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EARTHQUAKE ANALYSIS OF BUILDING STRUCTURES WITH FOUNDATION UPLIFT IN DOWNTOWN ADAPAZARI

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ABSTRACT: The primary objective of this study is to investigate the effect of foundation flexibility and uplift on the seismic response of building structures located in downtown Adapazari, where substantial geotechnical effects occurred during the earthquake. To perform the analysis, the basic data about the soil conditions at the site was collected from subsoil investigation reports that were compiled by various government agencies, local public body and private consultants. The geotechnical model included a nonlinear representation of the soil material below the mat foundation. This foundation model could accommodate both uplift and plastic yielding of the soil material. The superstructure was idealized as a typical R/C frame structure subjected to the E-W component of 17 August 1999 Marmara earthquake recorded at SKR station in Adapazari. The authors performed the analysis using the nonlinear computer program Drain-2DX.

Keywords : Geotechnical earthquake engineering, damage analysis, foundation flexibility and uplift

ÖZET: 17 Ağustos 1999 Marmara depreminin ardından, genç alüvyon zeminler üzerinde kurulan Adapazarı'nda, daha önce görülmemiş boyutlarda zeminin geoteknik özelliklerine bağlı hasarlar gözlenmiştir. Bu çalışmada, yumuşak zeminler üzerinde inşa edilen yapılarda deprem etkisi ile oluşan yukarı itme-kaldırma etkisi incelenmiştir. Zemin geoteknik özellikleri ile ilgili gerekli veriler çeşitli kuruluşlarca yapılan zemin etütlerinden toplanmıştır. Kullanılan geoteknik modelde, doğrusal olmayan zemin malzeme özelliklerine de yer verilmiştir. Üstyapı olarak, Adapazarı'nda tipik olarak rastlanan çerçeve sistemli betonarme yapılar ele alınmıştır. Sistemin çözümünde, Adapazarı SKR istasyonunda kaydedilen 17 Ağustos 1999 Marmara depremi D-B

bileşeni kullanılmıştır. Ele alınan problem, Drain-2DX bilgisayar yazılımı kullanılarak çözülmüştür.

Introduction

The seismic analysis of the buildings and other engineering structures is based on the assumption that the soil underlying the structure is perfectly rigid and the structural foundation is firmly bonded to the supporting soil. However, in reality, the soils are not infinitely stiff and structures are supported on the soil only through gravity forces, not through an adhesive bond.

Large lateral loads acting on the structure-caused for example, by a severe earthquake-will lead to a substantial overturning moments. This can result in tension occurring in part of the structure's and the soil's basemat area according to an analysis based on linear theory. As tension is incompatible with the constitutive law of soil, the basemat will become partially separated from the underlying soil (Wolf and Song, 2002).

Except intake-outlet towers, oil tanks or chimneys, seldom uplift of low-rise multistory structures has been observed. In Turkey, it is considered that design code forces were not large enough to initiate uplift. After the 17 August 1999 Marmara earthquake, the situation has changed. Hundreds of buildings settled, tipped or toppled due to loss of bearing capacity or liquefaction weakened soils beneath reinforced concrete mat foundations, especially, Orta Mahalle, Tiğcilar, Yenicami, Yenigün, Papuççular, Kurtuluş districts where they are located central of Adapazari.

Considerable work has been carried out on the subject of the effects of foundation uplift in computing the earthquake response of the structures. Huckelbridge and Clough (1978) performed an analytical experimental assessment of the influence of allowing the columns to uplift from their foundations during an earthquake. In Psycharis study (1981), the equations of motion for the analysis of simple structures considering the effects of foundation flexibility and uplift are developed. The authors Chopra and Yim (1985), in their consecutive works, a simplified approach for estimating the response of uplifting multistory structures was presented. Spyrakos and Chaojin Xu (1997) studied the seismic analysis of intake-outlet towers including soil-structure-water interaction. The study shows that the foundation uplift is greatly affected by the soil stiffness and the slenderness of the tower. Rodríguez and Montes (1998) analyzed the effects of temporary base uplift on the seismic response of buildings. It is found that the temporary uplift of the foundation mat may lead to important reduction on global seismic damage, as compared to the case of a comparable structure with a foundation mat firmly bonded to the supporting soil.

The aim of this work is to perform a parametric study of uplifting structures using the Drain-2DX nonlinear computer program (Prakash, Powell and Campbell, 1993) and the E-W component of 17 August 1999 Marmara earthquake recorded at SKR station in Adapazari. The acceleration trace of this earthquake is shown in Figure 1.

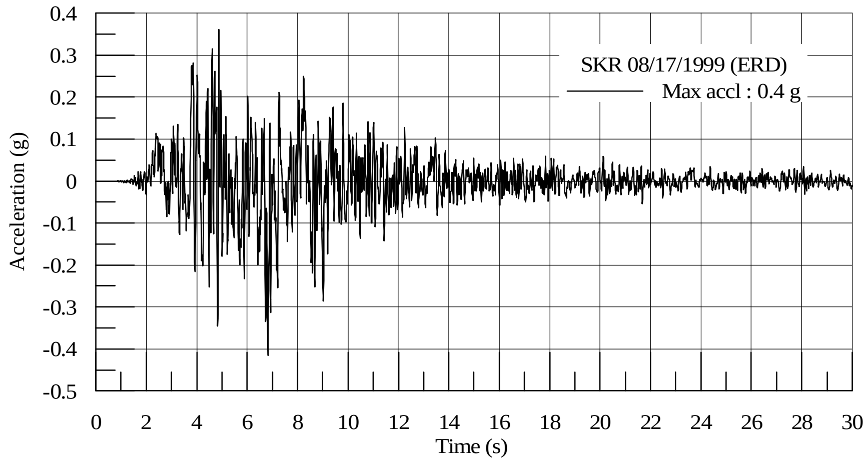

Figure 1. E-W component of 17 August 1999 Marmara earthquake acceleration–time history, recorded at Adapazari SKR station

Analytical Model

The system considered is shown in Figures 2a and 2b, consisting of the multistory building supported through a basemat on flexible foundation. It is assumed that the mass of the building is concentrated at the floor level. For the superstructure, viscous damping is assumed and slippage between the basemat and supporting elements is not considered. The system rests on the spring-damper elements, the basemat is not bonded to these supporting elements; then, it is free to rock about either edge of the basemat and uplift was resisted only by the gravity loads.

The spring-damper elements properties, which accommodate both uplift and plastic yielding of the soil material, are compiled from subsoil investigation reports that were collected by various government agencies, local public body and private consultants. These investigations indicates that the study area has soft and deep alluvial layers with a high water table. The bearing value of this site is obtained around 150 kN/m^2 and shear wave velocity is determined as Vs=150 m/s.

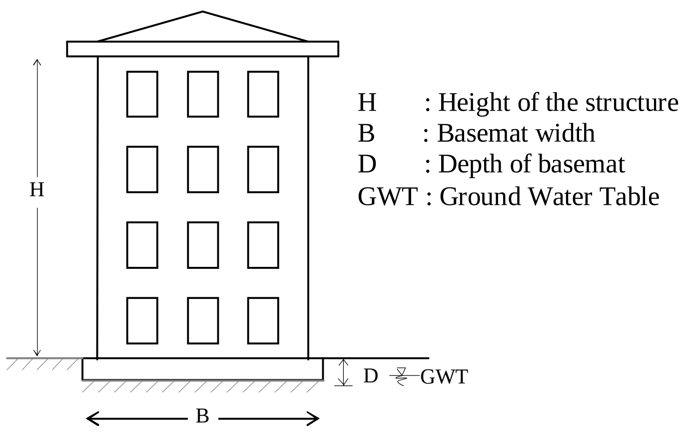

Figure 2a. Typical construction practice in downtown Adapazari

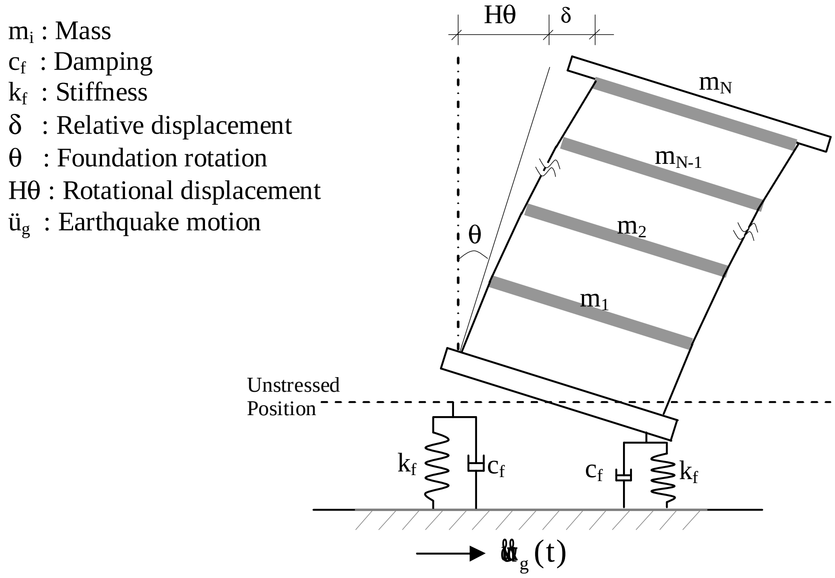

Figure 2b. Multistory building supported on two spring-damper elements (Modified from Yim and Chopra, 1985)

Results from Earthquake Excitation

In order to examine the effect of foundation uplift of multistory buildings, both uplift permitted and fixed base (constrained) multistory building systems are studied by comparing the earthquake responses. Response parameters analyzed in this work are the aspect ratio (H/B), the structural horizontal top displacement ($u_{t,h}$) and vertical displacement of the basemat edge ($u_{b,v}$). It is mentioned in various papers (Chopra and Yim, 1985; Yim and Chopra, 1985) that the beneficial effect of uplift were observed in terms of base shear, therefore, in this study, it is not included.

The natural vibration periods (T_i) of the considered systems are presented in Table 1, where the logical phenomenon has been come out; since the natural period increases with decreasing stiffness of the supporting medium.

Table 1. The natural vibration periods of the considered systems

	Period, T_1		Period, T_2	
	H/B=1.5	H/B=2.0	H/B=1.5	H/B=2.0
Fixed base	0.363	0.482	0.117	0.156
Uplift	0.608	0.854	0.182	0.210

Numerical results for the total top displacement-time history of the given structures subjected to the 17 August 1999 Marmara earthquake are shown in Figures 3 and 4. In these figures, for the case of fixed base structures, horizontal top displacement ($u_{t,h}$) is equal to the relative displacement (δ); but, for the flexible systems, it is the summation of the relative displacement (δ) and rotational (inclination) displacement (Hθ). According to these results, displacement ($u_{t,h}$) experienced by uplifting structures are bigger than those experienced by comparable fixed base structures. Aspect ratio (slenderness ratio, H/B) is the another key parameter, greatly affects the foundation uplift. As H/B ratio is built up, even during the moderate type of ground shaking, the displacement due to foundation rotation exceeds the critical deformation and the basemat rocks alternately about its two edges in a vibration cycle.

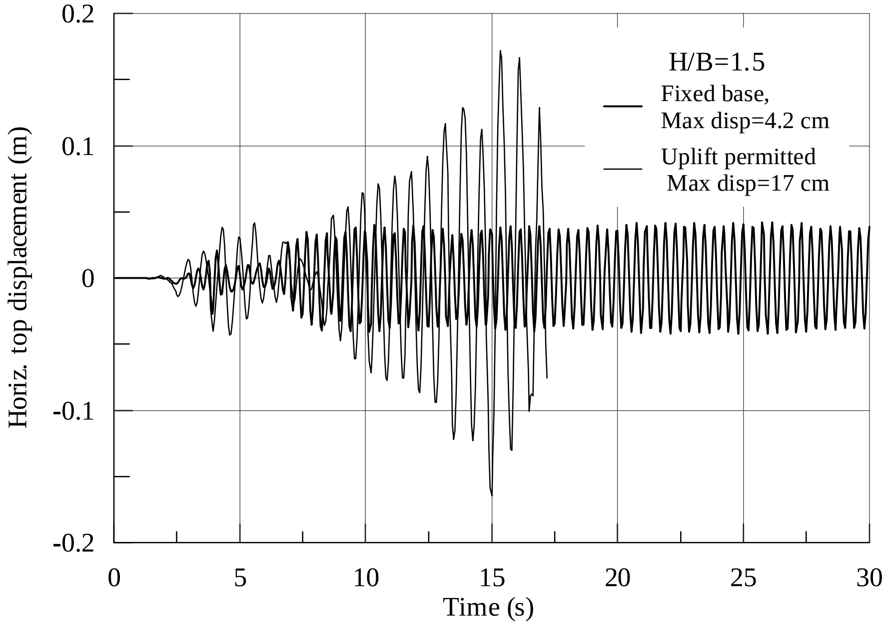

Figure 3. Comparison of horizontal top displacements for structures with H/B=1.5 aspect ratio

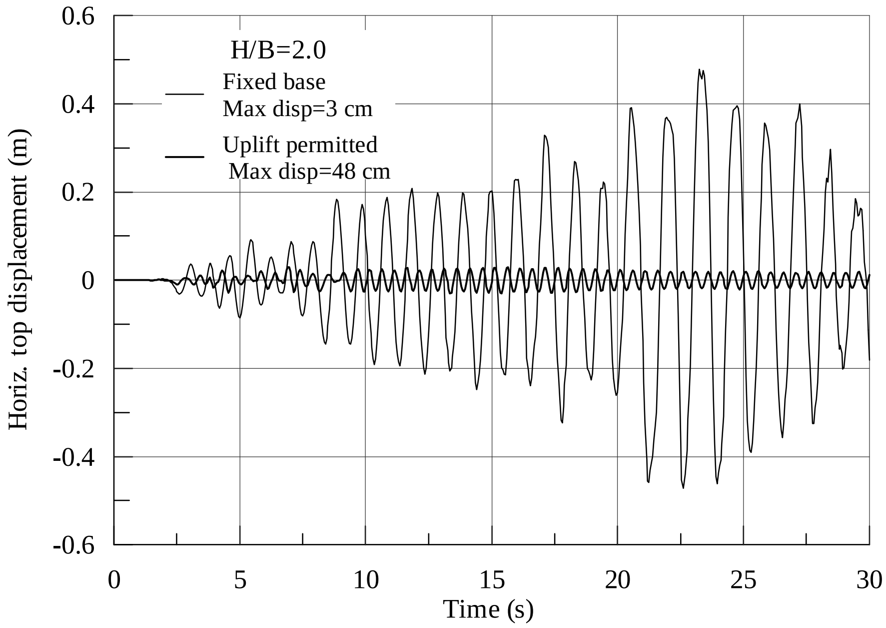

Figure 4. Comparison of horizontal top displacements for structures with H/B=2.0 aspect ratio

The vertical basemat edge displacement is presented in Figure 5, where the positive upward displacement (uplift side) is recorded as 25 cm, while the negative downward displacement (yielding side) is written down as 15 cm. These differences show that basemat rocking is activated. This kind of behavior is associated with tipped or toppled type of the structural damage during the earthquakes.

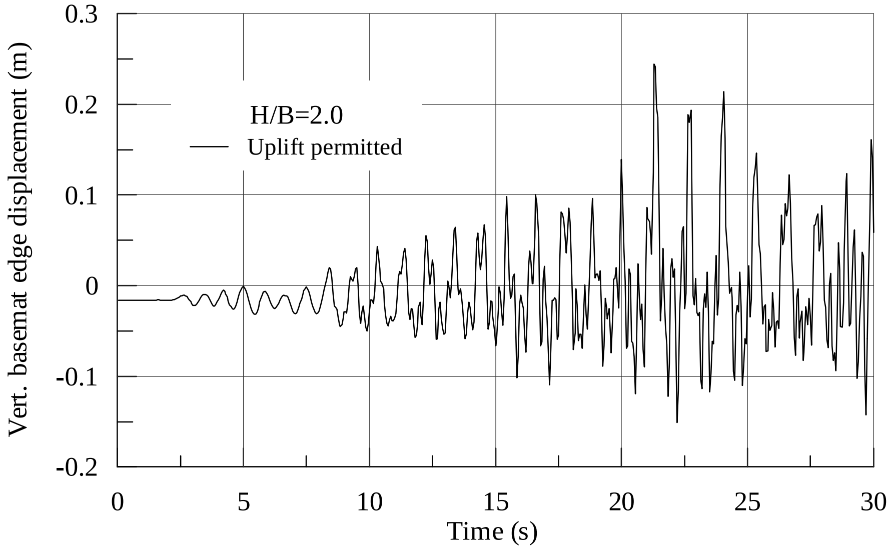

Figure 5. The vertical basemat edge displacement of the system subjected to the Marmara earthquake

Conclusion

Although the foundation flexibility and uplift have beneficial effect on the seismic response of the structure in terms of the base shear, during a strong ground shaking, these may cause the toppling of a building structure, expectedly.

In this study, buildings with two different aspect ratio as H/B=1.5 and H/B=2.0 are considered. However, no conclusive statements could be made about the response of the structure with aspect ratio of H/B=1.5.

For the case of Adapazari, since the ground water level is between -0.5m and -1.5 m depending on the seasonal fluctuations, most of the building foundations are located very close to the ground surface. During the last earthquake, certainly, this practice caused to sinking or toppling of many buildings. Therefore, enough depth of embedment of shallow foundation should be provided.

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