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SEISMIC RESPONSE OF BUILDING HAVING IRREGULARITIES UNDER UNI-DIRECTIONAL & BI-DIRECTIONAL FORCES: A REVIEW

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Abstract*— when a structure is subjected to ground motion in an earthquake, it responds by vibration. It can be resolved in two horizontal (x and y) and one vertical direction (z), with rotational ground motion neglected. In seismic design code (IS-1893(Part-1)-2016) recommendation given are simultaneous effect of two horizontal component of earthquake excitation is considered by applying 100% of earthquake force in the direction of building in main axis & 30% of those forces in another axis. While in reality the direction of the dominant component of excitations might not be one of the main directions of the building axes. Hence in this research work the response of building with different irregularities subjected to uni-directional & bi-directional earthquake forces have been obtained by considering arbitrary excitation angle of the ground motion. A set of value from 0 to 360 degree with different degree have been used for angle of excitation & find out critical angle.

***Keywords*— Angle of excitation, uni-directional and bi-directional force, seismic performance, irregularities**

I. INTRODUCTION

The buildings are subjected to gravitational and seismic loads. Earthquake action is considered with only the larger peak acceleration component acting in one direction (uni-directional earthquake) and with the two components acting in the lateral and in the transverse directions (bi-directional earthquake).

The component of the building, which resists the seismic forces, is known as lateral force resisting system (L.F.R.S). The L.F.R.S of the building may be of different types. The most common forms of these systems in a structure are special moment resisting frames, shear walls and frame-shear wall dual systems. The damage in a structure generally initiates at location of the structural weak planes present in the building systems. These weaknesses trigger further structural deterioration which leads to the structural collapse. These weaknesses often occur due to presence of the structural irregularities in stiffness, strength and mass in a building system. The structural irregularity can be broadly classified as plan and vertical irregularities. A structure can be classified as vertically irregular if it contains irregular distribution of mass, strength and stiffness along the building height. As per IS 1893:2002, a storey in a building is said to contain mass irregularity if its mass exceeds 200% than that of the adjacent storey. If stiffness of a storey is less than 60% of the adjacent storey, then a storey is termed as, weak storey‟. If stiffness of a storey is less than 70% or above as compared to the adjacent storey, then the storey is termed as soft storey‟.

In reality, many existing buildings contain irregularity, and some of them have been designed initially to be irregular to fulfil different functions e.g. basements for commercial purposes created by eliminating central columns. Also, reduction of size of beams and columns in the upper storeys to fulfil functional requirements and for other commercial purposes like storing heavy mechanical appliances etc. This difference in usage of a specific floor with respect to the adjacent floors results in irregular distributions of mass, stiffness and strength along the building height. In addition, many other buildings are accidentally rendered irregular due to variety of reasons like non-uniformity in construction practices and material used. The building can have irregular distributions of mass, strength and stiffness along plan also. In such a case it can be said that the building has a horizontal irregularity.

The different types of irregularities are presented from Figures

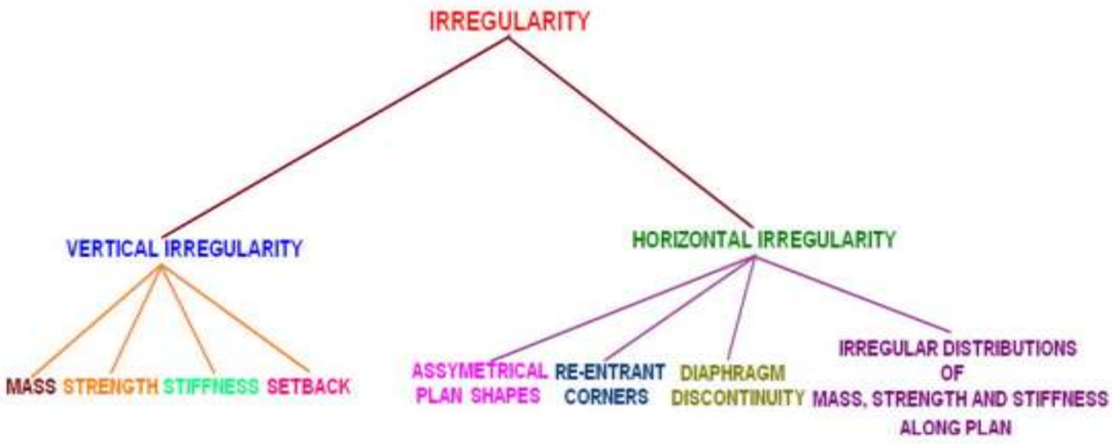

Figure1.1Classification of different types of structural irregularities
(https://image.slidesharecdn.com/organizationalstructure)

II. LITRATURE REVIEW

I. Fernandez-Davila, S. Cominetti and E.Cruz [6] Studied different methodologies to consider the bidirectional seismic effects in the building design process were analysed in this work.
i.e.
1. 30% method
2. SRSS method resulting from the use of a uni-directional earthquake applied in both directions;
3. A 20% amplification of the maximum force resulting from a uni-directional earthquake applied in the most unfavourable direction for the element. For these purpose six models of five story concrete buildings were analysed. The materials were considered as elastic. The seismic angle variation is studied, and critical angles for stated maximum responses are determined. From methodology they concluded that, the rules of combination of the 30% and of the square root, underestimate the seismic responses in 25% and a 20% amplification overestimate the response in 25 % respect of the 'exact' response.

G.Faella, V.Kilar and G.Magliulo [4] Studied the influence of the orthogonal horizontal component of the input ground motion on the seismic response of a reinforced concrete building was analysed by carrying out a comparison with the response under unidirectional excitation. To gain reliable results, numerical modelling of a four storey full scale r/c bare frame building tested in the ELSA laboratory at Ispra. The numerical analysis of the seismic response of the building under bi-directional input ground motion was performed for using an ensemble of five real earthquakes. The comparison between the response under bi-directional and unidirectional ground motion shows no significant difference in terms of global response parameters (base shear, top displacement and instantaneous periods). Under bi-directional excitation, the nonlinear rotations in the direction of the primary component action increase of about 10% compared to the unidirectional excitation and the increment in terms of yielded and crushed sections is about 60% and 400% respectively.

A. Lopez, K. Chopra and J. Hernandez [10] have been an explicit formula, convenient for code applications, to calculate the critical value of structural Response to the two principal horizontal components acting along any incident angle with respect to the structural axes, and the vertical component of ground motion. To determine this response, they developed the CQC3 rule, which describes the structural response as a function of the incident angle of seismic components described in terms of response spectra. To evaluate rcr/rsrss ratio they analysed single bay - single Symmetric and asymmetric building using derived explicit formula and SRSS combination. They demonstrated that the largest value of the ratio rcr/rsrss is √2. This implies that the critical response never exceeds √2 times the result of the SRSS analysis and rcr/rsrss is largest when the incident angle is either 450 or 1350.

F. Khoshnoudian and M. Poursha [3] analysed the effect of two horizontal component of earthquake on structure under arbitrary angle of excitation and also discussed the practice code recommendations. They also found out critical seismic excitation angle under two components with respect to one component in linear and nonlinear behaviour using time history analysis. For these purpose they studied 14 models of 5 storey steel buildings in which first seven have MRF and the last seven ones models possess EBF. They concluded that the maximum response under two components is usually more than one component in linear and nonlinear behaviour and the critical angle is property of the structure and critical angle isn't always in direction of reference axis. SRSS and 30% combinations in the studied buildings underestimate the response of structure with respect to maximum response under two components. 20% method is more realistic than two prior combinations. The 20% method can be used.

N. Ile and J. Reynourad [9] designed a lightly reinforced concrete wall specimen and tested under bi-directional seismic excitations. They investigated the simplifying assumptions made in designed and for this purpose a 3-D refined non-linear analysis was conducted. The specimen was tested on the AZALEE shaking table which allows for testing100 tons models under three directional excitations. During the shaking table tests the specimen was subjected to increasing horizontal artificial accelerations along the direction parallel and perpendicular to the walls plane. The following PGA levels of the uncorrelated input signals were applied during the test in both directions: 0.15g, 0.40g, 0.55g and 0.65g. From test results they concluded that the influence of bidirectional excitation with reference however much more differences are observed when examining the bending moment to unidirectional excitation on displacements is negligible and axial force at a critical section level.

H. Sesigur, C. Celik and F. cili [5] The spectrum intensity concept used to investigate the bi-directional effects of earthquakes on structures, for this purpose, a set of recent and past thirteen earthquakes (M>6) were selected to predict bi-directional effects. Elastic velocity response spectra of these earthquakes were numerically obtained and plotted for damping ratios of ξ =0.00, 0.05, 0.20, and 0.50. Spectrum intensities for both orthogonal directions and for the resultant direction were calculated using a computer program. They obtained Unfavourable response by equating the resultant spectrum intensity to principle direction’s intensity plus the other direction’s contribution as a percentage of the principle component. Based on the numerical study they concluded that, the combination rules given in the current codes are conservative (especially for buildings with larger importance) as a safe value of α=0.20 ~ 0.25 seems reasonable for structures having regular load carrying systems.

M. Hosseini and A. Salemi [8] In this paper two 5-story steel buildings with moment frames, one with square and the other with rectangular plan, have been designed base on the seismic design code for steel buildings, and then have been analysed by a Nonlinear Time History Analysis (NLTHA) program using simultaneously the accelerograms of two horizontal components of some earthquakes. A set of values from 0 to 90 degrees, with an increment of 10 degrees, have been used for angle of excitation. They divided Buildings’ columns into three main categories, including corner, side, and internal columns, and axial force and bending moment values in different columns, and total base shear forces of the buildings, have been investigated in all cases. They conclude that, the columns’ axial forces may exceed the ordinary cases up to 50% by varying the angle of excitation, and that this variation is more in buildings with rectangular plans. Furthermore, each column gets its maximum axial force with a specific angle of excitation, which is not 0 or 90 necessarily, and is different from column to column, and that specific angle is not the same for different earthquakes.

Magliulo G., Maddaloni G. and Petrone C. [7] Studied the influence of the earthquake direction on the seismic response of building structures was examined. For these purpose, three multi-story RC buildings, representing a very common structural typology in Italy, were used as case studies for the evaluation. Nonlinear static and dynamic analyses were performed by considering different seismic levels, characterized by peak ground acceleration on stiff soil equal to 0.35 g, 0.25 g and 0.15 g. They conclude that, the columns’ axial forces may exceed the ordinary cases up to 50% by varying the angle of excitation, and that this variation is more in buildings with rectangular plans. Furthermore, each column gets its maximum axial force with a specific angle of excitation, which is not 0 or 90 necessarily, and is different from column to column, and that specific angle is not the same for different earthquakes.

A. Reyes-Salazar, J. Juárez-Duarte, A. López-Barraza and A. Haldar [1] Studied the 30-percent (*30%*) and the Square Root of the Sum of the Squares (*SRSS*) rules, commonly used in seismic design procedures to evaluate the maximum effect of both horizontal components of earthquakes, and were reevaluated. Four 3D moment resisting steel frames, modeled as complex multi degree of freedom structures, representing different dynamic characteristics, were considered in the study. Using a time domain nonlinear finite element program developed by the authors, the maximum inelastic seismic responses of the models in terms of several parameters were evaluated by simultaneously applying both components. Then, the above mentioned combination rules and others were evaluated. The numerical study indicates that both, the *SRSS* and the *30%* combination rules, may underestimate the combined effect in terms of axial loads. It is observed that the underestimation is more for the *SRSS* than for the *30%* rule. In addition, for axial loads the underestimation is more for inelastic analysis than for elastic analysis. It has been indicated that the results for the elastic analysis may be quite different from those of the inelastic analysis.

E. Cruz and S. Cominetti [2] In these paper elastic and inelastic maximum responses of five story concrete buildings of different structural configurations of plant stiffness eccentricity, lateral stiffness, coupling and slenderness of the corner columns were studied. The buildings were subjected to gravitational and seismic loads. Earthquake action was considered with only the larger peak acceleration component acting in one direction (uni-directional earthquake) and with the two components acting in the lateral and in the transverse directions (bi-directional earthquake). The maximum response resulting from a time history analysis of the buildings was studied. They conclude that, differences between the responses of buildings subjected to uni- and bi-directional horizontal loads combined with gravitational loads are smaller than the differences of responses of those subjected to just seismic uni- and bi-directional loads. The columns seismic axial strength is smaller in buildings subjected to uni-directional earthquakes in regard to those of buildings subjected to bi-directional earthquakes.

III. CONCLUSIONS

1. The maximum response that is obtained in any structural element due to the application of a bi-directional seismic movement with angle of variable incidence, not necessarily coincides with any of the two principal directions of the buildings.
2. It is shown that the increment in damage produced by the action of the orthogonal horizontal component is particularly evident when the seismic behavior is analysed at the local of the member action.
3. The maximum response under two components is usually more than one component in linear and nonlinear behaviour and the critical angle is property of the structure.
4. The columns' axial forces may exceed the ordinary cases up to 50% by varying the angle of excitation.
5. The *SRSS* and the *30%* combination rules, may underestimate the combined effect in terms of axial loads. It is observed that the underestimation is more for the *SRSS* than for the *30%* rule & also observed that the safe value of α=0.20 ~ 0.25 seems reasonable for structures having regular load carrying systems.

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