Performance Assessment of Skyscrapers Comparing Moment Capacity Ratios using Pushover Curves

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Abstract - *This* paper summarizes the research work on the comparative study of skyscrapers with different lateral load resisting systems in skyscrapers and also the effect of moment capacity ratio at beam column joint. So in the present work models are created and pushover analysis was done for the models using ETABS 2015 for increasing moment capacity ratio at beam column joint and analyzed its effect on global ductility and lateral strength. A comparative study conducted based on lateral yield displacement capacity, lateral ultimate displacement capacity and lateral strength capacity using pushover curves generated with increasing MCR from 1 to 2. Another objective is to find out which lateral load resisting system results in more stable structure.

Key Words: **pushover, Moment Capacity Ratios, lateral strength, ductility, ETABS 2015**

1. INTRODUCTION

Mankind has always been fascinated by building higher. This resulted both from the need to provide more space to the increasing urban population, as well as from the competitive urge to create a new symbol of growth and an iconic representation of the place of origin.

Tall buildings represent nowadays a new form of city planning, the so called vertical cities, which aim to accommodate residential, office or hotel space or a combination of them. With the highest existing building reaching 828 m (Burj Khalifa) and the Jeddah Tower setting the barrier to 1008 m upon its completion in 2019, the expected question is how tall can we build, followed by what kind of structural system would be the most efficient.

In recent days high rise buildings and tall structures are becoming more slender which increases the possibility of extreme sway compared to prior high-rise buildings. This is bringing more challenges for the engineering field to resist both lateral loads i.e., wind and earthquake loads as well as gravity loads. Earlier structures were being designed only for the gravity loads but in recent years because of increase in height and seismic zone, the engineers are taking care of lateral loads due to wind and seismic forces.

This thesis aimed at testing the efficiency of the skyscrapers with different lateral load resisting systems for tall buildings. So in the present work pushover analysis is being done for these structures using software ETABS 2015 for increasing moment capacity ratio at beam column joints and its effect on the global ductility and lateral strength of the structure is studied. To incorporate the uncertainties in material properties, a probabilistic approach is followed to observe the effect of ground motion intensity on probability of exceedence of any specific damage state for structures designed considering different moment capacity ratios (MCR) at the connections.

The main objective of this study is as follows.

1. To compare the MCR and factors affecting MCR of the following types of lateral load resisting systems by pushover analysis
   - Shear wall/core
   - Perimeter frame
   - Belt wall
   - Outrigger

   And their combinations
2. Effect of MCR on lateral yield displacement capacity, ultimate displacement capacity and lateral strength capacity of the models.
3. Effect of MCR on elastic stiffening of the structures.
4. To find out the percentage increase of dead load with change in MCR.

2. SOFTWARE USED

A. ETABS (Extended 3D (Three-Dimensional) Analysis of Building Systems).

ETABS is an ultimate software package used for linear, non-linear, static and dynamic analysis and for the design and detailing of any type of building and its components.

2. METHODOLOGY

The following steps are involved in the work.

1. Modelling of Skyscrapers with different types of lateral load resisting structures
2. Linear Static Seismic Analysis
3. Designing
4. Ultimate moment capacity of beam should be determined from the design data obtained

5. Column reinforcement in the buildings should be progressively increased to attain different column to beam moment capacity ratio (MCR) at maximum moment, at zero axial load
6. Re-modelling by adding hinges as per ATC40 and FEMA273
7. Non-linear Static Pushover Analysis for gravity loads should be done
8. Non-linear Static Pushover Analysis for lateral loads should be done
9. Generating pushover curve (Base shear vs. Roof Displacement)
10. Idealization of Pushover curve to find out yield point and maximum deformation point
11. Calculation of yield strength and maximum strength from the pushover curve
12. Assessing failure mechanism of the structure

3. MODELING

For this present study five RC building frames are modeled in ETABS software for the analysis and design. Table 1, Table 2 and Figure 1to 5 show parameters of model design with different lateral load resisting systems.

- M60 concrete
- HYSD 550 steel bars
- Beams and braces -500mmx1000mm
- Column -1500mmx1500mm
- Mega Column-3mx3m with hollow core thickness-1m
- Shear walls -1500mm
- Non lateral load resisting columns are modelled as pinned
- Floor to Floor Height-4m
- No. of storeys- 50
- Total Height of building-164m
- 40mx40m square floor plan with central opening

TABLE 1 Wind Load (As per IS 875: part III)

TYPE	ANNOTATION	VALUE	SOURCE
Basic wind speed (Trivandrum)	V_b	39 m/s	Clause 5.2
Probability factor (Design life 50 years)	k_1	1	Clause 5.2.1
Terrain, Height and Structure height factor	k_2	1.6	Clause 5.2.2
Topography factor	k_3	1	Clause 5.2.3

TABLE 2 Earthquake Load (As per IS 1893: part I)

TYPE	ANNOTATION	VALUE	SOURCE
Zone factor (Zone 3)	z	0.16	Table 2
Importance factor	I	1	Table 6
Response reduction factor	R	5	Table 7
Rock and soil site factor	SS	1	Clause 6.4.2
Live load reduction factor		0.5	Table 8

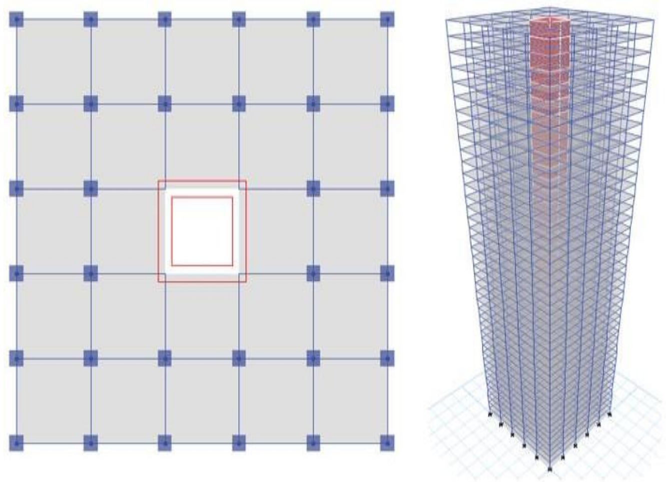

Fig. 1. Model with central core

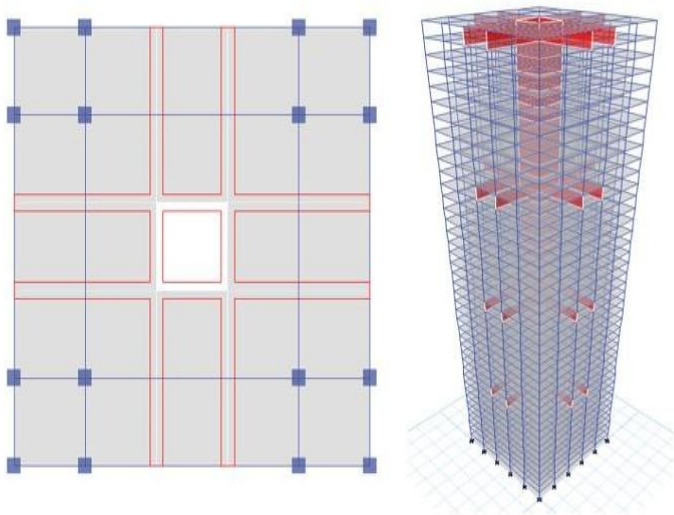

Fig. 2. Model with core and outrigger

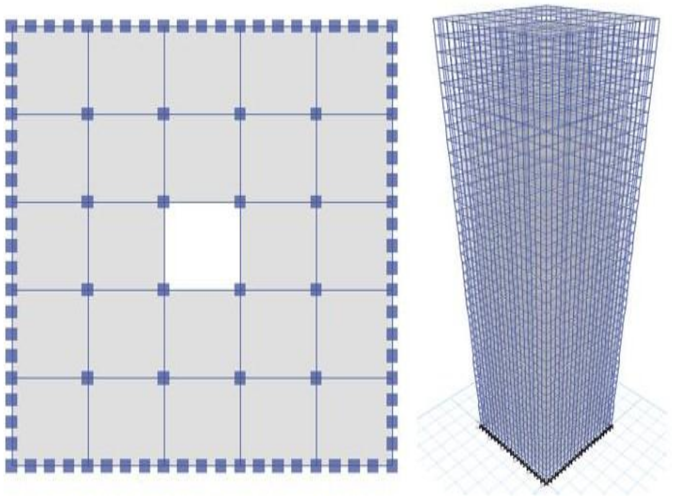

Fig. 3. Model with perimeter frame

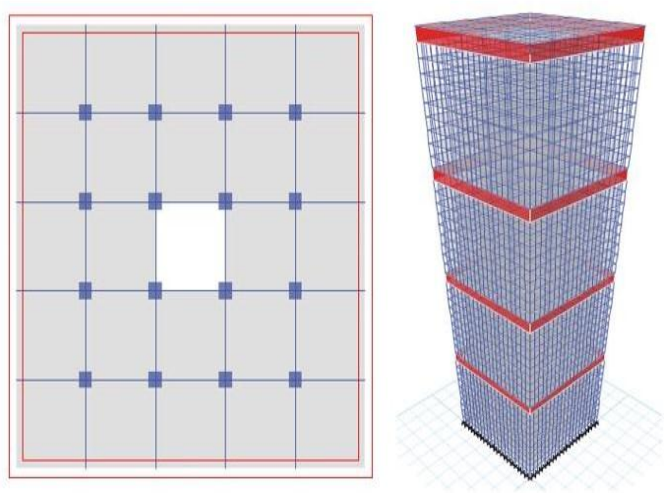

Fig. 4. Model with belt truss and perimeter frame

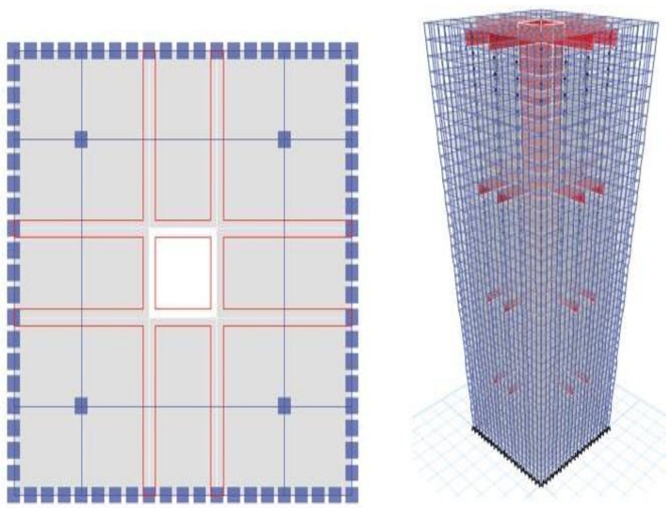

Fig. 5. Model with perimeter frame, outrigger and core

5. ANALYSIS

- **PUSHOVER ANALYSIS**

Performance based design philosophy includes the determination of two quantities for design and analysis purpose, one is seismic demand and the other is seismic capacity. Seismic demand is the effect of earthquake forces actually coming on the structure and seismic capacity is the ability of the structure to resist earthquake forces. The performance is evaluated in such a manner that capacity should be more than the demand. There are so many methods for inelastic structural analysis like linear static analysis, linear dynamic analysis, and nonlinear static and nonlinear dynamic analysis procedure.

Pushover analysis is a static nonlinear procedure in which the magnitude of the lateral load is increased monotonically maintaining a predefined distribution pattern along the height of the building. The structure is subjected to gravity loads and increasing lateral load until the target displacement is reached or the collapse state of the structure is reached. It is used to obtain a pushover or so called capacity curve from which we get the deformation capacity of the structure and describes how get it behave beyond its elastic state. This procedure is mainly used to estimate the strength and drift capacity of existing structure and the seismic demand for this structure subjected to selected earthquake.

6. RESULT AND DISCUSSION

The main output of pushover analysis is in the form of base shear versus roof displacement curve called pushover curves. Pushover curve is a type of strain curve. Yield displacement is the displacement at the end of elastic portion; ultimate displacement is the displacement at ultimate base shear portion. This capacity curve is generally constructed to represent first mode response of the structure assuming that fundamental mode of vibration is predominant. This assumption holds good for structures with fundamental period up to about one second. For more flexible building with fundamental period greater than one then effect of higher modes should be considered. The hinge properties can be calculated using the force deformation criteria for hinges developed by ATC 40 and FEMA 273 for concrete and steel have been used in pushover analysis.

Curves are based on base shear verses roof displacement for a 50 storey skyscraper with different MCR values. The curves show the elastic range followed by the full yielding of steel. Full yielding of steel (plastic hinge formation) occurs in the inelastic range indicated by the nonlinear portion of the curve. After attaining the peak base shear further increase of displacements decrease the strength of structure and leads to collapse.

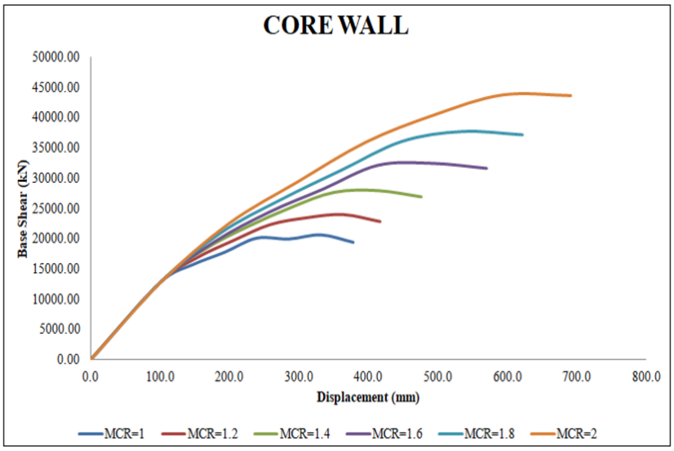

Fig. 6. Pushover curve of model with central core

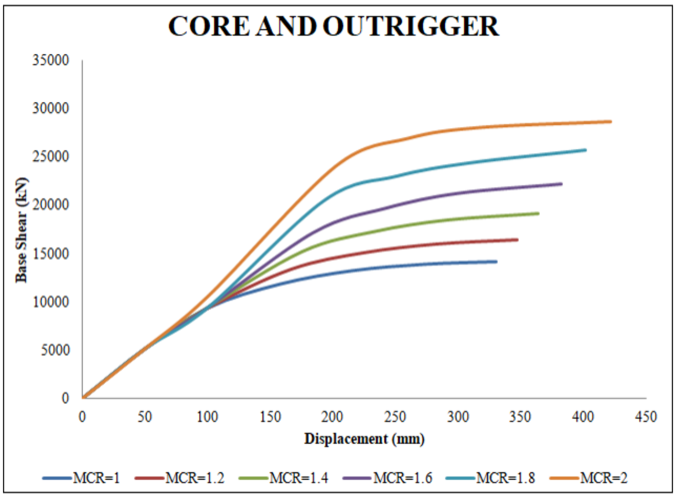

Fig. 7. Pushover curve of model with model with outrigger and core

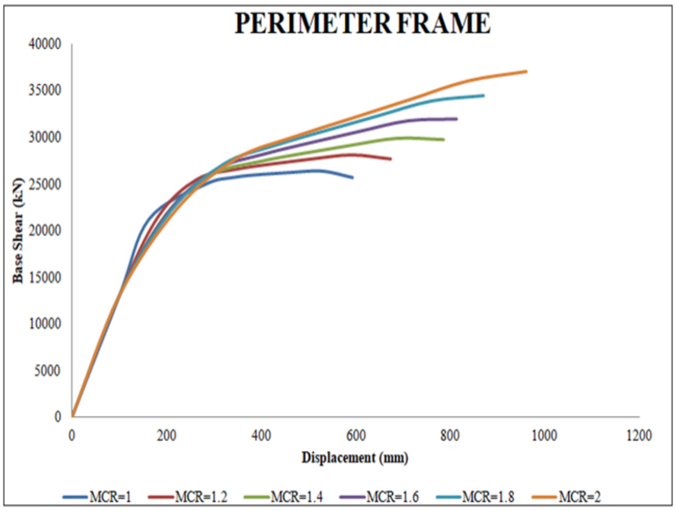

Fig. 8. Pushover curve of model with model with perimeter frame

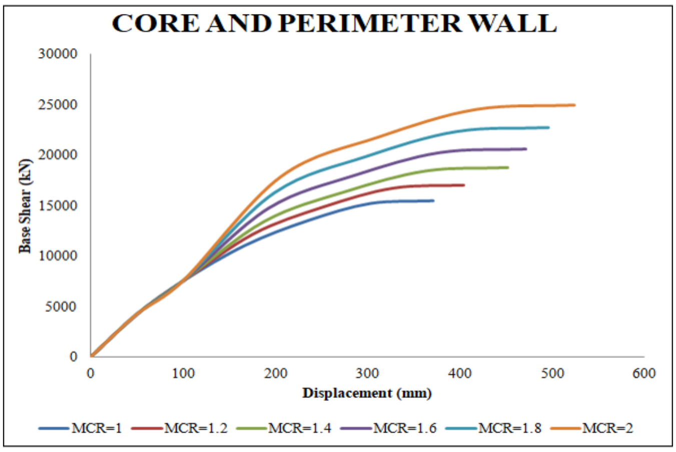

Fig. 9. Pushover curve of model with model with perimeter frame and core

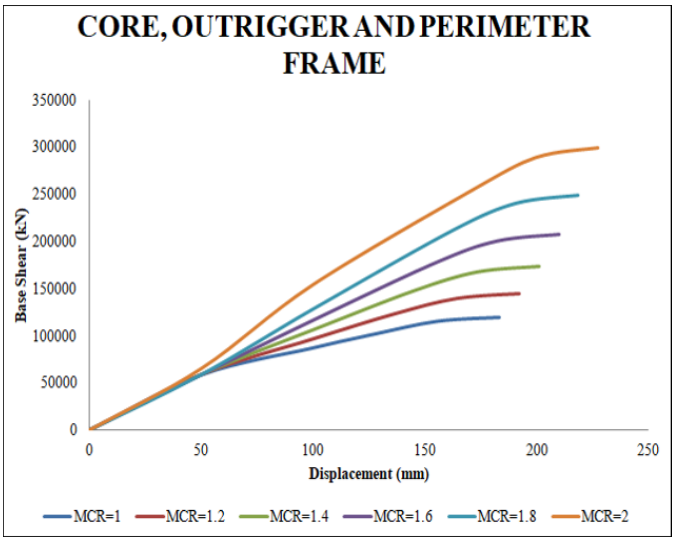

Fig. 10. Pushover curve of model with model with perimeter frame, outrigger and core

The points where sizeable number of components yield is taken as yield strength. The deformation where maximum strength degrades to 85% of peak strength is taken as maximum deformation where pushover curve shows a dropping portion after attaining peak strength. Elastic-plastic portion is considered for the idealized curves. For example, Fig.6, Model with central core, Lateral Yield displacement capacity increases by 42.3% with increasing MCR from 1.0 to 2.0.Lateral Ultimate displacement capacity increases by 63.5% with increasing MCR from 1.0 to 2.0. Lateral strength capacity increases by 27.7% with increasing MCR from 1.0 to 2.0

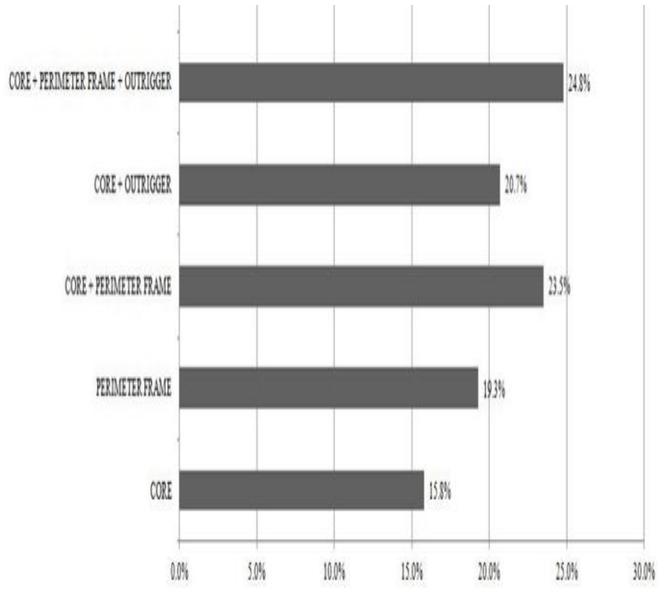

Chart-1 Percentage increase of dead load from MCR 1 to 2

7. CONCLUSIONS

From the analysis of the different load resisting patterns applied to the skyscrapers with application of different moment capacity ratios we can draw the conclusions.

- MCR doesn't affect elastic stiffening of the structures. (Initial portion Linear since Elastic Range)
- At lower MCR, the building displaces less because the concrete is actively resisting moment
- Lateral yield displacement capacity of structures increases by 20-80% with increasing MCR from 1.0 to 2.0.
- Lateral ultimate displacement capacity of structures increases by 60-70% with increasing MCR from 1.0 to 2.0.
- Lateral strength capacity of structure increases by 25- 30% with increasing MCR from 1.0 to 2.0
- Structure with Core, Outrigger and Perimeter Frame is heavier so the stability is higher, but for economic factor it is not a good option

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