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NONLINEAR BEHAVIOR OF BUILDING WITH FOUNDATION UPLIFT UNDER EARTQUAKE EXCITATIONS

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ABSTRACT

During strong earthquake motions, the base-overturning moment may be larger than the available overturning resistance due to gravity loads. since soil cannot take tensile stresses, uplift of part of the base occurs in such cases. So it is important to understand effects of uplift on earthquake response of building. In this paper, the effect of uplift on earthquake response of building was studied by earthquake response analysis. Finite element method was used for analysis. This model was analyzed for two phases 1-with foundation uplift 2- without foundation uplift. Response of buildings in those phases was compared. As results ,uplift reduced shear story force. Also effects of some parameters such as: slender of structure, elastic modulus of soil and cohesion coefficient of soil on foundation uplift were studied. Finally, earthquake response of models ,assuming linear behavior for materials was compared with earthquake response of models, that their materials behavior was nonlinear.

1-INTRODUCTION:

Dynamic soil-structure interaction problems have been mainly studied considering the foundation fixed to the soil. During strong earthquake motions ,however, the base-overturning moment may be larger than the available overturning resistance due to gravity loads. since soil cannot take tensile stresses ,uplift of part of the base occurs in such cases, and response of structure will have been different. There are two examples besides this to point out the possibility that uplift decreases damage of building. The first is a hospital due to 1971 San

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Fernando earthquake[1] and the second is an office building due to 1995 Hygo-Ken-Nabu earthquake.[2]

This observation prompted many researchers to consider this particular aspect of non-linear interaction between soil and structures. The phenomenon has been studied with reference to a single rigid body, but most engineering structure are flexible so many researchers followed those researches for flexible systems.[3-4]

Many researches studied effect of uplift in multi-story models, had caused later to use those results for building models.[5-7].

In previous researches on multi-story models had been used any simplified assumes such as: modeling soil with spring-damper (7)

Our study is conducted with attention to:[8]

-Using of complete model for soil and foundation

-Using of nonlinear behavior for materials of model

2-REFERENCE MODEL:

the effect of uplift on seismic response of 2-D frame by using nonlinear behavior was studied. The reference example was a frame which has 3 spans and 33 floors ,that was modeled with it's foundation and soil under foundation. Width of each span is 4m and stories height are 3m. Width of soil model was so selected that increasing in it doesn't effect on model response, so by sensitivity test, 202m had selected. For uplift modeling CONTACT elements had been used. It has 2 nodes and 2 degree of freedom per each node(u_x,u_y), also it cannot take tensile stresses. Figure1 shows force-displacement relationship in this element. Beam element was used for modeling of beams and columns, it has 3 degree of freedom per each node(u_x,u_y, θ_z). Soil and foundation were modeled by PLANE element. This element has 4 nodes and 2 degree of freedom per each node(u_x,u_y).

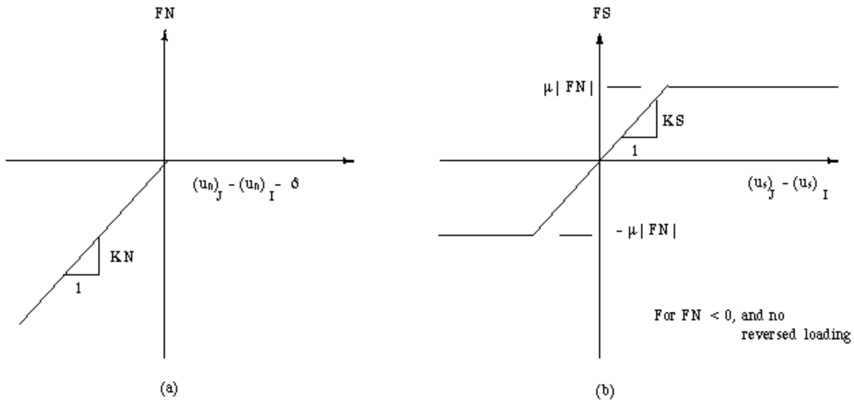

Figure1-Force-Displacement relationship in CONTACT element

Table1-Materials properties

Material Name	*Elastic Module (Mpa)*	*Poison Coefficient*	*Cohesion coefficient*	*angle of friction*
Steel	*2.1e4*	*.3*	-	-
Concrete	*2e3*	*.17*	***4.74MPa***	***54.4***
Soil	*40*	*.33*	***30 KPa***	***10***

For steel materials a bilinear model was used. Slope of primary section is equal to elasticity module (E) and secondary section's slope is 2% of initial elasticity module.
For nonlinear behavior of soil and concrete , Mohr-Coloumb model was chose. Input data for this model are angle of friction(ϕ) and cohesion value(C) . table1 shows C and ϕ values for concrete and soil.

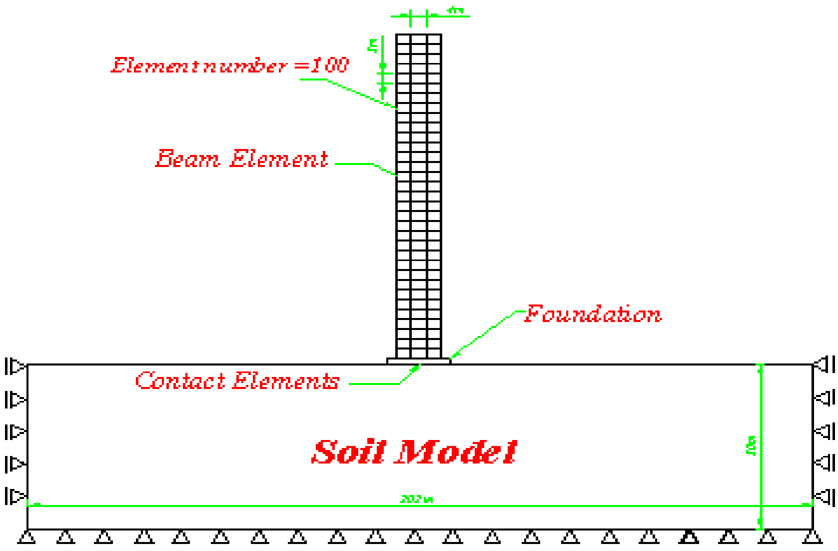

Figure2- Reference example

3- EFFETS OF UPLIFT IN REFERENCE EXAMPLE

Models subjected to Tabas accelerator. Each model has been analyzed for 4 cases: with or without foundation uplift and by assuming linear or nonlinear behavior for materials. For nonlinear time history analyses, newmark method has been used.
Earthquake response of models are compared. The results are shown in the following.

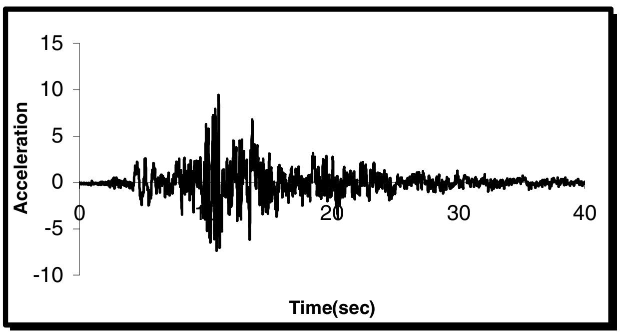

Figure3- ***Tabas Accelerator***

3-1- Variation of U_y

Figure 4 represents the variation of u_y at two edges of foundation, for linear and nonlinear materials. It is clear u_y at two edges of foundation, presents

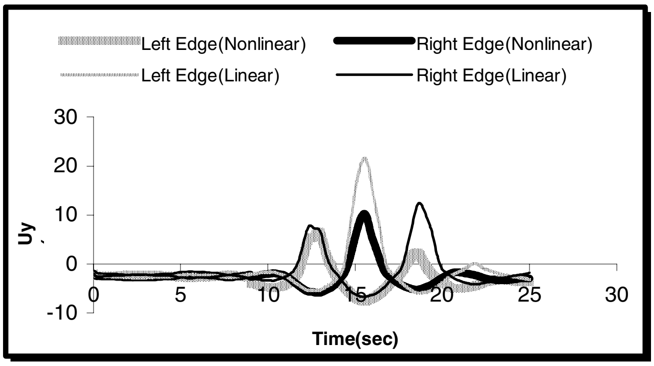

Figure4-U_y Variation

foundation uplift value. It has been observed that uplift value, decreases by considering to nonlinear behavior of materials, comparing to linear behavior .(uplift value for model with linear materials is 21.55^{cm} and for nonlinear material case is 10.34^{cm}.

3-2- Shear Base :

When the foundation uplift occurs, wherefore , lateral stiffness of system is reduced , so, the shear base in uplifted case is less than shear base in fixed case. For reference example if material behavior is linear shear base decreases 31% in uplifted case and for nonlinear materials one, shear base reduces 16%.

Table 2 shows that shear base difference between models with linear and nonlinear materials, in fixed case, is larger than it's difference in uplifted case.

Comparing to fixed case(Without uplift) ,shear stories also decreases in uplifted case, for both of linear and nonlinear behavior of materials. Figure5 represents maximum shear stories. It has been observed ,decreasing of shear stories ,because foundation uplift, in model with linear materials is more than it's decreasing in nonlinear material one.

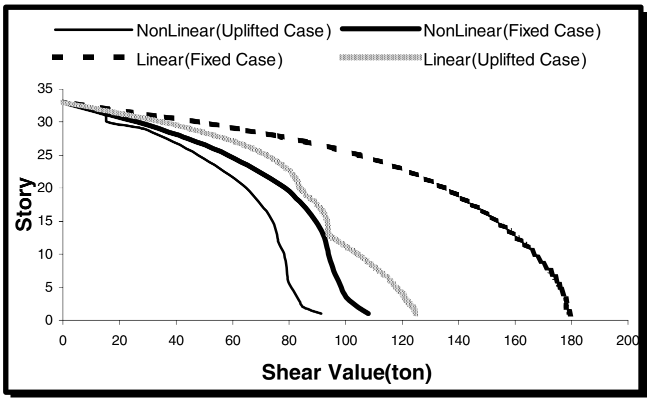

Figure 5- Comparison of Maximum Shear Story

Table2-Difference of shear base

Shear Base			
$(DV_{l,n})^*_f$ (%)	***$(D.V_{l,n})_u$ (%)***	***$(DV_{uf})_n$ (%)***	***$(D.V_{u,f})_l$ (%)***
40	*26.8*	*16*	*31*

* for example $(D.V_{l,n})_f$ presents difference between shear base in linear and nonlinear behavior and for fixed case

3-3-Member's Forces:

Table 3 represents that, members forces, such as axial force and bending moments, also reduce because of uplift phenomenon, in both of linear and nonlinear behavior of materials. It has been found as shear base, difference of member forces between uplifted and fixed cases in model with linear materials is larger than it's difference in nonlinear one.

Table3- Difference of axial force and bending moment

Element, Node	*Axial Force*				*Bending Moment*			
	$(D.N_{,n})_f$ (%)	*$(DN_{l,n})_u$ (%)*	*$(D.N_{u,f})_n$ (%)*	*$(DN_{u,f})_l$ (%)*	*$(D.M_{,n})_f$ (%)*	*$(DM_{l,n})_u$ (%)*	*$(DM_{u,f})_n$ (%)*	*$(DM_{u,f})_l$ (%)*
6033,5	*34*	*19*	*13*	*28.9*	*42.5*	*29.3*	*7*	*24.5*
6034,6	*12.6*	*2*	*11.8*	*21.5*	*46*	*33.7*	*10.7*	*27*
123,33	*33.5*	*19.7*	*10.8*	*26.1*	*38.8*	*34.9*	*20*	*25*
126,34	*11.4*	*2*	*15.9*	*24*	*39.9*	*30*	*20*	*31*
191,89	*32.2*	*23.8*	*7.8*	*18*	*41.6*	*26.6*	*8.9*	*27.6*
188,90	*5.1*	*1.4*	*18.9*	*22*	*43.3*	*25*	*10.7*	*32*

3-4-Hysteresis Curves:

Some hysteresis curves were drawn in figures6,7 . Horizontal axe presents ratio of lateral displacement to maximum lateral displacement at the top of the frame, and vertical axe shows axial force for each member.

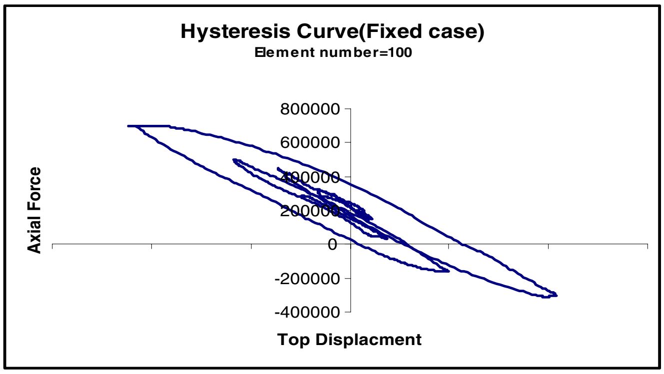

Figure 6-Hysteresis Curve in fixed case for(element number=100)

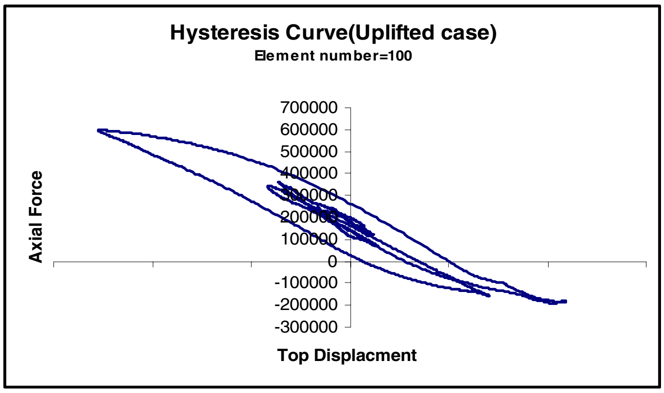

Figure 7-Hysteresis Curve in uplifted case for(element number=100)

The figures, has been showed that for fixed system(uplift prevented), element number100 arrived in plastic phase, but for uplifted system(uplift permitted) this element is in elastic phase at all of. The reason of this point is to decreasing of axial force when foundation uplift occurs.

4- PARAMETRIC STUDIES:

4-1- Structure Slender ; (h/b)

One of the important factors on foundation uplift is aspect ratio of frame(h/b)**,** it's called slender. Parametric study is conducted in this section by considering to five slender values:

h/b =2.75,3.75,5.25,6.75,8.25 . Results for uplifted and fixed cases were compared. Figure 8 represents that when h/b increases ,the foundation uplift also increases, in both of linear and nonlinear behavior. Figure 9 shows the difference between shear base in uplifted and fixed systems. It illustrate the increasing of h/b provide the increasing of the difference. It has also observed, for h/b=2.75,3.75 ,there is no difference between earthquake responses of models with linear and nonlinear behavior, because members of those two cases, are in elastic phase, and plastic strains are nearly equal to zero.

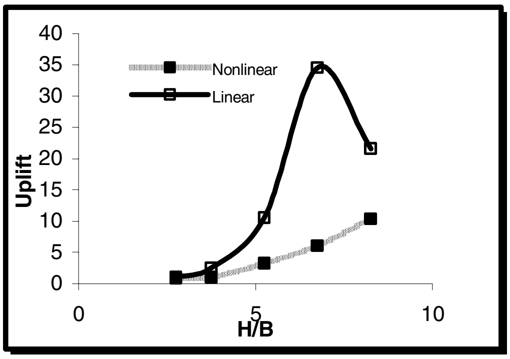

Figure8-Vriation of Uplift value by variation of h/b

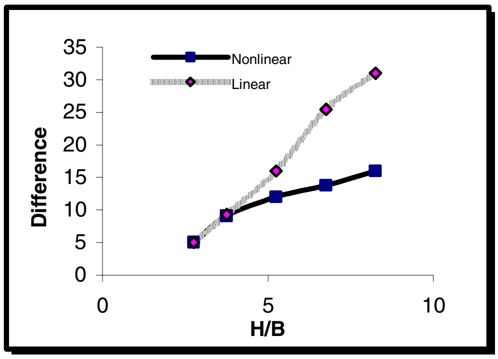

Figure9- Variation of difference of shear base by h/b variation

4-2-Elastic Modulus of Soil (E_{soil}):

In this section five different values for E_{soil} were selected(E_{soil} =10,20,40,80,160 MPa) the analyses were performed for linear and nonlinear behavior: 1-with foundation uplift 2- without foundation uplift . Results of analyses were compared;

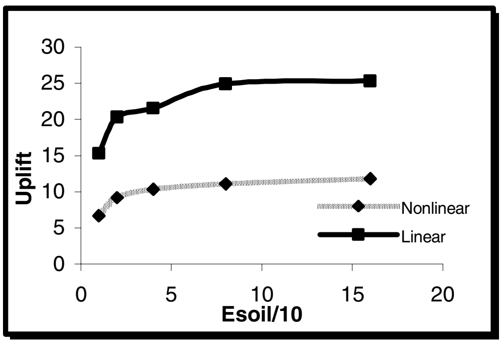

Figure 10-Vriation of Uplift value by variation of E_{soil}

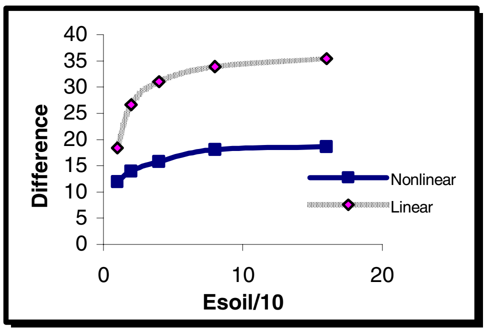

Figure11- Variation of difference of shear base by E_{soil} variation

Figure 10 represents that by increasing of E_{soil} **,** foundation uplift also increases.

Figure 11 represents that by increasing of E_{soil} , shear base difference between fixed and uplifted cases also increases.

4-3-Cohesion Coefficient:(C_{soil}):

One of the important parameters for nonlinear behavior of soil is cohesion coefficient. For evaluation of effect of C_{soil} on foundation uplift, three values of C_{soil} were selected

(C_{soil} =30,40,50 KPa). Models were analyzed for uplifted and fixed systems and results had been compared;

Figure 12 shows the increasing of C_{soil} causes to increasing in foundation uplift. Figure 13 represents that by increasing of C_{soil} ,shear base difference between uplifted and fixed cases also increases. Also figure 14 represents that effect of variation of C_{soil} on shear base in fixed system(without uplift) is more than effect of variation of this parameter on shear base in uplifted system, because fixed system is in full contact with soil at all of the time history analysis. The difference in shear base between uplifted and fixed cases is more significant when the soil cohesion increases.

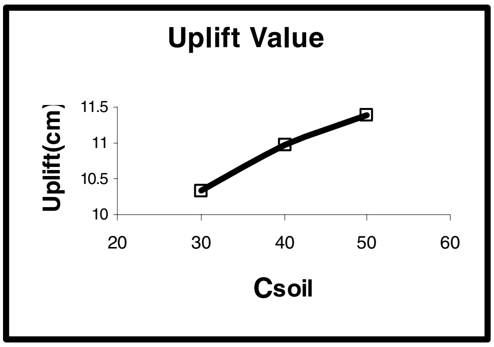

Figure12-Vriation of Uplift value by variation of C_{soil}

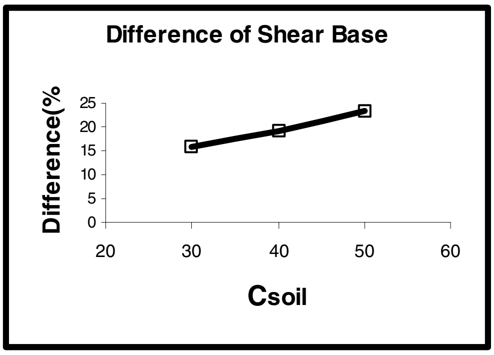

Figure13- Variation of difference of shear base by C_{soil} variation

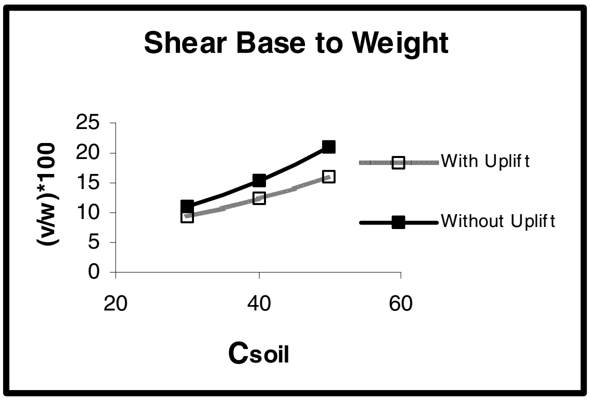

Figure14- Variation of shear base to weight by C_{soil} variation

5-CONCLUSIONS:

The following conclusions are derived by the above studies:

1) Foundation uplift reduces the lateral stiffness of system. So shear story, and member force are reduced in uplifted system.
2) By increasing in slender of structure(h/b), uplift value increases, and shear base difference between uplifted and fixed cases, also will increase.

3) For greater soil elasticity module , more uplift value occurs, and so shear base difference between uplifted and fixed cases is increased.
4) Effect of soil cohesion is similar to elasticity module of soil.
5) Uplift value in nonlinear behavior is less than linear behavior.
6) In fixed cases, difference of forces(such as shear base,…)between models with linear and nonlinear behavior of materials, is larger than

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