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TO STUDY THE EFFECT OF CENTER OF MASS, CENTER OF RIGIDITY, CENTER OF STRENGTH OF A BUILDING ON A TORSIONAL MOMENT USING NONLINEAR TIME HISTORY ANALYSIS

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ABSTRACT

Modern architectural design more often than not deals with irregular structures. In these structures, the torsion phenomenon can induce significant stresses, especially in the case of seismic motion. The seismic response of an asymmetric building subjected to ground motion tends to be significantly stronger due to torsional effects. These effects arise from the non uniform distribution of mass, the stiffness, the strength and the torsional components of the ground movement. Torsion has been the cause of major damage to buildings subjected to strong earthquakes, ranging from visible distortion of the structure to structural collapse. It occurs under the action of earthquake forces when the center of mass of the building does not coincide with the center of rigidity. The distance between them is called eccentricity. Lateral force multiplied with this eccentricity causes a torsional moment that must be resisted by the structure. In theory, reducing the distance between the center of mass and center of rigidity should minimize the torsional effects. Six models were considered to test the effects of torsion and rotation wherein, models one, five and six shared column size. Model one served as the basic model while model five had a base isolator incorporated in it and model six implements shear walls. Models two, three and four are similar to the basic model except for the column sizes with the redistribution of strength and stiffness and have no special parameters applied. In this project, it has been evaluated that it is possible to effectively reduce torsional and rotational effect within an irregular building up to 15 stories. Although the base isolator provided the best resistance to deforming forces over the structure, it is worthwhile to note that just the configuration of centers provides an acceptable levels of resistance with significant reduction in cost and is far more feasible in many parts of the world.

***Keywords**: Center of Mass, Center of Rigidity, Center of Strength, Torsional Moment, Nonlinear time history analysis.*

I. INTRODUCTION

The nature of forces induced is reckless, and lasts only for a short duration of time. Earthquakes are capable of significant damage in cases of under preparation and warrant meticulous steps to be taken in order to limit the extent of loss to person and property. It is with this understanding that advances have been made in various areas of sciences and engineering through the centuries, to enable some degree of predictability. With these advances, forecasting the occurrence and intensity of earthquakes for a particular region, has become possible and over the last century, great strides have been made in the field of designing structures able to withstand seismic forces. Improvements both in design philosophy and methods have continuously been researched, proposed and implemented.

Earthquakes motion can be recorded in terms of ground displacement, velocity or acceleration. During earthquakes, the ground movement is very complex, producing translations in any general direction combined with rotations about an arbitrary axis. Modern strong motion accelerographs are designed to record three translational components of ground acceleration.

Importance of seismic analysis

Relatively little of human civilization is designed to be earthquake resistant. Even in the developed world, earthquake design is often seen as having intangible risks, expensive preventative measures, and as being unnecessary away from seismic hot-spots. However, a seismic analysis assessment is often highly rational no matter the location, and we can often demonstrate seismic resistance with minimal or no redesign.

The prediction of the response of a structure to a particular type of loading is of utmost importance for the design of structure. Basically the codes and previous experiences provide us with a lot of information regarding the type of loads and their intensities for different types of structures and the site conditions. The analysis procedure to be adopted purely depends upon the engineers choice as per the accuracy of the work required. The nonlinear time history analysis can be regarded as the most accurate method of seismic demand prediction and performance evaluation of structures. Although, this method requires the selection of an appropriate set of ground motion, detailed site conditions and also a numerical tool to handle the analysis of the data, which is in many cases computationally expensive still it is regarded as the most detailed analysis and highly accurate analysis method.

Principle of Base Isolation

The basic principle behind base isolation is that the response of the structure or a building is modified such that the ground below is capable of moving without transmitting minimal or no motion to the structure above. A complete separation is possible only in an ideal system. In a real world scenario, it is necessary to have a vertical support to transfer the vertical loads to the base.

The relative displacement of ground and the structure is zero for a perfectly rigid, zero period structure, since the acceleration induced in the structure is same as that of ground motion. Whereas in an ideal flexible structure, there is no acceleration induced in the structure, thus relative displacement of the structure will be equal to the ground displacement.

Displacement occurs at CG of the structures for fixed base structures, which will be approx. two-third height for buildings and at isolation plane for base isolated structures with lesser displacement within the structure.

Purpose of Base Isolation

Wind and Earthquake are the most predominant loads that demands lateral design of a structure. Again, earthquake load is not controllable and it is not practical to design a structure for an indefinite seismic demand. Only practical approach left is to accept a demand and make sure the capacity is more than the demand. The inertial forces caused due to earthquake is directly proportional to the mass of structure and the ground acceleration. Increasing ductility of the building or increasing the elastic strength of the structure is the most conventional method of handling seismic demand. Engineer has to increase the capacity exceed the demand. Base isolation takes an opposite approach, i.e. to reduce the seismic demand instead of increasing the capacity. Controlling ground motion is impossible, but we can modify the demand on structure by preventing/reducing the motions being transferred to the structure from foundations.

II. LITREATURE REVIEW

Amin Alavi and Prof. P.SrinivasaRao published; “Influence of Torsional Irregularities of RC Buildings in High Seismic Zone” in 2013.In this paper, the torsional response of plan asymmetric RC building structures for predicting the seismic responses was investigated. The linear dynamic response of plan asymmetric with different eccentricities was initially compared, in order to evaluate the effects of the torsional response. The results shows that model with the highest eccentricity in both the directions has the maximum storey drift and if the eccentricity between center of mass (CM) and center of resistance (CR) of the building is less than 20% of its dimension, we can ignore the torsional irregularity.

Prof. Wakchaure M. R, Nagare Y .U published; “Effects of Torsion Consideration in Analysis of Multi Storey Frame” in 2013.They have discussed structural analysis and design of nine storey reinforced concrete asymmetrical frame building as per IS- 1893 (Part I: 2002) using Staad.pro software. The building is assumed as residential building. Linear static analysis has been done. The structure is assumed to be located in seismic zone III on a site with medium soil. Building contains different irregularity like plan irregularity and Re-Entrant corner irregularity. In building two cases are considered, case one is without considering torsion and case two is considering torsion.

Results are compared in terms of % Ast in columns. They concluded that, in case two the area of steel in the beams at critical stage are much smaller than those obtained in the case one. The bottom bars should be more critical, because they seem to be subjected to more tension than the top bars and the variation of Ast is much higher for small span beams.

III. METHODOLOGY

The purpose of the non-linear time history analysis (NLTHA) is to evaluate the nonlinear response of structural system with respect to torsion and rotation and to compare these parameters to available structures with configuration of centers, base isolators and shear walls that are going to be tested in this project.

Time-History analysis is a step-by-step procedure where the loading and the response history are evaluated at successive time increments, $\Delta t - steps$. During each step the response is evaluated from the initial conditions existing at the beginning of the step (displacements and velocities) and the loading history in the interval. With this method the non-linear behaviour may be easily considered by changing the structural properties (e.g. stiffness, k) from one step to the next. Therefore this method is one of the most effective for the solution of non-linear response, among the many methods available. The inelastic dynamic time history analysis can be viewed as a method for predicting seismic force and deformation demands, which accounts in an approximate manner for the redistribution of internal forces occurring when the structure is subjected to inertia forces that no longer can be resisted within the elastic range of structural behaviour. The NLTHA is expected to provide information on many response characteristics that cannot be obtained from a linear elastic analysis and linear dynamic analysis whose accuracy is still questionable, verification of the completeness and adequacy of load path, considering all the elements of the structural system, all the connections, the stiff non-structural elements of significant strength, and the foundation system.

Non-linear time history analysis in ETABS

Following are the general sequence of steps involved in performing NLTHA using ETABS 2015 in the present study:

1. A three dimensional model that represents the overall structural behavior is created.
   For reinforced concrete elements the appropriate reinforcement is provided for the cross sections.
2. Gravity loads composed of dead loads and a specified proportion of live load is assigned as seismic weight to the structure.
3. Free vibration un-damped modal analysis is performed to make note of the frequencies and time periods of the structure.
4. The time history function from a file is selected and the time history function is defined.
5. The non-linear direct integration time history load cases are defined by assigning the ground acceleration time history function as loading in X &Y direction and by assigning proportional damping NLTHA is set to run.
6. After the analysis is completed we get the response of the structure such as torsional moment, rotation, base shear, displacement and drifts.

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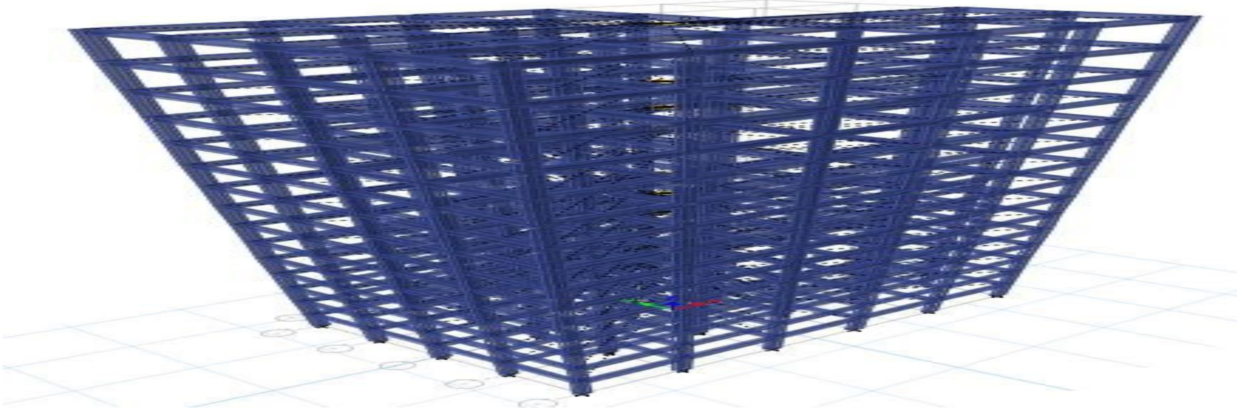

IV. ANALYSIS PROCEDURE

Every structure vibrates under external excitation. The response mainly depends on its mass, stiffness, damping and boundary conditions. All of these parameters can be expressed by a single parameter frequency ‘f ’or time period ‘T ’of vibration. A structure may be idealized into single degree of freedom system (SDOFS) or a multidegree of freedom system (MDOFS). These idealized systems can then be analyzed and its response to various excitations can be evaluated. The analysis procedure can be divided into linear procedure (linear static and linear dynamic) and non-linear procedure (non-linear static and nonlinear dynamic).

Table 5.2 Base torsion for non-linear dynamic analysis of a ten storey buildings.

Models (10-storey)	Torsion (k-Nm) NLTH-X	Torsion (k-Nm) NLTH-Y
M-1 (BM)	7749	6868
M-2 (es = 0)	2808	3614
M-3 (ev = 0)	1849	2269
M-4 (CV-CM-CR)	3383	3073
M-5 (BI)	1110	1474
M-6 (SW)	3974	3079

Position of center of mass, stiffness and strength for ten storey models

Model – 1	Model – 2
XCM = -0.426 YCM = -0.195	XCM = -0.426 YCM = -0.195
XCS = -1.5385 YCS = -0.9231	XCS = -0.444 YCS = -0.1574
XCV = -1.602 YCV = -0.9532	XCV = -1.373 YCV = -0.817

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Model – 3	Model – 4
XCM = -0.426 YCM = -0.195	XCM = -0.426 YCM = -0.195
XCS = 2.593 YCS = 1.446	XCS = 0.21 YCS = 0.201
XCV = -0.5031YCV = -0.388	XCV = -1.162 YCV = -0.686

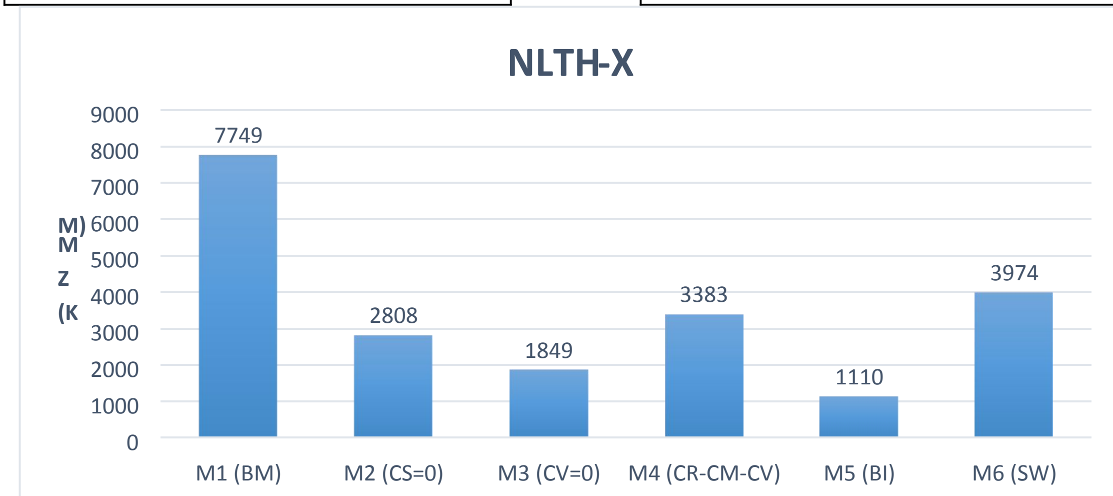

Fig 5.4 illustrates the variation of base torsion for non-linear dynamic analysis of a ten storey buildings in X-direction.

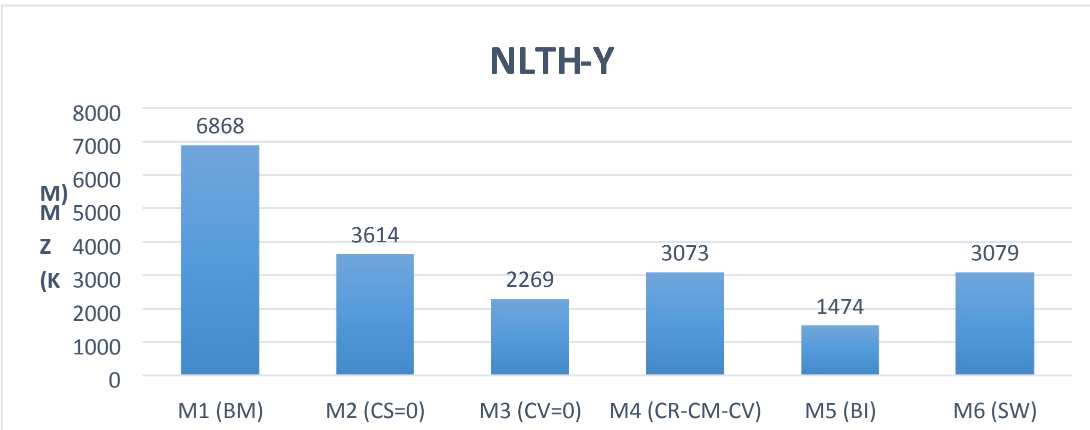

Fig 5.5 illustrates the variation of base torsion for non-linear dynamic analysis of a ten storey buildings in Y-direction.

V. DUCTILITY RATIO

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The following table contains the results of the analysis carried out for the models as discussed earlier. Ductility ratios of five, ten and fifteen storey buildings performing nonlinear static analysis (Push over analysis). Different Site classes are:

A- Hard Rock
B- Rock
C- Very dense soil and
D- Soft rock Stiff soil

Ductility ratio of 5-storey (using Fe 500 grade steel)

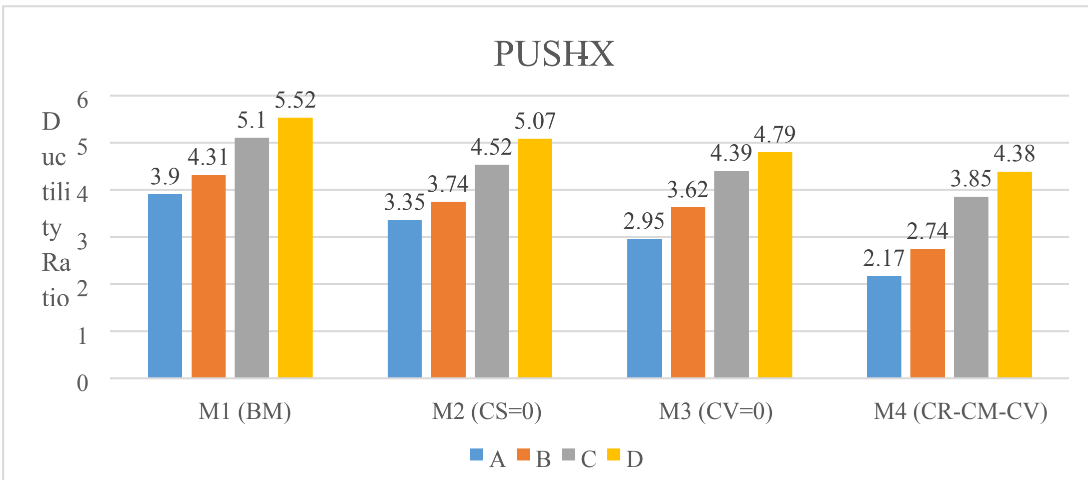

Fig 5.14 illustrates the variation of Ductility ratio (for Fe 500) w.r.t site classes for non-linear static analysis of a five storey buildings in X-direction

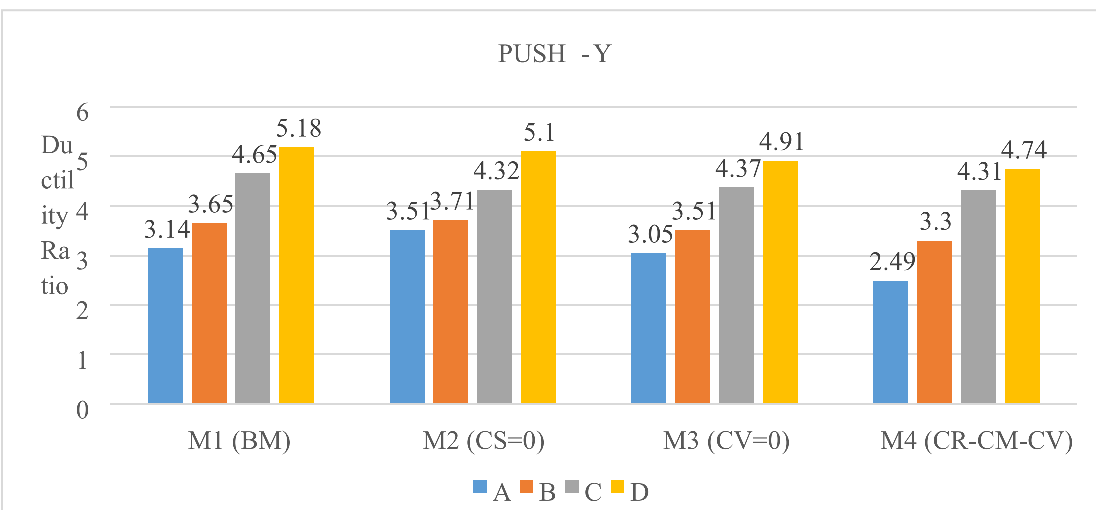

Fig 5.15 illustrates the variation of Ductility ratio (for Fe 500) w.r.t site classes for non-linear static analysis of a five storey buildings in Y-direction.

VI. DISCUSSIONS & RESULTS

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When there is an eccentricity between center of mass and center of rigidity i.e. in model1 base torsion and rotation was very high for five, ten and fifteen storey. When strength re-distribution is performed, as the center of mass is in between the center of strength and center of rigidity (i.e. model-4), the maximum reduction in base torsion is by 78% and 79% for five and fifteen storey. As for 10 storey when the center of mass coincide with center of rigidity (i.e. model-3) the maximum reduction in base torsion is by 76%. The maximum decrease in base torsion is by 86%, 86% and 79% in model-5 (i.e. basic model with base isolator) for five, ten and fifteen storey as the base isolator isolates the base of the structure from the strong ground movement. Maximum decrease of rotation is by 97% (model-6 with shear walls), 92% (model-2 ev=0) and 88% (model-4 CV-CM-CR) in five, ten and fifteen storey. The Ductility ratios of model-1, model-2, model-3 and model-4 increases with respect to site class A(Hard rock), B(Rock), C(Very dense soil and soft rock) and D(Stiff soil); in increasing order for all models tested. Fe415 is more ductile than Fe500. Yield strength of steel and ductility are inversely proportional.

VII. CONCLUSION

The following are the conclusions drawn from the present work: In the models that differ from Basic model (model-1) in column size only i.e. CS=0 (model-2), CV=0 (model-3) and CV-CM-CR (model-4), there was notable reduction in base torsion when non-linear time history analysis was done on five, ten and fifteen storey variants. In model 4 the desired reduction owes itself to the fact that CV and CR to be located on opposite sides of CM. Model-5 with base isolator implemented showed the highest reduction in base torsion across the board. In model-6 where in shear walls were implemented, there was better reduction in base torsion in five storey variant alone. However, the ten and fifteen storey variant did not fare any better than the comparative strength and stiffness redistribution models. The diaphragm rotation was decreased in M-2(center of mass coincide with center of rigidity), M-3(center of mass coincide with center of strength), M-4 (center of mass is equidistant from center of rigidity and strength), M-5(BI) and M-6(SW) when compared with M-1(BM). It is found that the strength eccentricity and proper configuration of centers are significant parameters in judging the non-linear response of the structure with respect to base torsion. Performing Push over analysis for model-1, model-2, model-3 and model-4 shows that the ductility ratio increases with respect to site class A(Hard rock), B(Rock), C(Very dense soil and soft rock) and D(Stiff soil); in increasing order for all models tested. The above analysis also shows that the yield strength of steel and ductility are inversely proportional. Within this project steel of yield strength 415 and 500 were tested.

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