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Analytical Study of Response of Multi-Storey Building under Biaxial Excitation

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Abstract
Conventional practice of dynamic analysis using seismic codes recommends that the dynamic analysis is done by considering earthquake force in one direction at a time i.e. uniaxial excitation. But the simultaneous effect of asymmetricities in both orthogonal directions is neglected because of uniaxial excitation approach. Also the behaviour of building during earthquake depends upon its shape size and overall geometry. The partial and complete collapse of reinforced concrete buildings in recent earthquakes has raised the need to design the building considering biaxial forces. Limited research has been carried out on effect of such biaxial excitation.
To get reliable results a regular and C shape model of multi-storey building is analysed using various time-histories in SAP2000 v17. The angle of incidence of earthquake forces will be varying between 0 to 360 degrees. The influence of the orthogonal horizontal component of input ground motion on seismic response of reinforced concrete building is analysed by comparing the response of biaxial excitation with the response of uniaxial excitation.
Change in maximum displacement values, considering this as the basic criteria, comparison of the responses due biaxial excitation and uniaxial excitation is done. Time history analysis has been carried out using SAP2000 after validating the model with results available in reference literature.
It is observed and recommended that considering biaxial forces is necessary for an accurate determination of response and also to reach an adequate design for serviceability earthquakes.
Index Terms— Biaxial excitation, Time history analysis, Multi-storey building, Maximum displacement.

I. INTRODUCTION

The conventional practice of analyzing the structures is using equivalent static force method. In this method, the respective zone is considered in which the structure is to be built. The zoning of earthquake intensity is clearly specified in the IS 1893:2002. Other parameters taken are depth of foundation, time period of structure, damping, etc. Depending on these parameters, the equivalent static force acting on joints are calculated and applied in two orthogonal horizontal directions separately. This method does not consider non-linear parameters.

As the clause no. 6.3.2.1 from IS 1983-2002 states that “When the lateral load resisting elements are oriented along orthogonal horizontal direction, the structure shall be designed for the effects due to full design earthquake load in one horizontal direction at time”. Hence, the structures are modeled and subjected to earthquake loading in two orthogonal horizontal directions separately. In other words, the structures are subjected to uniaxial excitation. However, during earthquake, the dynamic force can be subjected to structures at any angle. Hence, it is required to study the response of structure during such incident. In recent literature, this phenomenon is known as biaxial excitation. Also During strong earthquake, the structure tends to enter into non-linear response which makes it utmost necessary to analyze the structure with respect to non-linear parameters.

II. LITERATURE REVIEW

Most of the available literature focussed on issues related with design problems, numerous studies on analytical aspects have also been carried out. These studies aim to identify parameters which govern the non-linear response of asymmetric-plan building. However, final conclusions of earthquake forces in biaxial excitation multi-storey structure are still lacking.

Nishant K. Kumar and Rajul K. Gajjar studied the non-linear performance of multi-storey buildings under bi-axial excitation using various time-histories. The Angle of incidence of earthquake forces used varying at interval 22.5^o between 0 to 360 degrees. It is shown that biaxial excitation is not necessary for symmetric building but in case of asymmetric building it is required to get adequate design forces. Also it is concluded that for torsionally coupled building biaxial excitation is generating more forces in comparison to uniaxial excitation. Andrea Lucchini et. al studied the torsional response of a two way asymmetric single storey building under bi-axial excitation using incremental dynamic analysis. Numerical simulations are performed in this paper which conclude that the parameter governing the non linear response of the asymmetrical plan building are associated with the centre of resistances of the system. Christos A. Zeris and Stephen A. Mahin focused on the behavior of reinforced concrete structures subjected to biaxial excitation. A finite-element model is presented for the analysis of such members under generalized biaxial loading. Numerical simulations are presented of cantilever columns under static load and of an entire frame in bidirectional seismic excitation. The results demonstrate the complexity of the biaxial resistance mechanism and its influence on structural response, particularly related to the concentration of local damage in columns.

H.P. Hong carried out the investigations on the torsional response for one-way or two-way asymmetric linear/nonlinear structural systems under uni- and bi-directional seismic excitations which increases the maximum displacement demand on structural systems. In this study, instantaneous load eccentricities caused by the motion of the centre of mass is considered.

III. ANALYSIS OF MULTI-STOREY BUILDING

A. *Introduction*

Advance computing technology has been developing the structural analysis methods exponentially with time. A few decades ago a very few structural analysis methods were available to analyze complex structures. Now a days, together with modeling techniques various structural analysis methods have been developed which not only analyze the simple structures with greater efficiency but can also analyze the complex structures with ease in a very less time. These modeling techniques bridged the gap, up to a large extent, between model behaviour and the actual behaviour of the structure. It is easier to analyze the structures which are symmetric in nature than those which are asymmetric. However, as per the current practices, quite a number of today’s structures fall in asymmetric category which increases the complexity in simulating real behaviour under dynamic loads. It is always advisable to reduce asymmetricity with respect to stiffness and mass. However, it’s not always possible to design structures which are free from asymmetricity

B. *Types of Dynamic Analysis*

Various types of dynamic analysis have been introduced in order to get the actual behaviour of structure subjected to dynamic loading. They are,

1. Equivalent static analysis
2. Response spectrum analysis
3. Linear dynamic analysis
4. Nonlinear static analysis
5. Nonlinear dynamic analysis
6. Incremental dynamic analysis

Equivalent Static method defines a series of forces acting on a building to represent the effect of earthquake ground motion with the assumption that the building responds in its fundamental mode. In *Response Spectrum Method* the response of a structure can be defined as a combination of many modes that in a vibrating string corresponds to the harmonics. A response is taken from design spectrum for each mode based on modal mass, modal frequency and then they are combined to provide an estimate of the total response of the structure. . The input is modeled using either time history analysis or modal spectral analysis but in both methods, the corresponding internal forces and displacements are found using linear elastic analysis so this method becomes less applicable with increase in non linearities. *Nonlinear Static method* is known as pushover analysis in which total force is plotted against the reference displacement to define the capacity curve. This can be then combined with a demand curve which reduces the MDOF problem to a SDOF problem. *Nonlinear dynamic Method* utilizes the combination of ground motion records with a detailed structural model, therefore capable of producing results with relatively low uncertainty. In this method the detailed structural model subjected to a ground-motion record produces estimates of component deformations for each degree of freedom in the model and the modal responses are combined. *Incremental dynamic Analysis* involves multiple nonlinear analysis of a structural model under a suite of ground motion records, each scaled to several level of intensity.

IV. ANALYSIS OF MULTI-STOREY BUILDING USING SAP2000

A. *SAP2000*

SAP2000 is one of the latest software which allows non-linear analysis using finite element methods which makes it capable of producing results with greater accuracy. With the inclusion of non-linear dynamic analysis like time history analysis and push over analysis with modeling of damping effects, it has become more popular in analysis and design of complex structures. Moreover, the software is very user friendly and supports design by codes of almost every country.

In few softwares, the time history analysis is available but they lack the privilege of changing the angle of incidence of earthquake. However, SAP2000 provides the privilege to vary the angle of incidence of earthquake. Due to this facility, the biaxial excitation of structures is possible using this software.

B. Problem Definition

As said earlier non-linear behavior of the structure is studied under biaxial excitation. For the same the structure must possess some eccentricity and this will introduce torsion in the building. It is known that the irregularity in stiffness, plans, etc is the basic reasons in making structures active in torsion. Although in most of the buildings, eccentricities are reduced in order to avoid torsion, quite a good number of modern buildings are built to give good aesthetic appearance which makes the building torsionally coupled.

For analysis G+12 building was taken and to introduce eccentricity for non-linear analysis shape of building is modified. Models were used to record the response of structure during time history analysis. Models were analysed for different earthquakes and for different angles of 0, 15, 30, 45 degrees. After analysis in SAP 2000 time versus displacement graph is plotted.

The structure is analysed for the following data;

- Beam Size : 230 x 530, 230x600
- Column Size : 230 x 750, 230 x 530, 230x680
- Concrete : M20 for Beam and Column
- Steel : Fy415

Data related to Time history (accelerograms)
Name of the earthquake : Bhuj
Date of earthquake : 26/1/2001
Sampling time interval : 0.1 second
Magnitude of Earthquake : 6.9

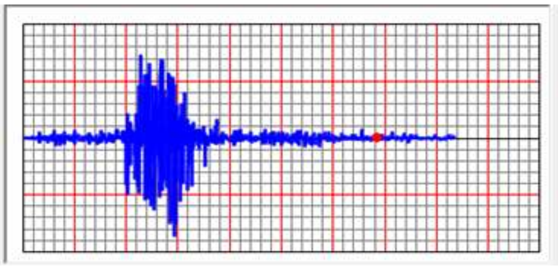

Fig. 1 Accelerogram of Bhuj Earthquake

Name of the earthquake : Big Bear City
Date of earthquake : 2001
Sampling time interval : 0.005 second
Magnitude of Earthquake :5.4

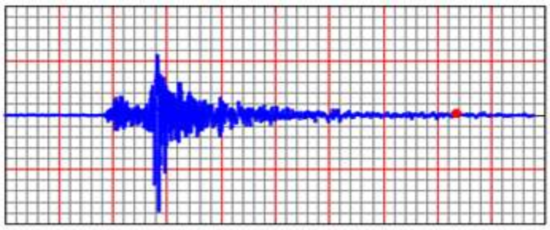

Fig.2 Accelerogram of Big Bear City(2001) Earthquake

Name of the earthquake : Big Bear City
Date of earthquake : 22 Feb 2003
Sampling time interval : 0.005 second
Magnitude of Earthquake : 6.9

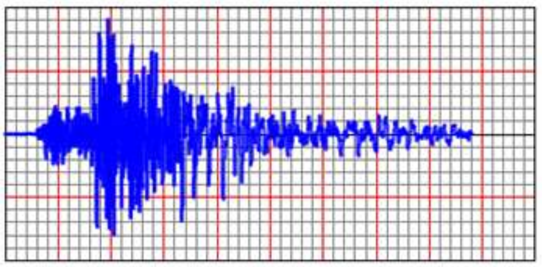

Fig.3 Accelerogram of Big Bear City(2003) Earthquake

For the analysis purpose, the problem defined above for G+12 regular and C shape structure is generated in SAP2000 v17. Time history analysis was carried out by varying by changing the inclination of the earthquake. Various Time-histories were used for analysis with different peak ground acceleration.

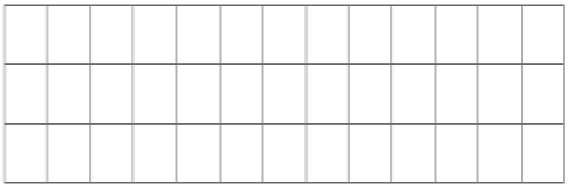

Fig.4 Sap2000 Model of Regular Building

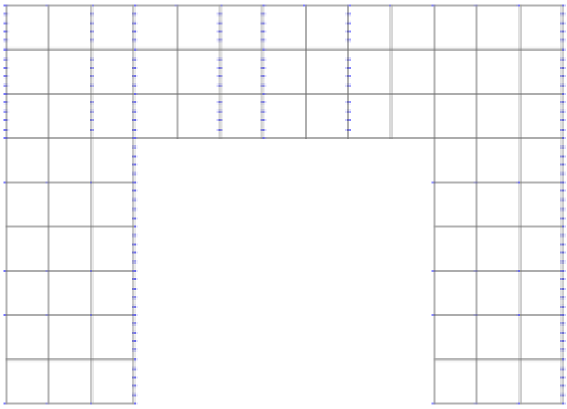

Fig.5 Sap2000 Model of Regular Building

Maximum value for the displacement for joint at different angle of incidence of earthquake are taken biaxial and uniaxial excitation and percentage between displacement due to biaxial excitation and uniaxial excitation is calculated.

V. RESULTS

Time versus maximum displacement graph was plotted and compared between the models for different earthquake and conclusions are drawn.

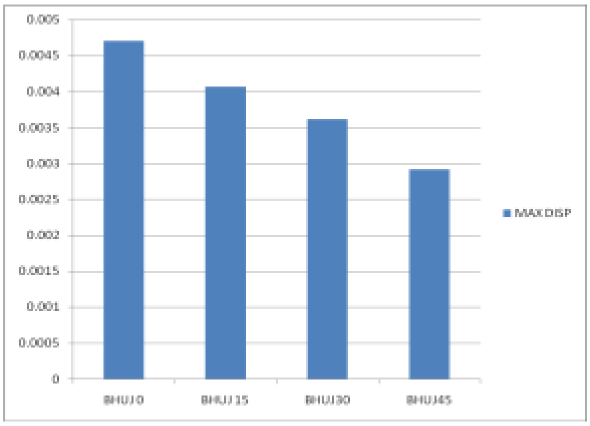

Fig. 6 Time Vs Maximum Displacement Graph For Bhuj Earthquake (Regular Building).

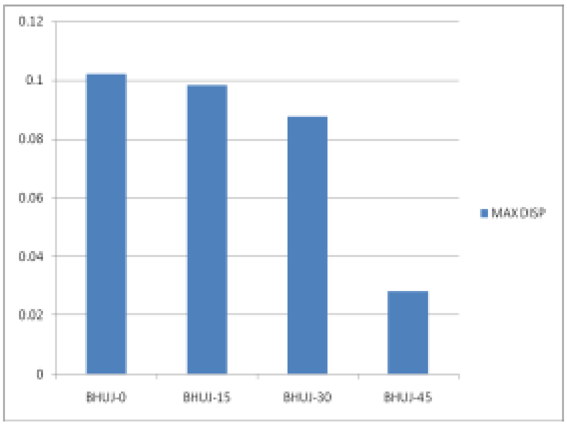

Fig.9 Time vs Maximum Displacement Graph For Bhuj Earthquake (C-shape Building).

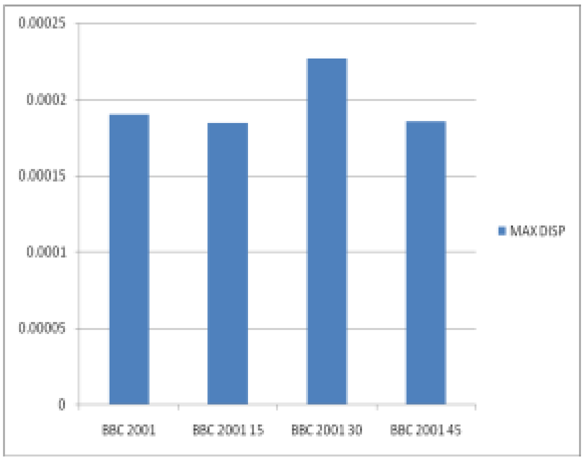

Fig.7 Time vs Maximum Displacement Graph For Big Bear City(2001) Earthquake (Regular Building).

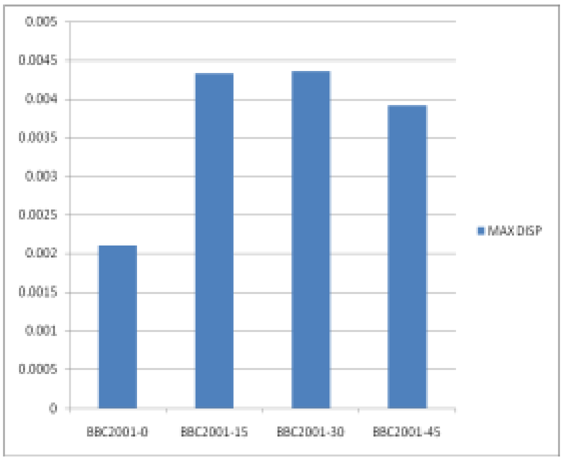

Fig.10 Time vs Maximum Displacement Graph For Big Bear City(2001) Earthquake (C-shape Building).

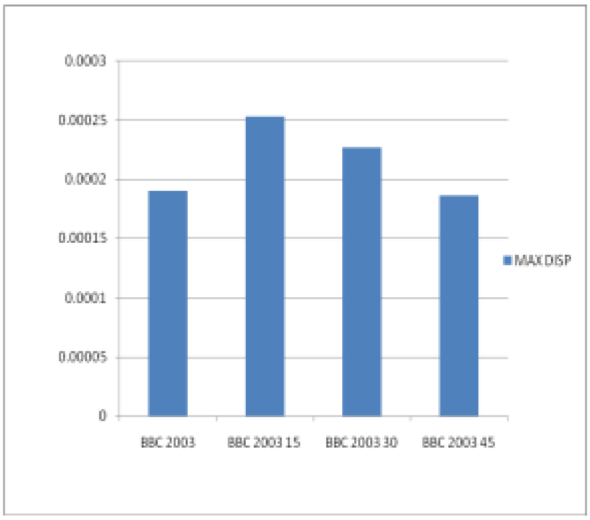

Fig. 8 Time vs Maximum Displacement Graph For Big Bear City(2003) Earthquake (Regular Building).

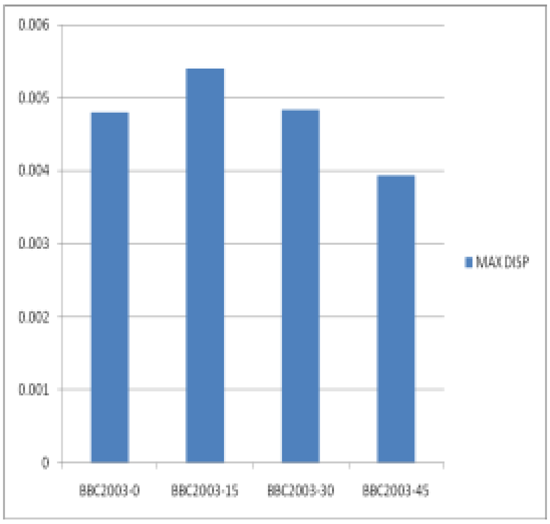

Fig.11 Time vs Maximum Displacement Graph For Big Bear City(2003) Earthquake (C-shape Building).

% difference between biaxial and uniaxial max. displacement / Earthquake	Building Type	
	C-shape	Regular
0 & 15 /Bhuj	-4	-16
0 & 30 /Bhuj	-17	-30
0 & 45 /Bhuj	-4	-16
0 & 15 /BBC2001	52	3
0 & 30 /BBC2001	52	17
0 & 45 /BBC2001	47	-3
0 & 15 /BBC2003	12	25
0 & 30 /BBC2003	1	17
0 & 45 /BBC2003	19	3

Table 1 Percentage difference between displacement due to uniaxial and biaxial excitation

VI. Conclusion

From the analysis and results following conclusions can be drawn.

- Displacement observed in case of uniaxial excitation in both the orthogonal directions in regular building is more than bi-axial excitation. Even if the earthquake force is higher, force due to uniaxial excitation will govern because of zero eccentricity. Hence, biaxial excitation will not be necessary for symmetric plan building.
- Maximum amount in deviation of displacement for C shape building is seen in case of Big bear City earthquake which was 52% and it is quite substantial. Hence, biaxial excitation is necessary to be performed to get realistic design forces.
- The difference between the uniaxial and biaxial excitation for BBC 2003 earthquake is seemed to be 19% for C shape building which is considerable while analyzing for unsymmetrical buildings.With the increase in the percentage of biaxial eccentricity, displacement increases as the displacement seen in biaxial excitation is more than uniaxial excitation.
- Regarding the variation in the modal time periods there is not much variation as the height of the structure is same and earthquake parameters are same like zone factors, Importance factor and response reduction factor.

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