Pushover Analysis of High Rise Building and Outrigger System With or Without In-Filled Walls

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Abstract - *High-rise buildings are under rapid development throughout the world which introduces new challenges to the structures. Now a days in tall buildings, lateral loads induced by wind or earthquake are met up by a system of shear walls, belt trusses, more sizes of column to increase inertia, Mechanical dampers and Outrigger beam system. But as the height of building increases we need to do some stronger system to control the lateral deflection of building. So that introduction of outrigger beams between the shear walls and external columns is often used to provide sufficient lateral stiffness to the structure. The outrigger system is commonly used one of the structural system to efficiently control the excessive deflection due to lateral loads.*

Pushover analysis is a static non-linear analysis using simplified non-linear technique to find out seismic structural deformations. It is a static analysis used to determine force-displacement relation, or to find the capacity curve, for structural element. Pushover analysis involves applying horizontal forces, in a prescribed pattern, to the structure, i.e. pushing the structure and finding the total applied shear force and lateral displacement for each case till the collapse condition. In this technique computer models of buildings are subjected to a lateral load.

The objective of this paper is to perform pushover analysis on reinforced concrete structure which are subjected to different structural systems. In which G+21 building was subjected to push in X and push in Y direction. Various cases of the structure are considered. Then the optimum location of outrigger is studied by the lateral deflection of the building. To study the effect of in-filled walls on the high rise structures equivalent strut method is used to model the walls. The analysis is done in ETABS 2016.

Key Words: Belt Truss, Core Wall, High-rise Building, In-filled Wall, Outriggers, Performance Point

1. INTRODUCTION

A. General:-

The development of tall buildings has increased at most extent nowadays. People from rural areas are migrating to cities due to the increase in job facilities and opportunities. Thus cities become densely populated and cost of land also increases which leads to the use of multi-storied building. As the height of the building increases effect of lateral forces on multi-storied building increases. Stiffness of building is big consideration when the height of the building increases.

B. Structural System

In the past years, structural members were assumed to carry only the gravity loads. Now by the advancement in structural systems we take into account the lateral forces such as wind and earthquake. Especially for tall structures, as slenderness, and flexibility increases, buildings are mostly affected from the lateral loads resulting from wind and earthquake. Hence, it is important to find the proper structural system for lateral loads resisting depending on the height of the building.

Following are some Structural systems for tall buildings
a. Rigid frame systems
b. Braced frame and shear-walled frame systems
c. Braced frame systems
d. Shear-walled frame systems
e. Outrigger systems
f. Framed-tube systems
g. Braced-tube systems
h. Bundled-tube systems

C. Outrigger structural System.

The outrigger system is mostly used as one of the structural system to effectively control the excessive lateral deflection due to lateral load. Thus For tall buildings, particularly in seismic active zone or wind load dominant, this system can be chosen. Structural form consists of a central core connected to the outer columns. A study of the optimum location of outriggers for tall concrete Buildings shows that use of outrigger in tall buildings increase stiffness and makes the structural system effective under lateral load. If the numbers of outriggers are increased the stiffness of building also increased.

The placement of outriggers increases the effective depth of the structure and improves the lateral stiffness under lateral loads. Outrigger system can also increases the inner storey drifts. The outrigger systems can be produced in any combination of steel, concrete and composite construction. Outrigger may extend up to both side of central core. Core may be located at one side of building with outrigger extending to other side column. Outrigger beams connected to the shear wall and external columns are more complicated and is understood that the performance of such systems depends on stiffness and strength of the outrigger beams.

As per Cl. No.7.11 of IS1893-2002 states the storey drift in any storey due to the minimum specified design lateral load shall not exceed 0.004 times the storey height.

According to the bureau of Indian standard –IS-875-part3 (1987) acceptable limit for top deflection in tall building for wind analysis is 1/500 of building height. Lateral drift at the top of building is one of the most important criteria for selection of structural system for tall building. However, as building increases in height, stiffness of core wall only is not sufficient to resist wind load.

The in-filled block walls in the building can also take some stiffness and contribute to the stiffness of the structure minimizing the lateral deflection of the building. Infill may also create soft stories and will cause destruction.

Following are some figures explaining the outrigger system:-

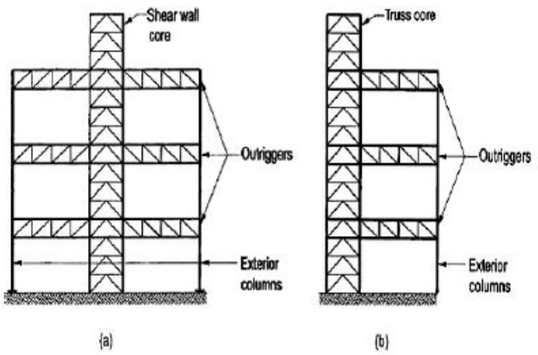

Fig.1 (a) Outrigger system with a central core (b) Outrigger system with offset core

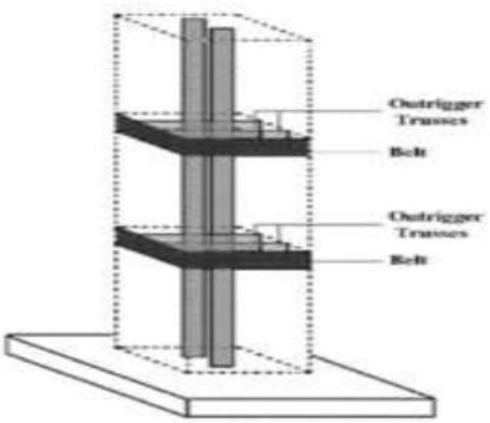

Fig. 2: Multi-Level Belt Truss and Outrigger

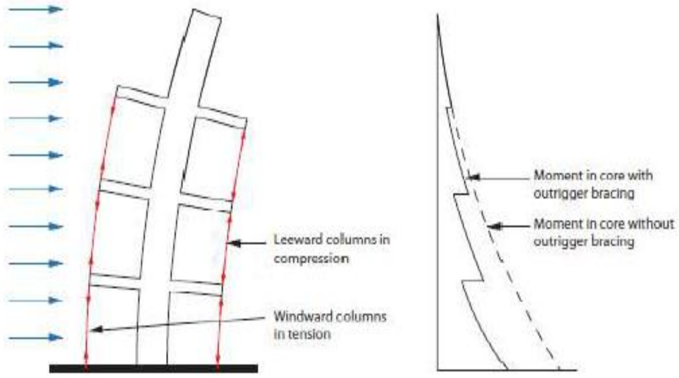

Fig. 3 Behavior of Outrigger Structural system (Retrieved from - CTBUH Technical Guide)

D. Pushover Analysis:-

The pushover analysis of structure is defined as static non-linear analysis of structure under permanent vertical load and gradually increasing lateral load. This lateral forces represents the forces of earthquake. The structure performance level is based on the roof drift or deflection due to lateral forces. The performance levels of a structural element are represented in the load versus deformation curve. The purpose of the pushover analysis is to calculate the expected performance of a structural System in earthquake ground motion.

Federal Emergency Management Agency (FEMA) and Applied Technical Council (ATC) are the two agencies which formulated and suggested the Non-linear Static Analysis or Pushover Analysis under seismic rehabilitation programs and guidelines. This included documents FEMA-356, FEMA-273 and ATC-40.

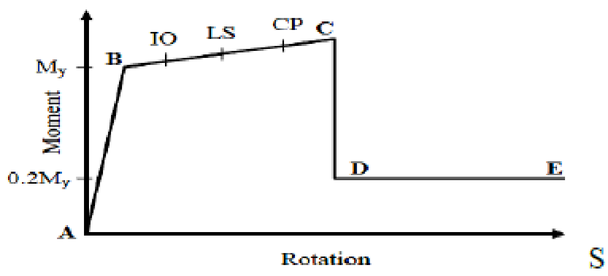

Fig .4: Performance Level of Pushover Analysis

IO-Immediate Occupancy Level

LS-Life Safety Level

CP-Collapse Prevention level

2. METHODOLOGY AND MODELING

In this paper three dimensional G+20 storey traditional beam and slab type reinforced concrete building model is presented. ETABS 2016 software was used for modeling and analysis of structure. The analysis was carried out for various building models as listed below

T1M1:-Building without core and outrigger.
T2M2:-Building with the core system.
T3M3:-Building with the core and outrigger system.
T4M4:-Building with core and in-filled masonry walls along with outrigger system.
T5M5:-Building with core and in-filled masonry walls only.
Note-T1M4 and T1M5 are same models only outrigger beams are replaced by normal beams in T1M5

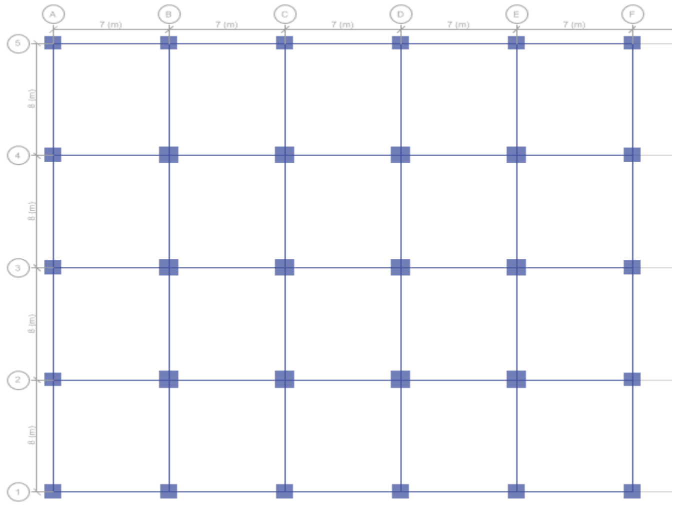

Fig .5: Building without core and outrigger (T1M1)

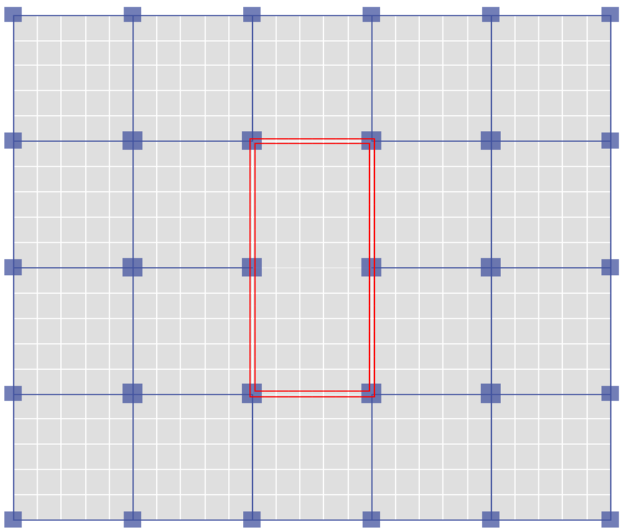

Fig .6: Building with the core System (T1M2).

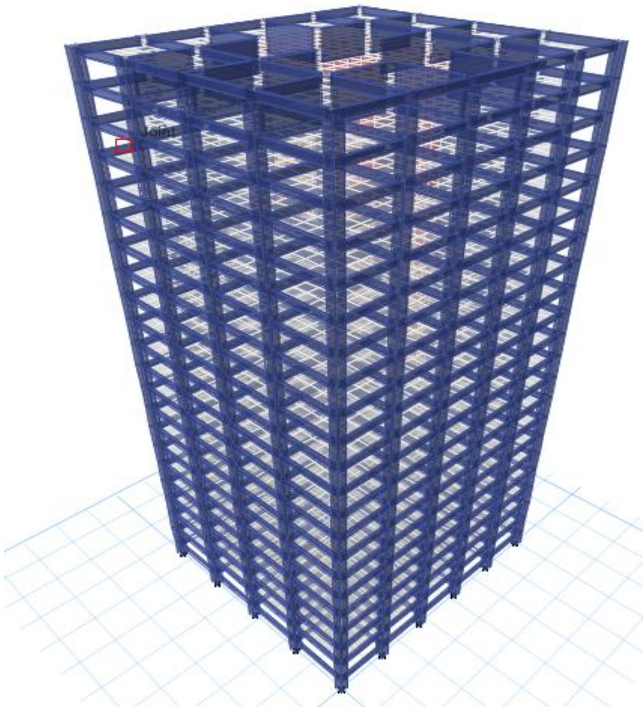

Fig .7: Building with the core and outrigger system (T1M3)

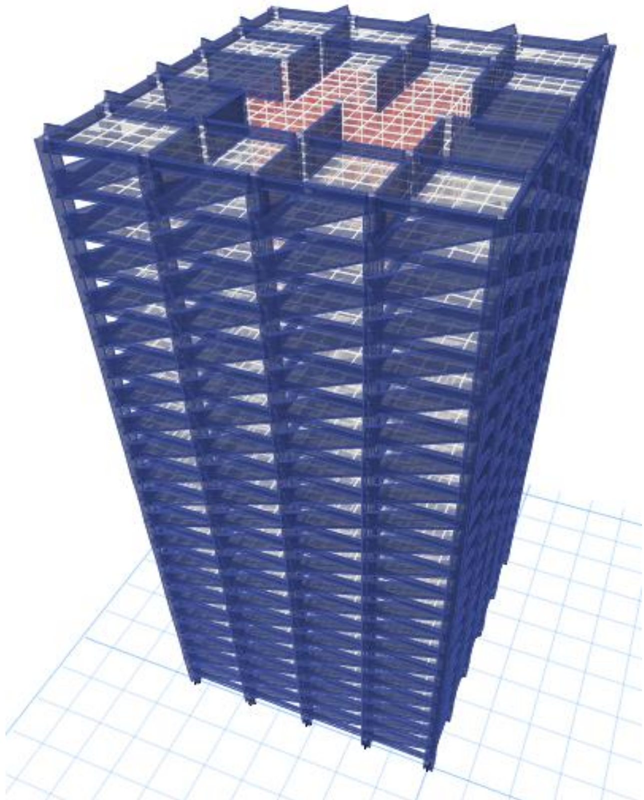

Fig .8: Building with core and in-filled masonry walls along with outrigger system (T1M4 & T1M5)

After analyzing the above models step by step with pushover analysis the maximum deflection of the building is calculated at this position the first outrigger is provided. Every latter iteration is done along with the previously fixed outrigger position. After fixing the required number of outrigger the same model with outrigger is defined with the in-filled masonry walls to study the effect of the same on the structure. (For this study purpose only one outrigger is used at top store of building.)

Building structure was traditional reinforced concrete slab with the beam grids. The model was regular shaped rectangular plan with dimensions 35mX32m and G+21storey. The floor to floor height was 3.5m and total height of building was 73.5m.

The slab thickness of each slab is 250mm and the core is located as shown in the fig.(6)

The size of exterior columns is 1000mmx1000mm and the interior column is 1200mmx1200mm.irrespective of the height of the structure. The size of all beams is assumed to be 300mmx800mm.

The core wall thickness is 300mm. The masonry in-filled wall of thickness 200mm is assumed.

The superimposed dead load of 2 KN/M2 and the live load of 2.5 KN/M2 is considered on the floors except roof. On the roof loading is SIDL of 2.5 KN/M2 and live load of 2 KN/M2 is considered. Wind and seismic load calculations are done as per the IS875-2002-Part-3 and IS1893-2002-Part-1 respectively.

First the model is analyzed for the linear static analysis to find the sizes of members then the non-linear pushover analysis is performed for the deflection. From that deflection data the position of the outrigger is finalized and the in-filled walls are modeled as the equivalent strut element with compressive strength of 5MPa.

Use of masonry in-fill walls in the building plays a major role in the damage and collapse of building during strong earthquake. Modeling of in-filled wall can be done by two methods Finite Element method and second by equivalent strut approach in this study Finite element method of modeling is considered.

The ETABS has inbuilt default ATC 40 and FEMA 273 hinge properties also it has capability also we can also provide or edit any input properties to it. The hinges are provided to each frame element i.e. columns and beams manually. The load cases for the pushover is defined as Push X and Push Y in X and Y directions respectively. While performing the pushover analysis only Dead, Live, Push X and Y are run all other linear cases are not run as it may duplicate the analysis for the response spectrum and pushover. Pushover analysis takes more time to run than the normal analysis as it is doing analysis for collapse or plastic stage of the structure.

As per FEMA 356 Cl. No. 7.5.2.1 the equivalent width of the in-filled Masonry wall as per concrete member is given by-

$$a = 0.175(\lambda_1 h_{col})^{-0.4} r_{inf} \qquad (7\text{-}14)$$

where:

$$\lambda_1 = \left[\frac{E_{me} t_{inf} \sin 2\theta}{4 E_{fe} I_{col} h_{inf}}\right]^{\frac{1}{4}}$$

and

h_{col} = Column height between centerlines of beams, in.

h_{inf} = Height of infill panel, in.

E_{fe} = Expected modulus of elasticity of frame material, ksi

E_{me} = Expected modulus of elasticity of infill material, ksi

I_{col} = Moment of inertia of column, in^4.

L_{inf} = Length of infill panel, in.

r_{inf} = Diagonal length of infill panel, in.

t_{inf} = Thickness of infill panel and equivalent strut, in.

θ = Angle whose tangent is the infill height-to-length aspect ratio, radians

λ_1 = Coefficient used to determine equivalent width of infill strut

3. ADVANTAGES AND DISADVANTAGES

a. Advantages

1. The outrigger systems may be formed in any combination of steel, concrete, or composite construction.
2. Core overturning moments and their associated induced deformation can be reduced through the "reverse" moment applied to the core at each outrigger intersection. This moment is created by the force couple at the exterior columns to which the outrigger connect. It can potentially increase the effective depth of the structural system from the core only to almost the complete building.
3. Significant reduction and possibly the complete elimination of uplift and net tension forces throughout the column and the foundation systems.
4. The exterior column spacing is not driven by structural considerations and can easily mesh with aesthetic and functional considerations.
5. Exterior framing can consist of "simple" beam and column framing without the need for rigid-frame-type connections, resulting in economies.

6. For rectangular buildings, outriggers can engage the middle columns on the long faces of the building under the application of wind loads in the more critical direction. In core-alone and tubular systems, these columns which carry significant gravity load are either not incorporated or underutilized. In some cases, outrigger systems can efficiently incorporate almost every gravity column into lateral load resisting system, leading to significant economies.

b. Disadvantages

The most significant drawback with use of outrigger systems is their potential interference with occupancy and rentable space.
This obstacle can be minimized or in some cases eliminate by incorporation of any of the following approaches:
1. Locating outrigger in mechanical and interstitial levels
2. Locating outriggers in the natural sloping lines of the building profile
3. Incorporating multilevel single diagonal outriggers to minimize the member's interference on any single level.
4. Skewing and offsetting outriggers in order to mesh with the functional layout of the floor.
5. Another potential drawback is the impact the outrigger installation can have on the erection process. As a typical building erection proceeds, the repetitive nature of the structural framing and the reduction in member sizes generally result in learning curve which can speed the process along.

4. RESULTS AND DISSCUSSION

In the present study, non-linear response of RC frame tall building with and without in-filled walls using ETABS under the lateral loading has been carried out. The objective of this study is to see the variation of load-displacement graph and check the maximum base shear and displacement of the frame with soft stories at different levels.
Pushover curve is obtained as shown in figures.

Table.1- Performance Points of various Models

Model Type-1	Performance Point	
	S_d (m)	S_a (m/sec2)
T1M1	0.013	0.089
T1M2	0.007	0.146
T1M3	0.008	0.159
T1M4	0.007	0.175
T1M5	0.008	0.170

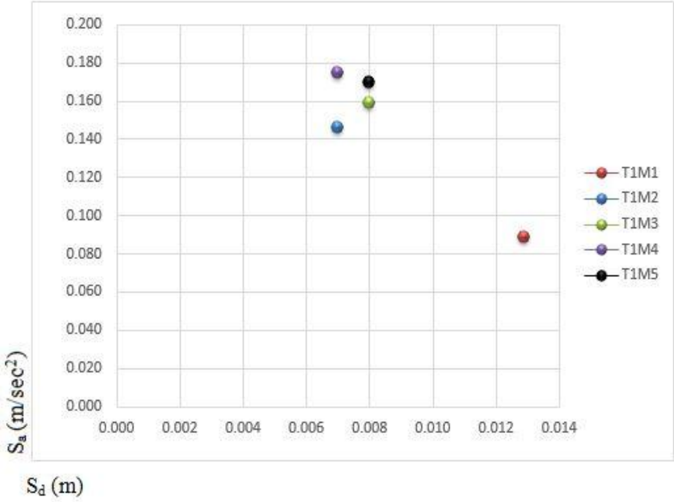

Fig .9: Performance points of various Models

Table.2- Displacements of the various models

Story	Displacement in X-direction mm			
	T1M2	T1M3	T1M4	T1M5
Stilt	4.95	3.89	5.57	5.47
1st	9.64	7.61	10.93	10.74
2nd	15.14	11.96	17.14	16.88
3rd	21.34	16.83	24.11	23.78
4th	28.08	22.11	31.67	31.28
5th	35.25	27.70	39.67	39.24
6th	42.71	33.49	47.98	47.53
7th	50.37	39.41	56.46	56.02
8th	58.12	45.39	65.03	64.63
9th	65.90	51.35	73.58	73.25
10th	73.64	57.25	82.04	81.83
11th	81.27	63.05	90.34	90.30
12th	88.76	68.69	98.43	98.61
13th	96.07	74.15	106.26	106.72
14th	103.18	79.41	113.80	114.61
15th	110.06	84.45	121.02	122.25
16th	116.73	89.26	127.92	129.65
17th	123.17	93.85	134.49	136.81
18th	129.43	98.24	140.80	143.76
19th	135.45	102.44	146.63	150.45
20th	141.23	105.70	151.18	156.56

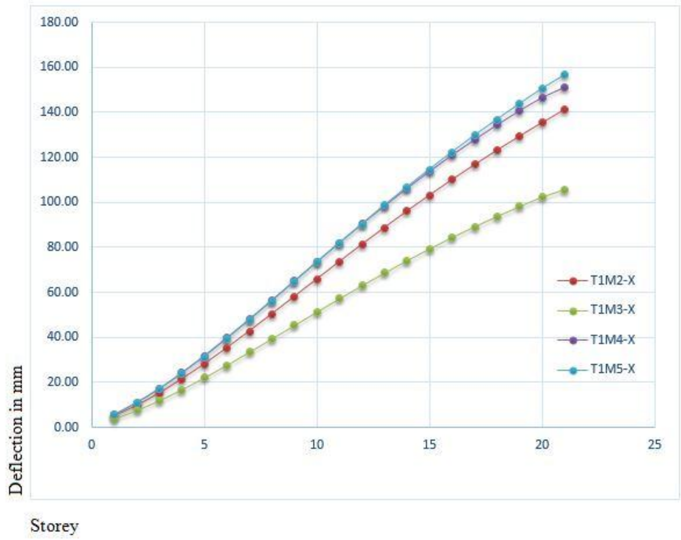

Fig .10: Deflection Curves various Models in X-direction

Note- T1M1 is not considered in the above table and graph as there are many variations in deflection and the other models may not be visible properly.

5. CONCLUSION

The result of the present study shows that the structural wall, structural outrigger system and the in-filled masonry wall have very important effect on the structure under seismic behavior.

It is recommended to use core wall and outrigger system to significantly reduce lateral deflection of the high rise buildings.

Along with the in-filled wall, it is better to use outrigger system to increase structural performance and reduce the formation of plastic hinges and lateral deflection.

Instead of using shear walls throughout the periphery, outrigger system can be used effectively and economically.

From the result it is seen that as the structural system changes to without core wall to in-filled wall the base shear of system increase by 4.5 to 5.2%.

From the pushover analysis the maximum deflection of the system is reduced 40% to 65% as we add the structural core, outrigger system and the in-filled wall.

The storey drift of the building also reduce to some extent.

For other 3 models the frame does not meet the demand as its capacity is less than the required. Most of the hinges developed in the beams and few in the columns.

It is also seen that the in-filled masonry wall is behaving like the structural member as it is taking the loads from the adjacent frame structure.

The results obtained in terms of demand, capacity and plastic hinges gave an insight into the real behavior of structures.

6. FUTURE WORK

Future work can be done on the building with more number of stories along with possible number of outrigger system.

The work can also be done to minimize the effect of the lateral forces on the in-filled walls as these are not capable of taking tensile loads or compression members only but very little compression capacity.

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BIOGRAPHIES

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