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A Parametric Study on Evaluation of Backfill Interaction on Seismic Response of a Cantilever Wall

Tufan ÇAKIR[*1]

[1]*Gümüşhane University, Faculty of Engineering and Natural Sciences, Department of Civil Engineering, Gümüşhane*

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Abstract

Knowledge of the seismic behavior of cantilever retaining walls is an important component for their successful design in earthquake prone areas. In this study, a finite element procedure was used to investigate the effects of backfill soil properties variation on seismic response of a cantilever retaining wall. In this procedure, not only soil-structure interaction but also backfill-wall interaction was taken into consideration. Considering four different backfill soil conditions, the dynamic analyses of backfill-cantilever wall-soil/foundation system were carried out in time domain through ANSYS program. The magnitudes of lateral displacements and stresses were determined by performing non-linear time history analyses. As a result, based on the response amplification/reduction pattern observed on the lateral displacements and stresses, it is concluded that the dynamic behavior of cantilever walls is highly sensitive to the backfill characteristics.

Keywords: Soil-structure interaction, Seismic response, Finite element method, Time history

Konsol Bir İstinat Duvarının Sismik Davranışı Üzerinde Dolgu Etkileşiminin Değerlendirilmesi Üzerine Parametrik Bir Çalışma

Öz

Konsol duvarların sismik davranışının bilinmesi, bu yapıların deprem bölgelerindeki başarılı tasarımını tesis etmek için önemli bir unsurdur. Bu çalışmada, konsol bir istinat duvarının sismik tepkisi üzerinde dolgu özellikleri değişiminin etkilerini incelemek için bir sonlu elemanlar yöntemi kullanılmıştır. Bu yöntemde zemin-yapı ve dolgu-duvar etkileşimleri dikkate alınmıştır. Dört farklı dolgu zemini koşulu dikkate alınarak, dolgu-konsol duvar-temel/zemin sisteminin dinamik analizleri zaman ortamında ANSYS programıyla gerçekleştirilmiştir. Yerdeğiştirme ve gerilmeler doğrusal olmayan analizlerle belirlenmiş ve dinamik davranışın dolgu özelliklerine oldukça duyarlı olduğu ortaya konmuştur.

Anahtar Kelimeler: Zemin-yapı etkileşimi, Sismik davranış, Sonlu elemanlar metodu, Zaman geçmişi

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[*] Sorumlu yazar (Corresponding author): Tufan ÇAKIR, *cakirtufan@hotmail.com*

1. INTRODUCTION

Retaining wall is a kind of structure that prevents soil from collapsing and sliding by withstanding the earth pressures generated by soil, and has been widely used in railways, bridges, building structures, hydraulic and harbor engineering. For the safety design of retaining wall under static and seismic load, earth pressures on retaining wall need to be estimated. However, reliable prediction of earth pressures is difficult due to the soil-structure interaction which is seriously influenced by backfill and subsoil material properties, wall flexibility, wall displacement, wave propagation and so on [1].

Reinforced concrete cantilever retaining walls represent a popular type of retaining system. It is widely considered as advantageous over traditional gravity walls since it combines economy and ease in construction and installation. The concept is deemed particularly rational, as it exploits the stabilizing action of the soil weight over the footing slab against both sliding and overturning, thus allowing construction of walls of considerable height. For walls of this type structural weight is not predominant as equilibrium depends mainly on backfill actions and the resistance of foundation soil [2].

There are mainly three categories of methods for design and seismic analysis of retaining walls: (a) analytic limit-state analysis methods where the wall can displace and/or rotate sufficiently at its base to induce a limit or failure state in the backfill, (b) analytic linear elastic or viscoelastic methods where the wall remains fixed at its base and the backfill soil is considered to respond in a linear elastic or viscoelastic manner, (c) numerical methods of solution, mainly finite element methods under the assumption of linear elastic or nonlinear elastoplastic soil behavior [3-6]. The present paper belongs to the third category of methods to seismically analyze the cantilever retaining wall under consideration. An extensive list of papers for each one of the above three categories can be found in [3-12], and the details need not be repeated herein.

Considering previous investigations on cantilever retaining walls, it is seen that most of them have concentrated on the estimation of earthquake-induced earth pressures. On the other hand, limited research has been done on the effects of soil-structure interaction on seismic behavior of cantilever walls under three dimensional conditions. Thus, the objective of this paper is to investigate the seismic response of a cantilever retaining wall considering the effects of backfill interaction. In line with this aim, a series of seismic analyses were carried out taking four different backfill soil conditions into consideration in time domain.

2. FINITE ELEMENT MODEL AND SEISMIC ANALYSIS

For solving the problem of backfill-cantilever wall-soil/foundation system, the general purpose structural analysis program ANSYS was used [13]. Numerical analysis of the cantilever retaining wall problem with backfill and subsoil interactions and subjected to earthquake loading is a complex problem. Figure 1 shows the proposed finite element model for the problem of cantilever retaining wall. The heights of the wall and soil stratum are considered to be the same. The vertical stem height of the cantilever wall is H= 6 m, the wall stem has a constant thickness of 0.4 m, the thickness of base slab is 0.6 m, and the base slab width is 4.0 m. The cantilever wall system is founded on a deformable soil layer of thickness 2H. In the finite element modelling, the structural wall is modelled with 3 D reinforced concrete solid elements (SOLID65) defined by eight nodes having three translational degrees of freedom in each node. The SOLID65 is used for the 3 D modeling of solids with or without reinforcing bars. The solid is capable of cracking in tension and crushing in compression. The backfill and soil/foundation system are modelled with 3 D structural solid elements (SOLID185) with eight nodes having three degrees-of-freedom at each node: translations in the nodal x, y, z directions. The SOLID65 has plasticity, hyperelasticity, stress stiffening, creep, large deflection, and large strain capabilities. It also has mixed formulation capability for simulating deformations of nearly incompressible elastoplastic materials, and fully incompressible hyperelastic materials. Reasonable modelling of the wall-backfill interface requires using special interface elements between the wall and the adjacent soil to allow for separation. Hence, as a special interface element, nonlinear spring (COMBIN39) is used between the backfill and the wall allowing for the opening and closing of the gaps (i.e. de-bonding and bonding) to model backfill-wall interaction in this study. COMBIN39 is a unidirectional element with nonlinear generalized force-deflection capability that can be used in any analysis. The element has longitudinal or torsional capability in 1 D, 2 D, or 3 D applications. The longitudinal option is a uniaxial tension-compression element with up to three degrees of freedom at each node: translations in the nodal x, y, and z directions.

Another important consideration in the dynamic finite element analyses is the modeling of semi-infinite extent of the soil medium. The general approach of treating these problems is to divide the infinite medium into the near field (truncated layer), which includes the irregularity as well as the non-homogeneity of the soil adjacent to the structure, and the far field, which is simplified as an isotropic homogeneous elastic medium [14]. In this study, the viscous boundary model [15] is used in three dimensions to consider radiative effect of the seismic waves through the soil medium. To represent the behavior of the semi-infinite backfill medium, the critical minimum distance from the face of the wall is taken as 10 H, a value which is believed to approximate adequately the behavior of the semi-infinite layer [4,9]. In this context, the dashpots were also placed 10H away from the wall in three dimensions to improve the accuracy of the simulation. Similarly, the artificial viscous boundaries have been placed in three dimensions on the boundaries of soil/foundation medium.

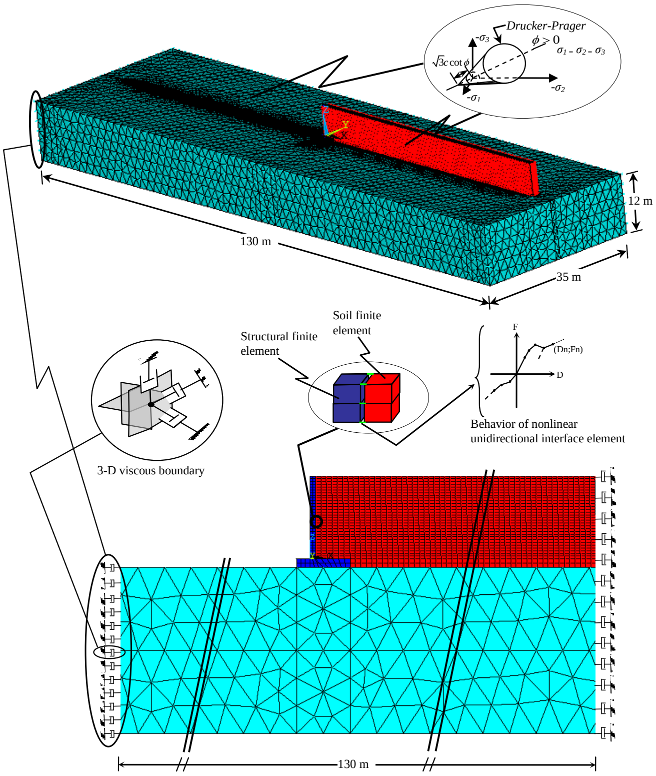

Figure 1. Finite element model of the system

A series of seismic analyses with variation of parameters such as physical and mechanical properties of backfill soil were carried out employing the proposed finite element model. The Young's modulus, Poisson's ratio and unit weight of the wall are 28000 MPa, 0.2 and 25 kN/m^3, respectively. The Young's Modulus, the Poisson's ratio and the unit weight of cohesionless foundation soil were taken to be 500 MPa, 0.35 and 19 kN/m^3, respectively. To evaluate backfill interaction effects on dynamic response of the cantilever retaining wall supported on flexible foundation, four different backfill soil types were considered in the analyses (Table 1). "CLS090" component of 1989 Loma Prieta earthquake was used in the nonlinear time history analyses (Figure 2). The horizontal peak ground acceleration for the record reaches 4.7 m/s^2. Furthermore, Rayleigh damping was taken into consideration in the analyses. The damping values for both structure and soil were presumed to be 5%.

Table 1. Backfill soil properties considered in this study

Soil types	E (kN/m^2)	G (kN/m^2)	υ	γ (kN/m^3)	V_s (m/s)	V_p (m/s)
S1	300000	111111	0.35	19	241.83	503.40
S2	150000	55556	0.35	19	171.00	355.96
S3	75000	26786	0.40	18	121.99	298.81
S4	35000	12500	0.40	18	83.33	204.12

E: Young's modulus, G: Shear modulus, ν: Poisson's ratio, γ: Unit weight, V_s: Shear wave velocity, V_p: Dilatational wave velocity

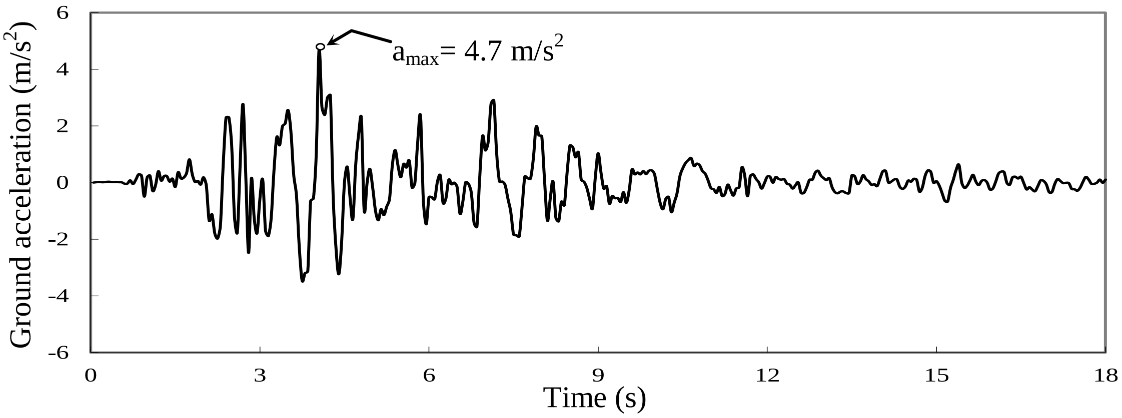

Figure 2. CLS090 component of 1989 Loma Prieta earthquake

3. RESULTS AND DISCUSSIONS

Table 2 summarizes the maximum top displacements and the stress responses at the front and back faces of the cantilever wall and their occurrence times depending on the variation of backfill soil properties. The table indicates that the responses of the system are different from each other so that the maximum values of both lateral displacements and stresses changed with changing soil conditions. It is worth stating here that the displacements represent the relative lateral displacements of the wall with respect to the ground.

It is observed from Table 2 that as the backfill soil stiffness decreases, the displacement response generally tends to increase for all conditions, and this reflects a significant backfill influence on the response. For example, while the maximum lateral displacement is estimated as 0.0043 m for S1 soil type, the same quantity is calculated as 0.0054 m for S4 soil type under Loma Prieta earthquake. Thus, it can be highlighted that SSI affects the wall behavior so that the increment in the displacement response is almost at a level of 26% between S1 and S4 soil types.

Table 2. Seismic analysis results considering backfill-wall interaction

Soil types	S1		S2		S3		S4	
	t (s)	Value	t (s)	Value	t (s)	Value	t (s)	Value
u_t (m)	4.00	-0.0043	4.00	-0.0050	4.00	-0.0054	4.00	-0.0054
S_{zb} (MPa)	4.30	-5.4828	4.30	-5.2210	3.90	4.6066	4.30	-3.7675
S_{yb} (MPa)	4.25	-0.8016	4.25	-0.7406	3.90	0.6381	3.90	0.5018
S_{xb} (MPa)	4.30	-2.0368	4.30	-1.9433	3.90	1.6775	4.30	-1.3360
S_{zf} (MPa)	4.30	5.5371	4.30	5.2822	3.90	-4.6663	4.30	3.8180
S_{yf} (MPa)	4.25	0.5423	4.25	0.4945	4.25	0.4182	3.90	-0.3274
S_{xf} (MPa)	4.25	0.7665	4.25	0.6772	4.25	0.5624	4.25	0.4356

u_t : Maximum lateral top displacement of cantilever wall; S_{zb}, S_{yb} and S_{xb} : Stresses estimated on the back face (backfill side) of the cantilever wall in *z*, *y* and *x* directions, respectively; S_{zf}, S_{yf} and S_{xf} : Stresses estimated on the front face of the cantilever wall in *z*, *y* and *x* directions, respectively.

The computed stress responses can also be compared to introduce the backfill interaction effects. As seen from Table 2, the maximum stresses obtained at the critical sections of the wall change with varying soil conditions. The table indicates that as the backfill soil stiffness decreases, the displacement response generally tends to decrease for all conditions, and this reflects a significant backfill influence on the response. For example, while the peak stress, as compression, has the value of 5.4828 MPa for S1 soil type, it is calculated as 3.7675 MPa for S4 soil type at the back face of the cantilever retaining wall in z direction. This reflects a stress decrement of about 31% between S1 and S4 soil types due to the variation of backfill soil conditions. A similar trend can be observed for the other directions.

4. CONCLUSIONS

The paper presents the results of a parametric study aimed to assess the dynamic response of a cantilever T-type retaining wall consisted of a concrete stem and base slab which form an inverted T considering not only soil-structure but also backfill-wall interactions. The analyses were carried out using advanced numerical modelling of backfill-cantilever wall-foundation/soil system. Four non-linear time-history analyses were performed using different backfill soil conditions. The results are presented in terms of the lateral displacements and stresses in the wall obtained from nonlinear time history analyses. It is obvious that the seismic response of cantilever retaining wall is significantly affected from the backfill-structure interaction, and it is found to be very sensitive to changes in backfill soil properties.

5. ACKNOWLEDGEMENTS

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