How to Cite:
Reddy, S. P. S., & Ali, M. A. (2022). Analysis of vertically irregular R.C structure using outrigger system. *International Journal of Health Sciences*, *6*(S2), 11029–11042. https://doi.org/10.53730/ijhs.v6nS2.7957

Analysis of vertically irregular R.C structure using outrigger system

MS. S. Pooja Sri Reddy
Assistant Professor, Department of Civil Engineering, Malla Reddy Engineering College (Autonomous), Hyderabad, Telangana, 500100, India
Corresponding author email: poojasrireddycivil@mrec.ac.in

Mohammed Ahmed Ali
Student, Department of Civil Engineering, Malla Reddy Engineering College (Autonomous), Hyderabad, Telangana, 500100, India
Email: ahmedali7097@gmail.com

***Abstract*---**Tall building construction is quickly rising across the world, posing new issues that must be addressed by engineering judgement. The rigidity of a structure decreases as it becomes taller. As a result, in the current analysis of work, an outrigger system is recommended to increase the performance of the structure under seismic loading. The current effort includes a comparison study of regular and irregular buildings with and without outriggers, as well as a centrally stiff shear wall and steel bracings as outriggers. The construction is modelled with the "ETABS" application. To avoid causing harm to the structures, the limitations should be kept to a minimum. The outrigger is one of the maximum effective systems for efficiently controlling excessive lateral drift owing to lateral load, so that the danger of structural and non-structural damage may be avoided under minor or medium lateral loads due to either wind or seismic stress. This technique may be used to construct high-rise buildings, especially in seismically active areas. This research investigates the effective usage of outrigger systems in regular and irregular buildings with and without outrigger systems when exposed to earth quake loads. The findings of a study on storey displacement and base shear reduction based on time history analysis are presented in this article. ETABS 2015 was used to do the modelling and analysis.

***Keywords*---**outrigger, storey displacement, time history analysis, bracing system, earthquake.

Manuscript submitted: 27 March 2022, Manuscript revised: 09 April 2022, Accepted for publication: 18 May 2022

Introduction

Tall skyscraper construction is on the rise all around the world. Wind or earthquake-induced lateral stresses are frequently resisted using a system of connected shear walls in recent tall buildings. However, as the building grows in height, the stiffness of the structure becomes more critical, and an outrigger system between the shear walls and exterior columns is frequently utilized to give appropriate lateral stiffness. Outrigger systems are one such famous system that is presently regarded the most popular and efficient since they are easier to construct, cost less, and give good lateral rigidity to the structure.

From the dawn of time, the growth of tall structures has piqued humanity's interest. Tall constructions have always been considered as a sign of power and growth in the past. Assembling a tall skyscraper is a difficult operation in the construction industry. The study of representations by involvement and important physics are used to design tall buildings. At a certain height, moment resistant structures and fixed cores become ineffective in providing rigidity alongside wind and seismic stresses. Outriggers are given by the shear core with outside borders in tall structures to boost rigidity action alongside wind and seismic loads. The investigation is being done to learn about outrigger performance in tall structures. In the analysis of tall buildings, the lateral stress put on the structure is an essential consideration.

Definition of Tall Buildings

The position of the structure and the nearby environment have a role in determining what constitutes a tall structure. A tall structure, on the other hand, may be characterized as a structure whose structural system has to be adjusted to make it cost-effective to withstand lateral loads from a structural engineering standpoint.

Effect of Vertical Irregularities

Asymmetrical constructions are those that have a structural break. The impact of irregularity was determined by the size and position of the irregularity, and differences in seismic reaction limits were discovered in the area of the irregularity.

Types of Outrigger Systems

The traditional or straight outrigger system is the initial kind. These outriggers are openly attached to the fixed essential or shear walls at the core, as well as the outside columns, as the name suggests.

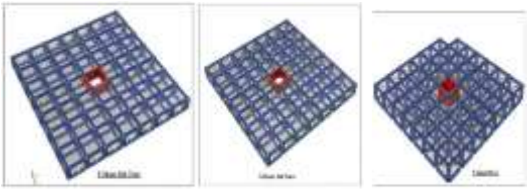
There are 2 kinds of outrigger trusses based on their connection to the core:

- Conventional Outrigger system
- Virtual Outrigger system

Outrigger systems are divided into 2 categories.

1. Conventional outrigger concept
2. Virtual outrigger Concept

Shapes of Outrigger Systems



X, V & N - Shape Belt Truss

Objectives of Study

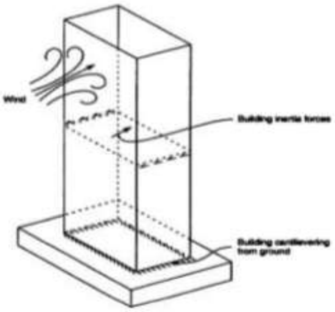
1. The usage of outriggers in a regular and vertical irregular building under earthquake stresses is the focus of this research.
2. Outrigger and non-outrigger structures are contrasted.
3. In structures, outriggers are added at 2 levels.
4. In order to reduce lateral displacements, the outrigger location in the building is determined.
5. Base shear and storey drift are investigated.

Concept of outrigger system

Outriggers are used by big cruising ships in the past and now to assist them resist the wind pressures in their sails. The heart of a tall structure can be compared to the mast of a ship, the outriggers to the spreaders, and the outside columns to the stays or shroud of the ship.

Structural concepts

When the structure is subjected to plane stress, the column-restrained outrigger resists the core's rotation, resulting in less lateral refractions then moments in the core than if the core stood alone. Constructions with vertical irregularity have staggered sharp drops in floor area throughout their height. Since of its practical and aesthetic design, irregular structure forms are becoming more common in modern multi-story structure building. In an urban environment with closely spaced tall buildings, such a setback design, in particular, allows ample daylight and ventilation for the lowest storey.

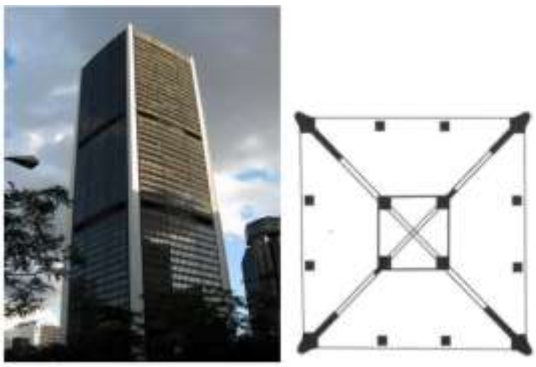


Structural Concept

Types of Outrigger System

Outrigger Systems

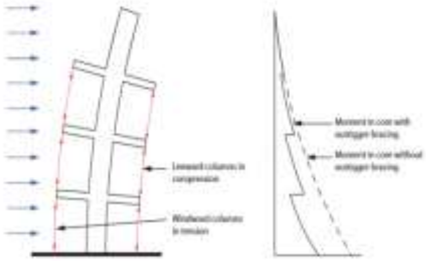
Outrigger systems are lateral load-resisting devices that may efficiently reduce lateral loads while also strengthening tall structures. The exterior and interior structures of this system work together to withstand lateral stresses. Outrigger trusses serve as strong arms that link the structure's primary to the external pillars. When the structure is subjected to lateral loads, the core attempts to alternate, causing pressures to be useful to the outrigger trusses, causing tension in the exposed pillars and three compressions in the leeward columns.



Outriggers and Core Interaction. (Source: Taranath 1998)

Historical Backgrounds of Outrigger Systems in Tall Buildings

Outrigger systems have been used to solve fundamental drawbacks for perimeter and bundled-tube frame structures then their introduction in the 1960s and 1970s. Architectural objectives can be met by varying the distance of exterior columns from outrigger structure projects. The outrigger mechanism was used for the first time in a concrete structure. To concentrate dead weight, the architect for this structure adopted a strategy of fewer but larger columns.



Tour de la Bourse, Montreal, Canada, and the tower mechanical floors layout
(Source: CTBUH)

The two office tower designs are identical, featuring traditional outrigger and belt trusses in the center and top of the structures, as well as belt trusses at the bottom of the towers enabling column spacing changes.

140 William Street in Melbourne (left), U.S. Bank Center in Milwaukee (right)
(Source: CTBUH)

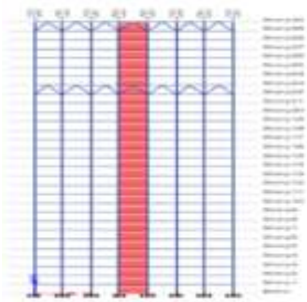
Following these huge constructions and the improvement of high-strength concrete, which provides the stiffness and strength required at a lower cost, outrigger systems have become a popular alternative for structures up to 60 storeys.

	Building	Location	Year of Completion	Stories	Height(ft)	Material	Use
1	Burj Khalifa	Dubai, UAE	2010	163	2,723	Composite	Multiple
2	Shanghai Tower	Shanghai, China	2015	128	2,073	Composite	Multiple
3	Ping An Finance Center	Shenzhen, China	2017	115	1,965	Composite	Office
4	Lotte World Tower	Seoul, South Korea	2017	123	1,823	Composite	Multiple
5	One World Trade Center	New York, USA	2014	104	1,792	Composite	Office
6	Guangzhou CTF Finance Center	Guangzhou, China	2016	111	1,739	Composite	Multiple
7	Tianjin CTF Finance Center	Tianjin, China	2019	98	1,739	Composite	Multiple
8	Taipei 101	Taipei, Taiwan	2011	101	1,667	Composite	Office
9	Shanghai World Financial Center	Shanghai, China	2008	101	1,622	Composite	Multiple
10	International Commerce Centre	Hong Kong, China	2010	118	1,588	Composite	Multiple

The Ten Tallest Completed Buildings Utilize Outrigger Systems

Conventional outrigger system

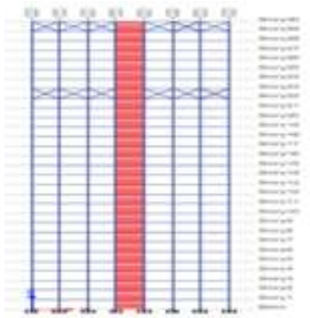
Outrigger trusses or girders are linked directly to shear walls or fixed borders at the core and to columns placed outboard of the core in a traditional outrigger arrangement. The columns are usually, but not always, located along the structure's perimeter. The outrigger will enable some rotation of the core by shortening and elongating the columns and deforming the trusses. The turning is usually minimal enough that the core reverses curvature beneath the outrigger in greatest configurations.



Conventional Outrigger System

Virtual outrigger system

Several of the complications related by the usage of outriggers are avoided by eliminating a straight joining among the trusses with the core. The effective outrigger's primary principle is to employ floor diaphragms, which are normally quite rigid and robust in their individual level, to transmit instant from the core to trusses or walls that are not linked directly to the core in the procedure of a horizontal pair.



Virtual Outrigger System

Advantages of Outrigger System

- The resistance to turn over is shared by all external columns.
- By applying a opposite moment to the core at individually outrigger joining, the core capsizing instant may be decreased.
- External bordering can be as basic as beam and column bordering, obviating the requirement for stiff border connections with lowering total costs.
- Without the column and foundation arrangement, there is a decrease or removal of improve and net tension pressures.
- The amount of improve and tension pressures in the columns and foundations can be greatly decreased.

Literature Review

Introduction

To comprehend the value and requirement of this examination in the context of wind and earthquake resistant project, procedural publications from different journals from India and outside are examined.

Thejaswini R. M. and Rashmi A. R. (2015) For this study, they created a geometrically irregular 14-story RCC high-rise building with several structural systems, including rigid frame, core wall, and shear wall structures with various shear wall placement combinations, tube structure, and outrigger structure.

Po Seng Kiran and Frits Torang Siahaan (2001) By joining outrigger and belt truss systems concerning core to outside column, we were able to boost the construction's rigidity and make it capable of surviving wind and seismic loads.

The use of transverse outrigger and belt truss by various configurations was examined by the writers in this study effort. They conducted the research on a 40-story 2-dimensional perfect subjected to wind stress by incorporating outrigger and belt truss structures by 8 distinct outlines by adjusting outrigger placements according to British standards.

N. Herath et al. (2009) The study was conducted by assumption that quake earth indication may happen everywhere in the globe, and that the danger connected by high structures, particularly during severe earthquakes, should be assumed extraordinary consideration, because High rise buildings often house thousands of people.

Kiran Kamath et al. (2012) completed a research of a cost-effective Outrigger Structural System in a high-rise reinforced concrete structure. The main goal of this study project was to enhance structural stiffness and make the important form more effective when subjected to lateral stresses such as wind and earthquakes. Their investigation looked at how different designs of outrigger systems affected the performance of reinforced concrete structures with central core walls. The authors of this article also considered the comparative tallness of the outrigger beam in tall structures when determining the best position for an outrigger system.

Kiran Kamath et al. (2012) By employing an outrigger essential system, investigated difference pillar shortening caused by long-term effects in high buildings. The essential principle behind this study is that cumulative difference column shortening leads slabs to tilt, causing partitions to rotate. Due to difference shortening of columns, elevators may not work properly, pipes may deform or be damaged, partitions and finishes may fracture, and a variety of other service issues may arise in the structure. As a result, it's critical to investigate the impact of column shortening, which necessitates extra plan considerations. The major goal of this study was to determine the best outrigger position in a high-rise RC structure in order to minimize variance column limitation.

Abbas Hangollahi et al. (2012) To optimize the position of outriggers, worked on a high-rise steel-framed structure that was subjected to an earthquake load. The main goal of this study was to compare the outcomes of response spectrum and non-linear time history approaches for determining the best outrigger site for lateral displacement and narrative drift.

Methodology

This outrigger analysis in positions of steel bracings is based on assessment of several essential methods on tall buildings of diverse heights with capacity strengths. The outrigger impression is used to its full potential then is assumed the attention it deserves. The purpose of the research is to resolve the uncertainty around the selection of the appropriate type of construction system in accordance with Indian norms. The structure is examined for seismic zones of varied severity. Structure breakdown begins at places of vulnerability during an earthquake. The discontinuity in mass, rigidity, and geometry of the structure is the source of this weakness. One of the most common causes of structural collapse in earthquakes is vertical abnormalities.

Sl.No.	Particulars	Model Data
1	Analysis Type	Response Spectrum
2	Software Selection	ETABs
3	Data Analysis	Max. Displacement Value, Story Drift Rotation Value
4	Load Pattern	Live Load, Dead Load, EQx&EQy
5	Zone Factor	IV Zone (Z=0.24)
6	Importance of Structure	1
7	Soil Type	II (Medium)
8	Type of Structure	RC Moment Resisting Building

Some of the parameters used for the analysis of building

Analysis of structural system

The suggested fundamental construction is analysed using ETABS software. For zone IV, the models are considered using an analogous static approach and a dynamic analytic method, which is the sole response spectrum method. The programme calculates the lateral load for the model based on the type of analysis utilized, and then this computation is used to the study of these models. The findings are summarized based on the behavior of the structural systems that were utilized.

Modeling and Analysis Program

A computer programme was built for this work to analyze reinforced concrete structures under wind and earthquake stresses, taking into consideration the latest revisions in the IS-1893 PART-1 2002. The base shear that resists the design lateral stresses is calculated using the software. It also figures out the building's Centre of mass and stiffness. The application graphically illustrates all of the findings in order to make the information apparent.

Building Configration

The study of structure model includes twenty stories with a constant storey height of 3 meters. The results are interpreted using various ZONE FACTOR values and their accompanying impacts. Other information is provided below:

PARAMETERS	ZONE II	ZONE III	ZONE IV	ZONE V
Seismic zone factor	0.10	0.16	0.24	0.36
Basic wind speed	44 m/s	39 m/s	47 m/s	50 m/s
Response reduction factor	5	5	5	5
Importance factor	1	1	1	1
Soil thickness	Medium	Medium	Medium	Medium
Slab thickness	0.150 m	0.150 m	0.150 m	0.150 m
Beam size	0.45x0.25 m	0.45x0.25 m	0.45x0.25 m	0.45x0.25 m
Column size	0.75x0.75 m	0.75x0.75 m	0.75x0.75 m	0.75x0.75 m
Live load	2KN/m^2	2KN/m^2	2KN/m^2	2KN/m^2
Dead load	4.5 KN/m^2	4.5 KN/m^2	4.5 KN/m^2	4.5 KN/m^2
Floor finish	1.1KN/m^2	1.1KN/m^2	1.1KN/m^2	1.1KN/m^2
Material properties	M_{30}	M_{30}	M_{30}	M_{30}

Table 1 Building configuration data

Loads

Loads Acting On G+20 Builiding

Tall structures vary from low-rise buildings in a number of aspects, including the significant accumulation of gravity loads on the floors from top to bottom, high-rise structures require accurate load assessments. Live loads can be estimated based on a mix of past field observations and expertise. Wind and earthquake loads are unpredictable and difficult to forecast in nature. They're calculated using a probabilistic method. The following section discusses some of the most frequent types of loads that may be applied to high-raised constructions.

a. Dead loads
b. Live loads (or) Imposed Loads
c. Gravity loads
d. Wind loads
e. Earthquake loads.

Load Combinations

As a result, the different loads should be blended in line with the appropriate design regulations. In the absence of such suggestions, the loading combinations listed below are used. The most adverse influence in the structure, as well as the structural part in question, may be used.

COMBINATION NUMBER	LOAD COMBINATION
COMB1	1.5(D.L+L.L)
COMB2	1.5(D.L+EQX)
COMB3	1.5(D.L+EQY)
COMB4	1.5(D.L-EQX)
COMB5	1.5(D.L-EQY)
COMB7	1.2(D.L.+L.L+EQX)
COMB8	1.2(D.L.+L.L+EQY)
COMB9	1.2(D.L.+L.L-EQX)
COMB10	1.2(D.L.+L.L-EQY)
COMB11	1.0(D.L+L.L)
COMB12	1.0(D.L+EQX)
COMB13	1.0(D.L+EQY)
COMB14	1.0(D.L-EQX)
COMB15	1.0(D.L-EQY)
COMB16	1.0D.L.+0.8L.L+0.8E QX
COMB17	1.0D.L.+0.8L.L-0.8EQX
COMB18	1.0D.L.+0.8L.L+0.8E QY
COMB19	1.0D.L.+0.8L.L-0.8EQY

Table 2 Load combinations

Results

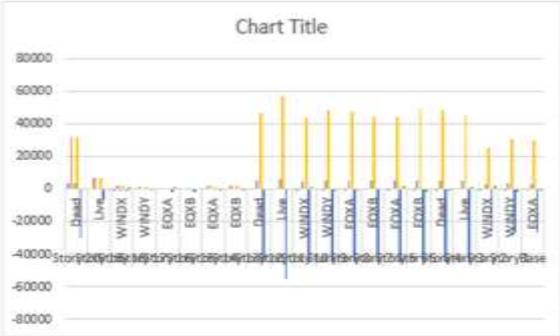
An apartment building of G+20 stories is analysed and designed. The study is carried out with the help of the programme ETABS V15.2, which has proven to be superior in terms of analysis and design of various portions. An isolated footing is given according to the soil investigation results. ETABS was used to design RCC frame members such as beams and columns. To the greatest extent feasible, the study and design followed conventional requirements. The structural engineer was also aware of the different challenges experienced during the design process, as well as the many limits he faced in designing up to the architectural drawing.

Support Reactions

Story	Load	FX	FY	FZ	MX	MY	MZ
Story 20	Dead	3392.0004	31192.9967	3392.0004	31192.9967	-29874.1549	0
Story 19	Live	773	7119	773	7119	-6795	0
Story 18	WINDX	-137.7701	1765.3167	-137.7701	1765.3167	-7.1655	1121.0991
Story 17	WINDY	0	1247.0968	0	1247.0968	0	-680.4533
Story 16	EQXA	0	0	0	0	-2238.838	1012.2531
Story 15	EQXB	0	0	0	0	-2238.838	834.8752
Story 14	EQXA	0	2238.838	0	2238.838	0	-939.7654
Story 13	EQXB	0	2238.838	0	2238.838	0	-762.3875
Story 12	Dead	0	0	5088.0006	48789.495	-44811.2324	0
Story 11	Live	0	0	6247.5006	57467.995	-55003.7324	0
Story 10	WINDX	-90.7271	40.675	4832.6763	43856.0159	-44011.5845	1345.3189
Story 9	WINDY	90.7271	-40.675	5163.3247	48092.7761	-43994.3873	-1345.3189
Story 8	EQXA	0	-90.7271	4998.0005	47470.9322	-44002.9859	-816.544
Story 7	EQXB	0	90.7271	4998.0005	44477.8798	-44002.9859	816.544
Story 6	EQXA	-113.4089	50.8437	4881.3454	44141.5199	-44821.9806	1681.6487
Story 5	EQXB	113.4089	-50.8437	5294.6558	49437.4701	-44800.4841	-1681.6487
Story 4	Dead	0	-113.4089	5088.0006	48860.1403	-44811.2324	-1020.68
Story 3	Live	0	113.4089	5088.0006	44918.8497	-44811.2324	1020.68
Story 2	WINDX	-113.4089	50.8437	2846.1451	25425.7219	-28897.4877	1681.6487
Story 1	WINDY	113.4089	-50.8437	3239.4556	30721.6721	-28875.9912	-1681.6487
Base	EQXA	0	-113.4089	3052.8004	29944.3423	-26886.7394	-1020.68

Maximum Story Shear for ESA along X & Y Axis

Shear force and bending moments are 2 forms of support responses. FX, FY, and FZ reflect the shear force of support responses. The bending moment support responses are represented in MX, MY, and MZ.



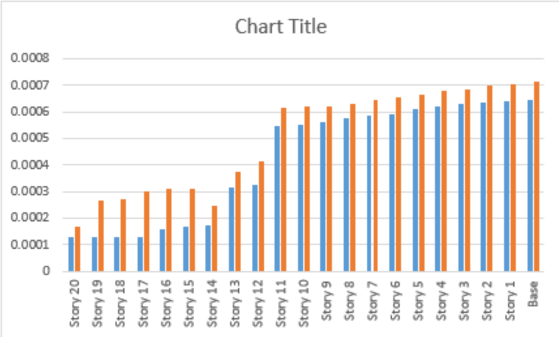
Graph for support reaction

Story Shear

Storey shear refers to the lateral forces that occur as a result of an earthquake on various levels. Its value is highest at the bottom and lowest at the top.

Story	Drift X	Drift Y
Story 20	0.000127	0.000166
Story 19	0.000127	0.000265
Story 18	0.000127	0.000270
Story 17	0.000130	0.000301
Story 16	0.000157	0.000310
Story 15	0.000166	0.000311
Story 14	0.000173	0.000245
Story 13	0.000317	0.000375
Story 12	0.000325	0.000415
Story 11	0.000545	0.000615
Story 10	0.000550	0.000618
Story 9	0.000562	0.000622
Story 8	0.000578	0.000632
Story 7	0.000584	0.000645
Story 6	0.000592	0.000655
Story 5	0.000610	0.000662
Story 4	0.000622	0.000677
Story 3	0.000628	0.000682
Story 2	0.000636	0.000699
Story 1	0.000639	0.000701
Base	0.000645	0.000715

Table 3 Story shear



Graph for story shear

Conclusions

1. The current research compares the differences in building behavior when outriggers are implemented. Based on the project research, the following results were reached.
2. The behavior of structures under the influence of earthquake loads differs from one building to the next.
3. When compared to the outrigger supplied on the intermediate levels, the displacement reduction at the top floor of the building is reduced.
4. Outriggers can be employed in areas with strong seismic activity.
5. By include outriggers in both regular and irregular building structures, time is reduced, which contributes to the structure's overall rigidity.
6. Because of its strength properties, the tall building structure's load-bearing capability is increased by introducing outriggers.
7. Because of the lower self weight, the irregular building with vertical floor irregularity is more effective than the regular construction.
8. By incorporating outriggers into the tall building system, inter-story drift will be reduced.

Scope of Future Study

1. The reaction of the tall building structure at each mode is collected for a detailed dynamic study of the building.
2. To offer greater information about the system's reaction, the building models are compared by modifying the soil interaction or kind of soil
3. Instead of a shear wall, a braced core wall might be employed.
4. The behavior of different types of irregular structures can be investigated.
5. Outriggers can be employed with the base isolation or springs approach.

References

1. J.R.Wu, Q.S.Li, ‘Structural performance of multioutrigger braced tall building’ Department of Building and Construction, City University of Hong Kong, Kowloon, 2002.
2. Z. Bayati , M. Mahdikhani and A. Rahaei , “Optimized use of multioutrigger systems to stiffen Tall building “The 14th World Conference on Earthquake Engineering October 12- 17, 2008, Beijing, China

3. Gerasimidis, Efthymiou and Baniotopoulos, “Optimum Outrigger Locations of High-Rise Steel Buildings foe Wind Loading”, Proceedings of EACWE-5, 19th to 23rd July, 2009.
4. Hearth, Haritos Ngo and Mendis, “Behavior of Outrigger Beams in High-Rise Buildings under Earthquake Loads”, Proceedings of Australian Earthquake Engineering Society Conference, 2009.
5. Hoenderkamp, “Shear Wall with Outrigger Trusses on Wall and Column Foundations, The Structural Design of Tall And Special Buildings, Volume 13, Page no. 73-87, 2004.
6. Dr.K.S. Sathyanarayan, A. Vijay, S. Balachandar, ‘Feasibility studies on the use of outrigger system for R.C core frames’ Department of civil Engineering, SRM University, India.