A Study on Outrigger System in a Tall R.C Structure with Steel Bracing

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***Abstract*—Tall building development has been rapidly increasing worldwide introducing new challenges that need to meet through engineering judgment. As the height of the building increases the stiffness of the building reduces. Therefore to improve the performance of the building under seismic loading, outrigger system is proposed in the present study of work. In the present work, contains a comparative study on regular building with and without outrigger and irregular building with and without outrigger with centrally rigid shear wall and steel bracings as outrigger. The modeling of the structure is done using "ETABS" program. The analysis of the model is carried out by equivalent static method and response spectrum method. The stiffness and efficiency characteristics of the structure is measured in terms of lateral displacement, drift, base shear and fundamental natural period for different types of buildings to provide stiffness against static and dynamic loads. The parameters should be minimized to prevent damage to the buildings.**

Keywords—Tall building; regular and irregular building; lateral displacement; base shear; fundamental natural period

I. INTRODUCTION

The development of tall building has always fascinated mankind from the ancient times. From the past, tall structures have always seen as a symbolic example of power and development. The challenging task in the construction field is to assemble the tall building. The design of tall building is based on analysis of models with experience and fundamental mechanics. As the height of the building increases the risk of horizontal and vertical load forces also increases. The moment resisting frames and braced core at certain height becomes inefficient to provide stiffness against wind and seismic loads. The lateral deflections due this load should be prevented for both structural and nonstructural damage to achieve the building strength and also stiffness against lateral loads in the analysis and design of tall building. To increase stiffness action against wind and seismic load outriggers are provided by the shear core with exterior frames in tall buildings. The effective depth of the structure is increased, when the outriggers are placed. The work is carried out to know the behavior of outriggers in the tall buildings. The building is analyzed for 20 storey building mainly four types of buildings are used and they are regular building with and without outrigger and also vertically irregular building with and without outriggers are used. In the proposed building instead of core wall shear wall is provided with columns inserted in it. The outrigger is made up of steel bracing. The analysis is carried out on building with varying zones using ETABS software (Engineering three dimensional analysis of structure) and results are generated with various parameters. The equivalent static analysis method and dynamic analysis method is adopted for analysis. The results generated are tabulated and graphed. The values are compared with different type of buildings for the lateral stiffness by seismic forces. The behavior of different types of building is known with various zones and also the effect of lateral load on the building when outriggers are provided. The lateral stiffness of the outrigger building is shown in this work. The primary purpose of the structural system is to effectively transfer the gravity loads without causing damage to the buildings. The gravity loads are mainly dead load, live load and snow load which affect the tall buildings. Apart from these loads the building is also subjected to horizontal lateral loading caused by the action of wind and earthquake forces. These lateral loads leads to huge damage to tall building by producing high stresses by causing vibration or sway movement. Therefore it becomes important that the tall buildings should be provided by necessary strength by installing these structural systems.

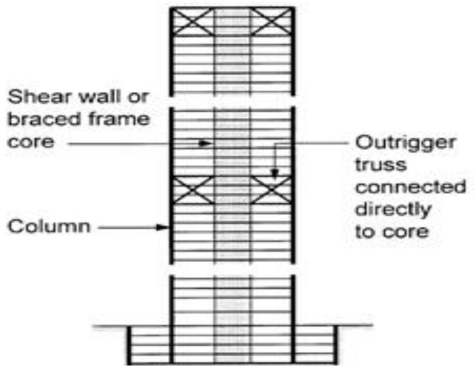
The tall structure is provided with shear walls which have columns; these columns are installed in the shear wall primarily to carry the gravity loads. The shear wall in the building will provide strength and lateral stiffness to the building in the direction of building orientation by reducing the lateral sway and damage to the structure. The outriggers with steel bracings are provided which increase the axial stiffness with the peripheral columns to resist the overturning moments. The system is very effective to resist the lateral loads. As the concept of outrigger and bracings are combined it decreases the bending moment in beams and shear forces in columns by increasing the column axial compression. The structure consists of central core comprises shear wall with horizontal girders or cantilever type trusses called outriggers made up of steel bracing, connecting to the outer columns of building. The shear wall is located centrally by extending outriggers on both sides of the columns. When the horizontal loads acts on the building the outriggers resist the rotation of the core wall or shear wall by causing the lateral deflection and minimizing the effect of the loads on the building. The effective depth of the building is increased when it acts as a vertical cantilever by inducing compression in the leeward columns and tension in windward columns. The outriggers are very effective in increasing its flexural stiffness while the shear wall in the building will provide the resistance to shear.

There are two types of outrigger system, they are

1. Conventional outrigger concept
2. Virtual outrigger Concept

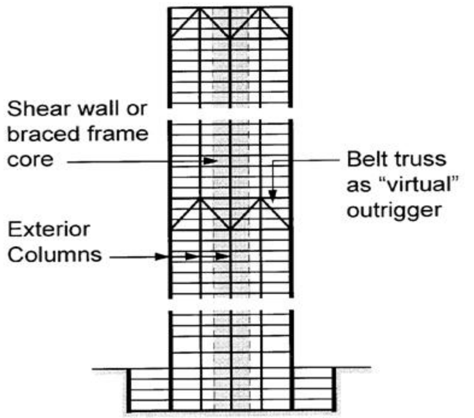
Conventional outrigger Concept:

In this concept of outrigger in tall buildings, the outriggers are connected to braced frames or shear wall directly at the core. But not necessarily to the columns located at outer edges of the building.



Virtual outrigger Concept:

In this concept the outriggers connecting core and perimeter systems is eliminated directly and instead a belt truss is used with a combination of stiff and strong diaphragms. The moment occurred in the core is converted in to horizontal couple in top and bottom of the floors of basement.



Affect of earthquake on Reinforced concrete buildings

In recent past year's reinforced concrete buildings have became common in urban places. The main challenge in tall building is to resist the wind and earthquake forces. The reinforcing steel bars and concrete are the two key materials used in reinforced concrete building. A typical RC tall building is made of horizontal and vertical member and supported by foundation on rest of the ground. To resist the earthquake forces the RC frames plays a vital role. The inertia forces generated by earthquake shaking are proportional to mass of the building. The mass of the building is present at the floor level, the inertia forces due to earthquake is always induced at floor levels. As the forces from top of the building are transferred to the base of the building, the base of the building is more affected by the earthquake induced forces.

II. OBJECTIVES OF STUDY

1. The objective of present study the use of outriggers in a regular and vertical irregular building under earthquake forces.
2. The buildings with and without outrigger are compared.
3. The outriggers are introduced at two levels in buildings.
4. The behavior of outriggers introduced as a steel bracing in a R.C tall structure.
5. The outrigger location in building is obtained for reducing lateral displacements.
6. To compare the effect of outriggers by both Equivalent static method and Dynamic Analysis method (Response spectrum method).
7. The results of base shear, storey drift are studied.

III. METHODOLOGY

The methodology of this study of outrigger in terms of steel bracings is on comparison basis of various structural systems on tall building with varying height and load intensities. The maximum utilization of the outrigger concept is achieved and given due importance. The study is intended to clear the ambiguity of choosing the required type of building systems as per Indian standards. The building is analyzed for varying seismic zones. During an earthquake, failure of structure starts at points of weakness. This weakness arises due to discontinuity in mass, stiffness and geometry of structure. The structures having this discontinuity are termed as Irregular structures. Vertical irregularities are one of the major reasons of failures of structures during earthquakes. Height-wise changes in stiffness and mass render the dynamic characteristics of these buildings different from the regular building. But lateral stiffness will be more when outriggers are provided.

1. Model Data

Structure	OMRF
No of stories	G+20
Type	Regular and Vertical irregular
Story Height	3.5m
Grade of concrete	M50, M40, M35, M30, M25
Grade of Steel	Fe415
Beam Size	0.45x0.6m, 0.45x0.55m
Column Size	1.0x1.0m, 0.8x0.8m,
Seismic Zone	IV
Soil type	II
Importance Factor	1
Reduction Factor	3
LL	4 kN/m^2
SDL	2 kN/m^2
Concrete outrigger	0.45X0.45 m, M50
Steel outrigger	ISA 130X130X10, Fe 345

2. The model is regular and vertical irregular shaped symmetrical plan with dimensions 42x42m. In all models slab spans are assumed to be 6m, arranged in eight bays in each direction. The plan has 6x6 central core opening. The storey height is assumed to be 3.5m. The three dimensional analysis for the model is carried out. The columns and beams

are represented by frame type element while shear walls are represented by shell type components.

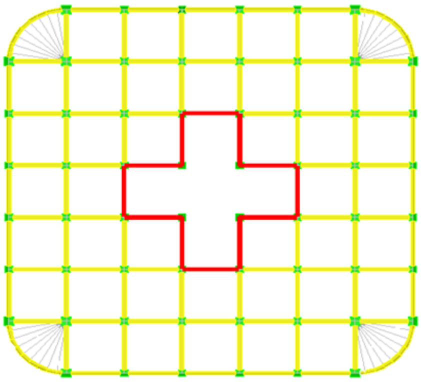


Fig.1. General Plan for all structural models

Loading

The load acting on tall building are classified in to following types

i. Loads due to gravity
ii. Lateral load due to wind and earthquake loads

Loads due to gravity

The load that acts vertically downward by the action of gravitational force is called gravity loads. The gravity loads are further classified as,

1. *Self weight of the structure*: Self weight is the overall weight of the structural elements in the structure. These are the permanent constant load acting on the structure.

2. *Slab weight:* The thickness of the slab is 250mm and is same throughout the height of the model.

3. *Beams*: The beam size is same throughout the height of the model.

4. *Column*: The column cross sectional dimension depends upon the load it carries. Thus the column dimensions goes on reducing as the height of the model increases. The column size remains constant for some stories in the model.

5. *Superimposed load*: In the model the floor finish, partition walls etc come under superimposed load.

6. *Live load*: The live load is comprises of the self weight of humans and live load is highly variable. Thus for residential buildings the Indian codes of practice suggest 4kN/m^2 load.

Lateral load due to earthquake or seismic loading as per IS 1893(part-1)2002.

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	Value	Page. No	Table	Clause
Zone factor	IV	16	2	6.4.2
Importance Factor	1	18	7	6.4.2
Response Factor	3	23	8	6.4.2
Soil type	II	16	2	6.4.2

Type of structure: The type of structure considered is ordinary reinforced concrete moment resisting frame. Therefore the response reduction factor, R=3.0 extracted from Table 7, clause 6.4.2 IS 1893(part I) 2002.

Importance of structure: The proposed structure is used as general building, the importance factor for the building is taken as, I=1.0 from table 6, clause 6.4.2 of IS 1893(Part I) 2002.

Soil Type: For calculation of lateral load it becomes necessary to know the type of soil. The average response spectrum coefficient (Sa/g) is depended on type of soil and also the fundamental natural time period (Ta).

Seismic Zones: In the present work of study, as per Indian codes of practice IS 1893 (Part I) 2002 the behavior of the model is checked for all the seismic zones given in the code. The zone factors and seismic intensity are taken from table 2 clause 6.4.2 IS 1893 (Part I) 2002.

Load Calculations: The proposed structural system is mainly subjected to primarily three types of load cases in accordance with the provisions made in Indian standard code of practices for safety of the structure.

The three types of loads used are

1. Dead Load [From IS:875-1987(Part I)]
2. Live load [From IS:875-1987(Part II)]
3. Seismic load [From IS:875-1987(Part I)]

Analysis of structural system

ETABS software is used for the analysis of the proposed structural model. The models are analyzed by equivalent static method and dynamic analysis method that is only response spectrum method for zone IV. Considering the method of analysis used for the model the lateral load calculation is made by the software itself and then this calculation are applied to carry out analysis of these models. The results are tabulated on the behavior of the used structural systems. In the present study the structure is subjected to lateral loads and analysis is carried out by using the Equivalent method and Response spectrum method due to symmetry of the structure.

Method of Analysis

In this present study method of analysis is made for Equivalent Static method and Dynamic analysis method (only response spectrum method) for seismic loads acting on the structure.

1. Seismic analysis is the calculation of the building response of structure to earthquake and is a relevant part of structural design where earthquakes are prevalent.

2. The seismic analysis of a structure involves evaluation of the earthquake forces acting at various levels of the structure during an earthquake and the effectiveness of such forces on the behavior of the overall structure. The analysis may be static or dynamic in approach as per the code provisions.

3. In the process of structural analysis system the analysis is carried out to predict its behaviors by using mathematical equation and physical laws.

4. Under various load effects, the main objective of structural analysis is to determine internal forces, stresses and deformation of structures.

The analysis of the building is carried out by following methods of analysis

1. Equivalent Static Analysis Method
2. Dynamic Analysis Method

1. *Equivalent Static Analysis*: The dynamic nature of the load must be considered when designing against seismic loads. The equivalent linear static method is sufficient for analysis for simple regular structure by using formula given in the IS code the distribution and estimate of base shear is calculated. Tall buildings with second and higher modes can be important with torsion effects are less suitable for this method and require more complex method to be used in these circumstances. Equivalent static Analysis method is used for estimation of structural displacement demands. The total applied force shall be equal to the product of the acceleration response spectrum (ARS) and the tributary weight. The horizontal force shall be applied at the vertical centre of the superstructure mass and is distributed horizontally in proportion for mass distribution.

2. *Response Spectrum Method*: The representation of maximum response of idealized multi degree of freedom (MDOF) system expressed in terms of superposition of modal response and each model being determined to single degree of freedom during earthquake ground motion. The undammed natural period for various damping values for maximum response is plotted which is expressed as maximum acceleration value and maximum relative velocity to maximum relative displacement. For this case response spectrum analysis has been performed according to IS 1893 (part 1):2002. The behavior of flexible structures by dynamic analysis is studied. Static analysis is carried out in which inertia forces can be neglected. But if there is any change in dynamic load, the response with the help of dynamic analysis must be determined in which the inertial force cannot be neglected and is equal to mass time of acceleration (Newton's 2^{nd} law)

$$F = M \times a \qquad (1)$$

Where F is inertial force,
M is inertial mass and
a is acceleration.

Fundamental natural period

Fundamental natural period is the first (longest) modal time period of vibration. It is the time required to complete one cycle of vibration at a given point. As per IS 1893 (part 1):2002 clause 7.6.2 the approximate fundamental natural period of all the moment resisting frames is calculated as

$$T_a = 0.075h^{0.75} \qquad (2)$$

Where, h is the height of building
The values of time period for earthquake are given in the table below for various types of building.

Table 1: Comparative values for fundamental natural period of various building

Modes	REG	REGO	IREG	IREGO
1	1.067877	1.030514	0.753317	0.824098
2	1.067854	0.981055	0.753305	0.824076
3	1.02655	0.981032	0.663654	0.661065
4	0.342334	0.342797	0.273515	0.27271
5	0.282568	0.266529	0.249112	0.254347
6	0.28256	0.266522	0.249109	0.254343
7	0.202422	0.203222	0.158577	0.15796
8	0.142458	0.142681	0.113766	0.117012
9	0.137495	0.135647	0.113765	0.117011
10	0.137482	0.135638	0.10646	0.106327
11	0.108887	0.108865	0.086466	0.086143
12	0.089726	0.087861	0.077798	0.078561

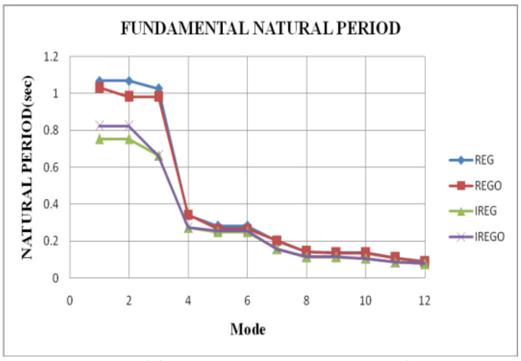

Fig.2. Comparison of fundamental natural period of various building

The graph shows the time period for different modes. This is the important aspect in earthquake waves. The graph shows the model time period results obtained. It is observed that by the introduction of regular and irregular building with outrigger, there is increase in time period compared to regular and irregular building without outrigger due to decrease in the stiffness of the structure. It was observed that by introducing outriggers is having less time period when compared to other model. By providing outrigger in regular and irregular building the time taken to complete one mode is considerably reduced.

Lateral Storey Displacement

Displacement refers to the lateral movement of stories from each other or from its original position by the action of seismic forces or earthquake action on the buildings.
As per IS 456:2000 the displacement should not be greater than the height of the building model taken for analysis by 500. The allowable displacement in the tall building is given as

$$D = H/500 \qquad (3)$$

Where, H is the total height of the building

Table 2: Comparative values for displacement by Equivalent static Analysis method

STOREY	REG	REGO	IREG	IREGO
1	0.0942	0.0925	0.0716	0.07
2	0.4168	0.4018	0.3167	0.3028
3	0.8661	0.8245	0.6579	0.6195
4	1.418	1.3362	1.0766	1.0009
5	2.0561	1.9203	1.5587	1.4326
6	2.7709	2.5665	2.0961	1.9049
7	3.5477	3.2595	2.6793	2.4067
8	4.3757	3.9877	3.2998	2.9271
9	5.2449	4.7403	3.9511	3.446
10	6.1448	5.5056	4.6218	3.866
11	7.07	6.2752	5.3279	4.423
12	8.0088	7.0345	6.0518	5.0109
13	8.9535	7.7605	6.7843	5.6104
14	9.8959	8.3445	7.5191	6.2123
15	10.8282	9.033	8.2499	6.8086
16	11.7447	9.7195	8.9718	7.3927
17	12.6379	10.3805	9.6794	7.9577
18	13.5032	11.0057	10.3691	8.4978
19	14.3389	11.5805	11.0388	9.0058
20	15.1356	12.033	11.6846	9.4464

Table 3: Comparative values for displacement by Response spectrum Method

STOREY	REG	REGO	IREG	IREGO
1	0.0974	0.1044	0.0866	0.0948
2	0.4178	0.4436	0.3682	0.3982
3	0.85	0.8957	0.7439	0.7972
4	1.3681	1.4319	1.1898	1.2642
5	1.9547	2.0328	1.6888	1.7792
6	2.5998	2.6866	2.231	2.329
7	3.289	3.3763	2.8062	2.8996
8	4.0132	4.0905	3.4067	3.4789
9	4.7642	4.8188	4.0269	4.0453
10	5.5342	5.5507	4.658	4.4951
11	6.3194	6.2788	5.3161	5.0827
12	7.1114	6.9901	5.9882	5.6993
13	7.9049	7.6646	6.6671	6.3258
14	8.6943	8.2021	7.3475	6.9534
15	9.4743	8.833	8.0243	7.5744
16	10.2411	9.4607	8.6934	8.1825
17	10.9893	10.0648	9.3503	8.7712
18	11.7157	10.6368	9.992	9.335
19	12.4193	11.1645	10.6169	9.867
20	13.09	11.5824	11.2217	10.3307

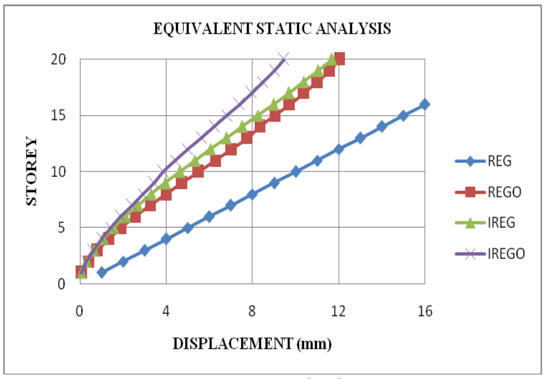

Fig.3. storey versus displacement

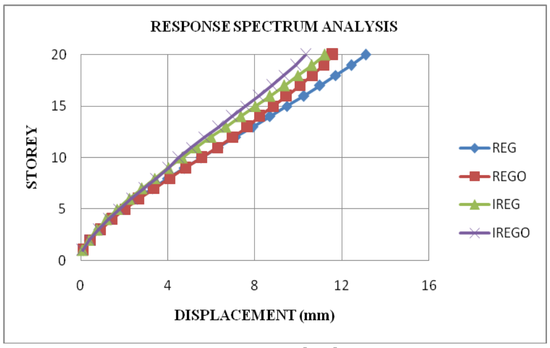

Fig.4. storey versus displacement

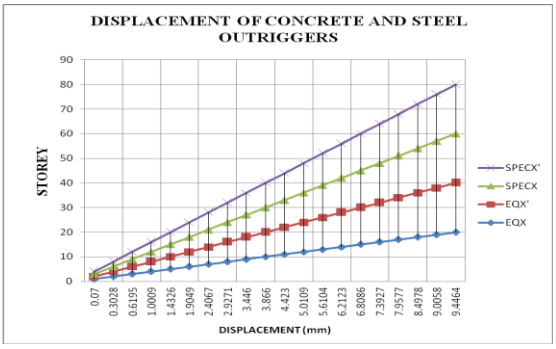

Fig.5. storey versus displacement

From the above graph the displacement of regular building and irregular building with outrigger is less compared to regular building and irregular building. The models are same but only the outriggers are placed.. By using equivalent static analysis method and response spectrum analysis the stories where the outrigger is provided has displacement very less compared to other storey. At the initial stories the displacement is same but after providing outrigger the displacement reduces much. When outrigger is provided the overall displacement of building is minimized. It is observed that the displacement of the irregular building using concrete outriggers is resisted up to 18% when compared with steel at the top floors by equivalent static method of analysis. The concrete outriggers is 16% less displaced the storey at the centre of the buildings. By response spectrum analysis the concrete outriggers are 6% less displaced compared to steel outriggers. The steel outriggers are less in providing stiffness against displacement may be due to connection problem between concrete and steel members.

Base Shear

Base shear is defined as the shear induced at the base of the building during earthquake. It depends on the mass and stiffness of building of the building. Base shear is an estimate of maximum expected lateral forces at the base of the structure due to earthquake ground motion.

Table 4: Comparative values for base shear by equivalent static method

Zones	REG	IREG	REGO	IREGO
2	4087.63	4087.63	4926.34	4527.28
3	6540.21	6540.21	7882.14	7243.64
4	9810.31	9810.31	11823.2	10865.5
5	14715.5	14715.5	17734.8	16298.2

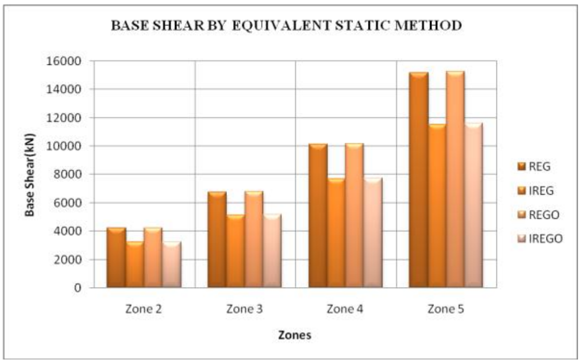

Fig.6. Comparison of base shear versus zones

Table 5: Comparative values for base shear Response spectrum method

Zones	REG	IREG	REGO	IREGO
2	4087.63	4087.63	4926.34	4527.28
3	6540.21	6540.21	7882.14	7243.64
4	9810.31	9810.31	11823.2	10865.5
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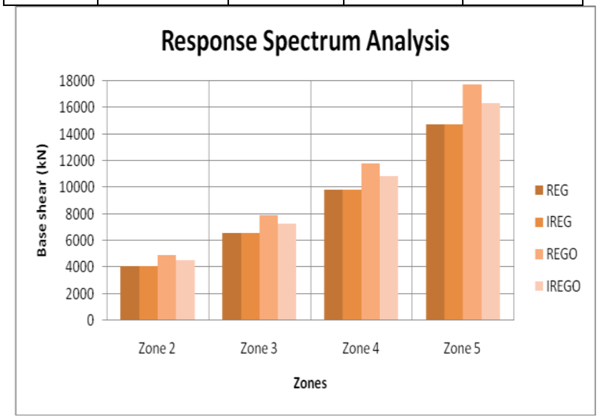

Fig.7. Comparison of base shear versus zones

The base shear in the regular building and irregular building with outriggers provided is less compared to regular and irregular building without outrigger in equivalent static and response spectrum method. By providing the outrigger the base shear is reduced.

IV. Conclusion And Scope For Future Study

1. The present study of work compares the difference in the behaviors of the building when outrigger is used. The following conclusions were drawn based on the project study.
2. The usage of outrigger system in the building increases the efficiency of the building when compared to building without outrigger under the action of lateral loads.
3. The outrigger plays an important role in increasing structural flexural stiffness by reducing base shear under the action of seismic static and dynamic loads.
4. The size of the outrigger members increases, the displacement in the tall building structural system decreases. Provision of shear wall at the central core with outrigger in the building decreases the forces in the core.
5. The behavior of building under the action of earthquake loads is different for different buildings.
6. The displacement reduction at the top floor of the building is less compared to the outrigger provided at middle floors.
7. The concrete outrigger is more efficient in reducing the lateral storey displacement than the steel outrigger (X bracing) in the tall RC building.
8. The outriggers can be used in the zones which have high seismicity.

9. Provision of outriggers in the regular building and irregular building structure, there is reduction in time period, contributing to overall stiffness of the structure.
10. The load resisting capacity of the tall building structure increases by providing outriggers due to its strength characteristics.
11. The irregular building with vertical floor irregularity due to the reduced self weight is more effectual than the regular building.
12. The introduction of outrigger in the tall building system will lead to minimization of inter storey drift.

Scope of future study

1. A detail dynamic analysis of the building is carried out by collecting the response of tall building structure at every mode.
2. The building models are compared by changing the soil interaction or type of soil to provide better information about the response of the system.
3. The building is compared with other structural systems such as belt truss.
4. The braced core wall can be used instead of shear wall.
5. The behavior of building for other type of irregular buildings can be studied.
6. The base isolation or springs technique may be used with outriggers.

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TEXT BOOK

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