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Analysis of Flat Slab Structures with Outriggers

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Abstract
When the height of the building increases, the building should have a good lateral load resisting capacity. There are many methods to incorporate lateral load resisting ability into a structure. One of these methods is an outrigger system. An outrigger system has two distinct types- conventional and virtual. The conventional outrigger system has a direct connection between the wall and the perimeter columns by using a truss or any other structural member. The virtual system eliminates the use of members in the interior of the structure. It instead uses the floor diaphragm action to achieve transfer of load. This paper aims to understand the behaviour of a flat slab system with outriggers under loads specified by Indian codes when analysed dynamically. This aims to find out the efficient way to reduce drift and storey displacement for a flat slab structure. It will also include observation of the behaviour of the building under different modes. Modal parameters such as mass participation factors and time periods have also been observed.

Keywords: ETabs; Flat Slabs; Outrigger System; Response Spectrum Method; Virtual Outriggers

Introduction
Outrigger system is used to resist lateral forces and overcome overturning moments in a high rise building. Outriggers can be defined as connections between the central or eccentric core and the perimeter columns. This can be achieved by using beams or trusses. These outriggers can be made up of either concrete, steel or a composite material. There are two types of outriggers, namely conventional and virtual outriggers. Conventional outriggers are those which have a direct connection between the perimeter truss and central core. Virtual outriggers do not have a direct connection but instead rely on the floor slab's diaphragm action to resist moments.

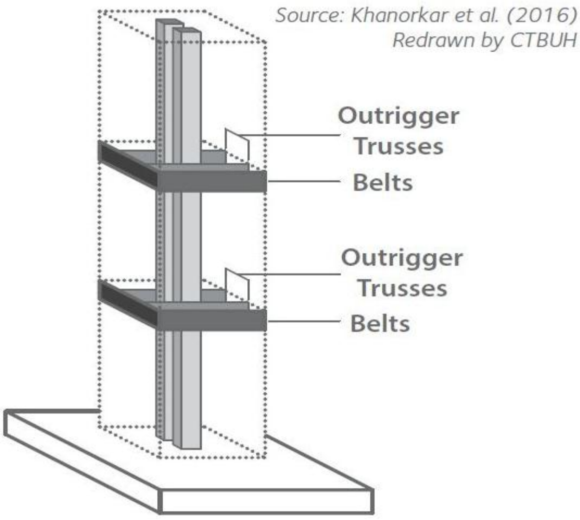

Fig. 1: Outrigger System depiction from CTBUH

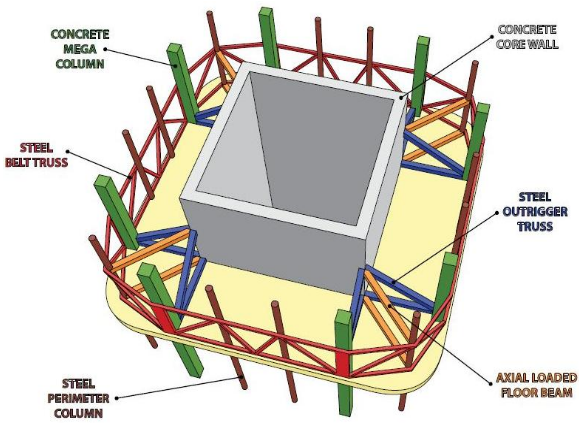

Fig. 2: Conventional Outrigger system depiction from CTBUH

Literature Review
Po Seng Kian et. al. [2001] [1] in their paper titled "The Use of Outrigger and Belt Truss System for High-Rise Concrete Buildings" investigated the use of outriggers for a framed structure at different levels using GT-Strudl software. They concluded that for two-dimensional model, single outrigger provided at the half the total height of the structure height

reduces the maximum displacement significantly and for a three dimensional structural model there is 18% reduction in lateral displacement.

N Herath et. al. [2009] [2] in their paper titled "Behaviour of Outrigger Beams in High Rise" analysed a model of 50 storeys with Australian codes using Strand 7 software. The models made use of pier wall on the perimeter connected to the core using one or two outrigger beams. They mostly focussed on getting efficient results by varying height of the outrigger. They concluded that it is between 0.44 to 0.48 times the height of the building.

Raj Kiran Nanduri et. al.[2013] [3] at Adama Science and Technology University, Ethiopia in their paper titled "Optimum Position of Outrigger System for High-Rise Reinforced Concrete Buildings Under Wind and Earthquake Loadings" analysed models with outriggers at different levels using Indian codes. They found that the optimum height is at the mid of the building and that the inner columns are less stressed.

Prateek Biradar et. al. [2015] [4] in their paper titled "A Performance Based Study on Static and Dynamic Behaviour of Outrigger Structural System for Tall Buildings" analysed a RC framed structure, 40 storeys in height. The structure had steel bracing. They achieved 15% reduction in lateral displacement. For time history analysis the reduction achieved was 3%.

Alpana L. Gawate et. al. [2015] [5] in their paper titled "Behaviour of Outrigger Structural System for High-Rise Building" analysed storey drift for 6 different models. The models had variations in different parameters like column sizes, location of outriggers, thickness of outriggers etc. It was found that drift was the governing factor for their models.

Abdul Karim Mulla [2015] [6] in his paper titled "A Study on Outrigger System in a Tall R.C. Structure with Steel Bracing" tested four different concrete structures with steel bracings to negate horizontal deflection. He found there is an inverse co-relation between displacement of the structure and member outrigger member size. He also found concrete members were more effective compared to steel members. He also found that there is a reduction in time period.

Raad Abed Al-Jallal Hasan [2016] [7] in his paper titled "Behaviour of Beam and Wall Outrigger in High–Rise Building and Their Comparison" analysed three different models. He considered a framed building with and without an outrigger. There were two buildings with outriggers - one with a beam outrigger and another with a wall outrigger. He analysed the moments and torsion coming on a column for a specific load combination. He concluded that the wall outrigger showed a better resistance than beam outrigger.

Abeena N et. al. [2016] [8] in their paper titled "Performance of Different Outrigger Structural Systems" analysed a model, square in plan, using time-history and response spectrum method and concluded that outriggers at storey levels 10n (n=1, 2, 3...) gave better results.

Kishan Solanki et. al. [2017] [9] in their paper titled "Behaviour of Outrigger System on High Rise Structure by Varying Outrigger Depth" analysed one model with different outrigger depth. They concluded that drift increases with reduction in depth of outrigger. They also found out that depth of outrigger did not make much difference for buildings up to 16 storeys of height.

Preeti. M. Nagargoje et. al. [2017] [10] in their paper titled "Analysis of Outrigger Structural System for Tall Building Subjected to Lateral Loads" analysed the same model and reduced the maximum lateral displacement by 31.8% using outriggers. Their models also showed a 42.59% reduction in storey drift.

Sathyamurthy K. et. al. [2017] [11] in their paper titled "Dynamic Analysis of Outrigger Braced Systems in High Rise Steel Building" used ETabs to analyse seven different steel building models. The models had different versions of bracings. They analysed shear coming at the base, drift of the storeys, displacement of the storeys and time period.

Objectives of study

The objectives of this research can be summarised as follows:

1. Modelling high rise flat slab buildings in ETabs software.
2. Analysing models using response spectrum method.
3. Understanding the behaviour of outriggers under effects of seismic and wind load.
4. Comparing virtual and conventional outriggers for different configurations.

Different models

The different models that have been modelled are listed as follows:

1. Flat slab with big shear wall.
2. Flat slab with big shear wall in virtual outrigger system.
3. Flat slab with big shear wall in conventional outrigger system.
4. Flat slab with big shear wall in conventional diagonal outrigger system.
5. Flat slab with big shear wall with beams at outrigger level.
6. Flat slab with small shear wall.
7. Flat slab with small shear wall in virtual outrigger system.
8. Flat slab with small shear wall in conventional outrigger system.
9. Flat slab with two small shear walls.
10. Flat slab with two small shear walls in virtual outrigger system.
11. Flat slab with two small shear walls in conventional outrigger system.

This research includes different variations of three different models. Models 1, 6 and 9 can be called as base models. Models 2, 3, 4 and 5 are variations of Model 1. Models 7 and 8 are variations of Model 6. Model 10 and 11 are variations of Model 9. Model 1 has a big shear wall in the centre of length 8 metres on three sides. The shear walls in Models 6 and 9 are of length 4 metres and hence smaller in size. Model 6 has one shear wall in the centre and Model 9 has two walls. All the models are of flat slab system. The outriggers that have been used are made of concrete of M35 grade in all the models. Belt trusses have also been used in the models.

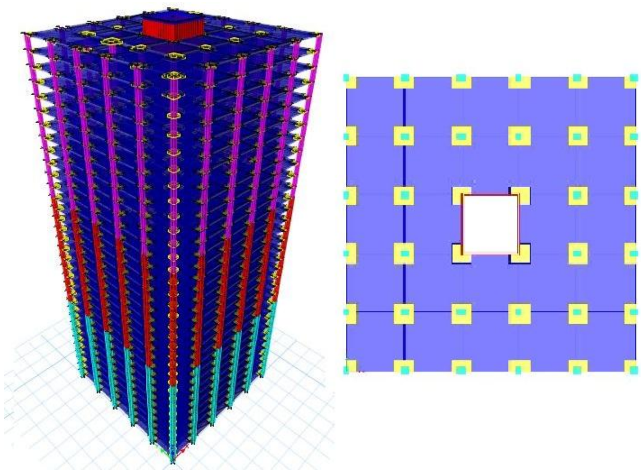

Fig. 3: 3D and 2D view of ETabs model

Model details

The typical model details are given below:

Table 1: Model details

Type of structure	Flat slab system with drops	
Location of the structure	Hyderabad	
Total length in both directions	40m in each direction	
Number of bays in each direction	5	
Length of each bay	8m	
Total height of building	100.5 metres	
Number of storeys	33 Storeys	
Storey height	3m	
Fixity at base	Translation and rotation restrained	
Grades of concrete	M40, M35, M30	
Column Sizes	1m x 1m, M40	Base to storey 11
	0.8m x 0.8m, M35	Storey 12 to storey 22
	0.6m x 0.6m, M30	Storey 22 to LMR
Beams	300mm X 600mm, M35	
Outrigger beams	400mm X 400mm, M35	
Outrigger location	Between 16th and 17th storey	
Floor slab thickness, grade	300mm, M30	
Thickness of drops, grade	450mm, M30	
Thickness of shear walls	300mm	

Loading on models

Gravity loadings

Dead load of members
Floor finish = 1.5kN/m^2
Floor finish on terrace = 3 kN/m^2
Live load = 2 kN/m^2
Live load on terrace = 1.5 kN/m^2

Seismic loadings

Zone = II
Zone factor = 0.1
Response reduction factor = 3 (for OMRF)
Importance factor = 1.2
Time period = $0.075\ x\ 100.5^{0.75} = 2.381$

Wind loads

Wind velocity = 44 m/s

Table 2: Pressure coefficients for ETabs models

Wind Direction	Global Direction	Pressure Coefficient	Internal Pressure Coefficient	Total Pressure Coefficient
Windward	X	0.8	0.5	1.3
Leeward	X	0.25	0.5	0.75
Windward	Y	0.8	0.5	1.3
Leeward	Y	0.25	0.5	0.75

Load combinations

Response spectrum analysis is done for all the models. The following load combinations are defined:

Serviceability combinations:
Total Dead Load + Total Live Load
Total Dead Load ± Spec X, Y
Total Dead Load ± Wind X, Y
Total Dead Load + Total Live Load ± Spec X, Y
Total Dead Load + Total Live Load ± Wind X, Y

Factored combinations:
1.5 (Total Dead Load + Total Live Load)
1.2(Total Dead Load + Total Live Load ± Spec X. Y)
1.2(Total Dead Load + Live Load ± Wind X,Y)
1.5(Total Dead Load ± Spec X, Y)
1.5 (Total Dead Load ± Wind X,Y)
0.9 Total Dead Load ± 1.5 Spec X. Y
0.9 Total Dead Load + 1.5 ± Wind X,Y

Results and observations

Storey Drift and Displacement

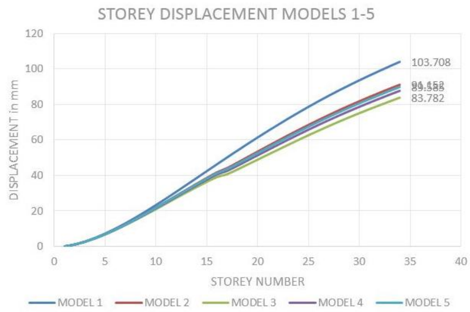

Fig. 4: Storey displacement for models 1-5

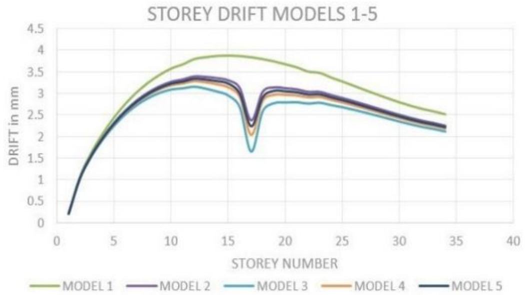

Fig. 5: Storey drift for models 1-5

The following observations are made:

1. Model 2 shows 12% reduction in storey displacement from Model 1.
2. Model 3 shows 17.6% reduction in storey displacement from Model 1 and 8.08% reduction from Model 2.
3. Model 4 shows 15.5% reduction in storey displacement from model 1.
4. Model 5 shows 13.6% reduction in storey displacement from Model 1.
5. Model 4 shows good results for lower number of outriggers.
6. The trough in the storey drift graph represents the presence of outriggers.
7. Model 2 showed 25% decrease in storey drift at outrigger level compared to Model 1.
8. Model 3 showed 57.5% decrease in storey drift compared to Model 1 and 30% decrease compared to Model 2 at outrigger level.
9. Model 4 showed 47% decrease in storey drift at outrigger level compared to Model 1.
10. Mod 5 showed 41.5% decrease in storey drift at outrigger level compared to Model 1.

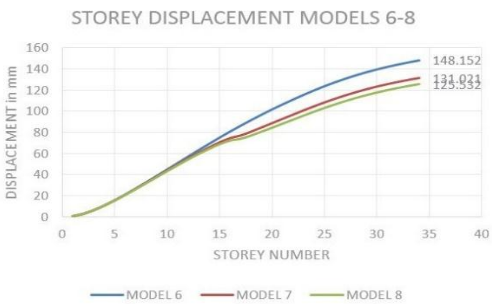

Fig. 6: Storey displacement for models 6-8

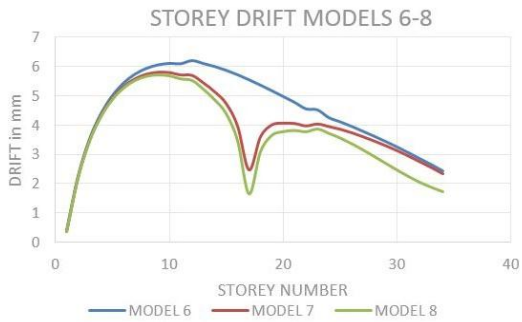

Fig. 7: Storey drift for models 6-8

1. Model 7 showed 11.5% reduction in storey displacement compared to Model 6.
2. Model 8 showed 15.27% reduction in storey displacement compared to Model 6 and 4.2% reduction compared to Model 7.
3. Model 7 showed 55.31% reduction in storey drift compared to Model 6 at outrigger level.
4. Model 8 showed 70% reduction in storey drift compared to Model 6 and 33% reduction compared to Model 7 at outrigger level.

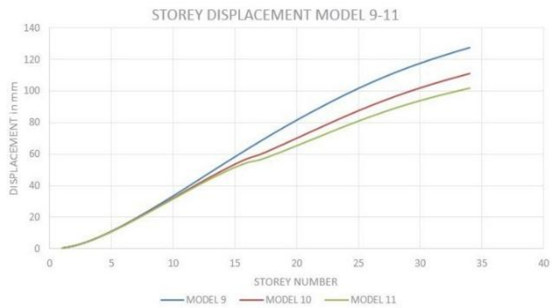

Fig. 8: Storey displacement for models 9-11

Fig. 9: Storey drift for models 9-11

1. Model 10 showed 13% reduction in storey displacement from Model 9.
2. Model 11 showed 20% reduction I storey displacement from Model 9 and 8% decrease from model 10.
3. Model 10 showed 31% reduction in storey drift at outrigger level from Model 9.
4. Model 11 showed 40% reduction in storey drift at outrigger level from Model 9 and 13.6% from model 10.

Time period

Fig. 10: Time period for first 12 modes of Models 1-5

Fig. 11: Time period for first 12 modes of Models 6-8

Fig. 12: Time period for first 12 modes of Models 9-11

1. The base models have the highest time period for all the models.
2. Time period reduces for virtual outrigger system.
3. Time period of conventional outrigger system is lower than that of virtual outrigger system.
4. Time period is directly proportional to maximum displacement.
5. First three modes show high time period for all the models.
6. Model 6 has the highest time period.
7. Model 4 has the lowest time period

Base shear

It is observed that the base shear increases for virtual outriggers. This can be related to the introduction of belt trusses. The base shear increases further for conventional outrigger system. This can be attributed to the interior trusses that are used in the conventional outrigger system. Of all the models, Model 1 had the lowest base shear whereas Model 11 had the highest base shear.

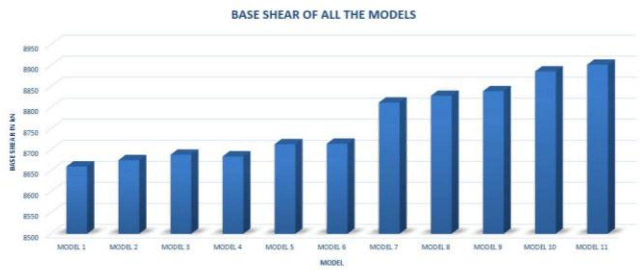

Fig. 13: Base shear of all models

Mass participation

The mass participation factor is above 90% or very close to 90% for all the models.

General observations

1. Storey drift for all models is within permissible limits.
2. Storey deflection for all models is within permissible limits.

Conclusion

After modelling, analysing and observing the results, the following conclusions are drawn.

1. A maximum reduction in lateral displacement of up to 20% is observed in this work. This reduction was also observed in published research done on framed structures.
2. Maximum drift reduction of 57.5% obtained at outrigger level.
3. Conventional outriggers are found to be better than virtual outriggers.
4. Direct connection with the core wall and the perimeter columns gives better results.
5. Model 3 with big shear wall and conventional outrigger showed the best results of all the models in reducing lateral drift and displacement.
6. Diagonal outriggers behaved better than perpendicular outriggers.
7. Virtual outrigger system showed significant reduction in lateral deflection but not as much as shown by conventional systems.

References

[1] Po Seng Kian, Frits Torang Siahaan, "The use of outrigger and belt truss system for high-rise concrete buildings", Dimension of Civil Engineering, Volume 3, No. 1, March 2001, Pages 36-41.

[2] N. Herath, N. Haritos, T. Ngo and P. Mendis, "Behaviour of ourigger beams in high rise buildings under earthquake loads", Australian Earthquake Engineering Society 2009 Conference

[3] Prateek N. Biradar and Mallikarjun S. Bhandiwad, "A performance based study on static and dynamic behaviour of outrigger structural system for tall buildings", International Research Journal of Engineering and Technology, Volume 02, Issue 05, Aug-2015

[4] P.M.B. Raj Kiran Nanduri and MD. Ihtesham Hussain, "Optimum position of outrigger system for high-rise reinforced concrete buildings under wind and earthquake loadings", American Journal of Engineering Research (AJER), Volume 02, Issue 08, Pages 76-89

[5] Alpana L. Gawate, J.P. Bhusari, "Behavior of Outrigger Structural System for High-rise Building", International Journal of Modern Trends in Engineering and Research, Volume 2, Issue 7, July 2015

[6] Abdul Karim Mulla and Srinivas B. N, "A study on outrigger system in a tall R.C Structure with steel bracing", International Journal of Engineering Research and Technology, Volume 4 Issue 07, July 2015

[7] Raad Abed Al-Jallal Hasan, "Behaviour of beam and wall outrigger in high -rise building and their comparison", International Journal of Civil, Structural, Environmental and Infrastructure Engineering Research and Development, Volume 6, Issue 1, Feb 2016, Pages 19-30

[8] Abeena mol N M and Rose mol K George," Performance of different outrigger structural systems" International Research Journal of Engineering and Technology (IRJET), Volume 03, Issue 09, Sep 2016

[9] Kisha P. Solanki , Pradeep Pandey, "Behaviour of outrigger system on high rise structure by varying outrigger depth" Journal of Emerging Technologies and Innovative Research, Volume 4, Issue 04, April 2017.

[10] Preeti. M. Nagargoje and Shilpa. Kewate, "Analysis of outrigger structural system for tall building subjected to lateral loads", International Journal of Science Technology & Engineering, Volume 3, Issue 12, June 2017

[11] Sathyamurthy K and Kavitha A, "dynamic analysis of outrigger braced systems in high rise steel building", International Journal of Informative & Futuristic Research, Volume 4, Issue 12, August 2017