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Technical Note

CONTACT ANALYSIS OF BASE ISOLATED MASONRY BUILDING

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ABSTRACT

The concept of reducing the damaging effects on structure during earthquake by introducing some type of support that isolates structure from the shaking ground is a well-known method, named as base isolation technique. The isolation system reduces the effects of an earthquake by essentially isolating the superstructure and its contents from potentially damaging ground motion. In case of base isolated system the behavior of system mainly depends on type of base isolators and their contact with the superstructure and substructure. In the present work, the contact analysis have been performed which is highly nonlinear and required significant computational efforts following the points on one surface relative to lines or areas of another surface. The dynamic time history analysis has been performed on single storey masonry building, which is modeled and analyzed using ANSYS.

Keywords: Base isolation; contact analysis; masonry.

1. INTRODUCTION

Base isolation is a technique used to provide higher energy dissipation capacity to structures which reduces the damaging effects on these structures during earthquakes. Energy dissipation capacity is provided through isolation systems which are placed between the superstructure and the substructure. There are primarily two types of isolation systems depending upon the type of bearings used viz. elastomeric bearings and sliding type bearings. Elastomeric bearings include applications of the lead rubber bearing and high damping rubber bearing. Sliding type bearings are reduced the horizontal acceleration of the superstructure by sliding during earthquake. Building behaves as if it is free to slide on bearings during earthquake.

A single storey building is considered as a case study and two models have been analyzed

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for fixed base (without base isolation) and sliding base (with base isolation) conditions using contact analysis in ANSYS.

2. LITERATURE REVIEW

Analytical and experimental studies were carried out by Roussis [1] on a 5 storey steel frame model with friction pendulum system and the computer programme 3D- BASIS-ME was used for identifying mechanical behaviour of the isolation system. Each floor mass was assumed to be lumped with three degrees of freedom. Analytical results showed good agreement with experiment results. Experimental results show effectiveness of the isolation system in uplift prevention.

Response of R. C. frame buildings with 10, 14 and 20 storeys were considered and analyzed by Jain [2] in 3D-BASIS-TAB computer programme. Base isolation systems reduced the roof acceleration of building for motion of higher frequency and broad range of frequency. Effectiveness of base isolated buildings was found to depend upon the number of stories and input frequency of base motion. Response was reduced by increasing the flexibility of the isolation system. For base motions of high frequency, response reduction is increased by increasing the damping of superstructure.

Kravchuk [3] developed a base isolation friction pendulum system in the laboratory and responses of single degree of freedom systems are evaluated for both models fixed base model and base isolated model. Results were compared for both free and forced vibrations by attaching the accelerometers at the top of the models. Free vibration results show that damping of isolated structure is increased significantly. For forced vibrations, spectral acceleration reduced at the roof level. Acceleration was found to have reduced by 60% with isolation system.

A model of two solids with friction contacts were analyzed by finite element method [4] and for this, ANSYS software was used. Top solid and bottom solid are made up of friction material and structural steel respectively. Finite element CONTA174 with 8 nodes was used for contact analysis for 3D surfaces. Stress distribution and temperature distribution depends upon the coefficient of friction and normal force acting at the contact surface.

Study on composition and material properties of sliding isolation system was carried out by Kawamura [5]. TASS system (Taisei shake suppression system) is composed of bearing plates, sliding bearings and horizontal springs. TASS system is used for evaluate the physics properties of sliding system. Mechanical properties of the isolation system are based on loading tests of isolation system. These bearings support the load of superstructure and reduce the seismic force transmitted to the superstructure from the substructure. Loading tests of isolation systems showed that the vertical stiffness was 1000 times of horizontal stiffness. The coefficient of friction depends upon the contact pressure and sliding velocity.

Building with laminated rubber bearings was analyzed by Deb [6]. Non-linear behaviours of LRB are explained by hysteresis loops of LRB models. Responses of these models are evaluated by solution algorithm as well experimentally. Horizontal shear force displacement hysteresis loops were found to have good agreement with each other. Responses of isolated building with laminated rubber bearing are computed by non-linear hysteresis behavior of LRB loops.

The general principal of base isolation is to decouple a building from its foundation by interposing a layer of low horizontal stiffness between superstructure and substructure. Non-linear time history analysis was carried out of a 5 storey R.C frame building (2D) for two major earthquakes (EI-Centro and Kobe) for both with and without isolation systems (by Monfared [7]). Fundamental frequency of building was found to be reduced by 50% with isolation system. Floor acceleration of building was nearly equal under EI-Centro earthquake but drastically reduced for Kobe earthquake. Therefore, effectiveness of the isolated building was found to depend upon the properties of isolation system as well as input earthquake data.

Multi-storey shear type structure with sliding system was modelled and EI-Centro earthquake (1940) is used for studying the response of this building (by Jangid [8]). Non-linear force displacement behaviors of sliding system are explained by optimum coefficient of friction. This friction coefficient depends upon the characteristics of superstructure as well as isolation system and input earthquake intensity. N-storey superstructure is modeled as N+1 degree of freedom system. Responses of one and four storey base isolated structure are described by optimum friction coefficient. Optimum friction coefficient increases with increases the number of storey of superstructure and earthquake intensity. Optimum friction coefficient was found to increase with decrease the damping ratio of isolation system.

An 8-storey R.C. framed building was modelled in SAP 2000 (by Subramani [9]). Responses of the building with fixed base and with isolation system are explained for different plans using SAP 2000. Responses of structures were compared for both, with and without damping. Base shear and displacement of fixed base building was found to be less than that for base isolated building. The story drift for both buildings are same at EQ-X direction and but different at EQ-Y direction.

Qamaruddin [10], carried out analytical as well as experimental studies on a single storied masonry structure for fixed base and sliding base conditions. In the present work, the contact analysis have been performed which is highly nonlinear and required significant computational efforts following the points on one surface relative to lines or areas of another surface. The dynamic time history analysis is performed on a single storey masonry building, which is modeled and analyzed using ANSYS.

3. ANALYTICAL MODELS

3.1 Conventional fixed base systems

Qamaruddin [10] analyzed six models with outside dimensions 8.764m x 13.029m in plan. Separate models with stories varying from one to four were considered. For three and four storied models, two cases were considered, one with uniform wall thickness and second with wall thicknesses varying from 1.5 brick thick in lower storey to 1 brick thick in upper stories. Damping varying from 5 to 15% of critical value was considered. The structure was represented by a multiple degree freedom shear-beam system for analysis. The mass of the walls and slabs were assumed lumped at the storey levels and connected to each other through mass less spring and viscous dampers. The degree of freedom of each mass in horizontal translation is one, neglecting the vertical translational and rotational degrees of freedom. Only first few modes of vibration have significant contribution to the dynamic response of the system. Mode superposition method was used for computing the seismic response of the system.

In all the models, maximum stresses (bending, overturning, net and shear) were lesser in the higher stories, but the rate of decrease and its pattern were different for different types of stresses. The overturning stresses increased towards base almost linearly but the bending stresses increased more slowly in a broken line. The tensile and shearing stresses were larger in the lower stories. The stresses in non-uniform buildings (where wall thicknesses are varying) are reduced in the lower storey where walls are thicker but increase in the upper stories. The stresses in all buildings decrease with an increase of the damping.

3.2 Sliding type systems:

Two single storied one room models, 914mm x 762mm in plan and 572mm high with an opening in each wall were considered. The seismic response of one storey sliding type building was worked out through a two mass mathematical model with a known coefficient of friction between the contact surfaces of bond beam (provided at base of walls) of the superstructure and plinth band in the substructure. These two masses were mutually connected through a spring and viscous dampers.

For no sliding condition, the equation of motion is expressed as

$$\ddot{X}_b - 2p\pounds\,(\dot{X}_t - \dot{X}_b) + p^2\,(X_t - X_b) = -\,\ddot{y}\,(t) \tag{1}$$

Where, X_b, X_t are the lateral relative displacements of masses M_b (mass of base raft) and M_t (mass of superstructure floor); p and £ are the natural circular frequency of the system and the fraction of critical damping. Here $\ddot{y}(t)$ is the ground acceleration at time t.

The equation of motion for sliding that would occur when the frictional resistance is overcome is expressed as

$$\ddot{X}_b - 2p\pounds\theta\,(\dot{X}_t - \dot{X}_b) - p^2\theta\,(Xt - X_b) + F = -\,\ddot{y}\,(t) \tag{2}$$

where, $\ddot{X}_b$ is relative acceleration of the bottom mass (M_b) and θ is mass ratio (M_t/M_b) and μ is the friction coefficient.

$$F = \mu g\,(1+\theta)\,sgn\,(X_b) \tag{3}$$

where, sgn ($\dot{X}_b$) = +1 if $\dot{X}_b$ is positive, sgn ($\dot{X}_b$) = -1 if $\dot{X}_b$ is negative.

The dynamic response of the system is obtained by integrating these equations. For this Runga-kutta fourth order method was used. Spectral acceleration of the sliding type system is much less than that of the corresponding conventional system. The flexibility effect predominates and the response is reduced due to sliding**.**

4. EXPERIMENTAL MODEL

4.1 Model description

Half scale single storey brick building model were tested under base shocks. This test was performed on a specially made railway wagon shake table. Two models, one with fixed base (Model 1) and second with sliding base were constructed. The outside dimensions of the model are 2.17m x 1.75m x 1.60m high above the plinth level with a 7.5m reinforced concrete slab roof. This model was constructed with 1:6 cement-sand mortars and strengthened with a 6mm diameter vertical steel bar set in cement mortar at each corner and at the jambs of the openings. A lintel band consisting of 3 steel bars of 6mm diameter each was also provided.

In model 2, a bond beam was provided below the walls at plinth level above the plinth band. The contact surfaces were well finished. A thin film of mobile oil was used to prevent bonding between the plinth band and the bond beam hence making the superstructure free to slide at plinth level.

4.2 Observations

It is observed that both models (sliding type and convention type) did not reach their total damage level even up to the last shock. Model 2 has less damage compared to model-1. The extent of damage of model-1 was about 15% more than that of model-2 at input energy of 7500 kgm which shows better performance of sliding base structure over strengthened one. In case of sliding type structure, the roof acceleration is seen to be remarkably less as compared to the table acceleration as well as the roof acceleration of the model-1 (convention building). This feature as exhibited by the sliding type model clearly establishes that seismic forces attracted by such structures would be significantly reduced in the event of earthquake type loads.

5. CASE STUDY

5.1 Model description

The same building dimensions as used in the experimental work done by Qamaruddin [10], was modelled using ANSYS. SOLID285 element was use for all volumes. Floor slab, roof slab and lintel bands were reinforced concrete elements and the walls of the superstructure were made up of masonry. Unreinforced plain concrete was considered for foundations. All materials were assumed to be linearly elastic and isotropic in nature. The first model (Model 1) was considered to be of fixed base type and the second model (Model 2) of sliding base type. An isotropic view of the model is shown in Fig. 1.

The sliding joint for Model 2 was modeled using contact elements. These elements were inserted between the floor slab and the foundation. The contact surface was defined using CONTA173 and the target surface was defined using TARGE170. The coefficient of friction μ was taken as 0.15. The base of the foundation was assumed to be fixed i.e. restrained against all degrees of freedom. It was observed that for very large values of μ, Model 2 exhibited the same behavior as Model 1.

5.2 Time history Analysis

Time history analysis was carried out for both models with 5% damping. The input time history used for analysis is given in Fig. 3.

6. RESULTS

Displacements obtained at roof level (node 1692) were higher for Model 2 (Fig. 4). Accelerations at node 1692 (on roof) and stresses at bottom of walls (node 3) were lesser for Model 2 (Fig. 5, 6). The reason for this is the higher energy dissipation capacity of the sliding base type structures. Greater dissipation of energy at the contact surface leads to lesser transfer of stresses to the superstructure. The nodes shown in Fig. 6 are those where cracks have been observed. Tensile stresses were found to develop in both cases leading to formation of cracks. However for Model 1 the cracks are much larger and more critical than for Model 2 where the cracks are very fine. The damage level for Model 1 was much higher that for Model 2. The material non linearity if incorporated during modeling would give the directions and extent of cracking. A comparison between roof displacements, principal stresses generated in both models are given in Table1 and Table 2.

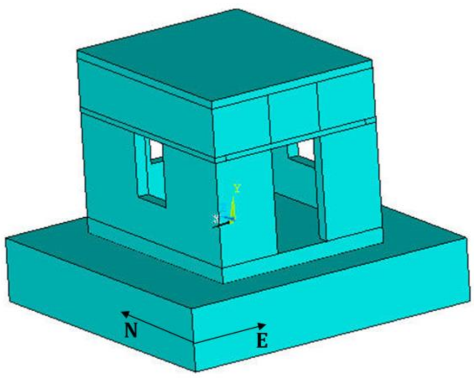

Figure 1. Isometric view of ANSYS model

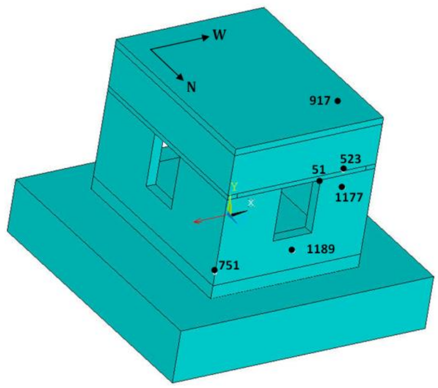

Figure 2. Nodes where cracks are observed

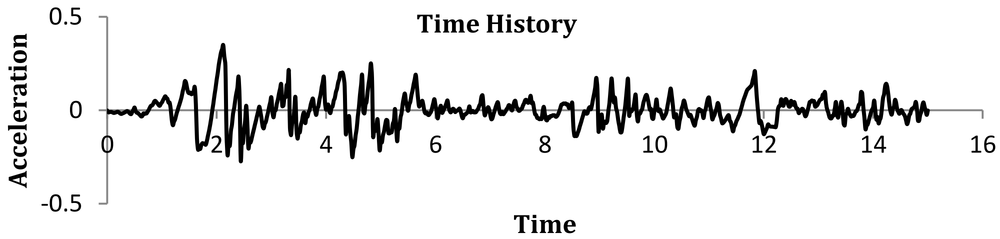

Figure 3. Input time history

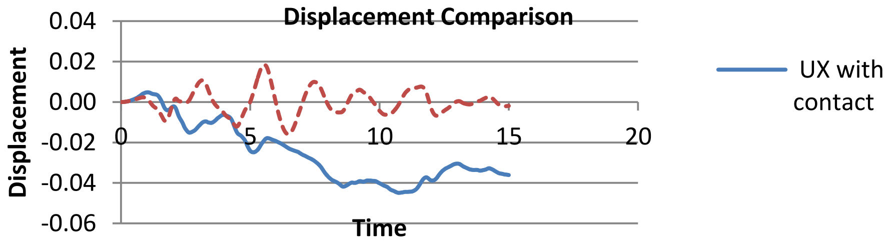

Figure 4. Roof displacements at node 1692 for Model 1(dotted) and Model 2(solid)

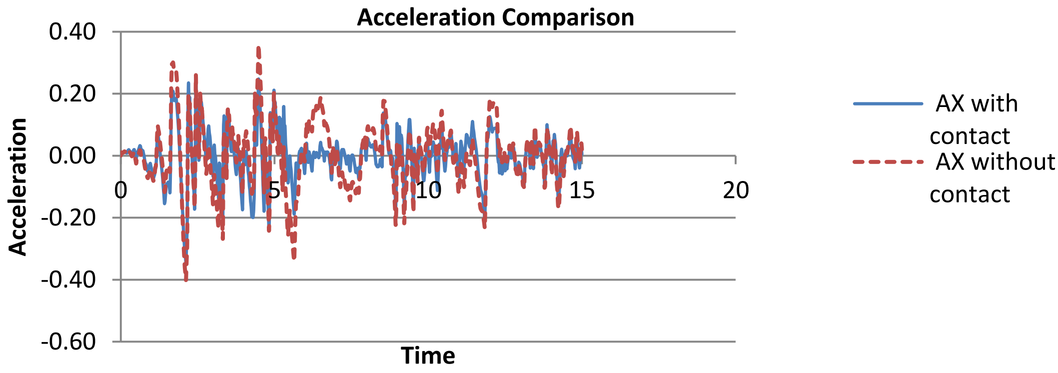

Figure 5. Accelerations at node 1692 for Model 1(dotted) and Model 2(solid)

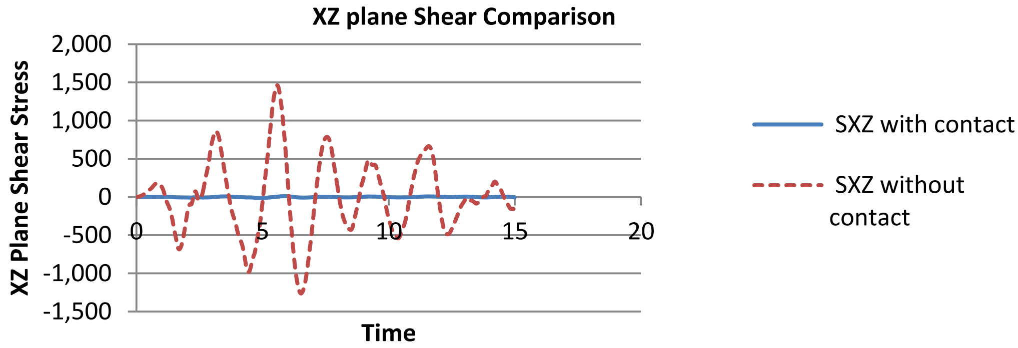

Figure 6. Shear stress at node 3 for Model 1(dotted) and Model 2 (solid)

Table 1: Roof Displacements and accelerations for Model 1 and Model 2

	Model 1	Model 2
Max absolute displacement value (in m)	0.018394	0.0449176
Max absolute acceleration value (in m/ sec^2)	0.4013	0.345645

Table 2: Principal stresses for Model 1 and Model 2

Principle Stresses (N/m^2)				
	Model 1		Model 2	
	Min	Max	Min	Max
Node 1177 (Below lintel band)	-282.97	6850.83	-4.35622	71.624
Node 523 (Above lintel band)	-797.237	8124.61	-12.7687	86.7265
Node 751 (Bottom region of the N-W corner)	-920.589	12511.8	-9.90856	107.397

Node 1189 (Bottom spandrel of N wall)	-198.094	6468.02	-2.259	52.7695
Node 917 (Top spandrel of E Wall)	1.4E-15	1047.79	-0.6	10.7492
Node 51 (Junction of lintel band and openings)	-2184.27	22833.9	-35.4354	241.503

7. CONCLUSIONS

From the above contact analysis as well as analytical and experimental studies that have been conducted earlier, it is observed that sliding systems offer much better response to earthquake ground motions. The isolation system introduces greater energy dissipation to the system thereby reducing the damaging response of the system. The roof acceleration of the sliding type building is less than roof acceleration of the fixed base building while roof displacement of sliding type building is more than the roof displacement of fixed base building. Response of the analytical model show good agreement with the experimental work of Qamaruddin [10]. Thus practical implementation of such systems could lead to much reduction of damage in structures during earthquakes.

REFERENCES

1. Roussis P, Constantinou M. Experimental and analytical study of seismically isolated structures with uplift restraint, *Proceeding of the 13th World Conference on Earthquake Engineering*, Vancouver, B.C, Canada, paper no. 1685, 1-6 August 2004.
2. Jain SK, Thakkar SK. Application of base isolation for flexible buildings, *13th World Conference on Earthquake Engineering*, Vancouver, B.C, Canada, paper no. 1924, August 2004, pp. 1-6.
3. Kravchuk N, et al. Development of a friction pendulum bearing base isolation system for earthquake engineering education, *Proceeding of the 2008 American Society for Engineering Education Pacific Southwest Annual Conference*, California state University, Sacramento, CA, 2008.
4. Stefancu AI, et al. Finite element analysis of frictional contacts, *Gheorghe Asachi, Technical University of Lasi*, 22 August 2011, pp. 131-139.
5. Kawamura S, et al. Study on a sliding type base isolation system-system composition and element properties, *Proceedings of Ninth World Conference on Earthquake Engineering*, Technology Research Centre, Japan, August 2-9, **V**(1988) pp. 735-740.

6. Deb SK, Paul DK. Simplified non-linear analysis of base isolated building, *11th World Conference on Earthquake Engineering*, Acapulco, Mexico, paper no. 1344, 1996.
7. Monfared H, et al. An investigation into the seismic base isolation from practice perspective, *International Journal of Civil and Structural Engineering*, No. 3, **3**(2013) 451-63.
8. Jangid RS. *Optimum Frictional Elements in Sliding Isolation Systems*, Department of Civil Engineering, Indian Institute of Technology, Bombay, India, 2000, pp. 651-661.
9. Subramani T, et al. Earthquake analysis of structure by base isolation technique in SAP, *International Journal of Engineering Research and Applications*, **4**(2014) 296-305.
10. Qamaruddin M. Development of brick building systems for improved earthquake performance, Ph.D. Dissertation, Department of earthquake engineering, University of Roorkee, 1978.