Stiffness Degradation of High Rise Structures

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Abstract:**Most Seismic Design Codes do not precise effective stiffness to be used in seismic analysis for structures of reinforced concrete elements, therefore uncracked section properties are usually considered in computing structural stiffness. But, uncracked stiffness will never be fully recovered during or after seismic response. 3 Dimensional Dynamic Analysis which considers the real and accidental torsional effects are performed using ETABS for 35 story structure with various lateral load resisting systems to study the effect of stiffness degradation of structure. The result findings exhibits that the dual system was the most efficient lateral load resisting system based on deflection criterion, as they yielded the least values of lateral displacements and inter-story drifts. Cracking found to be more impact over moment resisting frames compared to the Shear wall systems.**

Keywords: Stiffness degradation, response spectrum analysis; effective structural system, time period and mode shapes

I. INTRODUCTION

In buildings structures, the flexural stiffness reduction of beams and columns due to concrete cracking plays an important role in the nonlinear load-deformation response of reinforced concrete structures under service loads. The concrete cracking amplifies the lateral deflection of the building. The excessive lateral deflection may cause out of order of nonstructural components. Most world seismic standards do not establish effective stiffness for seismic analysis. But few researchers and some of the international codes suggested considering the effective stiffness. Some design codes recognize the influence of cracking. They consider stiffness of the cracked section EIe proportional to the stiffness of the gross uncracked section EIg, specifying reduction factors to be applied to the stiffness of the uncracked cross section. But Indian code is silent on the introduction of cracking effects for the global lateral response.

The present work has been carried out to study the quantitative effect of cracking and deflections amplification on the response of RCC building. The buildings with various lateral load resisting systems are analyzed. The lateral loads are generated as per the Indian code IS 1893 (Part 1): 2002. The ACI 318M-08 guidelines for effective flexural rigidity shown in Table 1 are followed to include the concrete cracking in absence of Indian standard recommendations for cracking.

Table 1
Reduction Factors

Element	Stiffness Considered
Slabs	0.25 Ig
Beams	0.35 Ig
Columns	0.70 Ig
Walls	0.70 Ig

In general, it is difficult to evaluate all aspects of the complete seismic behavior of structures due to the complexity and number of parameters involved. However this study is focused on the overall global seismic behavior and the economic dimensions that achieve the saving in concrete and steel amounts thus achieve lower cost of high-rise RC buildings in order to provide both the seismic engineering research field and industry with a methodology for analysis & assessment which may be used reliably & conservatively to estimate global seismic behavior.

II. LITERATURE REVIEW

To investigate current mathematical and analytical work which has been carried out with regard to lateral load resisting structures, a literature review is under taken and few of them are explained.

Haijuan Duan et al (2012) studied and investigated the seismic performance of a multi-story reinforced concrete frame building designed according to the provisions of the current Chinese seismic code (GB50011-2010). He has evaluated the frame structure using both a nonlinear static (push-over) analysis and nonlinear dynamic time-history analysis and found that the response intended by the code and satisfies the inter-story drift and maximum plastic rotation limits suggested by ASCE/SEI 41-06. Yong Lu et al (2001) studied and investigated regarding the selection of adequate ductility levels and the corresponding seismic force reduction factor for a specific class of structures, whereas the detailing requirements to ensure the desired ductility continue to be refined. In his investigation, three simple frames were designed for different ductility levels according to EC8 and confirmed the s performance was observed in the frame designed for medium ductility. Hyun Su Kim et al (2005) studied framed structure with shear wall for resisting horizontal forces effectively. In his study, Static and dynamic analyses of example structures with various types of opening were performed to verify the efficiency and accuracy of the proposed method and he was confirmed that the proposed method uses the super elements and fictitious beams can provide results with outstanding accuracy requiring significantly reduced computational time and memory. Thomas Paulay (1983) has given brief review of a deterministic design philosophy with respect to earthquake resisting ductile structures for reinforced concrete buildings and highlighted the capacity design procedures relevant to beams, columns and shear walls.

III. PROBLEM DESCRIPTION

This paper deals with 3 dimensional seismic analysis of typical 35 story building used for office functionalities to be constructed in critical seismic regions of India to assess the relative effectiveness of various lateral load resisting systems. Bhuj (Gujarat) woke up to the deadliest earthquake in India's recorded history with highest PGA in Indian seismic zone map of 0.36 is taken in the present research. Three different structural systems are taken in the study, namely Special moment resisting systems, Shear wall systems and Dual systems. Ductile systems are taken in the study, where inelastic analysis procedures effectively account for several sources of force reduction. Response Spectrum analysis of IS 1893 (Part 1):2002 is performed to analysis and design the structures. The ACI 318M-08 guidelines for effective flexural rigidity are followed to include the concrete cracking in absence of Indian standard recommendations for cracking. 3Dimensional Dynamic Analysis which considers the real and accidental torsional effects are performed using ETABS to determine the effective structural system, which ensures the performance and the economy.

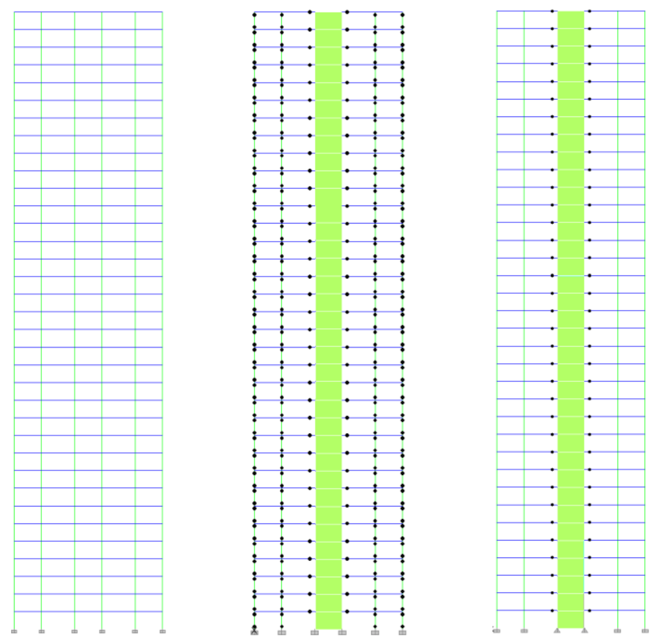
Table 2
Members dimensions of 35 Story building

STORY	SEISMIC ZONE	COLUMN (mm)		
		SMRF	SW	DUAL
35	Z III	900x900	900x900	900x900
	Z IV	950x950	900x900	950x950
	Z V	1000x1000	900x900	1000x1000

STORY	SEISMIC ZONE	BEAM (mm)		
		SMRF	SW	DUAL
35	Z III	400x400	350x400	400x400
	Z IV	400x500	350x400	400x500
	Z V	450x600	350x400	450x600

STORY	SEISMIC ZONE	WALL (mm)	
		SW	DUAL
35	Z III	900-200	300-200
	Z IV	1000-200	300-200
	Z V	1200-200	400-200

The base dimensions of the building are 39x25m. The total height of building considered in the research study is 112m. The structural system undertaken in the present study consists of conventional beam, column and slab system with lift walls and walls around periphery of the building acting as shear wall. Lateral Stability is provided by frames consisting of beams and columns in SMRF system. Both frames and shear walls contribute to the lateral stability in Dual systems, but 100% lateral force is considered to be resisted by walls in shear wall system. The dimensions of the structural members required based on this research study are given in Table 2 for 35 story structures. Fig. 1(a-c) shows the analytical model 35 Story SMRF, SW System and DUAL Systems respectively.



a) SMRF (b) Shear Wall (c) DUAL System

Fig. 1. 35 Story Analytical Models

IV. ANALYTICAL RESULTS

Analytical result is explained for 35 Story SMRF system which is assumed to be located in Bhuj (Gujarat, India) with peak ground acceleration of 0.36. Time period of the structure and modal participating mass ratios are displayed in Table 3. It is found that the first and second mode is in translation mode. First mode is in Y direction translation and excites 76.73% of the total mass. Second mode is in X direction translation and excites 77.84% of the total mass. It is found that 7th and 6th modes are satisfied with more than 90% of total mass participated by acceleration in X and Y direction respectively.

Table 3
Time Period and modal participating mass ratios

Mode	Period (in sec)	% of mass in X dir.	% of mass in Y dir.	Sum of % of mass in X dir.	Sum of % of mass in Y dir.
1	3.58	0.00	76.73	0.00	76.73
2	3.50	77.84	0.00	77.84	76.73
3	3.19	0.19	0.00	78.03	76.73
4	1.15	0.00	11.68	78.03	88.41
5	1.14	10.62	0.00	88.64	88.41
6	0.64	0.00	3.59	88.65	92.01
7	0.55	6.43	0.02	95.08	92.03
8	0.43	0.06	2.27	95.14	94.30
9	0.25	0.02	1.01	95.16	95.30
10	0.25	0.02	1.37	95.17	96.67
11	0.19	0.49	1.14	95.66	97.81
12	0.08	0.04	0.01	95.70	97.82

Fig. 2 shows the Time period Vs Modes for 35 Story structures of SMRF, SW and DUAL System for various zones.

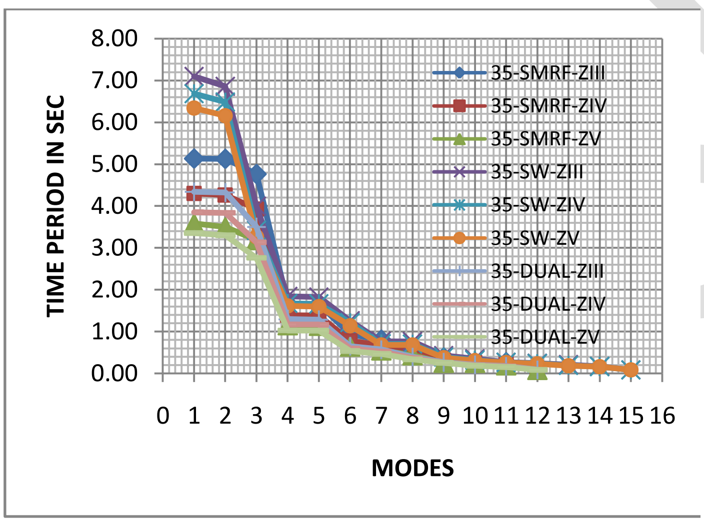


Fig. 2. Time period Vs Modes for 35 Story structures

As per Table 7 of IS 1893 (Part 1): 2002, the moment resisting frames are designed to independently resist at least 25 percent of the design seismic base shear for dual systems. It is found from dynamic analysis that the column attracts 20% of shear, where these values are less than 25% of design seismic base shear. The moment resisting frames in DUAL system are designed for 1.25 times more force than actual force to satisfy the codal provisions.

Fig. 3 shows the 35-Story Vs Seismic drift due to Spectral X direction force for various Structures with Uncracked and Cracked Properties. Fig. 4 shows the 35-Story Vs displacement due to Seismic Y direction for various structural systems with cracked properties.

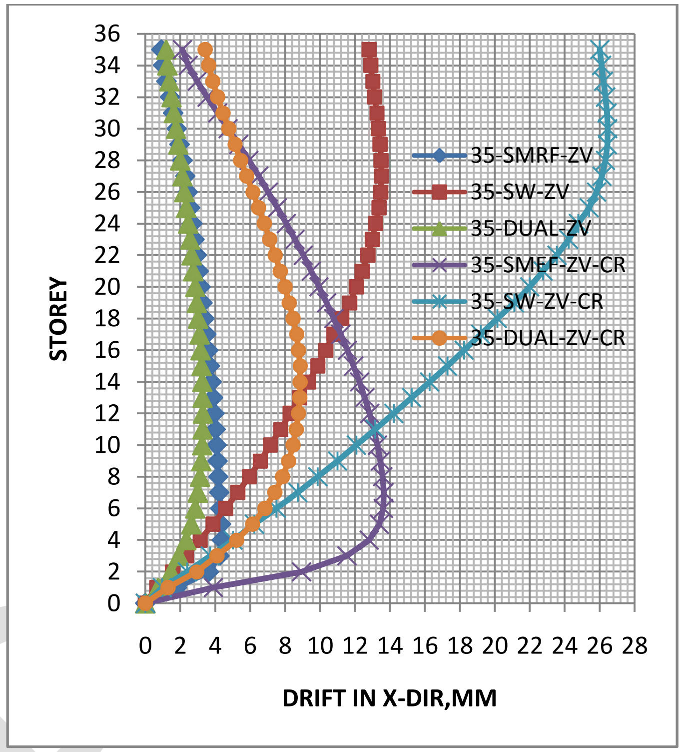


Fig. 3. Story Vs Seismic Drift due to Spectral X direction force

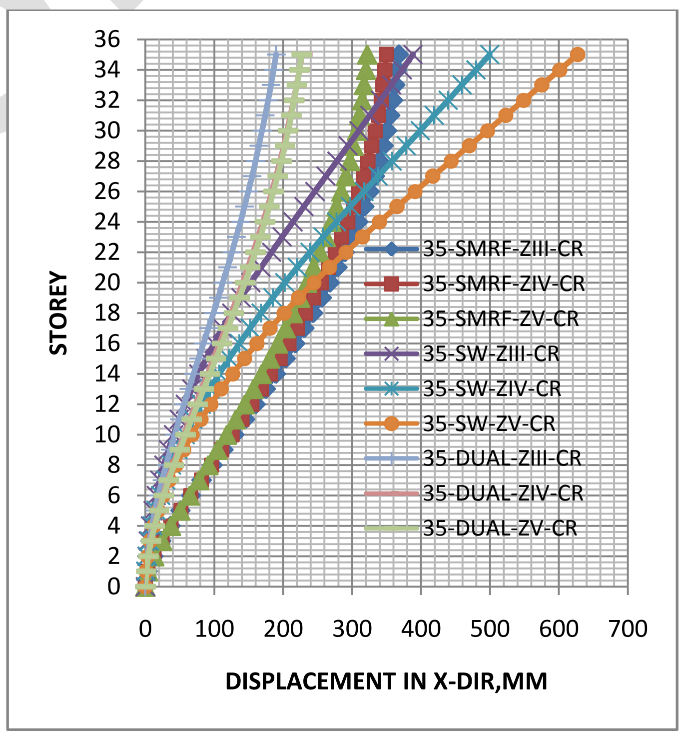


Fig. 4. Story Vs Seismic Displacement due to Spectral Y direction force

V. DISCUSSION OF RESULTS

- It is found that the translation mode occurs in first and second mode in all structural system considered in the present study. In SMRF System, almost 80% of mass participated in initial mode, whereas 70% and 60% of mass excited during initial mode in Dual and Shear wall systems respectively.
- It is found that the frames are attracted only 20% of shear in Dual Systems. So the frames are designed taking minimum 25% of total base shear in all dual systems.
- Wall systems execute tremendous stiffness at the lower levels of the building, while moment frames typically restrain considerable deformations and provide significant energy dissipation under inelastic deformations at the upper levels. But in cracked analysis, it is found that the lateral displacements are relatively high in SMRF systems compared to wall system at higher levels, since the cracking influence much impact on frames rather than stiff walls.
- It is found that the Dual/Shear Wall systems attracts relatively higher story shear in the lower stories and vice versa in upper stories compared to SMRF system.
- In cracked analysis the buildings are undergoing large displacement due to decrease in stiffness and increase in the natural fundamental period.
- Cracked analysis yield large displacement compare to uncracked analysis. Generally it is found that, 2.2 to 3 times, 2.0 to 2.4 times and 1.4 to 2 times displacements are higher in cracked analysis compared to uncracked analysis at roof levels for SMRF, DUAL and SW Systems respectively.
- There is no much variation between the cracked and uncracked analysis in terms of strength requirements and the difference is hardly 5% in material cost for vertical members.

CONCLUSIONS

Form the study it is concluded that cracked analysis of the buildings are undergoing large displacement due to decrease in stiffness and increase in the natural fundamental period. Strength criteria is not governing in Cracked analysis, but serviceability criteria found major impact compared to uncracked analysis which leads the structural engineers to consider the flexural stiffness reduction of beams and columns due to concrete cracking. Dual system was the most efficient lateral load resisting system based on deflection criterion, as they yielded the least values of lateral displacements and inter-story drifts. The shear wall system was the most economical lateral load resisting compared to moment resisting frame and dual system, but they yielded the large values of lateral displacements in top stories.

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LIST OF NOTATION

CR	- Cracked Analysis
SMRF	-Special Moment Resisting Frame
SRSS	-Square Root of Sum of Square
SW	-Shear Wall System
Z III	-Seismic Zone III as per IS 1893 (Part 1): 2002
Z IV	-Seismic Zone IV as per IS 1893 (Part 1): 2002
Z V	-Seismic Zone V as per IS 1893 (Part 1): 2002

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