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Seismic Analysis of Building Structures with Foundation Uplift in Ahmedabad during Republic Day Earthquake

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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 Ahmedabad, 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 nonlinearrepresentation of the soil material below the mat foundation. This foundation model could accommodate both uplift and plastic yielding of the soil material. The superstructurewas idealized as a typical RCC frame structure subjected to the E-W componentof 26January2001 Bhuj earthquake recorded at Ahmedabad station in Gujarat. The authors performed the analysis using the nonlinear computer program using MATLAB.*

Keywords -*Earthquake , multistory building , foundation , displacement , Soil properties*

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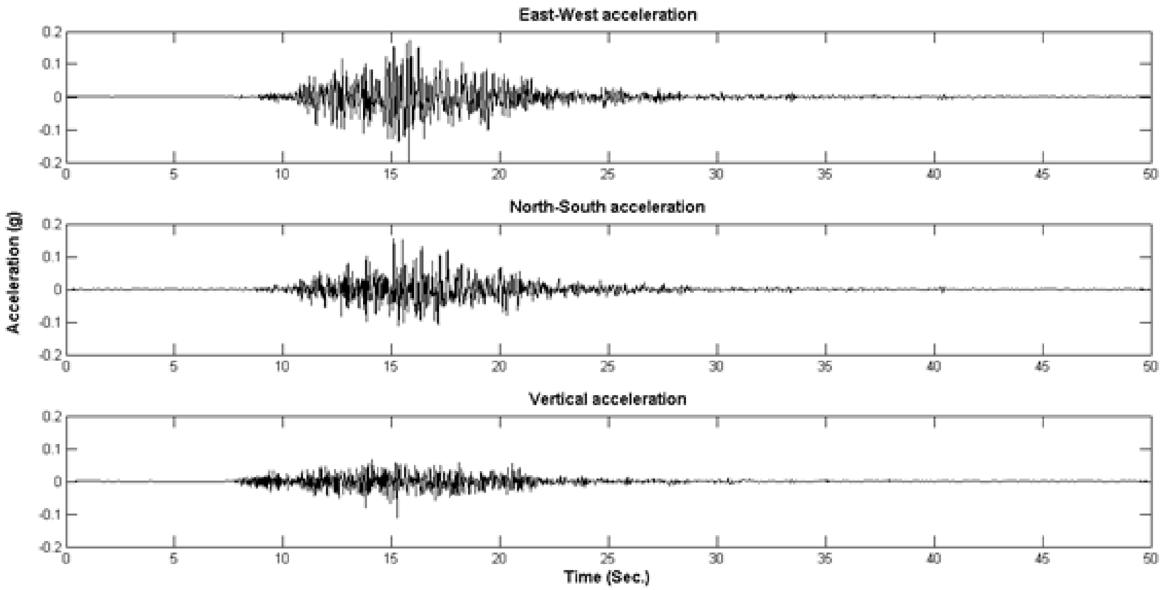
I. Introduction

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 footing area according to an analysis based on linear theory. As tension is incompatible with the constitutive law of soil, the footing will become partially separated from the underlying soil [7]. Except intake-outlet towers, oil tanks or chimneys, seldom uplift of low-rise multistory structures has been observed. In India, it is considered that design code forces were not large enough to initiate uplift.After the 26 January 2001 Bhuj earthquake, the situation has changed. Hundreds of buildings settled, tipped or toppled due to loss of bearing capacity or liquefaction weakened soils beneath reinforcedfoundations, especially, Anjar, Raper,Bhachau,Gandidham,Nakhatrana districts where they are located near of Bhuj. 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 [2] performed an analytical experimental assessment of the influence of allowing the columns to uplift from their foundations during an earthquake. In Psycharis [4] study 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 [1], in their consecutive works, a simplified approach for estimating the response of uplifting multistory structures was presented. Spyrakos and ChaojinXu [6] 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 [5] 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 MATLAB and the E-W component of 26January2001Bhuj earthquake recorded at Ahmadabad station in Gujarat. The acceleration trace of this earthquake is shown in Figure 1.



ANALYTICAL MODEL

The system considered is shown in Figures 2a and 2b, consisting of the multistory building supported through a footing 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 footing and supporting elements is not considered. The system rests on the spring-damper elements, the footing is not bonded to these supporting elements; then, it is free to rock about either edge of the footing 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 indicate that the study area has silt layers. The bearing value of this site is obtained around 150kN/m^2.The interaction between the pier footing and the soil is modeled using translational spring and damper arrangement at footing. Details of earthquake analyzed here have mention in Table 1 and soil properties have mention in Table 2.

Table 1. Details of Bhuj Earthquake recorded in present study

Earthquake	Recording station	Applied in longitudinal direction of the building		Applied in transverse direction of the building	
Bhuj, 2001	Ahmedabad	Component N120W	PGA (g) 0.080	Component N780E	PGA (g) 0.106

The spring coefficients have been computed by the method suggested in Specification for building and IS 1893 (1981). In the suggested method, it should be mentioned that, when using equations (1) and (2), the units of Be and E must be centimeters and kgf/cm2respectively. The horizontal and rotational spring coefficients for each part of foundation are obtained by multiplying k by the area and the inertia moment of its surface perpendicular to the excitation direction, respectively. As for the bottom face of foundation, the soil reaction coefficient per unit area in horizontal direction is taken as 1/3 of k.

Table 2. Soil properties and lateral and rocking stiffness coefficients for Ahmedabad

Silty soil Properties	
Unit weight of soil-γ; kN/m³	18
Shear wave velocity Vs; m/ sec	82.54
Shear Modulus-Gs; kN/m²	12500
Young's modulus of Elasticity-E ; kN/m²	35000
Poisson's Ratio-μ	0.4
Kx (kN/ m)	4.6 x 106
Kr (kN m/rad)	156 x 106

$$k_0 = \frac{1.2E}{30} \quad (1)$$

$$k = k_0^{-3/4}\sqrt{Be/30} \quad (2)$$

Where, k_0= reference soil reaction coefficient, E=Young's modulus of elasticity for soil, k =The soil reaction coefficient per unit area, Be= the width of foundation perpendicular to the considered direction. Although it has been recognized that spring coefficients are frequency-dependent, the spring coefficients computed using the method are frequency- independent for practical use. In the seismic response calculation, one-dimensional analysis of soil deposit is first conducted, and accelerations at various depths are computed, which are then used as the input from the springs at corresponding depth.

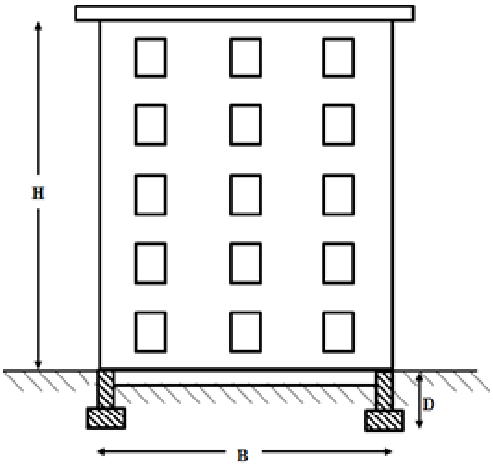


Figure 2(a) Typical construction practice at ahmedabad

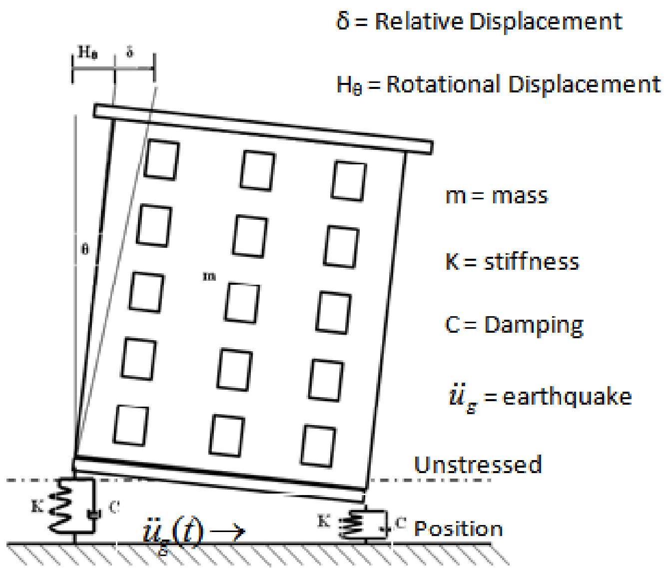


Figure 2(b) Multistory building supported on spring –damper system under seismic excitation

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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 (ut,h) and vertical displacement of the footing edge (ub,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 (Ti) of the considered systems are presented in Table 3, where the logical phenomenon has been come out; since the natural period increases with decreasing stiffness of the supporting medium.

Table 3.The natural vibration periods of the considered systems

	riod, T1		riod, T2	
	/B=1.5	/B=2.0	/B=1.5	/B=2.0
xed Base	363	482	117	156
plift	608	854	182	210

Numerical results for the total top displacement-time history of the given structures subjected to the 26 January2001 Bhujearthquake are shown in Figures 3 and 4. In these figures, for the case of fixed base structures, horizontal top displacement (ut,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 (ut,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 footing rocks alternately about its two edges in a vibration cycle.

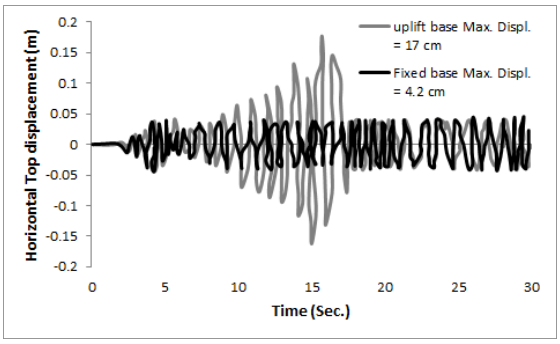

Figure 3. comparison of horizontal top displacement for structure with H/B = 1.5

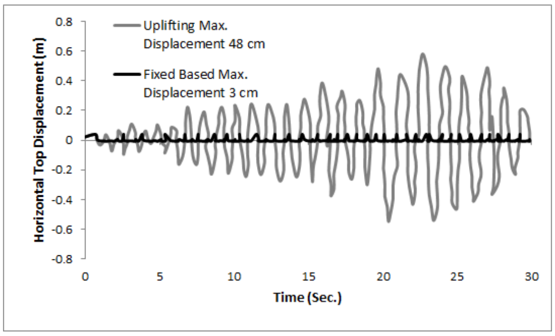

Figure 4. comparison of horizontal top displacement for structure with H/B = 2

The vertical footing edge displacement is presented in Figure 5, where the positive upward displacement (uplift side) is recorded as 30 cm, while the negative downward displacement (yielding side) is written down as 20 cm. These differences show that footing rocking is activated. This kind of behavior is associated with tipped or toppled type of the structural damage during the earthquakes.

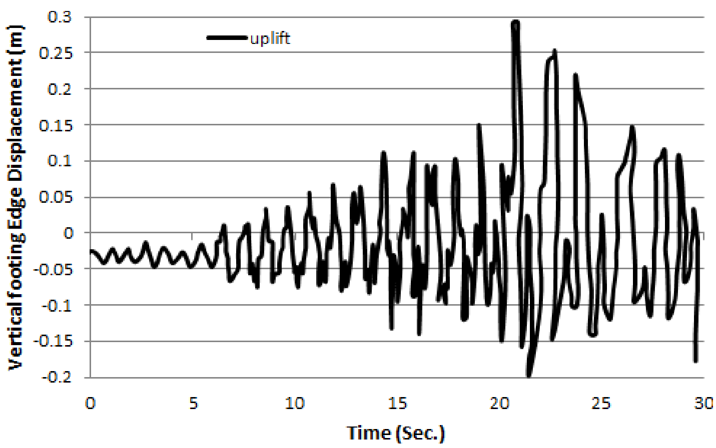

Figure 5.Vertical edge displacement of footing subjected to Ahmedabad earthquake with H/B = 2

II. 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 earthquake response at Ahmedabad, the building foundations with strip footing are located very close to the ground surface. During the last earthquake, certainly, this practice caused to topple or shear damage to many buildings. Therefore, enough depth of embedment of shallow foundation should be provided.

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