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Effect of Lateral Force Resisting Systems for Tall Buildings

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ABSTRACT: In recent years construction of high rise building is widely increased due to highly increasing cost of land and scarcity of land in metropolitan cities. These structures are sensitive to wind and earthquake forces. Behavior of such structures can be controlled by effective lateral structural systems, which increases stiffness of building. Although in present days computer technology allows for precise analysis and design of different systems for high rise buildings, it does not readily insight for choosing among the alternatives of these systems to arrive at the best overall design. While studying uncontrolled response it was observed that response in terms of displacement and acceleration was exceeding IS code limits. The enhancement in the performance of the building is studied under earthquake loads by installing lateral force resisting systems, such as bracing system and steel plate shear walls. These systems were applied at various positions with different cross-sectional properties. Modeling and analysis was carried out using ETAB. It is evident from the observations that all the proposed arrangements improve the performance of the building in controlling storey displacements, accelerations as well as drift. The present work is expected to accelerate the implementation of steel plate shear walls as a lateral force resisting systems to earthquake excited tall slender buildings.

KEYWORDS: Tall building; Steel plate shear wall; Bracing system.

I. INTRODUCTION

Amongst the natural hazards, earthquakes have the potential for causing the greatest damages. Since earthquake forces are random in nature & unpredictable, the engineering tools needs to be sharpened for analyzing structures under the action of these forces. Earthquake loads are to be carefully modeled so as to assess the real behavior of structure with a clear understanding that damage is expected but it should be regulated. In this context time history and response spectra analysis which is an iterative procedure shall be looked upon as an alternative for the orthodox analysis procedure.

Population explosion has made high-rises the order of the day as it is only logical solution and way of accommodating growing population within the boundaries of cities. It is needless to emphasis that tall buildings are prone to larger movement and damages than low rise structures during earthquakes and as the number of people occupying in high rise building at any given time is far greater so also the risk of collateral damage. Apart from ensuring structural safety during earthquakes high rise are giving engineer another cause of concern that is mitigation of wind induced vibrations that cause occupant discomfort. Excessive floor displacements and accelerations which are caused by relatively frequent strong ground motions can render building unserviceable for reasons for occupant discomfort. The effect is more pronounced in tall and slender buildings and for buildings to qualify for serviceability. The dynamic response of structures to earthquakes needs to be reduced.

In general, the structural system of building is a complex three dimensional assemblage of various combinations of interconnected structural elements. The primary function of structural system is to carry dynamic and static loads, wind loads, external or internal explosion and impact loads. A variety of factors has to be considered in the process of selecting most suitable structural system for high rise building. The selection is complicated process, and no simple clear cut process available. The design team must use every available means, such as imagination previous experience, and relevant literature to arrive at the best possible solution in each particular case. Although present day engineering

computer technology allows for precise analysis and design of different systems of high rise building, it does not provide readily insight for choosing among alternative of these systems to arrive at the best overall design.

II. RELATED WORK

R.Tremblay, M.H. Archmambault, A. Filiatrault (2003) describes an experimental study on the seismic performance of concentrically braced steel frames made with cold-formed rectangular tubular bracing members. A total of 24quasistatic cyclic tests were performed on full size X bracing and single diagonal bracing systems. Two loading sequences were considered: a symmetrical stepwise increasing deformation sequence and a displacement history obtained from nonlinear dynamic analyses of typical braced steel frames. All specimens buckled out-of the plane of the frame and the tests were interrupted when fracture of the braces occurred in the region of highest curvature. For X bracing, the results clearly show that the effective length of the braces can be used to determine their compression strength and to characterize their hysteretic response, including energy dissipation capability. Simplified models are proposed to predict the out-of- plane deformation of the braces as a function of the ductility level. These models are then used to develop an empirical expression to assess the inelastic deformation capacity before fracture of bracing members made of rectangular hollow sections.

Brace slenderness ratio can be reduced by adopting an X bracing configuration, it is shown that tension acting bracing can provide an efficient support at the brace intersection point for compression bracing ($k=0.5$). Rectangular hallow section are very effective in compression and their use in X bracing forms an efficient means of resisting lateral seismic load. Cem Topkaya, Can Ozan Kurban. (2008) explains about Design specifications provide empirical formula to estimate fundamental natural period of system. In this study a class of steel plate shears walls that has uniform properties through their height was considered. The fundamental time period of these class of structures were determined using three dimensional geometrically linear finite element analysis and compared with estimation provided by seismic design specifications. Comparison reveals that estimations using approximate formula can lead to unsatisfactory results. Based on these observations a simple hand method has been developed to predict the fundamental period of shear walls. Kyoung Sun Moon.(2011) gives information Tall buildings are built with an abundant amount of resources because of their enormous scale. This paper presents sustainable structural engineering strategies for tall buildings, which will lead to the construction of tall buildings with less amount of structural material to meet design requirements. Selecting a particular structural system for tall building design involves many complex factors such as availability of resources, architectural aesthetics, spatial organizations and structural efficiency.

III. METHODOLOGY

The main objective of applying lateral force resisting systems to tall building is to increase the stiffness when building is subjected to lateral loads and restrict performance criteria's to the specified limit by IS Codes. For this purpose Response spectra and linear time history analysis is used to evaluate performance of the building. The modeling and analysis is done through ETAB 14 software.

Description of Structure:

The building considered for analysis is a G+75 story tube in tube structure composite building designed using Indian codes IS 456-2000 and 875 (I & II)-2002. The plan area of building is 40 x 60m with 4.2m height of each typical story (excluding bottom and top story which are 6m height). It consists of 8 bays of 5 m. each in X-direction and 12 bays of 5 m. each in Y-direction. Material properties are assumed to be 25 and 60MPa for the concrete compressive strength. The labels of beam and column along with the frame dimensions are shown in Table

Assumption:

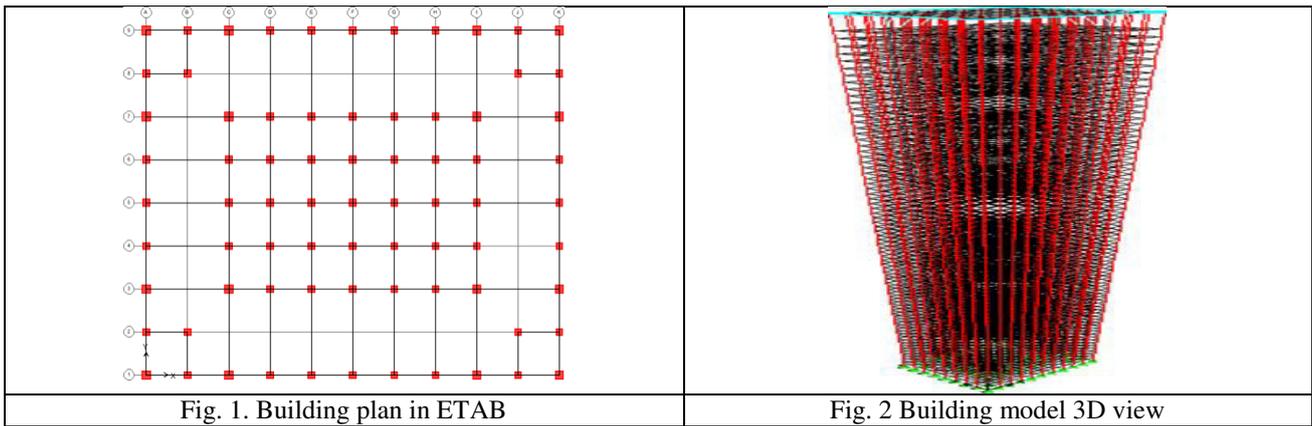
- 1.The material is homogeneous, isotropic.
- 2.All columns supports are considered as fixed at the foundation.
- 3.Tensile strength of concrete is ignored in sections subjected to bending.
- 4.The super structure is analyzed independently from foundation and soil medium, on the assumptions that foundations are fixed.
- 5.The maximum target displacement of the structure is calculated in accordance with the guidelines given by IS Code for maximum roof level lateral displacement and drift.

6.The building is designed by according to I.S. 456:2000 for Dead Load and Live load.

Sectional Properties of Elements:

Table 1. Sectional properties

Member(Columns)	Size in mm.
1 st to 25 th (outer tube)	1200 x 1200
1 st to 25 th (inner)	1000 x 1000
25 th to 50 th (outer tube)	1000 x 1000
25 th to 50 th (inner)	800 x 800
50 th to 75 th (outer tube)	800 x 800
50 th to 75 th (inner)	600 X 600
Exterior Beams (I Section)	800X300X32
Interior Beams (I Section)	ISMB 500



Loads Considered:

The following loads were considered for the analysis of building. The loads are in accordance with I.S. 875 (Part-I, II).

•Gravity Loads:

The intensity of dead load and live load at various floor levels and roof level considered in the study are listed below:

•Dead Load:

Self-weight of slab (150 mm thick) = $25 \times 0.15 \times 1.0 = 3.75$ kN/sq.m.

Total Dead load on floor = 3.75 kN/sq.m

•Live Load:

Total Live load on floor = $5.0 \times 1.0 = 5.0$ kN/m.

PERFORMANCE CRITERIA:

For a normal building there are mainly two performance criteria’s maximum displacement and drift. But in case of high rise buildings due slenderness of building acceleration is also important performance criteria. If acceleration goes above comfort level, building will be unserviceable.

• Displacement:

According to IS 456 lateral deflection at the top of building should not greater than $H/500$. Where, H is total height of structure.

Max displacement = 0.6432 m

• Drift:

According to IS 1893 the story drift in any story due to minimum specified design lateral force shall not exceed 0.004 times story height

Max drift = 16.8 mm

- Acceleration:

Any Indian code does not give detailed criteria about maximum acceleration level in building. According to research papers human beings can sense acceleration above 0.1 m/s² and 0.1 to 0.2 is perceptible. At levels 0.4 to 0.5 humans faces difficulty to walk on floor. Humans can sustain acceleration up to 0.7 m/s² and above this level objects in the building starts falling.

RESPONSE SPECTRA ANALYSIS USING ETAB-14:

After the design is complete the model is unlocked and response spectra analysis is performed to check the performance of the structure.

The following steps are included in the response spectra analysis. Steps 1 to 4 are to create the computer model, step 5 runs the analysis.

Create grid lines in X and Y direction as per plan and column positions from grid option. Specify number of stories and story height from edit story data option. Define properties of various materials like steel and concrete such as weight per unit volume, modulus of elasticity poisons ratio etc.

1. Steel or concrete various types of sections for beam and columns are defined.
2. Create the basic computer model (without the response spectra data). The graphical interface of ETAB14 makes this quick and easy task. Assigned sectional properties & applies all the gravity loads i.e. Dead load and Live load on the structure.
3. Define the maximum target lateral roof displacement for the specific level of structural performance and allowable drift by applying IS 456 and IS 1893 considerations and the damping for specific structure.
4. Run the basic response spectra analysis.

TIME HISTORY ANALYSIS:

As described earlier first three steps are same like response spectra analysis. Difference comes in assigning time history acceleration data to the structures.

1. Define properties of various materials like steel and concrete such as weight per unit volume, modulus of elasticity poisons ratio etc.
2. Create the basic computer model (without the response spectra data). The graphical interface of ETAB14 makes this quick and easy task. Assigned sectional properties & applies all the gravity loads i.e. Dead load and Live load on the structure.
3. Define the maximum target lateral roof displacement for the specific level of structural performance and allowable drift by applying IS 456 and IS 1893 considerations.

fig. 5.7 Defining time history function

4. After creating model time history data file is assigned to the model. File contains number of time steps and acceleration value in each time step. After application of this file ETAB converts all values in to time history graph as shown in Figure

5. After assigning time history data, apply this force in two perpendicular directions X and Y. If model contains any member in angle with X or Y direction apply force in that direction also

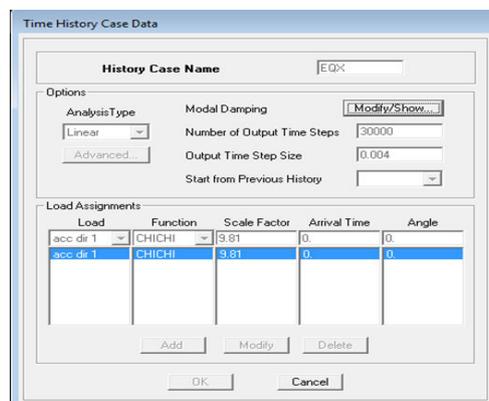


fig.3. Application of time history

- Acceleration Time History Data:

For the time history analysis of present building model, acceleration time history data for past three major earthquakes are considered, two of which occurred in India. Following is the description of earthquake data considered with respect to location and other details.

1) Bhuj Earthquake (January 2001):

The earthquake occurred on January 26, 2001 at Kachh region, Gujarat, with magnitude of 7.0. This event is recorded at 1 accelerograph station at Ahmadabad. Following are details of earthquake:

- Origin Time – 08:46:42.9 IST
- Epicenter – 23.400N, 70.280E
- Focal Depth - 25 km

Three time history data files are available with details, out of two horizontal time history data maximum PGA i.e. peak ground acceleration data is applied to both lateral and transverse direction of the building. The total acceleration time history data available is of 26706 acceleration points at 0.005 interval i.e. of approximate 133 second's earthquake. To reduce the computational efforts this data is reduced and 25 sec. data near to PGA is considered for the analysis.

2) North East Earthquake (6 August 1988):

The earthquake occurred on August 6, 1988 at India-Bangladesh border region, with magnitude of 6.8. This event is recorded at 1 accelerograph station at Berlongfer. Following are details of earthquake:

- Origin Time - 6:07 IST
- Epicenter - 25.15oN, 95.13oE
- Focal Depth - 91 km

3) Chi-Chi Earthquake (6 August 1988):

The earthquake occurred on September 21, 1999 at central Taiwan region, with magnitude of 7.3. This event is recorded at 1 accelerograph station at Berlongfer. Following are details of earthquake:

- Origin Time - 1:47 am
- Epicenter - 23.77°N, 120.98°E
- Focal Depth – 9.2 km

In all earthquakes out of three data, data having maximum PGA was applied in longitudinal and transverse direction of building.

Applying above three ground acceleration earthquake data time-history analysis was carried out and response spectra analysis also done for normal building and after application of bracing system and steel plate shear walls. Various response quantities output data like displacements drift and acceleration was collected.

IV. EXPERIMENTAL RESULTS

The present chapter describes the results of various analysis carried out. The present chapter is divided mainly into three parts depending up on various performance criteria's. The first part describes results of displacement. In second part acceleration and third part shows results of drift.

- DISPLACEMENTS:

The detail discussion about performance criteria is carried out in the chapter 5. As described in the chapter 5, normal building model is considered for initial analysis, and to the same building bracing system and steel plates were applied. The present section describes the outputs of all three model analyses.

Response Spectra Analysis:

Response Spectra analysis of all three models was carried out as per discussion in chapter 5. The output shows the effect of lateral force resisting systems on building displacement. This variation is observed for normal, bracing system and steel plate shear walls. The following figures describe the pattern of displacement variation for building.

Table 2 Displacement comparison of response spectra analysis

RESPONSE SPECTRA						
	NORMAL	BRACING	SPSW	REDUCTION NOR & BRC	REDUCTION NOR & SPSW	DIFFERENCE NOR & SPSW
Max-X	0.872	0.5804	0.5433	33.44%	37.69%	6.39%
Min-X	0.8937	0.6019	0.5653	32.65%	36.74%	6.08%
Max-Y	1.0823	0.6309	0.5990	41.70%	44.65%	5.06%
Min-Y	1.0454	0.6031	0.5719	42.30%	45.29%	5.17%

The table above shows displacement values of all three models for response spectra analysis and percentage reduction in displacement after application of bracing systems and steel plate shear walls. Last column shows percentage difference between bracing system and steel plate shear walls.

• Time History Analysis:

Time history analysis of all three models was carried out as per discussion in chapter 5, for three different earthquake ground accelerations. The output shows the effect of lateral force resisting systems on building displacement. This variation is observed for normal, bracing system and steel plate shear walls. The following figures describe the pattern of displacement variation for building.

Table 3 Displacement comparison of Bhuj earthquake

BHUJ EARTHQUAKE						
	NORMAL	BRACING	SPSW	REDUCTION NOR & BRC	REDUCTION NOR & SPSW	DIFFERENCE NOR & SPSW
Max-X	0.7189	0.5294	0.4678	26.36%	34.92%	11.64%
Min-X	0.7362	0.5484	0.4859	25.51%	34.00%	11.40%
Max-Y	1.059	0.5838	0.5289	44.87%	50.06%	9.40%
Min-Y	1.034	0.5582	0.5049	46.01%	51.17%	9.55%

Table 4 Displacement comparison of North East earthquake.

NORTH EAST EARHQUAKE						
	NORMAL	BRACING	SPSW	REDUCTION NOR & BRC	REDUCTION NOR & SPSW	DIFFERENCE NOR & SPSW
Max-X	0.7191	0.5533	0.4705	23.06%	34.57%	14.96%
Min-X	0.7364	0.5724	0.4887	22.27%	33.64%	14.62%
Max-Y	1.0167	0.6273	0.4889	38.30%	51.91%	22.06%
Min-Y	0.991	0.6018	0.4649	39.27%	53.08%	22.74%

The table above shows displacement values of all three models for North East earthquake and percentage reduction in displacement after application of bracing systems and steel plate shear walls. Last column shows percentage difference between bracing system and steel plate shear walls.

• Chi-Chi Earthquake:

Following table and diagrams shows displacement results for Chi-Chi earthquake for normal structure and after application of bracing system and steel plate shear walls

Table 5. Displacement comparison of Chi-Chi earthquake

CHI-CHI EARTHQUAKE						
	NORMAL	BRACING	SPSW	REDUCTION NOR & BRC	REDUCTION NOR & SPSW	DIFFERENCE NOR & SPSW
Max-X	0.5179	0.4545	0.4067	12.24%	21.47%	10.52%
Min-X	0.5399	0.4754	0.4267	11.95%	20.97%	10.24%
Max-Y	0.5719	0.493	0.4364	13.80%	13.69%	11.48%
Min-Y	0.5411	0.4629	0.4103	14.45%	24.17%	11.36%

• ACCELERATION:

The detail discussion about performance criteria is carried out in the chapter 5. As described in the chapter 5, normal building model is considered for initial analysis, and to the same building bracing system and steel plates were applied. The present section describes the outputs acceleration results of all three model analyses. Table below shows maximum acceleration results of all three models in X and Y direction when earthquake force was applied in both direction.

Table 6 Acceleration comparison of Bhuj earthquake

BHUIJ EARTHQUAKE								
	EQX				EQY			
	Acc-X		Acc-Y		Acc-X		Acc-Y	
	Max-X	Min-X	Max-Y	Min-Y	Max-X	Min-X	Max-Y	Min-Y
NOR	0.6031	0.6312	0.9449	0.9503	0.0594	0.0501	0.9709	0.8660
BRC	0.4769	0.4114	0.1368	0.1452	0.1721	0.1770	0.5060	0.3936
SPSW	0.5194	0.5013	0.2375	0.1970	0.1481	0.1414	0.4711	0.4802

Diagrams below shows acceleration comparison of normal model and after application of bracing and steel plate shear walls. In following diagrams ground acceleration applied in one direction results in that direction are shown only, because other results are not significant. Whereas above table show all the results.

Table 7 Acceleration comparison of North East earthquake

NORTH EAST EARETHQUAKE								
	EQX				EQY			
	Acc-X		Acc-Y		Acc-X		Acc-Y	
	Max-X	Min-X	Max-Y	Min-Y	Max-X	Min-X	Max-Y	Min-Y
NOR	0.7402	0.4939	1.4539	1.4906	0.0809	0.1094	1.0858	0.9319
BRC	0.6687	0.5043	0.3077	0.2998	0.2753	0.2607	0.6447	0.5262
SPSW	0.6252	0.5170	0.4713	0.4108	0.3351	0.3239	.6898	0.6290

Table above shows acceleration comparison for North East earthquake for all three models, whereas table below shows acceleration comparison for Chi-Chi earthquake.

Table 8 Acceleration comparison of Chi-Chi earthquake

CHI-CHI EARTHQUAKE								
	EQX				EQY			
	Acc-X		Acc-Y		Acc-X		Acc-Y	
	Max-X	Min-X	Max-Y	Min-Y	Max-X	Min-X	Max-Y	Min-Y

NOR	0.6828	0.5442	0.1369	0.1274	0.0444	0.0445	0.5163	0.6086
BRC	0.6485	0.6000	0.1112	0.1275	0.1034	0.0879	0.5580	0.4278
SPSW	0.6572	0.5124	0.0982	0.0916	0.1547	0.1855	0.5028	0.5624

• DRIFT:

The detail discussion about performance criteria is carried out in the chapter 5. As described in the chapter 5, normal building model is considered for initial analysis, and to the same building bracing system and steel plates were applied. The present section describes the outputs drift results of all three model analyses.

•Response Spectra Analysis:

Response Spectra analysis of all three models was carried out as per discussion in chapter 5. The output shows the effect of lateral force resisting systems on building drift. This variation is observed for normal, bracing system and steel plate shear walls. The following figures describe the pattern of drift variation for building.

•Time History Analysis:

Time history analysis of all three models was carried out as per discussion in chapter 5, for three different earthquake ground accelerations. The output shows the effect of lateral force resisting systems on building drift. This variation is observed for normal, bracing system and steel plate shear walls. The following figures describe the pattern of drift variation for building.

Table 9 X-Drift comparison for all earthquakes

	RS EQ	BHUJ EQ	NE EQ	CHI-CHIEQ
	Max-X	Max-X	Max-X	Max-X
NORMAL	0.003783	0.004007	0.00417	0.002211
BRC	0.002799	0.003739	0.002927	0.002512
SPSW	0.002639	0.003004	0.002672	0.00189

Table 10 Y-Drift comparison for all earthquakes

	RS EQ	BHUJ EQ	NE EQ	CHI CHI EQ
	Max-Y	Max-Y	Max-Y	Max-Y
NORMAL	0.004371	0.005352	0.004947	0.002432
BRC	0.002874	0.003623	0.002847	0.002064
SPSW	0.002711	0.002976	0.002564	0.002020

The bar chart above shows comparison of maximum story drift of normal building and after application of bracing system and steel plate shear walls in X and Y direction. In which red bar shows drift of normal structure, blue bar shows drift of building after application of bracing and green bar shows drift of building after application of steel plate shear walls.

Above results shows effect of lateral force resisting systems for tall buildings. It is seen that bracing system reduces displacements by 12 to 46 percent, whereas steel plate shear walls reduces displacement by 21 to 54 percent. Percentage difference between bracing system and SPSW is 5 to 23. Both systems brings acceleration below human tolerance level (0.7 m/s²), but bracing is more effective to reduce bracing. SPSW and bracing both reduces story drift, in which SPSW are more effective in reducing drift.

V. CONCLUSION

Numerical study of G+75 story normal building and after application of bracing systems and steel plate shear walls is carried out under earthquake load. The comparison of the response quantities and performance criteria is made with those obtained with uncontrolled state to observe effect of lateral force resisting system to reduce the response to

earthquake excitations. Additionally an exhaustive parametric study is carried out to critically examine the performance of the building. From the trends of the numerical results of the present study, the following conclusions may be drawn:

- 1.SPSW and bracing as a lateral force resisting systems gives superior performance against displacement and drift as compared to uncontrolled state.
- 2.SPSW is most efficient to control displacement and drift compared to bracing system.
- 3.After installing SPSW and bracing the response in terms of acceleration is brought down within human tolerance level.
- 4.Bracing system gives superior performance against acceleration as compared to SPSW.
- 5.Displacement reduces by 5 to 22% after application of SPSW when compared to bracing system.
- 6.SPSW is much lighter than RC shear wall, resulting less seismic mass.
- 7.Bracing system is lighter than SPSW, contributing less seismic mass compared to SPSW.

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