Experimental Study of Seismic Behaviour of Unsymmetrical Structure by Using Shake Table Test

Tejaswini Ganesh Pawar, Rahul Raghunath Kharade, N.P.Phadatare

[1]*First Tejaswini Ganesh Pawar civil engineering pvpit,sangli*
[2]*Rahul Raghunath Kharade civil engineering pvpit,sangli*
[3]*N.P.Phadatarecivil civil engineering pvpit,sangli*

---***---

Abstract - In this thesis work it is proposed to study the behaviour of seismic response of asymmetrical models, Building structures with respect to normal symmetrical building with same material and specification. For this the models coupled with various end conditions are to be tested on shake table equipment. The test are to be performed for various models by considering structural changes such as increasing storey height, provision of parking floors, slender columns, asymmetrical plan at various floors and mass effect etc. All this asymmetrical models are to be tested with respect to building having symmetrical structure in plan and section. The dissertation work also checks the compatibility and effectiveness of asymmetrical structures under various seismic excitation by using shake table test.

An earthquake shake table was constructed with three orthogonal directions of motion to simulate seismic waves. The peak amplitude and directions of motion are adjustable by the user. The table's acceleration was measured at different amplitude settings for all three directions of motion, and that data was fit to the Peak Ground Acceleration (PGA) scale. This allows the table motion to be calibrated to the proper magnitude of an earthquake. An earthquake equivalent to 5.0 intensity on the PGA scale was achieved.

***KeyWords*:**ShakeTable,Seismic,earthquake,shear,amplitude,Stiffness,vibration,motion,etc

1. INTRODUCTION

In past earthquakes, collapse or severe damage too many buildings were due to asymmetry in the lateral load resisting system, or horizontal irregularity. For example, damage statistics from the September 1985 Mexico Earthquake show that up to 50% of failures could be attributed, directly or indirectly to asymmetry. During the last two decades extensive research effort has been devoted to studying the effects of asymmetry which, in brief, lead to lateral-torsional coupling of the buildings response, and to concentration of damage in some resisting elements, mainly the ones located at the edges. The last tens of years shaking table is attested as one of the most validate instrument for studying structures and sub- structures behaviour under dynamic input. If properly used, they provide effective ways to subject specimens of structural components, substructures, or entire structural systems to dynamic excitations similar to those induced by real earthquakes. On the other hand, shaking table experiments represent a good substitution for information on the behaviour of structures obtained under the effect of actual earthquakes.

Although in the first half of the 20th century some efforts were made to build a laboratory system for simulation of earthquakes, the first types of earthquake simulators with programmable effect were produced and made available to the earthquake engineering scientists as late as the beginning of the seventies due to the insufficient level of technological knowledge in the mechanical, electrical and electronic industry. According to a report of the European Association of Earthquake Engineering (EAEE) Task Group (TG) 8 most of the available studies present parametric numerical analyses of the seismic response of simple one-storey building models in the elastic as well as in the inelastic range. The more recent studies following this approach, consider the inelastic response of one-storey building models under bi-directional excitation. Up to date, only a few studies have presented analyses of the seismic response of simple multi-storey building models. The results of thelarge number of analytical studies have not been practically validated by experimental testing programs using either scale models or full scale testing.

The only significant experimental program that has been carried out is the one conducted at the shaking table facility of the Earthquake Engineering Research Centre of the University of Bristol early in the nineties. A series of parametrically defined small scale models were tested under different earthquake records that were exciting the models in the elastic range of behaviour. The capability of modal analysis and of time history analysis to predict test response was checked. The lack of experimental validation of theoretical research is a serious limitation of present design approaches, and unless resolved is likely to hamper the updating process of earthquake design provisions of irregular structures.

The seismic torsional resistance of an asymmetric building is evaluated based on the assumption that the torsional resistance of each element can be neglected. However, for some particular asymmetric structural configurations which are usually found in regions of low seismicity, such assumption might not lead to a conservative design. In this paper, a simplified one-story single-wall-frame structural model was adopted to study the effects of the torsional stiffness/resistance of the wall on the overall seismic response of the model. It is found that the torsional resistance of the wall can be substantially mobilized due to the large rotational displacement underground motions. Simultaneously, the shear resistance of the wall can also be utilized because of the dynamic effect due to the rotary inertia of the mass.

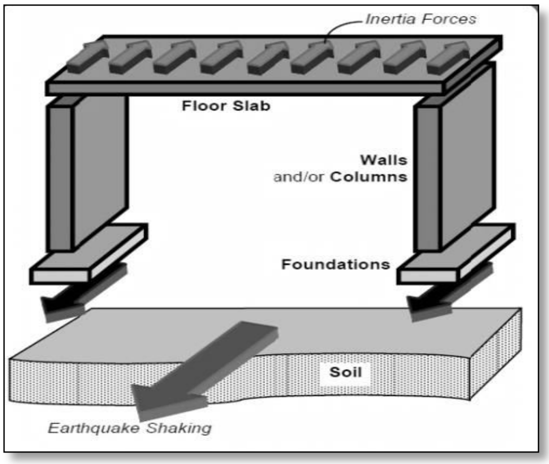
As a result, the interaction of shear and torque of the wall should be considered. It is also shown that this special structural system may actually fail under the combined shear-torsion loadings, in which the system is considered to be safe when the torsion stiffness/resistance of the wall is neglected. Moreover, the exclusion of the torsional resistance of the wall does not always lead to a conservative estimation of its shear demand. In some cases, the consideration of the wall torsion stiffness/resistance considerably reduces the torsional twist of the structural system.

2. Body of Paper

Continuous Load Path

One of the most fundamental considerations in earthquake – resistant design is a Continuous load path. At least one Continuous load path with adequate strength and stiffness should be provided form the origin of initial load manifestation to the final lateral load resisting elements. It has been observed that proper selection of the load carrying system is essential to good performance under any loading. A properly selected structural system tends to be relatively forgiving of oversights in analysis, proportion, detail, and construction.

Buildings are generally constructed of horizontal and vertical members. The horizontal elements are usually diaphragms, such as floor slab, and horizontal bracing in special floors, and vertical elements are shear walls, braced frames, and moment resisting frames. Horizontal forces created by seismic motion are directly proportional to the masses of building elements and are considered to act the centre of the mass of these elements. The general path for transfer the load is opposite to the direction in which seismic loads are delivered to the structural elements. Thus the path for load transfer is as fallows – inertia forces generated in an elements, such as exterior wall are delivered through structural connections to a horizontal diaphragm; the diaphragm distribute these forces to vertical components; and finally through the foundation to ground as shown in following fig.

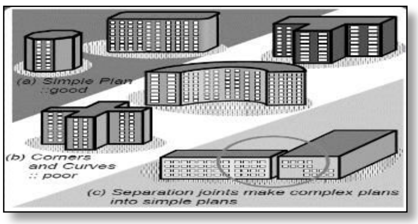


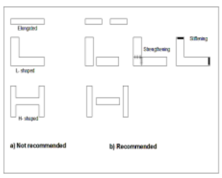
Flow of seismic Inertia forces through all structural components

A deviation or discontinuity in this load path results in poor performance of the building. Failure to provide adequate strength and toughness of individual elements in the system or failure to tie individual elements together can result in complete collapse of system. Structural and non-structural elements must be tied to the structural system. Concrete diaphragms with strut, ties, and boundary elements, should be provided with adequate reinforcement to transmit the seismic forces.

Overall Form

A structure is conceived and designed to transfer the seismic forces to the ground safely. However well the





structure may have been designed, it is said to be

acceptable only if it meets all the established configuration related requirement from the observed failures during past earthquake. Buildings having simple, regular, and compact layouts, incorporating a continuous and redundant lateral force-resisting system, tend to perform well during earthquakes and, thus, are desirable. While planning a particular structure, the guiding principles to be borne in mind are as follows.

The structure should

a) Be simple and symmetrical
b) Not be to elongated in plan or elevation, i.e., the size should be moderate
c) Have uniform and continuous distribution of strength ,mass, and stiffness
d) Have horizontal members which form hinges before the vertical members
e) Have sufficient ductility
f) Have stiffness related to the sub-soil properties

Simplicity and Symmetry

A simple and symmetrical structure like, a square or circular shape, will have the greatest chance of survival for the following reasons

a) The ability to understand the overall earthquake behaviour of a structure is markedly greater for a simple one than it is for a complex one.
b) The ability to understand structure detail in considerably greater for a simple structure than it is complicated ones.Building regular in plan and elevation, without re-entrant corner or discontinuous in transferring the vertical load to the ground, display good seismic behaviour. It is important that the plan of structure is symmetrical in both direction in general, building with simple geometry in plan perform well during earthquakes. Building with re-entrant corner, such as U, V, T, and + shapes in plan, may sustain significant damage during earthquakes and should be avoided. H-shapes, although symmetrical, should not encouraged

International Journal of Scientific Research in Engineering and Management (IJSREM)
Volume: 05 Issue: 10 | Oct - 2021 ISSN: 2582-3930

either. The probable reason for the damage is lack of proper detailing at the corners, which is complex. To check the bad effects of these interior corner in the plan, the building can be broken in to part using as separation joint at the junction. There must be enough clearance at the separation joints so that the adjoining portion do not pound each other as fig

Geometrical plans of building

A building may have a simple plan, but a lack of symmetry in the columns of walls or an irregularity in the elevation, produces torsional effect which are difficult to assess properly and can be destructive. External lifts and stairwell provide similar danger; they tend to act on their own in earthquakes, making it difficult to predict force concentration, torsions, and out of balance forces. To avoid torsional deformation, the centre of stiffness of building should coincide with the centre of mass. It is desirable to have symmetry both in the building configuration, as well as in the structure, in order to satisfy these condition the torsion of unsymmetrical structure can lead to a failure of corner columns and wall at the perimeter of the building.

Vertical and plan irregularities result in building response significantly different from those assumed in the equivalent static force procedure. A building with an irregular configuration may be design to meet all codal requirements but it will not perform well as compared to building with a regular configuration. If the building has an odd shape that is not properly considered in the design, good details and construction are of secondary value. Although the code gives certain recommendations for assessing the degree of irregularity, and corresponding penalties and restriction, it is important to understand that these recommendation are to discourage and to make the designer aware of the potential detrimental effect of irregularities.

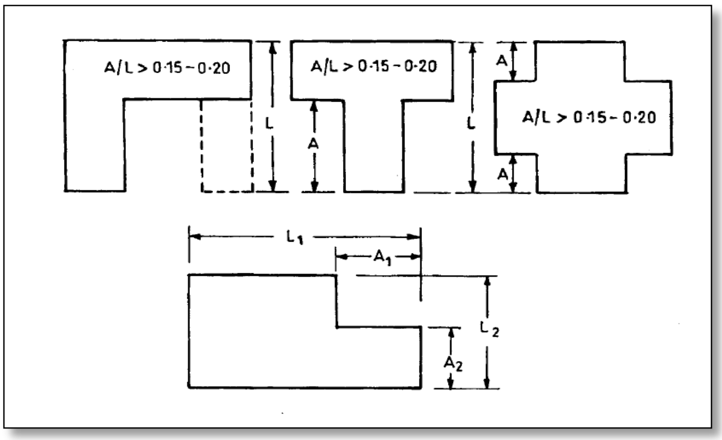
Plan Irregularity by IS 1893 (PART I): 2002

Torsion Irregularity

To be considered when floor diaphragms are rigid in their own plan in relation to the vertical structural elements that resist the lateral forces. Torsional irregularity to be considered to exist when the maximum storey drift, computed with design eccentricity, at one end of the structures transverse to an axis is more than 1.2 times the average of the storey drifts at the two ends of the structure

Re-entrant Corners

Plan configurations of a structure and its lateral force resisting system contain re-entrant corners, where both projections of the structure beyond there-entrant corner are greater than 15 percent of its plan dimension in the given direction. A



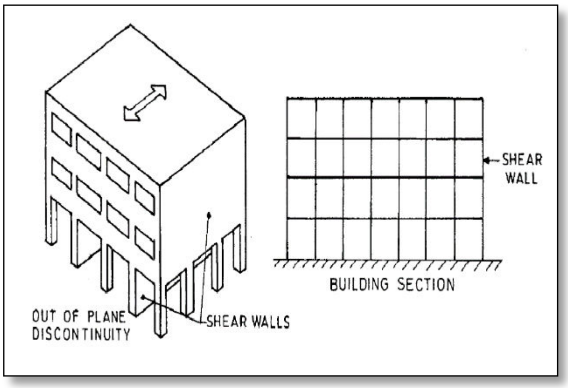
International Journal of Scientific Research in Engineering and Management (IJSREM)
Volume: 05 Issue: 10 | Oct - 2021 ISSN: 2582-3930

Diaphragm Discontinuity

Diaphragms with abrupt discontinuities or variations in stiffness, including those having cut-out or open areas greater than 50 percent of the gross enclosed diaphragm area, or changes in effective diaphragm stiffness of more than 50 percent from one storey to the next.

Out-of-Plane Offsets

Discontinuities in a lateral force resistance path, such as out-of-plane offsets of vertical elements. As fig.



Out-of-Plan Offsets

Non-parallel Systems

The vertical elements resisting the lateral force are not parallel to or symmetric about the major orthogonal axes or the lateral force resisting elements.

Elongated Shapes:

Building of great length or plan area may not respond to earthquake in the way calculated. Analysis customarily assumes that ground moves as rigid mass over the base of building but these is reasonable assumption only for a small area. Also, the ground is assumed to be elastic and the propagation of seismic waves is not instantaneous. If different part of building are being shaken out of step with each other, additional, incalculable stress are being imposed, and this effect increases with size. Thus, building that are too long in plan may be subjected to different earthquake moment simultaneously at the two ends, leading to disastrous results. As an alternative, such building can be broken into a number of separate square building. Building such as warehouses, having large plan area, will, in addition, be subjected to excessive horizontal seismic forces that will have to be carried by the columns and walls.

In tall buildings with large height-to-base ratio, the horizontal movement of the floors during ground shaking is large. For buildings with slenderness ratio less than 4, the movement is reasonable. The more slender a building, the worse overturning effects of an earthquake. The axial column force due to the overturning movement in such building tends to become unmanageably large. Also, the compressive and pull out forces acting on foundation increases tremendously.

Stiffness and Strength

Strength is the property of an element to resist force. Stiffness is the property of an element to resist displacement. When two elements of different stiffness's are forced to deflect the same amount, the stiffer element will carry more of the total force because it takes more force to deflect it. Stiffness greatly affects the structure's uptake of earthquake generated forces. On the basis of stiffness, the structure may be classified as brittle or ductile. A brittle structure, having greater stiffness, proves to be less durable during an earthquake, while a ductile structure performs well in earthquakes. Sudden changes in stiffness and strength between adjacent storeys are very common. Such changes are associated with setbacks (in penthouses and other small appendages), changes over the height of a structural system (e.g. discontinuous shear walls), changes in storey height, changes in materials, and unanticipatedparticipation of non-structural components

A common problem with such discontinuities is that inelastic deformations tend to concentrate in or around the discontinuity. These sudden changes in stiffness, strength, or mass in either vertical or horizontal planes of a building can result in distribution of lateral loads and deformations different from those that are anticipated for a uniform structure.

A sudden change of lateral stiffness up a building is not advised for the following reasons:

a) Even with most sophisticated and expensive computerized analysis, the earthquake stress cannot be determined adequately.
b) The structural detailing poses practical problems.

Drastic changes in the vertical configuration cause changes in stiffness and strength between adjacent stories of a building and should be avoided. Such discontinuity in the vertical configuration of a building as shown in fig. is not recommended. Failures due to discontinuity of vertical elements of the lateral load-resisting system have been among the most notable and spectacular.

Building with vertical setback as shown in cause a sudden jump of earthquake forces at the level of discontinuity. A large vibrational motion takes place in some portions and a large diaphragm action is required at the border to transmit forces from the top to the base. The effects of setbacks cannot be predicted by normal code equivalent static analysis.

Buildings that have fewer columns or walls in a particular storey, or that have a usually tall storey are prone to damage or collapse. One of the most common forms of discontinuity of vertical elements occurs when shear walls that are present in upper floors are discontinued in the lower floors. The result is frequent formation of a soft storey that concentrates damage. Fig. shows a building having shear walls (RCC walls for carrying earthquake forces) that do not go all the way to the ground, but terminate at an intermediate storey level.

It is advocated that the stiffness of the lower storey, the so-called soft storey, be reduced, so that a reduced dynamic force is transmitted to the superstructure. However, this argument is based on simple elastic analysis. When realistic inelastic and geometrical non-linear effects are taken into account, the plastic deformations tend to concentrate in the soft storey, and may cause the entire building to collapse.

The unequal height of the columns causes twisting and damage to the short columns of the building. It is because shear force is concentrated in the relatively stiff short columns which fail before the long columns. In a structural frame, long columns can be turned into short columns by the introduction of spandrels. Buildings with columns that hang or float on beams at an intermediate storey have discontinuities in the load transfer path.

The most common form of vertical discontinuity arise because of unintended effect of non-structural element. The problem is most severe in structure having relatively flexible lateral load-resisting system, because in such cases the non-structural component can comprise a significant portion of the total stiffness. A common causes of failure is the in filled frames. If properly designed, the infill can improve the performance of the frame due to its stiffening and strengthening action. However, soft storey may result if infill are omitted in single storey (often the first storey). Even if infill are placed continuously and symmetrically throughout the structure, a soft storey may be formed if one or more infill panels should fail.

Partial height frame infill are also common. In this form of construction infill extends between columns, from the floor level to bottom of the window line, leaving a relatively short portion of the column exposed in the upper portion of the storey. The shear required to develop flexural yield in the shortened column can be substantially higher than for the full-length column. If the designer has not considered this effect of the infill, shear failure of this so-called captive column can result before flexural yield. Complete collapses of the column (and building) can occur if it is not well equipped with traverse steel. This form of distress is a common cause of building damage and collapse during earthquakes.

Apparent vertical irregularities can occur due to the interaction between adjacent structures having inadequate separation. A tall building adjacent to a shorter building may be experience irregular response due to the effect of impact between the two structures. This effect can be exacerbated by local column damage due to the pounding of the roof of the small building against the column of the taller one.

Mass, stiffness, and strength plan irregularities can result in significant tensional response cannot, at present, be rectified with the result of elastic analysis. Techniques for inelastic analysis of complete building system which take torsion into account are largely unavailable and unverified. Given such uncertainties and difficulties with analytical techniques, the building should be designed to have substantial torsional resistance, near symmetry, and compactness of plan.

A building will have maximum chance of survival if it conforms to the following:

(a) The load bearing element should be uniformly distributed. This checks the torsion in the building.
(b) The columns and walls should be continuous and without offsets from the roof to foundation.
(c) The beam should be free of offset.
(d) Columns and beams should be coaxial.
(e) Beams and columns should be equal to width. This promotes good detailing and aids the transfer of moments and shear through the junction of the member concerned.
(f) To avoid stress concentration, there should not be sudden chance of cross-section of any member.
(g) The structure should be continuous (redundant) and monolithic as possible. The earthquake resistance of an economically designed structure depends on its capacity to absorb apparently excessive energy input, mainly by repeated plastic deformation of its members. Hence, the more continuous and monolithic the building is, the more plastic hinges and shear a thrust routes are available for energy absorption. This requires the structure to be highly redundant

3. CONCLUSIONS

From brief study of literature and study material it can be stated that the experimental setup by Shake Table Test and experimental modelling of R.C.C. structure with respect to symmetry and asymmetry is possible. Realistic modelling of R.C.C. structure can be assured by using scale factor, comparison of model and material properties

Vertical irregularity in the form of slender columns are shows reduction in the accelerations in all the floor levels as compared to the normal structure decreasing which results in increase in fundamental time period.

In floating column condition the response on the top storey is similar to the normal structure but the response observed for second floor (the floor with floating column) increases by 30% of response of normal structure which is dangerous in the seismic excitations; But the response in Y direction increases by 300% and 95% for Z direction as compare to normal structure which results in torsion of the structure.

In all types of asymmetry mass irregularity and floating column in particular for vertical irregularity is very saviour from earthquake resistance point of view and they should be prohibited as far as possible.

ACKNOWLEDGEMENT

I am thankful to Prof. N. P. Phadatare, Associate Professor and PG Co-coordinator, Civil Engineering Department, for his inspiration and encouragement. He has immensely helped in providing all opportunities and facilities for the dissertation work.

REFERENCES

1. **eizhen Li, Peng Zhao and Xilin Lu** *"Parameter Identification and Analysis of Shaking Table Tests on SSI System"* Journal of Asian Architecture and Building Engineering/November 2011

2. **M.S. Gong, L.L. Xie and J.P. Ou** *"Modal parameter identification of structure model using shaking table test data"* 14th World Conference on Earthquake Engineering October 12-17, 2008, Beijing, China

3. **Lakshmi Keshav, and V. G. Srisanthi** *"Masonry CSEB Building Models under Shake table Testing-An Experimental Study"* World Academy of Science, Engineering and TechnologyVol:6 2012

4. **Rucha S. Banginwar, M. R. Vyawahare, P. O. Modani** *"Effect of Plans Configurations on the Seismic Behaviour of the Structure By Response Spectrum Method"* IJERA, ISSN: 2248-9622 www.ijera.com Vol. 2, Issue 3, May-Jun 2012, pp.1439-1443

5. **Juan C. Delallera, José L.Almazan, Ignacio Vial, Victor Ceballos, Marcos Garcia** *"Analytical and experimental response of asymmetric structures with friction and viscoelastic damper"* 13th World Conference on Earthquake Engineering, Vancouver, B.C., Canada (August, 2004) Paper No. 531

6. **G. De Matteis, G. Brando, F.M. Mazzolani** *"Experimental and numerical analysis of pure aluminium shear panels for seismic protection of structures"* HERON Vol. 55 (2010) No. 3 / 4

7. **Y. Bozorgnia1 and W. K. Tso, M.** *"Inelastic earthquake response of asymmetric structures"* ASCE

8. **S. H. Chen, W. Lin & A. Qi** *"Shaking Table Test of Long-span Connected Structure under Multi-supported Excitation"* 15th World Conference on Earthquake Engineering,2012

Design Codes:

1. IS Code 1893 (Part I) (2002) *"Criteria for Earthquake Resistance Design of Structure-General Provisions & Buildings."*

2. IS Code 13920 (1993) *"Code of practice for ductility detailing of reinforced concrete structures subjected to seismic forces*