$$P_{AE}=H^2\overline{\gamma}_{sa}K_{sa1}+H\overline{c}_{sa}-\frac{2HK_{sa2}}{\cos\alpha}\times\sqrt{\left(\frac{\overline{\gamma}_{sa}H\sin(\phi+\delta)}{\cos(\alpha+\delta+\phi-\beta)}+\frac{(k+c)\cos\delta}{\cos(\alpha+\delta+\rho)}\right)\left(\frac{\overline{\gamma}_{sa}H\cos(\alpha+\delta+\rho)\sin(\phi-\beta-\rho)}{\cos(\alpha+\delta+\phi-\beta)}+c\cos(\beta+\rho)\right)} \tag{8}$$

where β = slope angle of backfill; c = cohesion of backfill soil; ϕ = friction angle of backfill soil; k = cohesion between backfill and wall; and $\overline{\gamma}_{sa}$, $\overline{c}_{sa}$, $\overline{K}_{sa1}$ and $\overline{K}_{sa2}$ have been presented in Chen, X.L. and Tao, X.X. (2002). Seismic angle $\rho=\ddot{x}_g/g$, in which g= gravity acceleration. When $c=k=0$, the Eqn. (8) degenerates into the M-O formula. When $c=k=\rho=0$, $P_{AE}=P_A$, and the Eqn. (8) becomes the Coulomb earth pressure formula.

3. EXAMPLE AND PARAMETRIC STUDY

An acceleration time history (Fig. 4) corresponding to the earthquake intensity of 9 was used in the revision project of the *China Specifications of Earthquake Resistant Design for Highway Engineering* by Chen, X.M.

(2003). This time history is used as ground motion in this paper. Fig. 3 shows the dimensions of the example wall section. The soil properties are shown in Table 1. For the backfill soil, four different cohesions, 0kPa, 5 kPa, 10kPa, and 15kPa, combined with four different friction angles, 24°, 27°, 30°, and 33°, are chosen to check the effect of backfill soil properties on the permanent displacement of the wall.

For the combination of ϕ=30° and the four kinds of cohesion, computed cumulative displacements at wall top versus time are shown in Fig. 5. Fig. 6 shows the final permanent displacements at wall top versus backfill cohesion. The backfill soil friction angles are 24°, 27°, 30°, and 33°, respectively. The dynamic active earth pressures are computed and plotted versus backfill cohesion in the Fig. 7. As shown, the decreasing range reaches over 60% with *c* value increasing from 0kPa to 15kPa. This suggests that cohesion of backfill soil affects seismic earth pressure significantly. Seismic displacement of wall also decreases with the increase of backfill cohesion, as seen in Fig. 5 and Fig. 6. However, the decreasing range of displacement is smaller than that of earth pressure. Final displacement only decreases about 16% as *c* value increases from 0kPa to 15kPa. A possible reason is that, although the seismic earth pressure is a key factor leading to the displacement and the backfill cohesion obviously affects the seismic earth pressure, the backfill cohesion has no influence on the inertia force of the wall which is another key factor.

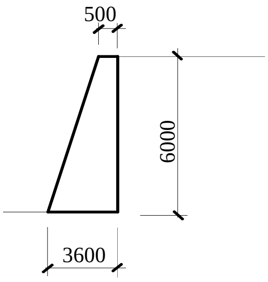

Figure 3 Section of the wall（unit: mm）

Table 1 Soil parameters of backfill and subgrade

parameters	subgrade	backfill
Unit weight (kN/m^3)	19	22
Void ratio	0.46	0.35
Water content	10%	10%
Poisson's ratio	0.3	0.3

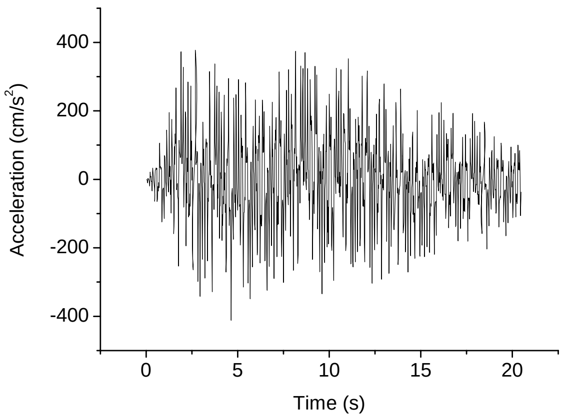

Figure 4 Ground motion inputted

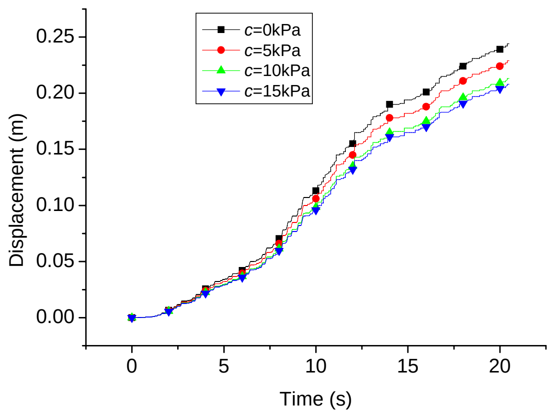

Figure 5 Computed displacement at wall top

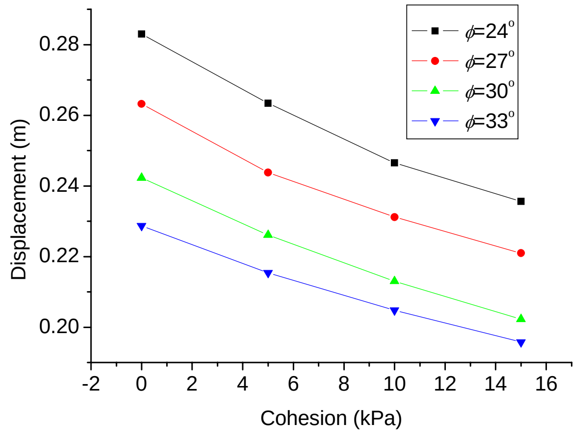

Figure 6 Backfill cohesion effect on displacement

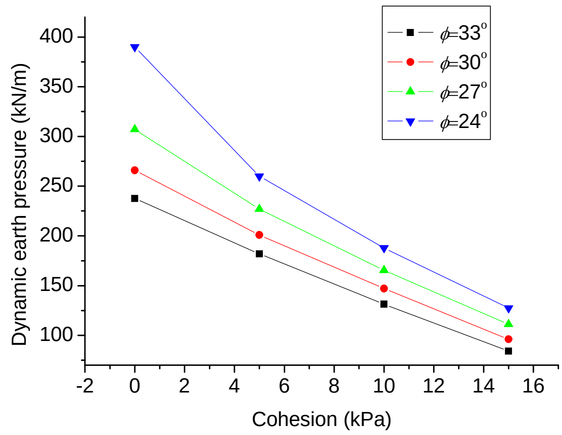

Figure 7 Backfill cohesion effect on earth pressure

4 CONCLUSION

A model for computing seismic displacement of gravity retaining walls is extended to investigate backfill soil cohesion effect on the displacement of walls subjected to earthquake. Different values of backfill cohesion and friction angle are adopted to compute the cumulative displacement at an example wall top. The result shows that the displacement decreases with the backfill cohesion increasing. However, the decreasing range is very small compared with seismic active earth pressure. Hence, it is rational not to consider the displacement decrease caused by backfill cohesion in the displacement-based seismic design of gravity retaining structures.

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