Comparative Study of Multistoried Building With Core And Out Trigger Structural System

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Abstract- *Tall building development has been rapidly increasing worldwide introducing new challenges that need to be met through engineering judgment. In modern tall buildings, lateral loads induced by wind or earthquake are often resisted by a system of coupled shear walls. But when the building increases in height, the stiffness of the structure becomes more important and introduction of outrigger beams between the shear walls and external columns is often used to provide sufficient lateral stiffness to the structure.The outrigger and is commonly used as one of the structural systems to effectively control the excessive drift due to lateral load, so that, during small or medium lateral load due to either wind or earthquake load, the risk of structural and non-structural damage can be minimized. The objective of this thesis is to study the behavior of outrigger and, outrigger location optimization and the efficiency of each outrigger when two outriggers are used in the structure. In G+20 storey three dimensional models of core and outrigger structural system are subjected to wind and earthquake load, analyzed and compared to find the lateral displacement reduction related to the core and outrigger system.*

Keywords- Core and outrigger structural system, Wind, Earthquake, Lateral Displacement, Storey Drift, Storey Shear.

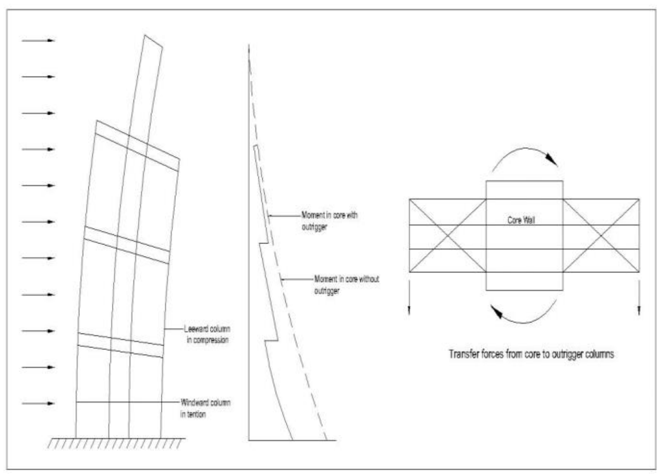
I. INTRODUCTION

General Overview

The outrigger structural system is a lateral load resisting system in which the external peripheral columns are tied to the central core with very stiff outriggers and belt truss at or more levels. The belt trusses are tied to the peripheral columns of the building while the outriggers engage them with main or central shear wall. The outrigger acts as a stiff arm engaging outer columns and central core. The lateral load when induced in the central core is transferred to peripheral columns via outriggers and the overturning moment reduced. This structural system is commonly used as one of the structural systems to efficiently control excessive drift due to lateral load, so that during small or medium lateral load due to either wind or earthquake, the risk of structural and non-structural damage is minimized. The structural response of an outrigger system is based on tension compression couple induced in the outer columns.

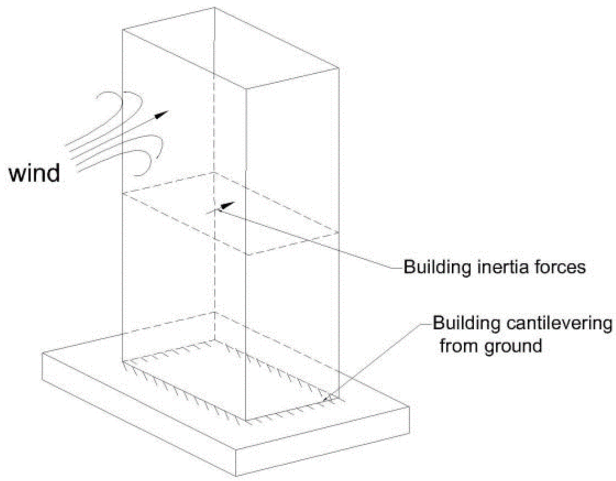
Behaviour of Outrigger

Outrigger wall is act as a stiff-arm engaging perimeter column. When Central core tries to tilt, its rotation at outrigger level develops a tension compression couple in perimeter column and actin in opposite to that moment. Result is in acting a restoring moment on the core at that level. As a result, effective depth of structure for resisting bending increases when central core bends as a vertical cantilever, by the action of tension in the windward columns and by compression in the leeward columns. In addition to those columns connected to outriggers, it is also possible to mobilize other perimeter column in to assist in restraining the rotation of outriggers. This can be achieved by connecting perimeter column with a one story or two-story deep wall, termed as belt wall around the building.



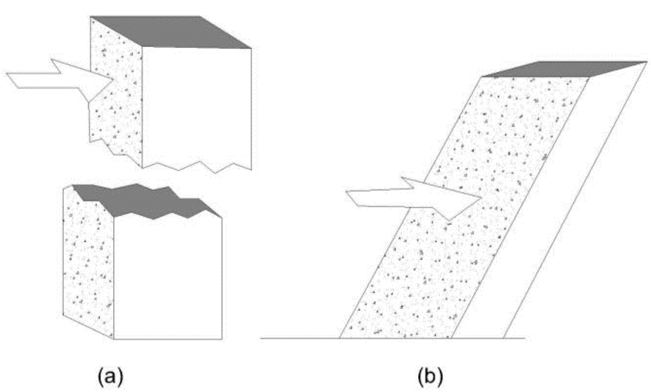
Structural Concept of Tall Building

For understanding the structural concept of tall building, main concept is that, building is act as a cantilever beam from the ground. (Fig below) Lateral forces are generated due to wind flow and inertial forces are developed due to ground shaking. Building tends both to snap it (shear) and push it over (bending).



In resisting shear forces, the building must not break by shearing off (figa) and must not strain beyond the limit of elastic recovery (figb).

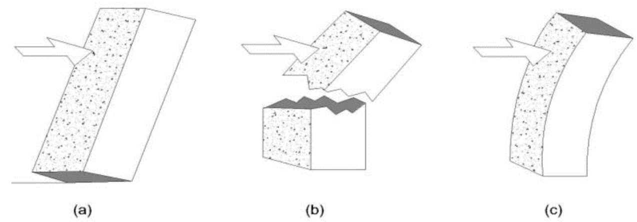
Therefore, structural system of building must have efficiency to resist shear as well as bending.



Similarly, the system resisting the bending must satisfy three needs (fig. below)

a) The building must not overturn due to combined effect of gravity loads and lateral loads. Fig(a)
b) Column must not fail due to crushing or by excessive tensile forces Fig(b)
c) Bending deflection of column should not exceed the elastic limit. Fig (c)

In addition, a building in seismically active regions must be able to resist realistic earthquake forces without losing its vertical load carrying capacity



Historical Background of Outrigger

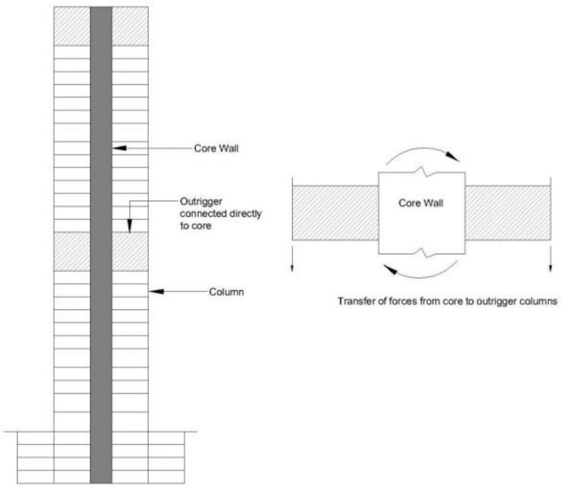
Sr. No	Buildings	City	Country	Height (m)	Floors	No. of Outriggers
1	Burj Khalifa	Dubai	UAE	828	160	5
2	Trump International Hotel and Tower	Chicago	USA	423	96	3
3	Taipei 101	Taipei	Taiwan (ROC)	509	101	11
4	International Commerce Centre	Kowloon	Hong Kong	483	118	4
5	Shanghai World Financial Centre	Shanghai	China (PRC)	492	101	8
6	Petronas Tower 1	Kuala Lumpur	Malaysia	452	88	1
7	Petronas Tower 1	Kuala Lumpur	Malaysia	452	88	1
8	Nanjing Greenland Financial Centre	Nanjing	China (PRC)	450	89	3

Types of Outriggers

On basis of connectivity of core to exterior columns, this system may be divided as in two types:

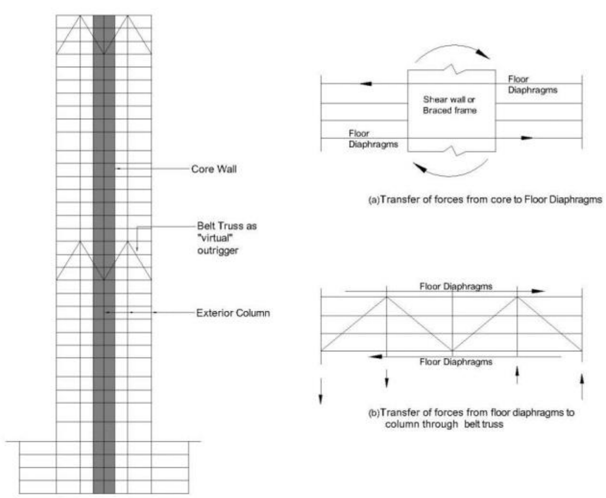
II. CONVENTIONAL OUTRIGGER SYSTEM

Structural system consists of Outrigger walls /beams connected to central core and perimeter columns is known as Conventional outrigger system. The number of outriggers may vary along the height of building. It may be two, three or more. The outriggers restrain rotation of the core and convert part of the moment in the core into a vertical couple at the columns. Shortening and elongation of the columns and deformation of the trusses will allow some rotation of the core at the outrigger. In most designs, the rotation is small enough that the core undergoes reverse curvature below the outrigger.



Virtual Outrigger System

The structural system consists of belt truss wall which is directly connected to perimeter column around the building. There is no direct connection between belt wall and core. The basic concept of virtual outrigger is that it uses floor diaphragm which are typically very stiff and strong in their own plane to transfer the moment in the form of a horizontal couple from the core to belt walls that are not connected directly to the core. Belt wall then converts the horizontal couples into vertical couples in perimeter columns.



Lateral Displacement

Lateral displacement is important when structures are subjected to lateral loads like earthquake and wind loads. Lateral displacement depends on height of structure and slenderness ratio of the structure because structures are more vulnerable as the height of building increases by becoming more flexible to lateral loads.

Story Drift

Story drift is the lateral displacement of one level relative to the level above or below it. Story drift ratio is the story drift divided by story height.

Base Shear

Base shear is an estimate of the maximum expected lateral force on the base of the structure due to seismic activity. It is calculated using seismic zone, soil material and building code lateral force equation. Storey shear factor is the ratio of the story shear force when story collapse occurs to the story shear force when total collapse occurs.

Fundamental Time Period of the Building

The time taken (in seconds) for each complete cycle of oscillations (i.e., one complete back-and-forth motion) is the same and is called Fundamental Natural Period T of the building. Fundamental natural periods T of normal single storey to 20 storey building are generally in the range of 0.05-2.00 sec.

III. PROBLEM STATEMENT

Study the effect of out trigger wall in tall building subjected to lateral loads.

Comparative study of different parameters like lateral displacement, story drift, story shear, base shear etc. in three different structures i.e., structure with center core only, structure with center core and out triggers at story 6 and story 9 and structure with center core and out triggers at story 15 and story 19

Objective of the Project

- To study the effect of out trigger wall in tall building subjected to lateral loads.
- Comparative study of parameters like base shear, lateral displacement, story shear and story drift by taking various models for analysis

Scope of the study

- Outrigger system is adopted for buildings that are subjected to large overturning moments compared to shear and lateral deflections. Outrigger in structures **reduces the overall drift and core wind moments**. The outrigger system reduces the overall building acceleration due to high winds and improves occupant comfort.
- With an outrigger, you can place your bait farther away from the boat where the water is clear and still.
- Outrigger. **An extension of a rafter beyond the wall line**. Usually, a smaller member nailed to a larger rafter to form a cornice or roof overhang.

IV. LITERATURE REVIEW

Kang

The FEM model used for skyscrapers. The outcomes of this study are useful for structural engineers and researchers involved in construction of outriggers in tall and super tall building.

Park

Optimum design method to minimize volume of core, belt wall and external columns and calculating optimum location of outriggers using genetic algorithms with aim of controlling lateral displacement of building.

Kim

In this current paper, the optimum design of the outrigger, including areas as well as locations, is performed. FEA rather than analytic equations is utilized to calculate the lateral displacement of tall buildings.

Asai and Watanabe

The focus of this study is to experimentally investigate and verify smart outrigger damping systems for high-rise buildings subject to scaled El Centro and Kobe earthquake records using RTHS

Jagadheeswari and Christy

This present study is focused on the performance of multi -outrigger structural system for a 40-storey building. Static and dynamic analysis of various models were examined using SAP2000 software for concrete outrigger with central shear wall, without out rigger and outrigger bracing with belt truss.

Badami and Suresh

This paper describes an investigation which is carried out to examine the most common structural systems that are used for reinforced concrete tall buildings under the action of gravity and wind loads. These systems include “Rigid Frame”, “Shear Wall/Central Core”, “Wall- Frame Interaction”, and “Outrigger”. The basic modelling technique and assumptions are made by “ETABS” Program, in 3-D modelling. Design considerations are made according to Indian Standards. This comparative analysis has been aimed to select the optimal structural system for a certain building height. The structural efficiency is measured by the time period, storey displacement, drift, lateral displacement, base shear values and core moments.

Shrinivas and Mulla

Author consider regular and irregular shape of building. Study for both buildings with and without outrigger has been carried out. Steel bracing is used as an outrigger. The modelling of the structure is done using ETAB programme. The analysis of the structure is carried out by Equivalent Static Method and Response Spectrum Method. Results for lateral displacement, drift, base shear and fundamental natural period are compared for both models. The values of this parameters are decreased after application of outrigger for both regular and irregular structures.

Gowda and Manohar

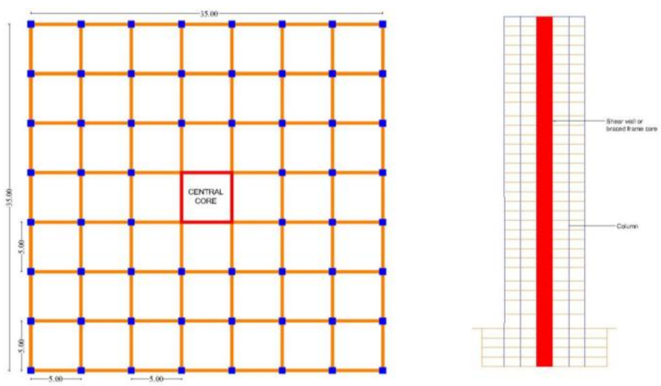
This proved to be cost effective to improve the performance of building subjected to earthquake load. Basically, belt truss is the truss which is provided along the peripheral columns of structure at certain height of building to improve the stiffness and firmness against lateral loads. In this research work researchers have carried out a comparative study by using different types of belt truss which includes X, V, inverted V diagonal etc. for different seismic zone criteria to understand the importance of belt truss. To execute this study researchers have modelled 30 storied 3-dimensional models by implementing different types of belt truss and analyzed the model by equivalent static analysis and response spectrum method as per the Indian Standard codes. A comparative study has been performed based on percentage reduction of displacement and story drift at the different seismic zones. It is found from the study that for reducing lateral displacement and story drift, Concrete belt truss is more efficient compared to structural steel belt truss as it gives negligible results.

V. METHODOLOGY

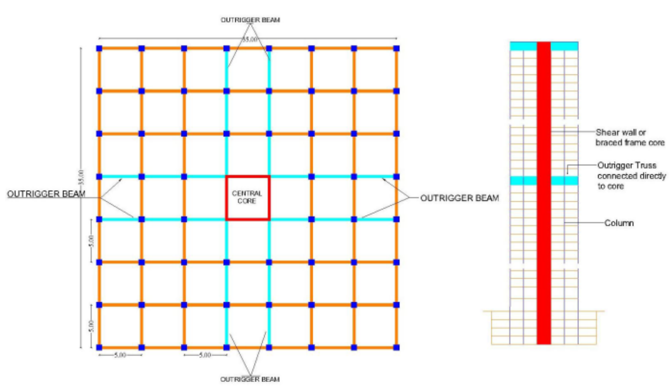
For the modelling and analysis ETABS 2016 software program is selected to perform Linear analysis of the models. following three types of models are considered for analysis:

Model 01: Building with center core only

Model 02: Building with center core and outrigger wall connected to core and external column i.e., conventional outrigger system (Trail 01, and Trail 02)



Building with centre core only



Building with centre core and out trigger wall

Input Data

- Plan of 20 storey building -(35m x 35m)
- Building Type- RC Building with special moment resisting frame - SMRF
- Centre to centre of column – 5m
- Storey height – 3m
- Column details - (750 x 750) mm
- Beam details - (450 x 600) mm
- Slab thickness – 150mm
- Grade of concrete – M30
- Grade of steel – Fe500
- Young's Modulus - $5000\sqrt{fck}$
- Intensity of live load on each floor – $2kN/m^2$
- Weight of floor finish – $1.5kN/m^2$
- Intensity of roof live load – $1kN/m^2$
- Intensity of roof dead load – $3kN/m^2$
- Wall load on beam – $11.04kN/m^2$
- Soil type- taken as per IS 1893 (part 1) 2016 Clause 6.4.2.1 - Medium (Type II)
- Importance factor- **I** as per table 8 of IS1893 (part 1) 2016 – 1.5
- Response reduction factor- **R** as per table 9 of IS1893 (part 1) 2016 – 5.0
- Time period- As per IS 1893 (part 1) 2016 Clause 7.6.2. c
- Where h= height of building in m, d= base dimension of the building at the plinth level along the considered direction of earthquake shaking in m - $(0.09 \times h)/\sqrt{d}$
- Zone as per seismic zones map of India given in IS1893 (part 1) 2016 for Nashik - III
- Zone factor- **Z** As per table 3 of IS1893 (part 1) 2016 – 0.16
- The design horizontal seismic coefficient as per clause 6.4.2. of IS 1893 (part 1) 2016
- Where (Sa/g) = design acceleration coefficient taken as per 6.4.2. of IS 1893 (part 1) 2016 – **Ah =** [(Z/2) (Sa/g)]/(R/I)
- Seismic weight **W** for **n** no. of floors is calculated as ∑n x floor area x (D.L.+0. 25L.L) Live load reduction is as per clause 7.3.2. IS1893 (part 1) 2016
- Design base shear as per clause 7.2.1 of IS 1893 (part 1) 2016 **Vb - Ah x W**
- Wind speed as per Appendix A of IS 875 (part 3) 1987 – 39m/s
- Terrain category as per clause 5.3.2.1-d of IS 875 (part 3) 1987 – Category 4
- Risk Coefficient, k1 as per table 1 of IS 875 (part 3) 1987 – 1.0
- Terrain height & structure size factor, k2 as per table 2 of IS 875 (part 3) 1987 – 1.15
- Topography factor, k3 as per clause 5.3.3.1 of IS 875 (part 3) 1987 – 1.0

Loads acting on Building

Gravity Loads

Gravity loads include self-weight of building, floor finish which is taken as 1.5 kN\m2 and live load which is taken as 2 kN\m2 as per IS 875(part-II) for a residential building that would be acting on the structure in its working period. We have also considered wall load as imposed load on internal beams as 7.5 kN\m2 and on external beams 13kN/m2

Lateral Loads

In contrast to the vertical load, the lateral load effects on buildings are quite variable and increases rapidly with increase in height. Most lateral loads are live loads whose main component is horizontal force acting on the structure. Typical lateral loads would be a wind load, an Earthquake load, and an earth pressure against a beachfront retaining wall. Most lateral loads vary in intensity depending on the buildings, geographic location, structural material, height and shape.

Earthquake Loads

Earthquake loading is a result of the dynamic response of the structure to the shaking if the ground. Earthquake loads are another lateral live load. They are very complex, uncertain and potentially more damaging than wind loads. It is quite fortunate that they do not occur frequently. The Earthquake creates ground movements that can be categorized as a “shake”, “rattle” and “roll”. Every structure in an Earthquake zone must be able to withstand all three of these loadings of different intensities. Although the ground under a structure may shift in any direction, only the horizontal components of this movement are usually considered critical in analysis. The magnitude of horizontal inertia forces induced by earthquakes depends upon the mass of structure, stiffness of the structural system and ground acceleration.

Stepwise Procedure for Etabs Modelling

Grid formation along X & Y direction in order to develop the model of the building in grid pattern and input for storey data right from base to topstorey.
Define Material properties for concrete -M45 &rebar-Fe500
Define sectional properties for column, beam, slab & core wall
Creation of slab & beam layout for typical story.
Assign properties to column, beam, slab and core wall.
Define load patterns
Define load cases
Define load combination
Assign the loads.
Assign diaphragms to whole structure
Assign meshing to slab elements & shear wall
Define mass source to complete structure (D.L.+0.25L.L.)

Since the live load class is 2 kN /sqm (< 3 kN /sqm), Only 25 % of the live load is lumped at the floors. -As per Table 10 of IS1893(Part 1):2016

Total seismic weight of the structure = ∑ n x floor area x (D.L.+0.25L.L.) Where n= no. of floors.

Check model before analysis
Run analysis for static earthquake load combination
If base shear is calculated by dynamic analysis is less than base shear in static analysis (i.e., RSX < EQX; RSY < EQY), all response quantities are to be scaled up as below:

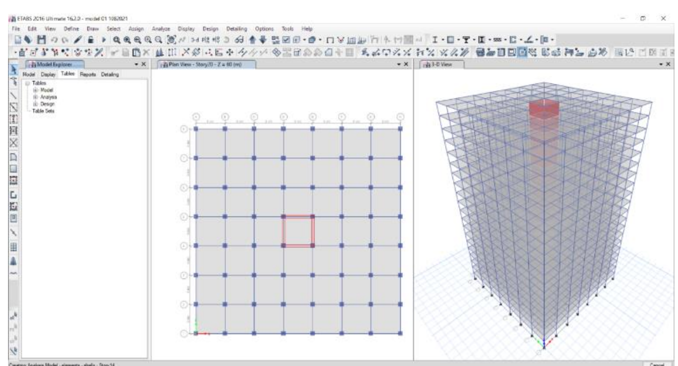
Scale factor = (I x g)/2R x (0.8) x (Eq static base shear / Response spectrum base shear)
Where I: Importance factor =1.5
g: acceleration due to gravity
R: response reduction factor

Final run analysis using scale factor
Results are tabulated to study structural behaviour of building.

VI. MODELS CONSIDERED FOR PROJECT

Introduction to Model 01

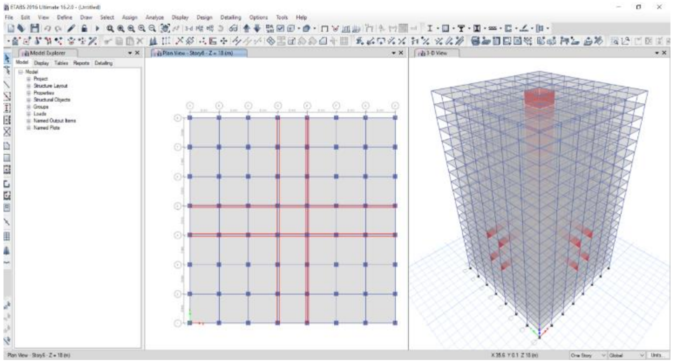
Building with center core only is termed as Model 01**.** Geometry of building is given in fig. Geometry and Input Parameters are already described above. ETAB Modelling procedure also discussed already. Response Spectrum Analysis method is used for the givenstructure



Introduction to Model 02 (Trail 01)

As per discussion of result for model 01 two outriggers are provided for model 02 trail 01 at story 6 and story 9

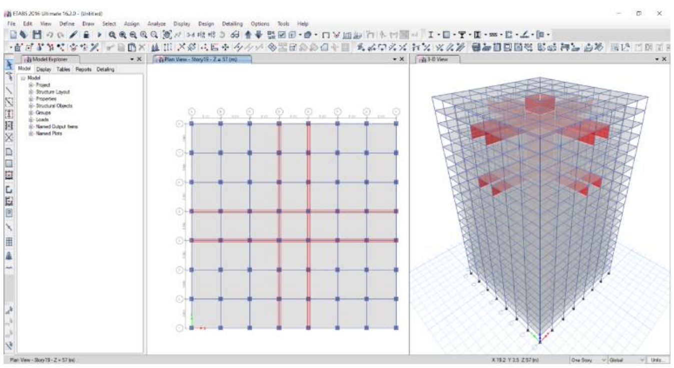
Geometry of the building is as shown in the building.



Introduction to Model 02 (Trail 02)

As per discussion of result for model 02 two outriggers are provided for model 02 trail 02 at story 15 and story 19

Geometry of the building is as shown in the building.



After analysis of Model 01 and Model 02 (Trail 01 & 02) results for following parameter are obtained:

Displacement for load cases RSX & RSY (Response spectrum in X &Y direction)
Drift for load cases RSX & RSY (Response spectrum in X &Y direction)
Shear for load cases RSX & RSY (Response spectrum in X &Ydirection)
Displacement and drift for Load combination C4 = 1.5D.L. +EQY (This load combination is selected for plotting results because values for drift and displacement for this load combinations aremaximum)

VII. RESULTS AND DISCUSSION

Summary of results for Model 01 & 02 (Trail 01 & 02)

Model 01

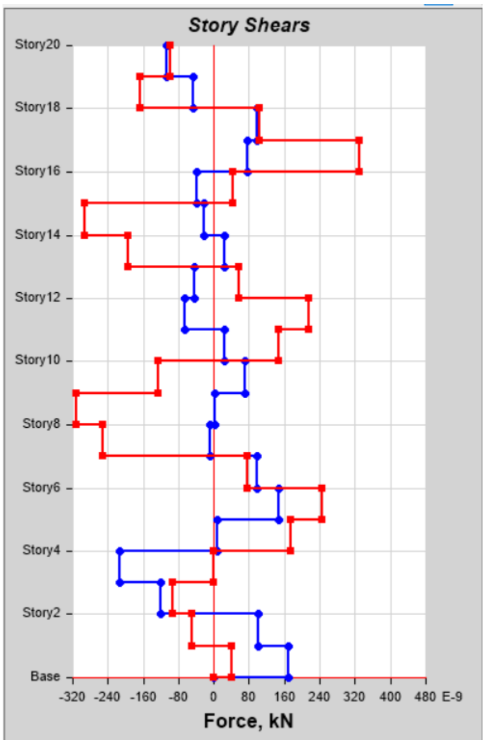
Load Case /Combination	Max. Displacement Mm (Top Story)	Max. Drift mm	Base shear
RSX	7.7	0.000186	1378.812
RSY	0.755	0.000018	135.1923
C4	-----	4.272	

Model 02 (Trail 01)

Load Case /Combination	Max. Displacement Mm (Top Story)	Max. Drift mm	Base shear
RSX	156.953	5.009	14365.0742
RSY	144.098	4.551	14364.8633
C4 (1.5D.L. +EQY)	261.794	8.055	

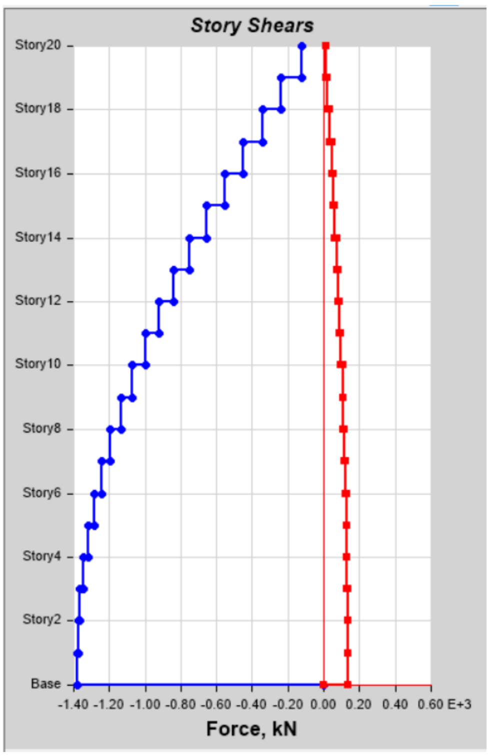
Model 02 (Trail 02)

Load Case /Combination	Max. Displacement mm (Top Story)	Max. Drift mm	Base shear
RSX	139.01	4.978	14364.83
RSY	127.497	4.675	14364.93
C4(1.5D.L+EQY)	255.745	8.713	

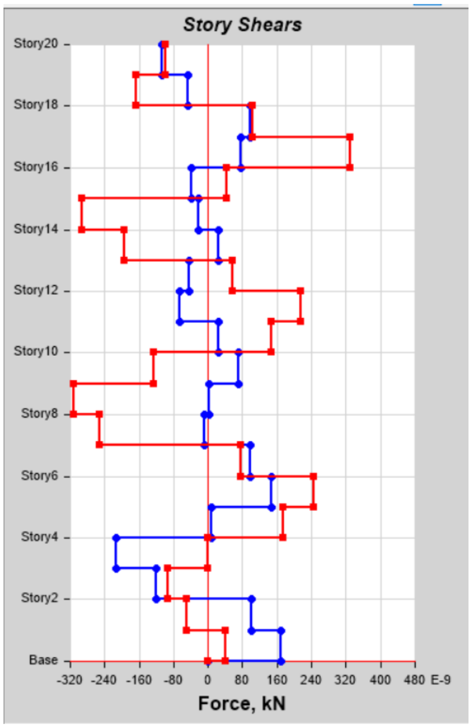


Story Shear Vs Story (Model 02 Trail 01)

Graphs for Story Shear of Model 01 & 02 (Trail 01 & 02)

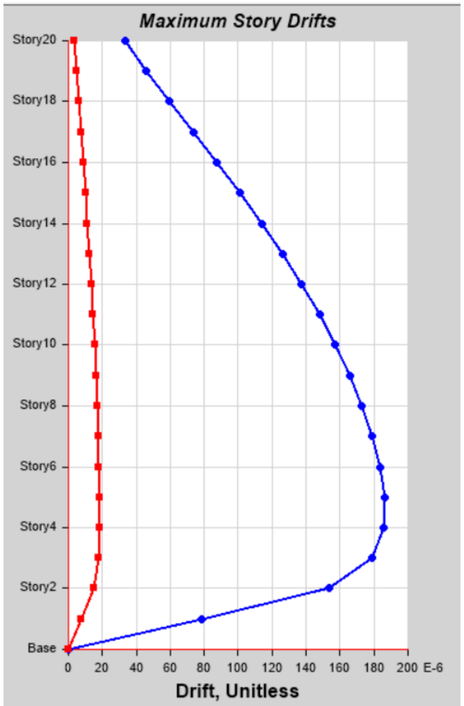


Story Shear Vs Story (Model 01)

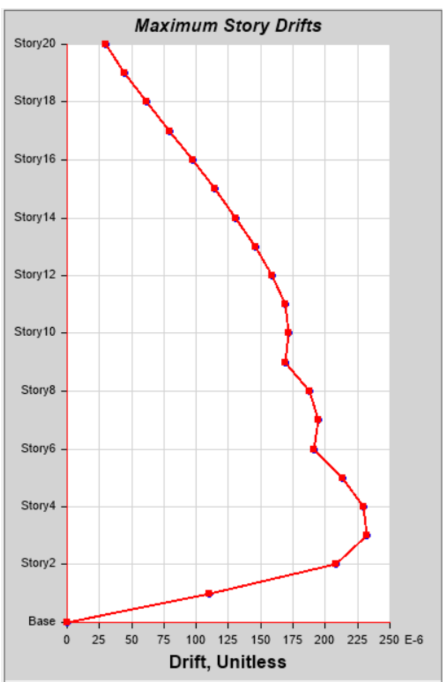


Story Shear Vs Story (Model 02 Trail 02)

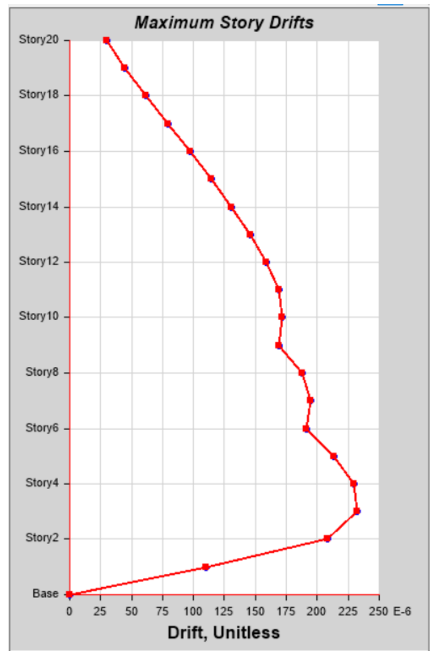
Graphs for Story Drift of Model 01 & 02 (Trail 01 & 02)



Story Drift Vs Story (Model 01)

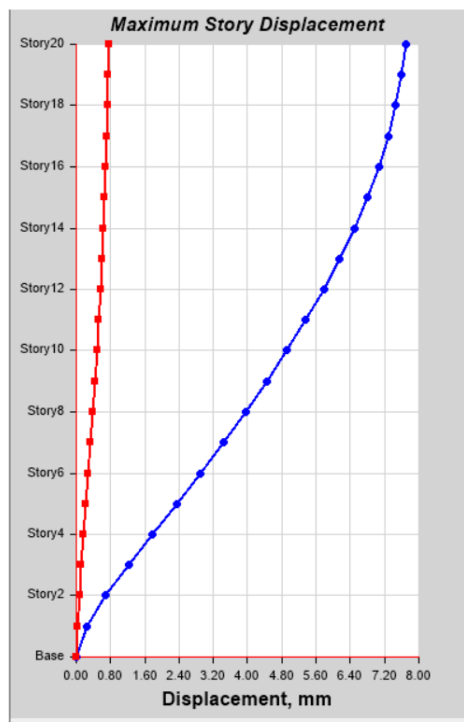


Story Drift Vs Story (Model 02 Trail 01)

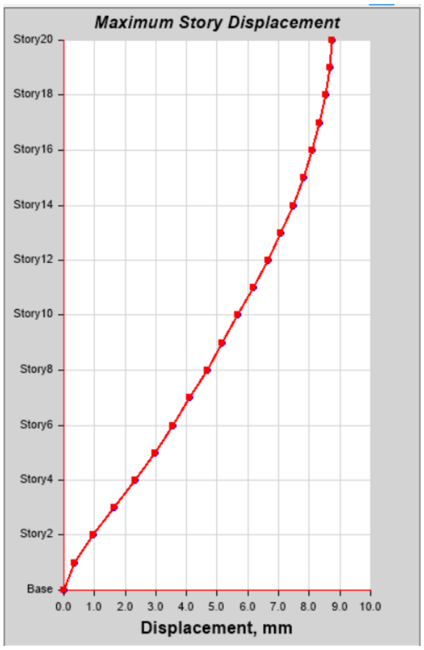


Story Drift Vs Story (Model 02 Trail 02)

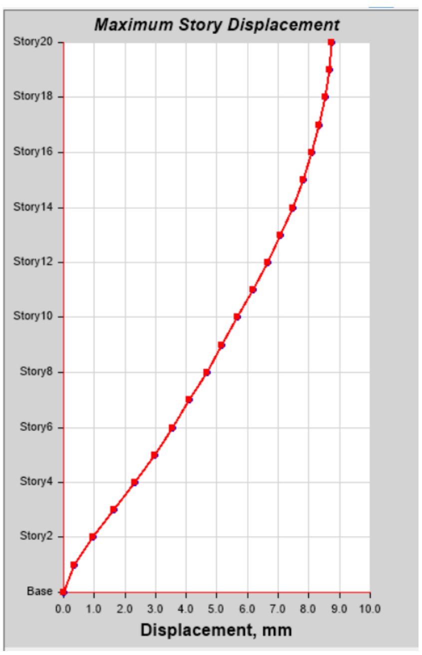
Graphs for Story Displacement of Model 01 & 02 (Trail 01 & 02)



Story Displacement Vs Story (Model 01)



Story Displacement Vs Story (Model 02 Trail 01)



Story Displacement Vs Story (Model 02 Trail 02)

Discussions of Results

Model 01

- **MAX DISPALCEMENT**: As per clause 20.5 of IS 456:2000, the lateral sway at the top should not exceed H/500, where H= building height. From summary it has been observed that it should not satisfy the above criterion i.e., displacement is greater than allowable displacement
- **MAX STORY DRIFT:** As per Clause 7.11.1.1 of IS 1893(Part 1):2016, Story drift in any story shall not exceed 0.004 times the story height. In our case, it should not exceed 0.004 x 3000=12mm. In our case max story drift is 10.199mm which satisfies above criterion
- **BASE SHEAR:** As base shear is VB = Ah. W, Base shear increases as seismic weight of building increases. Maximum Base shear value is 14738.31 kN
- **MODAL PERIOD AND FREQUENCIES:** it has been observed that largest time period for first mode is 5.341 sec.

Model 02 (Trail 01)

- **MAX DISPLACEMENT:** It has been also observed that maximum displacement reduced satisfactorily as compared to displacement in Model 1 (without outrigger) and satisfies the criteria of allowable displacement as per clause 20.5 of IS 456:2000 i.e., it is less than H/500.
- **MAX STORY DRIFT:** All values of drift are observed within limit of 0.004h
- **BASE SHEAR:** Maximum Base shear value due to RSX and RSY are less than that obtained in Model 1 (without outrigger).
- **MODAL PERIOD AND FREQUENCIES:**largest period for mode 1 is 1.724 sec. which is less than largest period for mode 1 in Model 1 (without outrigger).

Model 02 (Trail 02)

- **MAX DISPLACEMENT:** Max. displacement value is effectively reduced for second trial of Model 2. Maximum displacement due to other load cases/combinations are also reduced satisfactorily for trial 2 and are within limit of H/500.
- **MAX STORY DRIFT:** All drift values are observed within limit of 0.004h.
- **BASE SHEAR:**Maximum base shear value is slightly decreased in trial 2 as compared to trial 1 but is less than Model 1 (without outrigger).
- **MODAL PERIOD AND FREQUENCIES:**Largest time period for mode 1 is 4.024 sec. which is almost same as trial 1 of Model 2 but effectively reduced as compared to Model 1 (without outrigger).

Comparative Chart of Results

PARAMETER	MODEL01	MODEL02
LATERAL DISPLACEMENT	363.695	217.71
STORY DRIFT	10.199	6.265
BASE SHEAR	1473.8	1443.5
FUNDAMENTAL TIME PERIOD	5.341	4.024

Comparative Statements of Results

- Top displacement is reduced to 40.139 % when Conventional Outrigger system is used
- Maximum drift is reduced to 38.57 % when Conventional Outrigger system is used
- Base Shear is reduced to 2.027 % when Conventional Outrigger system used
- Largest time period for model 1 is reduced by 24.65 %
- From the result of Model 1, It has been observed that mass of the building is less and stiffness is also less as compared to other Models. Time period of building is more than other Models

VIII. CONCLUSION

- Story Drift is main decision parameter and plays an important role in deciding optimum location of building.
- For building with less mass & less stiffness, Period increases.
- lateral sway of building increases as stiffness of building decreases. Displacement can be reduced satisfactorily when multi-Outriggers and belt walls used in structural system of tall building

IX. ACKNOWLEDGEMENT

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