RESEARCH ARTICLE

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Investigation on Seismic Performance of Outrigger Structure For High Rise Building

Pratiksha Patil[1*], P. R. Satarkar[2]

[1*,2] Department of Civil Engineering, AISSMS College of Engineering, Pune, India; e-mail*: patilpratiksha0101@gmail.com

Abstract

As of today's growing population, tall buildings are now being built, with various sorts of high-rise buildings in terms of lateral resisting systems. Outriggers are one of the most effective lateral load resisting techniques for increasing the stiffness and seismic capabilities of a building. Shake table tests are effective ways of determining a building's seismic capacity in seismic engineering. Due to the limited size and capacity of existing shake tables, scale structural models will be required. However, to know the real effect of a building and because of the limited capacity of shake table, we can use software to analyze building's seismic performance. In this paper, an investigation of the seismic performance of past experimental work has been performed in the software Etab, and to validate the result same method has been applied. A software tool was used to do modal analysis on the prototype structure, and the experimental data was compared with the software results to acquire a better understanding of the building's seismic performance. In past experimental study, free vibration test was carried out to know the time period of the structure. In order to observe the same result, modal analysis is performed in software to find out modal period and the damping ratio was calculated manually. After comparing the software result and experimental values of time period and damping, it was clear that the software application and the experimental findings were in good concordance.

Keywords - Shake table test, high-rise building, outrigger, ETABS

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Introduction And Literature Review

As of today's growing population and limited horizontal space, tall buildings are becoming increasingly necessary. However, as building height increase, we must choose the appropriate structural system for a tall structure. Tall structures are subjected to a variety of loads. It's crucial to choose the right structural system for a tall building that will be subjected to horizontal loads. The responsiveness of tall structures to horizontal loads is a fundamental aspect that influences their design.

In modern tall buildings, moment resisting frame structures, shear wall structures, braced frame structures, and tubular structures may not provide enough stiffness to resist lateral loads for structures taller than a certain height, so outriggers between the core walls and exterior columns are used to provide adequate lateral stiffness to the structure. Outriggers

Corresponding Author : Pratiksha Patil, Department of Civil Engineering, AISSMS College of Engineering, Pune, India; e-mail : patilpratiksha0101@gmail.com

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are a stiff beam that connects the core wall to the exterior columns to improve the stiffness and strength of the building against overturning.

The core outrigger system is a type of very effective lateral load resisting structural system that has been widely used in high rise buildings. Outriggers connect the core and perimeter columns in this system, potentially increasing the lateral rigidity of the system. As a result, it considerably lowers roof displacement and controlling drifts is the primary function of outriggers in tall buildings.

As building height increases it get affected by lateral forces so we use shake table test to know the real effect of building affected by seismic behavior. Shaking table tests are effective ways for determining a building's seismic capacity in seismic engineering. Due to the limited size and capability of conventional shaking tables, scale structural models appear to be required. Many experiments have been carried out in recent years employing shaking table testing to measure the seismic response of structure models exposed to varied earthquake records.

Sun et al. (2017), used a 1/40 scaler model of a 56-story core outrigger building to test the seismic behavior of the structure on a shake table. Wang (2017) provided experimental results on a new type of steel-concrete hybrid outrigger system for high-rise buildings with metal dampers, concluding that it improves the building's overall structural performance. Tan et al (2012) conducted a shake table test of the building with damped outriggers and compared the results to a set of earthquake records, finding that it improved the frame core structure's performance. Lu et al. (2014) analyse the seismic performance of a high-rise building in Shanghai, China, with steel reinforced concrete columns and reinforced concrete core tubes, and find that outrigger truss are the key structures to withstand a substantial portion of seismic action. Zhou et al. (2008) investigated the usage of core walls with steel perimeter frames to create an efficient hybrid structural system. Lu et al (2006) conducted a shaking table model test of the Shanghai World Financial Center Tower, using a 1/50 scaled model with steadily rising acceleration amplitudes, to investigate the structure's seismic behavior and failure process. Outrigger, Ring truss, Buttress core, and shear wall types are discussed in 2018. Kavyashree (2021) gave a presentation on the evolution of the outrigger structural system from conventional to damped outrigger concepts, as well as the benefits of outriggers. Smith et al. (2007) offer a new approach for high-rise building structural design in which damped outriggers are employed to establish a high level with the primary goal of decreasing dynamic wind effects.

Many experimental researchers used shake table tests to assess seismic response of structures subjected to varied earthquake records, have been conducted in recent years. However, just a few academics are working on the software technique for creating the model and validating it with experimental data.

The key objective of this paper is to validate the model in ETABS with past experimental studies to check the accuracy. So, in this study a full technique for modelling the experimental data was performed and results were compared.

In this paper section 1 defines introduction and literature review. Section 2 explains background, concept and history of topic. Section 3 describes case study of building. Section 4 describes methodology adapted for analysis. Section 5 explains how modelling is done in software. Section 6 is about result and discussion and section 7 consists of conclusion from obtained results.

BACKGROUND

History (Gore,2018)

The philosophy of the outrigger system is based on the practice of rigging a float ahead of the side of a boat to improve the vessel's strength against the wind at sea. This simple procedure sharpened the ideas of modern researchers to develop the outrigger structural system. Outriggers are used by famous sailing ships in the past and present to help resist wind forces in their sails. The tall building's core is compared to the ship's mast, the outrigger to the spreaders, and the outside columns to the stays or shroud.

Concept of Outrigger System

The external columns are attached to the central core wall with exceptionally rigid outriggers in the outrigger system, which is one of the lateral load resisting systems. The purpose of adopting an outrigger system is to improve structural lateral stiffness and overall stability by connecting the core-tube and external columns with rigid horizontal cantilevers.

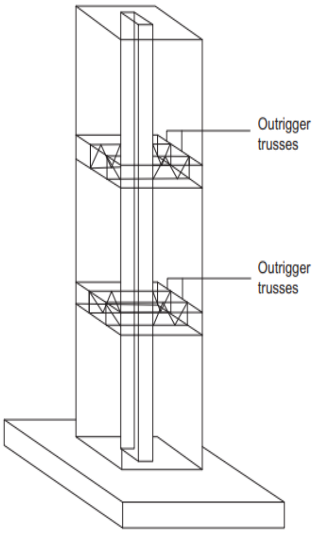


Figure 1 : Concept of Outrigger (2018)

CASE STUDY BUILDING

To validate the model in ETABS considering past experimental study for checking the accuracy. Experimental paper chosen for validation was by Feifei Sun (2017).

Table 1 shows, the model information of prototype and etab model.

Table-1: Model Information

Name	Prototype	Test model	Etab model
Plan	32x32 m	0.8x0.8m	0.8x0.8 m
Storey	56	28	28
Building height	201.6 m	5.04 m	5.04 m
Storey height	3.6 m	0.18 m	0.18 m
Outrigger storey level	$18^{th}19^{th}$ 37^{th} 38^{th}	9^{th} 19^{th}	9^{th} 19^{th}
Core brace	1-56	1-28	1-28

A 1/40 scaled planar test model of a 56-story core outrigger structure was tested on a shaking table to study the devastating seismic resonance effect of ground vibrations on tall building constructions. The 56-story prototype structure has a height of 201.6 m, constant height of storey is kept as 3.6 m and plan is of 32 m x 32 m. There are five grid line in x direction and five grid line in y direction with each column spaced at 8 m distance. Outriggers were put on the 18th, 19th, 37th, and 38th stories in that model. A planar model was used in the test to make the creation of the test model easier. By taking one planar core outrigger system from the prototype structure and integrating every two storeys into one, a simplified structure was created. So, simplified structure has 28 storeys. Members' section sizes were also changed as a result. As a result, on the 9th and 19th levels, outriggers of the reduced structure appeared.

For performing the same building model in software etab, scaled down model were considered and for free vibration test, modal analysis was carried out. Section sizes and material properties were applied as it is.

METHODOLOGY

An Investigation on the software performance comparison with experimental data of outrigger structures exposed to seismic loads is conducted. Etab version 18 was used to create the model.

Etab is an engineering software that helps with multi-story building analysis and design. Etab can be used to evaluate basic or advanced systems under static or dynamic situations.

The behaviour of the building was checked by performing a free vibration test. The parameters like the time period, logarithmic decrement and damping ratio were checked. For this purpose, modal analysis was used to capture the response for the building.

MODELLING IN ETABS

Table-2 and 3 shows the section and material properties considered for modeling.

Sectional Properties of Member

Table- 2: Sectional Properties of member

Member	Floor	Section (mm)
Frame column	1-11	35 × 1.5
	12-17	30 × 1.2
	18-28	22 × 1.0
Frame beam	1-28	18 × 12 × 0.8
Core column	1-6	30 × 1.2
	7-12	22 × 1.0
	13-28	20 × 0.8
Core beam	1–28	18 × 12 × 0.8
Core brace	1–28	16 × 10 × 0.8
Outrigger brace	9^{th} and 19th	18 × 12 × 0.8

(Feifei Sun, 2017)

Material Properties

Table-3: Properties of Material

Name	Prototype	Test model	Etab
YIELD STRESS (MPa)	345	190	190
ELASTIC MODULUS (MPa)	2.06E5	1.14E5	1.14E5
POISSONS RATIO	0.3	0.3	0.3
DENSITY (kg/m3)	7,850	9,096	9,096

(Feifei Sun, 2017)

Modelling

To model the building in etab Chinese Standard code GB 50011 is considered for seismic design of building. Etab version 18 is used for modelling the section followed by steps:

New model > Select code > Grid line > Edit grid data > Creating geometry > Define material properties > Define section properties > Assign property> Define load cases > Define mass source > Define modal cases > Analyse > Set modal cases to run > Plot results.

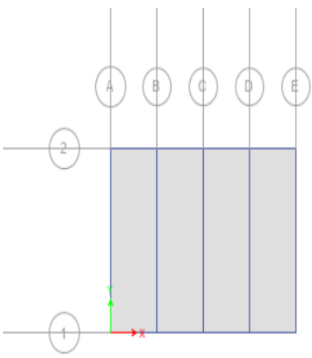


Figure 2: Top View of The Model

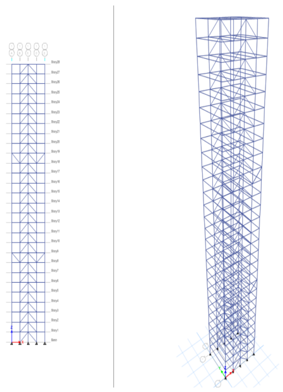
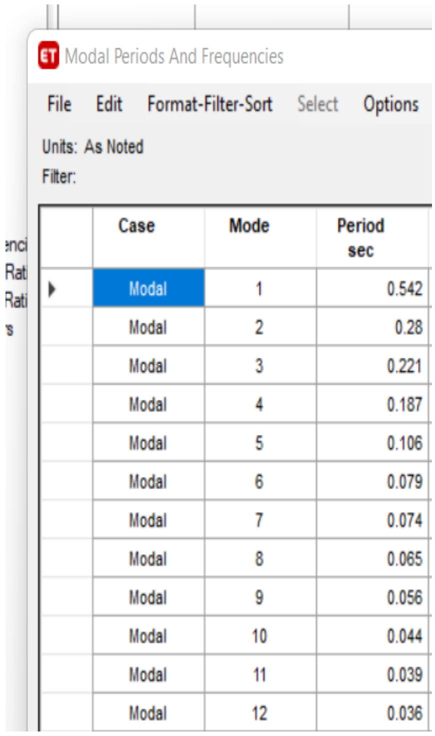


Figure 3: 3D model

Figure 2 and 3 displays the plan view and 3D model of the building where, outriggers are provided at 9th and 19th floor level.

Result and Discussion

In considered experiment, Free vibration tests are used to determine the structure's inherent frequencies and damping ratios. The first natural period (T1) and the accompanying damping ratio are 0.54 s and 0.0083, respectively, based on the decay of the acceleration on the top floor. After performing the modal analysis in software, got the first time period as 0.542 sec.



Case	Mode	Period sec
Modal	1	0.542
Modal	2	0.28
Modal	3	0.221
Modal	4	0.187
Modal	5	0.106
Modal	6	0.079
Modal	7	0.074
Modal	8	0.065
Modal	9	0.056
Modal	10	0.044
Modal	11	0.039
Modal	12	0.036

Figure 4: Result of Time Period

Figure 4 shows, the software result of first time period.

In a free vibration test, the top floor's acceleration time history was recorded and the graph obtained as:

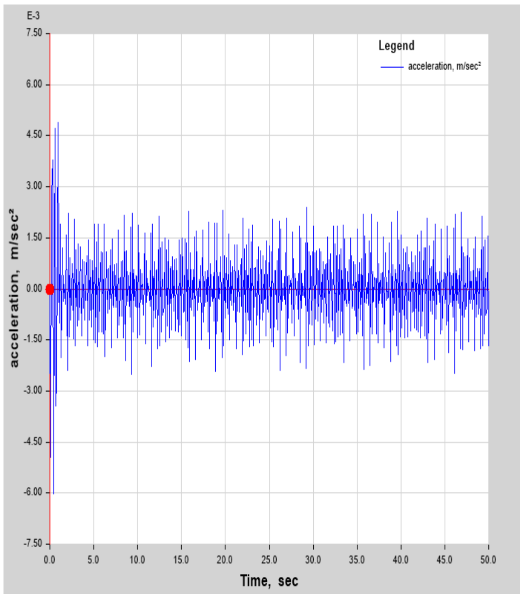


Figure 5: Graph of Accleration vs Time

Calculation for Damping Ratio

For calculation of damping ratio, a graph is plotted from 35 to 40 sec time from a graph obtained by free vibration test.

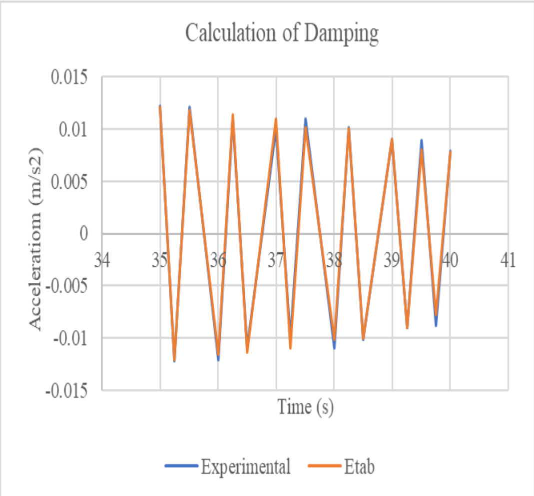


Figure 6 : Calculation of Damping

Figure 6 shows, the graph of acceleration vs time from 35 sec to 40 sec. Blue color shows the graph obtained by experimental result and orange color shows the graph obtained by Etab, which is overlapped on experimental graph.

$$\varepsilon = dampingratio = \frac{damping\ coefficent}{criticaldampina\ \ coefficient}$$

$$= \frac{c}{c_c}$$

δ = logarithmic decrement

$$\delta = In\left(\frac{x_i}{x_{i+1}}\right)$$

$$\delta = \frac{\text{In}\,\frac{a_i}{a_{i+k}}}{n} = \frac{\text{In}\,\frac{0.0118}{0.0078}}{7} = 0.059$$

$$\delta = 2\mu\varepsilon$$

$$\varepsilon = \frac{\delta}{2\mu} = \frac{0.059}{2\mu} = 0.00795 \approx 0.008$$

$$\varepsilon = 0.008$$

As per Figure 6, the values obtained from etab and the results obtained by experimental data are overlapped. Hence, after comparing the software result and experimental values of time period and damping, it was clear that the software application and the experimental findings were in good concordance.

Table-4: Comparison of Results

Name	Experimental	Etab
1^{st}Time period(T1)	0.54 s	0.542 s
Logarithmic decrement	0.0523	0.059
Damping ratio	0.0083	0.008

Conclusion

The shake table test is a method for determining a building's seismic capacity, but for performing shaking table test we need huge setup, space, material and availability of big shake table, which leads to more cost consumption. Hence, after performing the same test on software, it is observed that result of the experimental data and software are correctly matched. It is easy to analyze the behavior of structure using software and it is cost effective. As the primary objective of this paper is to validate the model in ETABS with past experimental data, the analysis is performed successfully.

1. Results are validated with experimental data by performing the analysis in software etab.
2. Time period obtained by software is 0.542 s and time period obtained by experimental analysis was 0.54 s which is almost same, that means it shows the accurate bonding between experiment and software application.
3. Logarithmic decrement obtained by software is 0.059 and by experiment was 0.0523. It shows that approximately 90% results are same.
4. Damping ratio is calculated and resulted 0.008 which is almost same as result obtained by experimental data that is 0.0083.

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References

[1] Feifei Sun, Zhibin Hu, Guangyuan Chen, Liming Xie, Li Sheng, "*Shaking table test on seismic resonant behavior of core outrigger structure*", Struct Design Tall Spec Build 2017, © 2017 John Wiley & Sons, Ltd.

[2] A.J. Wang, "*Experimental studies into a new type of hybrid outrigger system with metal dampers*", Structural Engineering and Mechanics, Vol. 64, No. 2 (2017) 183-194.

[3] P. Tan, C.J. Fang, W.R. Tu & F.L. Zhou, "*Experimental Study on the Outrigger Damping System for High-Rise Building*", 15th World Conference on Earthquake Engineering 2012 (15WCEE) Lisbon

[4] Xilin Lu, Bin Zhou, Bin Zhao and Wensheng Lu, "*Shaking table test and numerical analysis of a high-rise building with steel reinforce concrete column and reinforce concrete core tube*", The Structural Design Tall and Special Building 2015.

[5] Y. Zhou, X.L. Lu, W.S. Lu, L.Z. Chen, and Z.H. Huang, "*Shaking Table Test on a Reinforced Concrete Core Wall-Steel Frame Hybrid Structure*", The 14th World Conference on Earthquake Engineering October 12-17, 2008, Beijing, China.

[6] Xilin Lu, Yun Zou, Wensheng Lu and Bin Zhao, "*Shaking table model test on Shanghai World Financial Center Tower*", Earthquake Engineering and Structural Dynamics 2007; 36:439–457 Published online 12 September 2006 in Wiley Inter Science.

[7] Hamid Reza Tabatabaiefar, Bita Mansoury, "*Detail design, building and commissioning of tall building structural models for experimental shaking table tests*", The Structural Design of Tall and Special Buildings, 2016; 25: 357–374.

[8] Safi Baig, Khalid Nayaz Khan, Dr. N S Kumar, "*A Comparative study between tall buildings with conventional outrigger systems, offset outrigger systems and convectional RCC structure*", International Research Journal of Engineering and Technology (IRJET) Volume: 08 Issue: 07 | July 2021.

[9] Chinese Standard, GB, 50011–2010, "*Code for Seismic Design of Buildings*", Chinese Building Press, Beijing, China 2008.

[10] B. G. Kavyashree, Shantharam Patil, Vidya S. Rao, "*Evolution of Outrigger Structural System: A State of the Art Review*", Arabian Journal for Science and Engineering, April 2021.

[11] Shear Wall, Core, Outrigger, Belt Truss, and Buttress Core System for Tall Buildings, "*Design and Analysis of Tall and Complex Structures*", © 2018 Elsevier Ltd.

[12] Rob J. Smith, Michael R. Willford, "*The Damped Outrigger Concept for Tall Buildings*", Structural Design of Tall and Special Building, 16, 501–517 (2007).

[13] N. G. Gore, Miss Purva Mhatre, "*Outrigger Structural System – A Review and Comparison of the structural system*", International Journal of Engineering Trends and Technology (IJETT) – Volume 64 Number 1 – October 2018 .