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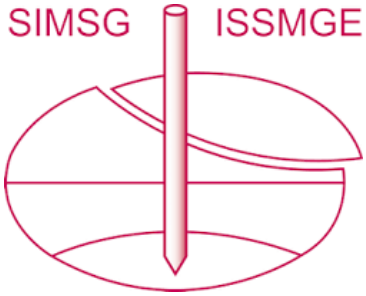

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Investigation of dynamic response of cantilever retaining walls using FEM

L´analyse dynamique des murs retenants par la méthode des éléments finis

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ABSTRACT

Dynamic response of cantilever retaining walls under seismic loads is of great importance due to the vast application of this kind of structures in civil engineering field. In this paper, finite element analysis, using Plaxis software, has been employed to investigate the effects of mechanical properties of the soil and wall on the dynamic behavior of a cantilever retaining wall. Also the effects of amplitude and frequency of the source vibration on the response of the wall have been studied and discussed. The results show that wall displacement increases when soil density and amplitude of harmonic load increase, while the dynamic response of the wall decreases with increase in the values of friction angle, cohesion, elasticity and damping of the soil. The response also increases when the stiffness of the retaining wall increases. Finally, it is shown that amplification occurs when input motions coincide with the natural period of the backfill and produce considerably permanent displacements.

RESUME

L´analyse dynamique des murs retenants sollicités par des charge de tremblement de terre est importante. Dans cet article, la méthode des éléments finis par la logiciel Plaxis est utilisée par modéliser les propriétés mécaniques des sols et du mur dans la comportement du mur retenant. Aussi l´influence de l´amplitude et de la fréquence de la source de la vibration est utidieé dans la réponse du mur. Les résultants montrent qu´avec l'augmentation de la densité des sols et de la amplitude de la charge harmonique, le déplacement du mur augmente et qu´avec la diminution de l´angle de frottement, l´adhesion, le propriété élastique et l´aténuation du sol, la réponse dynamique du mur diminue. Aussi avec l´augmentation de la rigidité du mur, le réponse du mur augment. A terme, on a montré que si la fréquence entrante du déplacement provenant de la vibration soit homogène, des grands déplacement résiduels seront provoqués.

1 INTRODUCTION

The application of the earth retaining walls is very common and important in civil engineering field, especially in connection with the construction of ports, bridges, coasts and nearby structures. Seismic analysis and design of earth retaining walls is therefore of great importance in seismic-prone areas. However, it is not a simple problem, as requires the determination of the dynamic soil pressures on the wall as well as the dynamic response of the retaining wall due to the seismic loads.

Despite the numerous studies conducted over the years, the dynamic response of the cantilever retaining walls is far from being well-understood and there is inadequacy of conclusive information that may be used in design applications. The available techniques for analysis of the dynamic response of the retaining walls can be classified into two categories: (1) elastic analysis and (2) limit-state analysis. In elastic analysis, the wall is considered to be fixed against both deflection and rotation at the base, and backfill is presumed to respond as a linearly elastic or viscoelastic material. In limit-state analysis the wall is assumed to displace sufficiently at the base to mobilize the full shearing strength of the backfill.

The most well-known methods of the first category are the contributions of Matuo and Ohara (1960), Wood (1973), Veletsos and Younan (1994a, b), and Wu and Finn (1996). In the second category one can mention the works of Mononobe-Okabe (MO) method (Mononobe and Matuo 1929, and Okabe 1924), Seed and Whitman (1970), Richards and Elms (1979), Nadim and Whitman (1983), Whitman and Liao (1984), Fishman and Richards (1996), and Steedman and Zeng (1996) which have widespread acceptance in practice. More detailed accounts of previous analytical and experimental studies on the subject matter have been presented by Nazarian and Hadjian (1979), Prakash (1981), and Veletsos and Younan (1995).

In this work, finite element analysis, using Plaxis software, is employed to investigate the effects of mechanical properties of the soil and wall on the dynamic response of a cantilever retaining wall. Also the effects of amplitude and frequency of the harmonic source vibration on the response of the wall are studied and discussed.

2 SYSTEM CONSIDERATIONS

The soil is presumed to act as a uniform, homogeneous and isotropic medium. Assuming plane strain conditions, the displacement at the top point of the wall is considered as the maximum displacement of the wall and is assessed as the dynamic response of the soil-wall system (Theodorakopoulos et al., 2001; Veletsos and Younon, 1994a, b).

Soils tend to behave in a highly non-linear way under load. This non-linear stress-strain behavior can be modeled at several levels of sophistication. The well-known Mohr-Coulomb model can be considered as a first order approximation of real soil behavior. The soil is modeled with 15-node volume elements in finite elements model. When 15-node soil elements are employed then each beam element is defined by 6-node.

Interface elements are placed around the wall to model the interaction between the wall and the soil. Material damping in the soil is generally caused by its viscous properties, friction and development of plasticity. In research usually a global damping term is assumed, which is proportional to the mass and

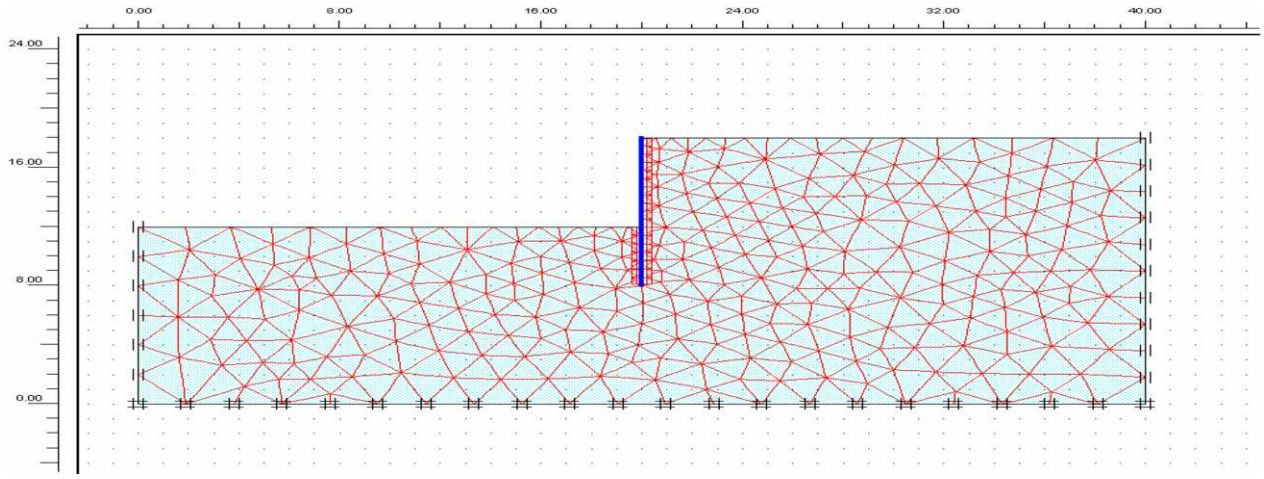

Figure 1. Finite element model of system (uints in meter)

stiffness of the system (Rayleigh damping). Special boundary conditions have to be defined to account for the fact that in reality the soil is a semi-infinite medium. Without these special boundary conditions the waves would be reflected on the model boundaries, returning into the model and disturbing the results. To avoid these spurious reflections, absorbent boundaries are specified at the right and left hand side boundaries. These boundaries are based on Lysmer-Kohlmeyer model.

The finite element model of the system examined is illustrated in Figure 1. The basic system studied consists of a semi-infinite uniform layer of viscoelastic material and a uniform, flexible cantilever wall being elastically constrained against rotation at its base. There is no groundwater and the coefficient of at-rest earth pressure is assumed to be 0.5.

The properties of the soil stratum are defined by its density γ, internal friction angle ϕ, cohesion c, modulus of elasticity E and material damping factor D. The wall is presumed to be a concrete diaphragm retaining wall when the effect of soil parameters on the dynamic response of the wall is under investigation. In this case, the properties of the wall are defined by its flexural rigidity EI, axial rigidity EA, Poisson's ratio υ, weight per unit of surface area w and its height H.

A harmonic load as an acceleration is imported to the bedrock and is used to analyze the model. The harmonic sinusoidal load has a maximum amplitude of $0.25g$ and the frequency of the load is ranging from 0.5 to 10 Hz. The length of the retaining wall is much larger than its width. The dynamic load is also supposed to have a dominant effect across the width of the retaining wall. Hence, a plane strain analysis can be performed.

3 METHOD OF ANALYSIS

It is desired to use the Newmark step-by-step method to numerically solve the dynamic motion equation. In this method, the displacement and velocity at the time $t+\Delta t$ are calculated using the following expressions:

$$u_{t+\Delta t} = u_t + \dot{u}_t \cdot \Delta t + \left[\left(\frac{1}{2} - \alpha \right) \ddot{u}_t + \alpha \, \ddot{u}_{t+\Delta t} \right] \Delta t^2 \qquad (1)$$

$$\dot{u}_{t+\Delta t} = \dot{u}_t + \left[(1-\beta) \ddot{u}_t + \beta \, \ddot{u}_{t+\Delta t} \right] \Delta t \qquad (2)$$

The Newmark α and β parameters determine the numeric time-integration according to the implicit Newmark scheme. In order to obtain a stable solution, these parameters have to satisfy the following conditions:

$$\beta \geq 0.5 \quad , \quad \alpha \geq 0.25 (0.5 + \beta)^2 \qquad (3)$$

Special boundary conditions have to be defined in order to avoid the spurious reflections of the waves on the model boundaries. These boundaries are based on the Lysmer-Kohlmeyer model. According to this model, the normal and shear stress components absorbed by a damper are determined as follows:

$$\sigma_n = -c_1 \rho v_p \dot{u}_x \qquad (4)$$

$$\tau = -c_2 \rho v_s \dot{u}_y \qquad (5)$$

where ρ = mass density; v_s= shear wave velocity; v_p = longitudinal wave velocity; $\dot{u}_x$ and $\dot{u}_y$ = velocity of particle motion in the directions of x and y, respectively. c_1 and c_2 are relaxation coefficients used to improve the wave absorption on the absorbent boundaries. c_1 corrects the dissipation in the direction normal to the boundary and c_2 in the tangential direction. The research and experience findings recommend to choose c_1 = 1 and c_2= 0.25 for best results (Brinkgreve and Vermeer, 1998). These data are required to generate the initial conditions of the model and to complete the general settings of the input program needed for running the Plaxis code and performing the planned dynamic analysis.

4 PARAMETRIC STUDIES

The parametric studies are conducted in order to investigate the effects of these parameters on the dynamic response of a cantilever retaining wall. These studies can be grouped into the following three categories: (1) soil properties including density, friction angle, cohesion, Young's modulus and damping ratio; (2) retaining wall parameters including flexural rigidity, axial rigidity, Poisson's ratio and height of the wall; and (3) frequency and amplitude of the harmonic loading.

The general approach for conducting the parametric studies is employed in such a way that when a parameter is selected as a variable and its effects on the dynamic response of the system is under investigation, the value of that parameter is changed each time and the corresponding response is calculated while the other parameters of the system remain unchanged during that study. This approach is followed and applied for all studies and analysis done using Plaxis code. The

results of analysis for all three groups mentioned above are given in the following sections.

4.1 Soil properties

Figures 2 to 6 show the soil properties effects on the dynamic response of the system.

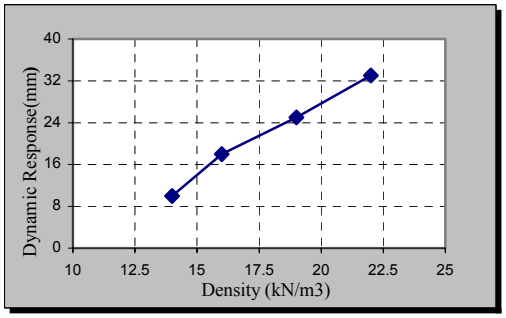

Figure 2. Effects of density on dynamic response

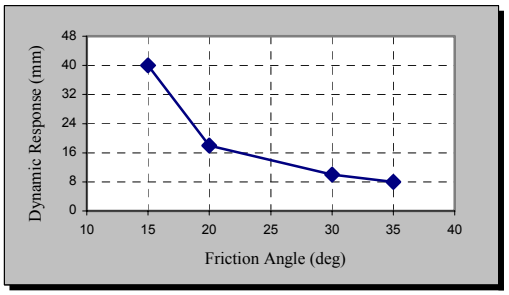

Figure 3. Effects of friction angle on dynamic response

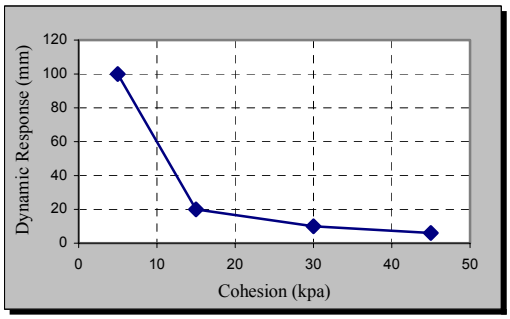

Figure 4. Effects of cohesion on dynamic response

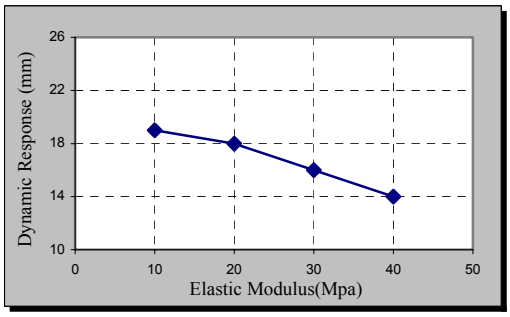

Figure 5. Effects of elastic modulus on dynamic response

It can be seen from these figures that the response increases with increasing density, while decreases with increasing internal friction, cohesion, Young's modulus and soil damping.

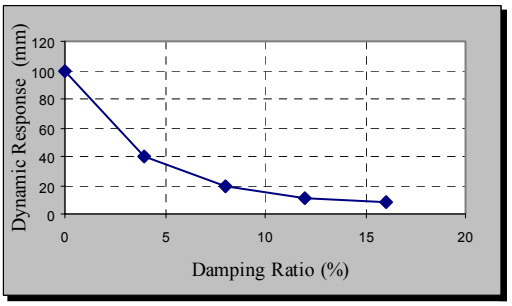

Figure 6. Effects of damping on dynamic response

4.2 Retaining wall properties

The mechanical and geometrical properties of the studied retaining walls are given in Table 1.

Table 1: Specifications of studied cantilever retaining walls

Wall Type	Steel Soft Wall	Steel Sheet Pile	Concrete Diaphragm	Rigid Concrete
	1	2	3	4
EI(kN.m2/m)	2×10^4	8×10^4	2×10^6	1.5×10^9
EA(kN/m)	4×10^6	4×10^6	4×10^7	2.5×10^{10}
υ	0.3	0.3	0.17	0.17

Figure 7 shows the effects of the type and stiffness of the walls explained in table 1. It is seen that the response of the system decreases as the stiffness of the wall increases.

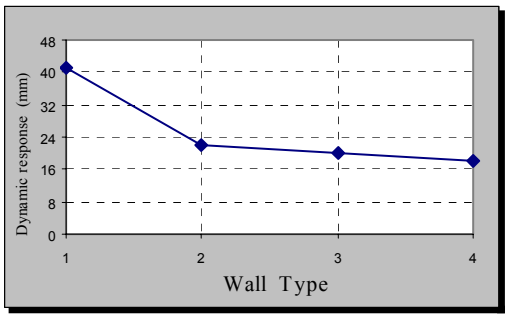

Figure 7. Effects of wall stiffness on dynamic response

4.3 Harmonic loading parameters

The amplitude and frequency of harmonic loading are the important parameters of the loads influencing the dynamic response of the system. The relationship between the amplitude of the applied harmonic loading and the bedrock acceleration is expressed by the following equation:

$$r = \frac{a}{(2\pi f)^2} \qquad (6)$$

where $a = \alpha g$ and a, α, g, r and f are the acceleration imported to the bedrock, coefficient of the imported acceleration, gravitational acceleration, amplitude and frequency of the har-

monic loading, respectively. *f* has been assumed to be 5 Hz in the analyses performed for this section.

Figures 8 and 9 show the variations of the response of the system against amplitude and frequency of the loading. From Figure 8 one can see that the magnitude of the wall's top displacement increases as the bedrock acceleration increases. Also it is observed from Figure 9 that the peak top displacement or resonant phenomenon occurs at exciting frequency equal to the natural frequency of the system, i.e. at $f = 4$ Hz for this case, which produces considerably permanent displacement in the system.

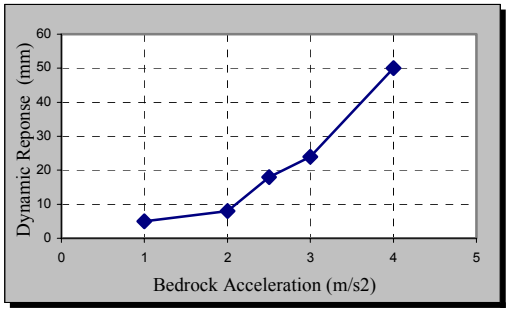

Figure 8. Effects of amplitude on dynamic response

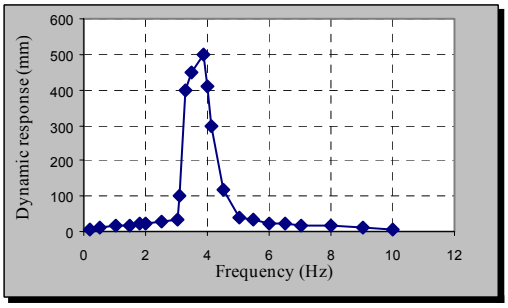

Figure 9. Effects of frequency on dynamic response

5 CONCLUSIONS

On the basis of the preceding studies, the following conclusions can be drawn:

The top displacement of the cantilever retaining wall, considered as the maximum dynamic response of the system, decreases with increasing backfill soil friction angle, cohesion, elastic modulus and damping of the soil, while increases with increasing density of the soil.

The response of the system increases sharply when the frequency of the loading coincides with the natural frequency of the system. This amplification leads to a considerably permanent displacement being occurred in the system. Also the maximum displacement of the wall increases as the imported acceleration to the bedrock increases. Furthermore the response of the system decreases when the stiffness of the retaining wall increases.

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