Paper No. 1433. (quote when citing this article)
Eleventh World Conference on Earthquake Engineering
ISBN: 0 08 042822 3

BEHAVIOR OF IRANIAN LOW RISE BUILDINGS ON SLIDING BASE TO EARTHQUAKE EXCITATION

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ABSTRACT

The buildings base isolation system , because of emphasize on reduction of earthquake effects on building , is a suitable and economical solution to aseismic buildings. Using from sliding foundation is one of the simplest method of seismic isolation.

To execution of the sliding foundation , at first characteristics of conventional structures of Iran is considered and experimental studies is done for selecting of suitable materials. Also for predicting the behavior of sliding foundation system during earthquake , the numerical analysis subjected to most important earthquakes records of Iran is performed.

The material examinations with represented method accomplished for the first time. Also numerical analysis of system behavior subjected to Iran earthquakes with characteristic which represented in this essay , presented for the first time.

KEYWORDS

Base Isolation ; sliding foundation ; sliding base ; pure friction .

INTRODUCTION

Security of the stability of masonry buildings with creating the sliding layer between the structure and it's base, is very desirable about costing of materials and execution technology. This method prevent the transferred motion from ground to structure.

A practical system is performed in China. The sliding layer of these buildings consist of 2 smoothed reinforced tile surface with a cleaned sand layer between them. Dynamic friction coefficient of this system is 0.2 according to shake table tests. [Li, 1984.]

For accepting to a suitable and practical sliding layer for conventional buildings in Iran, details of their foundation construction is studied. Using of asphaltic felt and/or sand cement mortar as waterproof material is usual method in these buildings. On the other hand, waterproofing layer usually has a poor strength against shear forces. Thus, sliding of wall during earthquake is possible. On the basis of these facts, the sliding layer can be executed between wall and it's pedestal. Then, the properties of materials for creating the sliding layer and also their durability in actual conditions and during the time is studied.

To showing the behavior of structures on sliding foundation, a computer program is presented. This numerical analysis is on the base of time history method and assumes rigid body behavior for low rise structures. Analysis is performed for all of important recorded earthquakes of Iran and also Elcentro record for better comparison of results. This results are important factors in detailing of foundation construction.

EXPERIMENTAL METHODS

A Mohr-Columb model is assumed for material testing. In this way, the values of C and Ø must be measured. Two testing system for this purpose is shown in Fig.1.

Fig. 1. Testing models

In method (I) , total force has two component s and t on sliding surface. With the variation of angle a , the model curve is resulted. This method is suitable specially for mortars. [Sharif-Abadi, 1990]

Method (II) is defined well by Tehrani, 1992. In this method shear and compression forces is separately controlled and measured.

For the aim of creating a low cost system, rural material is used in experiments. These materials are bitumen, sand, clay, dune sand and light expanded clay.

THE RESULTS OF EXPERIMENTS

The friction coefficient of materials that is obtained from above test methods, is shown in table 1.

Table 1. Friction coefficient of materials

Material	Test Method (I)	Test Method (II)
Dune sand	0.25	0.23
Clay	0.16	-
Sand-clay mortar	0.38	0.30
Light expanded clay	0.2-0.3	0.25
bitumen	0.00	0.00

Cohesive Materials

As it is shown in table 1, clay and bitumen have low friction coefficient. Although this property is useful for sliding behavior, but their characteristics in variable environmental conditions are not stable. Also resisting force in these materials in the form of cohesion or viscosity is an important problem.

For example, bituminous material in low temperature is hardened and in high temperature is flowed. Also against the ground motion with high velocities, the viscosity of these materials is prevention of sliding behavior.

So, clay property is sensitive to water and moisture. Therefore using cohesive and viscous material not to be recommended.

Mortars

Tehrani, 1992 showed that sand clay mortars with low amount of clay (only for stability of layer) have the lowest friction coefficient in relation to other mortars. But sliding resistance of this mortars is not enough low to prevent building from earthquake effects. Also while layer thickness is increased, this resistance is decreased. In this case, homogeneity and stability of layer is the most important problem.

Granular Materials

Similarity of dune sand and light expanded clay results obtained from two above mentioned test method is represented low sensitivity of these material in various loading conditions. Their friction coefficient is also acceptable.

It must be noted that in the sliding system that is used in China (Li, 1984), sand aggregates are as roller grains. For this behavior, top and bottom covering surface of sliding layer must be smoothed. But in rural and adobe buildings, the surface of pedestals or walls blocks is not enough smooth to allow rolling behavior. On the other hand replacing of these blocks with the suitable surface increases costs.

There are two solution for this problem. The first is using of greater size material -e.g. light expanded clay aggregates -, so the roughness effect of block on the rolling behavior of layer is reduced. The second is using of dune sand with smaller grain sizes. In this condition, sliding occurs inside the layer and then roughness of surface is not a problem.

In construction of sliding layer with dune sand, thickness of layer is important. Also total shear strength of this layer is increased with increasing of vertical loading and then confined pressure. For light expanded clay, it must be noted that with increasing of vertical loads, breakage of aggregates and then resistance to sliding is increased. Therefore, maximum value of vertical load must be considered in design of system.

NUMERICAL ANALYSIS METHOD

Tehrani, 1992 shows that low rise masonry building behavior can be modelled with a rigid body system. The accuracy of this assumption for adobe building is very

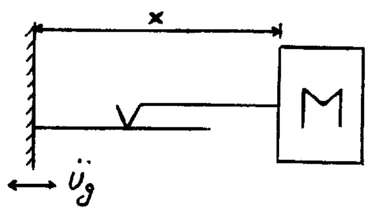

Fig. 2. Analytical model of rigid body on sliding foundation , [After Ahmadi et al., 1989.]

acceptable. Analytical model is shown in fig. 2.

For a sliding system with pure Columb friction, while the structure slides on foundation, the motion equations can be write as bellow :

$$-m(\ddot{x}+\ddot{U}g)=f.m.g.sgn(\dot{x})$$

$$\ddot{x}+f.g.sgn(\dot{x})=-\ddot{U}g \qquad (1)$$

where $\ddot{U}g$ is horizontal ground acceleration , f is friction coefficient and g is gravity acceleration. When structure and foundation stick together, equation (2) is governed.

$$\dot{x}=0 \qquad (2)$$

Above equation is continued while the applied force from ground is smaller than resistant friction force between structure and base. That means :

$$f.g-|\ddot{U}g|>0 \qquad (3)$$

As soon as above condition is cancelled, sliding is occurred and equation (1) is governed. Whenever $\dot{x}$ equals zero, it must be controlled that sliding is stopped or continued.

If foundation surface has a little inclination as i, the motion equation during sliding is [after Li, 1984] :

$$-m(\ddot{U}g+\ddot{x})cos(i)=m.f.sgn(\dot{x})\{g.cos(i)+(\ddot{x}+\ddot{U}g).sin(i)+m.g.sin(i)$$

and thus :
$$-\ddot{U}g=\ddot{x}+\frac{f.sgn(\dot{x})+tan(i)}{1+f.sgn(\dot{x}).tan(i)}.g \qquad (4)$$

Therefore, non-sliding condition is :

$$f.g+tan(i).g-|\ddot{U}g|>0 \qquad (5)$$

For considering the vertical effects of earthquake excitation, the term 'g' is replaced by '$g+\ddot{V}g$', in relations (1) and (3). Then the motion equation in sliding phase is :

$$-\ddot{U}g=\ddot{x}+f.(g+\ddot{V}g).sgn(\dot{x}) \qquad (6)$$

and non-sliding condition is :

$$f.(g+\ddot{V}g)-|\ddot{U}g|>0 \qquad (7)$$

Above equation are solved by time history method and with time steps between 0.0002 to 0.02 second in sliding and sticking phases. Since the solution accuracy is based upon the time steps, automatic selection of time steps is considered in computer program.

NUMERICAL ANALYSIS RESULTS

Effect of Friction Coefficient

When friction coefficient of sliding layer is increased, maximum acceleration of rigid structure is increased linearly up to maximum value of base acceleration. Also relative velocity and displacement of structure is decreased. With comparing the results of various earthquakes records it can be concluded that maximum relative displacement has important role in selection of materials with optimum friction coefficient. Also this value must be selected in according to design base earthquake characteristic.

Table 2. Results of Rigid Structure Analysis in Iran Design Base Earthquake

Record Charact-eristic	Friction Coeff.	Maximum Absolute Accel.	Maximum Relative Velocity cm/sec	Maximum Relative Displ. cm	Residual Relative Displ. cm
TABAS	0.10	0.10g	84.64	60.48	9.04
-1978	0.15	0.15g	60.41	29.50	12.83
N16W	0.20	0.20g	48.84	21.10	3.79
COMP.	0.25	0.25g	43.60	15.23	9.22
0.93g	0.30	0.30g	35.37	10.39	7.38
NAGHAN	0.10	0.10g	40.42	7.17	6.40
-1977	0.15	0.15g	33.34	5.31	5.03
LONG.	0.20	0.20g	30.95	5.44	5.33
COMP.	0.25	0.25g	25.09	4.88	4.70
0.72g	0.30	0.30g	16.37	3.68	3.56
AB-BAR	0.10	0.10g	22.61	5.05	1.46
-1990	0.15	0.15g	18.66	2.54	1.53
LONG.	0.20	0.20g	14.45	1.64	0.99
COMP.	0.25	0.25g	10.16	1.01	0.63
0.53g	0.30	0.30g	7.71	0.55	0.33
ELCENTRO	0.10	0.10g	20.31	2.87	1.50
-1940	0.15	0.15g	17.82	1.71	0.88
NOOW	0.20	0.20g	10.49	1.24	0.84
COMP.	0.25	0.25g	4.32	0.37	0.26
0.32g	0.30	0.30g	0.34	0.01	0.01

Bonding Effect

For cohesive and/or viscous material, sliding is occurred when the ground force becomes larger than total of bonding and friction forces. Thus the maximum applied acceleration is increased. With considering the value of acceleration increasing up to 0.70g - for cohesive force equals to 0.5 Kg/cm^2 - it can be concluded that this type of materials are not significant.

Table 3. The Effect of Bonding in TABAS 1978 (*)

Maximum Base Accel.	Bonding Stress Kg/cm^2	Friction Coeff.	Maximum Absolute Accel.	Maximum Relative Velocity cm/sec	Maximum Relative Displ. cm	Residual Relative Displ. cm
0.93g	0.0	0.20	0.20g	48.84	21.10	3.79
0.93g	0.25	0.20	0.44g	49.47	21.64	4.34
0.93g	0.50	0.20	0.70g	48.90	19.39	2.10

(*) Structure Weight = 100 ton , Foundation Area = 10 m^2

Foundation Surface Inclination Effect

With deviation of balance of foundation surface than horizontal balance, it could be expected that maximum acceleration of structure is increased a little. The results show that %1 inclination causes %5 increasing in acceleration, %4.8 increasing in relative velocity and %20 increasing in relative displacement. According to this fact that deviation of foundation surface often is less than this value, it can be assumed that increasing of above terms have not important effect in practical design of system.

Table 4. The Effect of Base Inclination in TABAS 1978

Maximum Base Accel.	Surface Inclin-ation rad	Friction Coeff.	Maximum Absolute Accel.	Maximum Relative Velocity cm/sec	Maximum Relative Displ. cm	Residual Relative Displ. cm
0.93g	0.000	0.20	0.200g	48.84	21.10	3.79
0.93g	0.005	0.20	0.205g	50.06	23.14	8.41
0.93g	0.010	0.20	0.210g	51.19	25.27	12.86

Maximum Base Acceleration Effect

As it is mentioned above, increasing of maximum base acceleration higher than limits of ±f.g causes no change in structure acceleration. But it can be severely increase relative velocity and displacement of structure. For better evaluation of this effect, the analysis results of Elcentro earthquake is compared with it's magnified record with amplification factor 2.0 . Thus other parameters effects e.g. frequency content can be avoided.

The results show that although maximum acceleration of structure has no change - and it is one of the advantages of sliding systems -, but relative velocity and displacement are increased over than %250 and %50 respectively. It is considerable that in a elastomeric system, these values are increased %100. But in sliding system with existing the high relative velocity, the relative displacement less increased. On the other word, applied forces effected as quick shocks and could not produce high displacements.

Table 5. The effect of Base Acceleration in ELCENTRO 1940 and Magnified Record of ELCENTRO 1940

Maximum Base Accel.	Friction Coeff.	Maximum Absolute Accel.	Maximum Relative Velocity cm/sec	Maximum Relative Displ. cm	Residual Relative Displ. cm
0.32g	0.20	0.2g	10.49	1.24	0.84
0.64g	0.20	0.2g	40.68	5.75	3.02

Base Excitation Period Effect

The results of sinosoidal excitation analysis is shown for 0.1 to 2.0 second periods and 0.5g maximum base acceleration. It is observed that with period increasing, relative velocity and displacement are severely increased.

Vertical Excitation Effect

With considering the vertical component of ground acceleration and adding it to gravity acceleration, horizontal acceleration of structure due to the friction

Table 6. The Effect of Period in Sinosoidal Excitation

Maximum Base Accel.	Excitation Period Sec	Friction Coeff.	Maximum Absolute Accel.	Maximum Relative Velocity cm/sec	Maximum Relative Displ. cm
0.5g	0.1	0.20	0.2g	7.06	0.26
0.5g	0.2	0.20	0.2g	14.13	1.00
0.5g	0.5	0.20	0.2g	35.34	6.26
0.5g	1.0	0.20	0.2g	70.68	25.17
0.5g	2.0	0.20	0.2g	141.38	100.51

behavior can be increased and become greater than $\pm f.g$ limits. The value of this increasing in most of the earthquakes is less than %10. Only for some records e.g. Naghan, Deyhok, Tabas and Ab-Bar, maximum acceleration increases over than %50. The vertical acceleration in these records are greater than 0.2g.

Table 7. The Effect of Vertical Excitation in Iran Earthquakes (*)

Station	Epicenter Distance Km	Maximum Base Acceleration Hor. g	Ver. g	Maximum Structure Horizontal Acceleration Hor. Comp. g	H. & V. Comp. g
Bandar-Abbas	33	0.13	0.04	0.100	0.100
Ghaen	15	0.16	0.17	0.100	0.108
Vandik	9	0.30	0.09	0.100	0.109
Naghan	7	0.72	0.51	0.100	0.150
Deyhok	20	0.38	0.24	0.100	0.113
Tabas	44	0.93	0.75	0.100	0.153
Hashtpar	11	0.17	0.11	0.100	0.107
Bajestan	156	0.11	0.04	0.100	0.101
Ghaen	69	0.21	0.11	0.100	0.106
Ghazvin	54	0.19	0.09	0.100	0.106
Abhar	91	0.13	0.06	0.100	0.102
Lahijan	97	0.17	0.07	0.100	0.105
Tonekabon	131	0.13	0.03	0.100	0.100
Gachsar	185	0.10	0.04	0.100	0.100
Ab-Bar	43	0.53	0.55	0.100	0.151
Zanjan	75	0.13	0.05	0.100	0.102

(*) The Friction Coefficient equals 0.1 .

The Effect of Other Characteristics

The maximum relative displacements as shown in table 1 is different subjected to various records. This value for most of records is less than 1 cm. But in some records e.g. Vandik, Naghan, Deyhok, Tabas and Ab-Bar this values is increased up to 13 cm. The study on characteristics of these records show that they have maximum acceleration greater than 0.30g. Also epicenter distance of earthquake is less than 4 kilometers. Only in Bandar-Abbas, Ghaen and Hashtpar records, because of the low earthquake magnitude, this effect is not observed. Thus it can be seen that two parameters included epicenter distance and earthquake magnitude can effect behavior of the structure on sliding foundation. So for Earthquake with minimum magnitude (Mb) 6.0 up to 50 kilometers, and with minimum magnitude 4.0 up to 10 kilometers, high relative displacements are occurred and this fact must be considered in design and construction of structures.

Table 8. The Effect of Record Characteristics in Iran Earthquakes (*)

Station	Magnitude Mb	Epicenter Distance Km	Maximum Base Accel. g	Maximum Structure Accel. g	Maximum Relative Displ. cm
Bandar-Abbas		33	0.13	0.100	0.021
Ghaen		15	0.16	0.100	0.195
Vandik		9	0.30	0.100	1.250
Naghan		7	0.72	0.100	5.750
Deyhok		20	0.38	0.100	6.704
Tabas		44	0.93	0.100	13.32
Hashtpar		11	0.17	0.100	0.114
Bajestan		156	0.11	0.100	0.004
Ghaen		69	0.21	0.100	0.117
Ghazvin		54	0.19	0.100	0.631
Abhar		91	0.13	0.100	0.169
Lahijan		97	0.17	0.100	0.924
Tonekabon		131	0.13	0.100	0.578
Gachsar		185	0.10	0.100	0.000
Ab-Bar		43	0.53	0.100	5.047
Zanjan		75	0.13	0.100	0.047

(*) The Friction Coefficient equals 0.1 .

Conclusions

The main aim of experiments in this project is definition of material sliding behavior model according to Mohr-Columb modelling. In this way friction coefficient of some rural materials is accepted. It must be noted that the results must be evaluated in according to testing system characteristics e.g. static loading, specimen sizes and etc. The final results are shown that dune sand and light weight expanded clay aggregates are good material for creating sliding layer in adobe building in Iran. It is considerable that friction coefficient of materials must be selected according to construction details to minimize costs.

It is founded from experimental study and numerical analysis that any resistance force in base, such as bonding, increases structure applied force.

The most important result of numerical analysis is study on the effects of earthquake characteristics in Iran. Results show that although structure acceleration is independent on base excitation characteristics, but relative displacements of structure on his base is dependent on these parameters such as earthquake magnitude, epicenter distance, excitation period and vertical acceleration. It is notable that inclination of foundation surface has no considerable effect.

Acknowledgments

This project is developed in Building and Housing Research Center.

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