Inelastic Effects of Biaxial Excitation on Geometrically Asymmetric Plan Building with Biaxial Eccentricity

Nishant Kumar K., Rajul K. Gajjar

Abstract— Seismic analysis is generally performed by creating a structural model which is excited with forces in two orthogonal directions separately i.e. they are subjected to uniaxial excitation. But an actual earthquake will have its effect in both the directions simultaneously. Limited research has been carried out on effect of such biaxial excitation on two way geometrically asymmetric plan having biaxial eccentricity. This paper deals with the inelastic effect of biaxial excitation on non-linear performance of geometrically two way asymmetric multi-storey buildings with biaxial eccentricity using various time-histories. The angle of incidence of earthquake forces will be varying between 0 to 360 degrees. The building, having of L-shaped plan with eccentricity along each of x and y directions, has been studied. Time history analysis has been carried out using SAP2000 after validating a preliminary model with experimental results available in reference literature.

Index Terms—Biaixial excitation, Multi-storey building, geometrically asymmetrical plan, inelastic effects.

I. INTRODUCTION

The plan geometry of the building is becoming more complex because of architectural constraints and aesthetic constraints. Due to which, the structure tends to become more irregular in plan. When the structure is regular in plan geometry, then it is easy to achieve sound earthquake resistant design. As per IS:1983:2002, A structural system is considered irregular, when the plants symmetrical axes are not noticeably regular and perpendicular to each other, when there are projections or entrants majors to 20%, when the vertical resistant elements to the lateral loads are not parallel, nor symmetrical with respect to main the orthogonal axes of the system that resists the lateral forces, when discontinuities in a trajectory of lateral force exist, like deviations outside the plane of the vertical elements[15]. The other point to be considered is that code specifies dynamic structural analysis by performing uniaxial excitation only whereas in real the structures are subjected to biaxial excitation. The simultaneous effects of asymmetricities in both the orthogonal direction are neglected because of uniaxial excitation approach. Ozhandecki and Polat (2008) have concluded that In most of the codes, the torsional irregularity of buildings is defined by the ratio of the maximum drift of a floor corner to the average drift of the considered edge of the floor in the excitation direction. Since this ratio is calculated under the static loading, it does not consider the eccentricity in the direction parallel to the excitation direction [6].

Manuscript received on April, 2013.

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Roul and conuelo (2008) concluded that the structures are more vulnerable when they are irregular [4]. Rucha S. Banginwar et al have performed response spectrum analysis on regular and irregular buildings and concluded that storey shear as well as storey drift is severe in the buildings having irregularity in plan geometry [7]. From the literature review carried out by the authors, it is observed that in all the previous studies, authors have taken regular plans where as actually structures seldom have regular plan. Most of the literature mentioned above mainly focussed on the issues related with design problems, numerous studies on analytical aspects have also been carried out. However, For example, non-linear seismic response on asymmetric plan buildings by Andrea Lucchini et al(2009), influence of bidirectional seismic motion on the response of asymmetric building by Julio J. Harnandez and Oscar A. Lopez (2000), non-linear response of two way asymmetric single storey building under biaxial excitation by Andrea Lucchini et al (2011).

The main aim of this paper is to overcome certain above mentioned deficiencies related to bi-directional seismic analysis of building having bi-axial eccentricities. An L-shaped ground + five storey building plan, shown in fig 1, is considered having 42 columns with beams and rigid diaphragm. The support of columns is considered hinged. The effects on the seismic response of orthogonal components, the angle of incidence and intensity of earthquake are studied. In order to cover the non-linearities in response, time history analysis is carried out for 6 different accelerograms..

II. BACKGROUND

To initialize the study, the investigations carried out under the reference literature "non-linear response of two way asymmetric single storey building under biaxial excitation" are considered which was published in Journal of Structural Engineering in January 2011 by Andrea Lucchini, Giorgio Monti and Sashi Kunnath. Numerical study has been carried out on a single storey building having 6 columns and rigid diaphragm. Time history analysis and incremental dynamic analysis have been performed. Time history analysis has been performed for the Kobe earthquake and Erzincan earthquake having Peak Ground Acceleration (PGA) value 0.51g. The incremental dynamic analysis is performed for PGA value 0.1g, 0.5g and 0.9g. The evolution of the maximum displacement demand in the different resisting elements of the system and of corresponding global restoring forces has been investigated for earthquakes of increasing intensities characterized by different angle of incidence. The major conclusions [1] derived in this literature are;

- When response in nonlinear zone is increased then the different global forces acting on the system that produce the maximum demand in the resisting elements tends to converge toward a single distribution;
- This distribution is related to resistance distribution only and not to the elastic properties of the system. In particular, it has been found that the nonlinear response is governed by specific points of that surface known in the literature as Base Shear Torque surface. Such points denoted as CRs by the authors corresponding to the BST combinations with each fixed β-direction to the maximum lateral strength of the building.;
- The direction of the pushing force, whose identification is not the focus of this study, dependent on the type of seismic analysis considered. In this only those buildings are studied whose Base-Shear Torque (BST) surface does not depend on the excitation i.e. structures with columns whose resistances are not affected by hardening or softening behaviour are studied;
- The convergence of the response toward the CR may not occur in those cases where low intensities of the seismic excitation or premature brittle failures of some resisting elements of the structure do not result in sufficient inelastic behaviour of the system.

III. MODEL VALIDATION

Time history analysis is carried on the similar model prepared in SAP2000 platform for different PGA i.e. 0.1g, 0.5g and 0.9g. The result in form of graph showing maximum displacement in the y-direction normalized with respect to the storey height is considered for model validation in SAP2000. The graph shows that the results occurred in the reference literature and in SAP2000 are almost similar with a little difference. These differences might have occurred due to certain difference in assumptions of parameters.

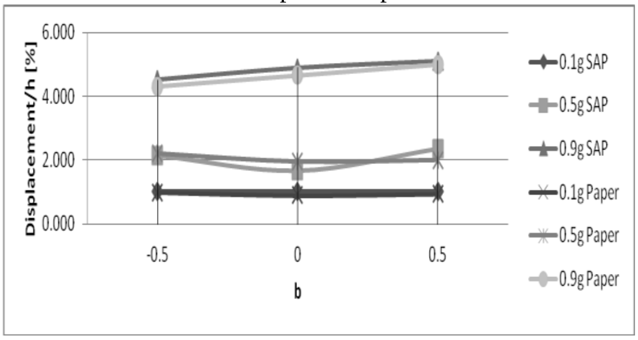

Fig 1 Comparison graph of results in reference literature and SAP2000

IV. ANALYSIS OF MULTISTOREY BUILDINGS

A G+5 building was considered whose autoCAD plan is shown in fig 2. From this plan four different structural plans were generated having different eccentricities. These eccentricities were brought by changing the alignment of lateral resisting elements i.e. columns. To carry out the biaxial excitation, the angle of incidence was varied from 0 degree to 360 degree with interval of 22.5 degree. The y axis direction is taken as 0 degree and the angle is varied counter-clockwise. Building was analysed for following data;

- Dimension of beam : 230mm x 560mm
- Dimension of column: 300mm x 600mm,350mm x 300mm, 300mm x 700mm, 600mm x 300mm
- Concrete : M20 for beam, M25 for column
- Steel : fy415
- Ex : 3.8m
- Ey : 3.07m

The column placement and orientation is also shown in SAP plan in fig 2. Different time history was used whose details are provided in table 2.

Nonlinear and direct integration method (Hilber-Hughes-Taylor) has been used to record the response of structure during time history analysis. The geometric non-linearity parameters are not introduced in this study.

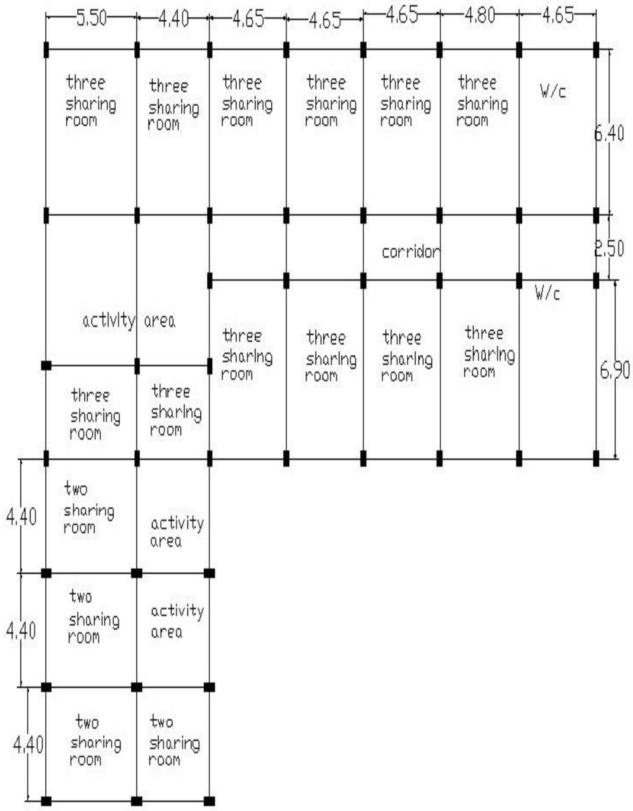

Fig 2 Plan of building and position of columns in SAP model

The model was then subjected to time history analysis with different angle of incidence and different PGA. Certain parameters are there on which the response for different angle can be compared. For this study, forces at the support in X and in Y directions are recorded and compared. The angle is varied from 0 degree to 360 degree with the equal interval of 22.5 degree.

Table I Earthquake time history details

Name	San farnando	Kobe	Loma prieta	San Farnando	Nahanni	Baja Calif
Station	CDMG 128	Takatori 000	LGPC 000	Pacoima Dam	Site 1, 010	Cerro Prieto
Date	02/09/1971	10/18/1989	10/18/1989	02/09/1971	23/12/1985	02/07/1987
PGA	0.35g	0.65g	0.76g	1.16g	0.9g	1.27g

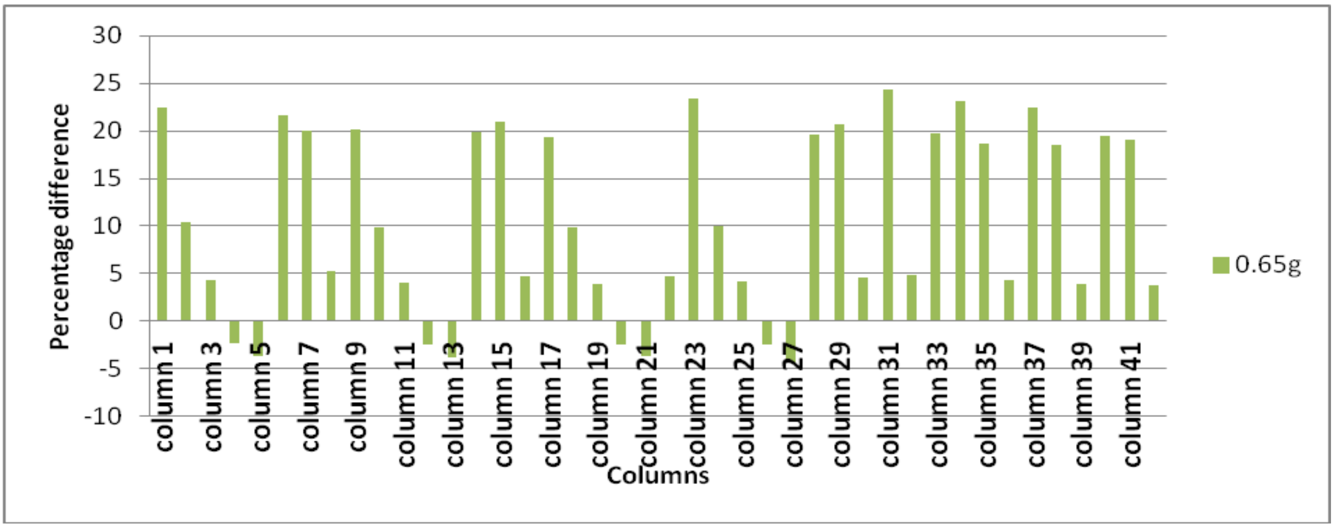

Fig 3 Typical graph showing Percentage difference between base forces due to uniaxial and biaxial excitation for PGA 0.65g

Comparison of forces in two orthogonal directions for uniaxial excitation and biaxial excitation is done as per the following formula.

$$\%\Delta F_i = \frac{max(F_{bi}) - max(F_{ui})}{max(F_{ui})} \times 100$$

Where F_i is the force in i^{th} direction,

F_{bi} = base forces due to biaxial excitation in i^{th} direction

F_{ui} = base forces due to uniaxial excitation in i^{th} direction

V. RESULTS

Variation of base forces in x and y direction with change in angle of incidence of earthquake is extracted for all the columns by time history analysis. Overall difference in forces for all the columns for different PGA value is shown in table 2. For the different PGA value in biaxial excitation, the number of columns affected is showing those columns for which the base forces due to biaxial excitation is exceeding uniaxial excitation. The last column of the table represents the maximum deviation of base forces due to biaxial excitation when compared against the base forced due to uniaxial excitation. Except for the PGA 0.35g, during biaxial analysis by all other PGA, more than half of the columns are being governed by forces due to biaxial excitation. The different effect of PGA 0.35g can be justified by smaller force generation during time history analysis which ultimately depends on a lots of other factors i.e. frequency, duration of shaking, peak ground displacement, response spectra. The same factors are responsible for such elevated results shown in table while analysing using PGA 0.65g earthquake.

From the above chart it's clear that the base forces for almost all the columns are exceeding during biaxial excitation for peak ground acceleration of 0.65g. For few columns like column 4, 5, 12, 13, 20, 21, 26 and 27, base forces are dominant in uniaxial excitation. Similar charts were prepared for different PGA and the results were consistent for a given column. For a few columns during analysis using other PGA, forces due to uniaxial were governing as compared to that during analysis using 0.65g PGA.

Table II Results for different PGA value

PGA (g)	total column	no. of column affected	% of column affected	maximum difference in base force (%)
0.35	42	14	33.33	9
0.65	42	34	80.95	25
0.8	42	24	57.14	15
0.95	42	23	54.76	26
1.16	42	29	69.04	17
1.27	42	24	57.14	15

There is asymmetricity along both the orthogonal directions. Due to this condition, when the angle of incidence of earthquake is 0 or 90 degree then eccentricity in other orthogonal direction doesn't come into picture. However, while biaxial excitation asymmetricities along both the direction take part in generating base forces due to which forces due to biaxial excitation exceeds the forces due to uniaxial excitations for almost all the columns. For every column, there exists a particular angle for which Fx and Fy reaches it maximum value.

VI. CONCLUSIONS

The When the angle of incidence of earthquake changes then the direct force reduces sinusoidally; however the torsion increases which ultimately increases the forced induced in columns due to torsion. So there exists an angle at which the summation of these forces reaches its maximum value. On the basis of the previously mentioned results, following conclusions can be drawn for such ground + five storey building which is geometrically two way asymmetric having biaxial eccentricity of 10%.

- The maximum amount of deviation of base forces due to biaxial excitation is ranging from 15%-26% for different PGAs.
- For some of the columns which are close to the centre of rigidity, this deviation is negative because of lesser lever arm.
- The exceedence of 26%, which may be more for a different earthquake, is quite substantial. Hence, biaxial excitation is necessary to be performed to get realistic design forces.
- Only 10% of the total columns are affected for the PGA 0.35g as compared to others because the dynamic force is so less that it cannot generate enough torsion in the building whereas for all other PGA more than half columns are showing positive deviation under biaxial excitation.

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