OPTIMIZATION OF COST AND STRUCTURAL RESPONSE OF DUAL FRAME SYSTEMS BY USING REDUCED DEPTH-OUT-RIGGERS

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ABSTRACT

This paper presents the analytical results for dual frame system using the reduced depth outrigger technology. A 30 storey square plan symmetrical building is considered in this research for analysis and design and different models were made to optimize the structural stability with respect to inter storey drift. Full depth outriggers are compared with different reduced depth outriggers and their cost comparison are also made. The reduced depth out-riggers ranging from 3 ft to 8 ft are employed in this research and optimization is made with respect to variation in concrete strength which varies from 3 ksi to 7 ksi. The concrete strength is varied in both the frame members of columns and beams. The effect of increasing concrete strength in shear walls are also observed. UBC-97 design manual is incorporated in the study to determine the seismic performance of the structure. Although the building is purely design for moderate seismic zones (typically zone 2B) but for the sake of future recommendation all the seismic zones were analyzed. The results are concluded for moderate seismic zones and some suggestions are made on over all response of the building analysis with an optimized design parameters.

Keywords: Reduced Depth Outriggers, Optimization & structural stability**.**

INTRODUCTION

The rapid growth of urbanization has boomed the construction industry all over the world. With this rapid urban growth, land availability especially in city centre's and business hubs of metropolitan cities has become a serious issue due to high land costs and little or no availability of land area. Hence the need for tall/ high rise structures; consequently structural engineers have developed so many structural systems in order to maintain the structural stability not only for the gravity loadings but also for lateral load stability.

LITERATURE

One of the most popular design technologies is outriggers braced frames. The three main reasons for introducing the outriggers to the structures exterior column are shorter elongation of column, bending, racking shear (Nicoreac *et al.*, 2012). Outrigger is horizontal stiff arm which is connected between cores to periphery of column, whereas central core tries to rotate and bends at the outrigger level which induces tension and compression couple (Siddhaling *et al.*, 2016). The main objective of providing outrigger is to control the inter story drift and reduce deflections. Different researchers have studied the outriggers technology for the lateral stability of high rise building structures. To find the optimal location of providing outrigger in building frame is quite difficult in high rise structural design due to the reason that curtailed structural sections result in occurrence of maximum deflections that's why most of the working is associated with the optimization of outrigger location on building system. Hoenderkamp *et al* considered 29 storey of 87m high building by placing braced outriggers. They found reduction in horizontal displacement and overturning moments in their model. Hong and Alex studied the seismic behavior of Taipei 101 story building in which belt truss outriggers were placed at every ten story which makes equal stiffness for structure thus reduction in lateral deformation. Most of the researchers have studied optimal location of outriggers but not so much significance has been laid on the optimization of outrigger depth in addition to its location. There is a need of investigating the depth optimization of outrigger so that design engineers can get benefit of it.

METHODOLOGY

Building Description

For the sake of simplicity a square dimension plan is taken for this research and the building is assumed to be located in seismic zone 2B. The general description of building is given in table

Table 1: Building Description

Plan dimension	90'x 90'
Number of stories	30 stories at 10' height each
Number of spans	5 in both directions
Seismic zone	2B
Exposure	B
Importance factor	1
Wind speed	100 mph

Analysis

This research aims toward controlling the lateral stability of high rise building structure using the outriggers braced frames on the optimized locations but in addition it is also focused on optimizing the depth of outrigger bracings. In order to perform the analysis ETABS software is used for building design. For analytical purpose several models have been studied. A research study conducted at Sir Syed University of Engineering and Technology (Abdul Latif, *et al.*, 2016) suggested the most optimized location of outriggers at 10 story interval and for 30 story building two outriggers at 10 story interval. The same building plan is studied for some other alternative location with an optimized outrigger depth in this research. For this purpose numbers and thickness of outriggers has been changed and five outriggers at 6 stories interval with thickness varying from 1' to 8' have been investigated. The plan and three dimensional view of the studied building are shown in figure 1 and 2 respectively.

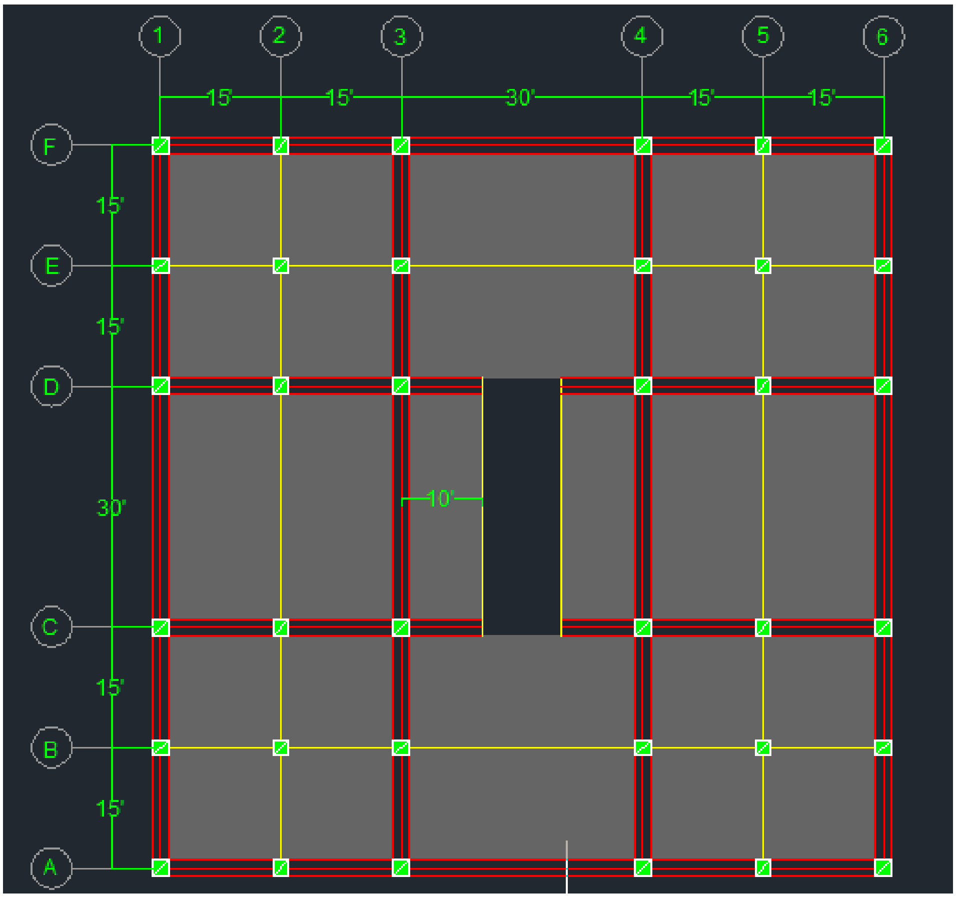


Figure 1: Building plan considered for analysis

Initially the reinforced concrete beam, column and shear wall is taken as having 3 ksi, 4 ksi and 5 ksi strength concrete, respectively. Outrigger depth is optimized using trial and error technique. The outriggers depth is varied from 1 ft to 8 ft. For each outrigger depth, different models of frames having different cross sectional dimensions of structural members are analyzed and results was noted down with respect to inter story drift and structural displacement. Moreover, these building models were also analyzed by varying strength of concrete in beams from 3 ksi to 7 ksi and maintaining strength of other structural members constant. Similarly the effect of concrete strength variation in columns has been analyzed for each outrigger frame model. Finally the concrete strength of all structural members is varied simultaneously in each model and the response was observed. Furthermore the results of all these models were compared with those of the building frame system and moment resisting frame system using the same strength parameters of structural members. The analysis also includes the concrete and steel quantity and cost comparison of different structural framing systems with different reduced depth outriggers and on the basis of overall response with respect to story drift conclusions were made.

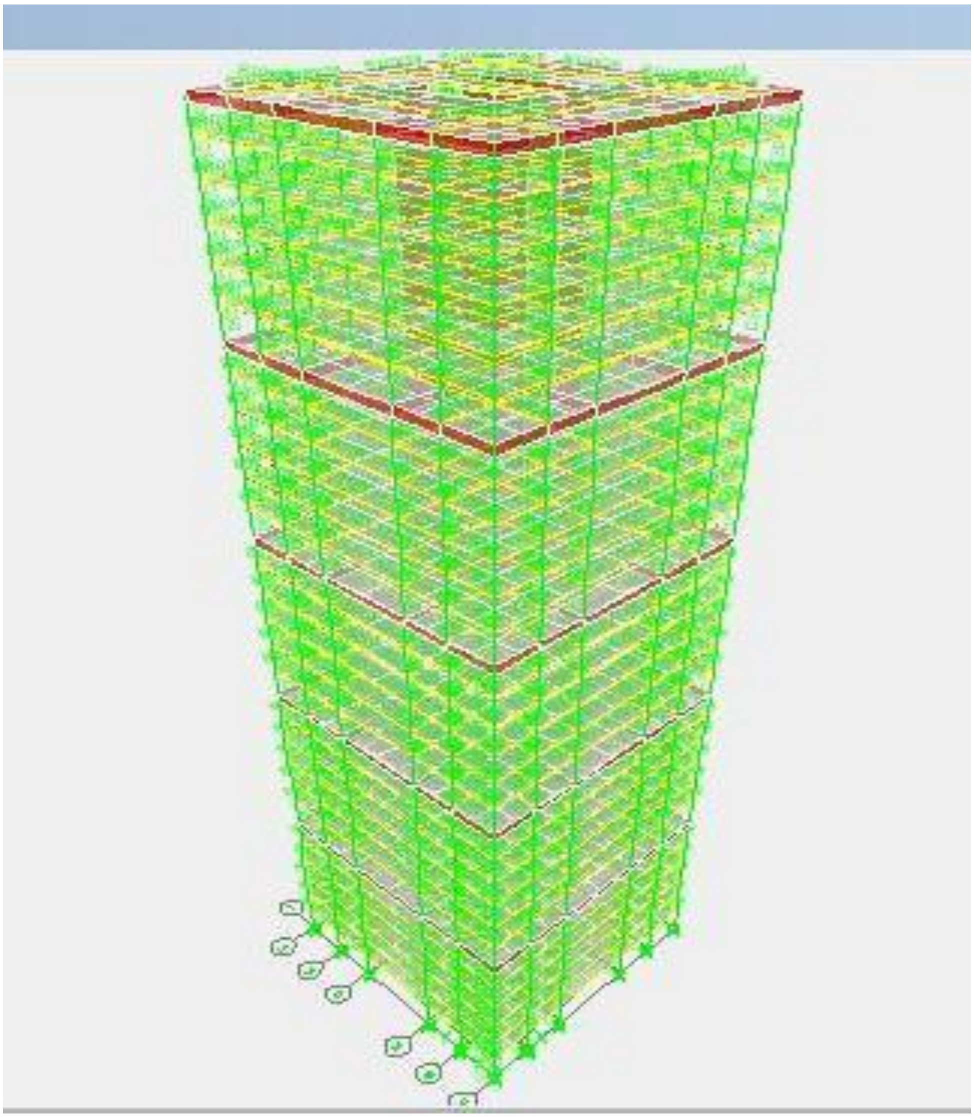


Figure 2: 3D view of structure considered for analysis

Although this research scope is limited to the seismic zone 2B and soil type SC only but for the sake of understanding the complete response of these reduced depth outrigger frames their effects were analyzed against zone 3 and 4 as well. In addition the building response with different soil profiles was also studied for future research extension.

RESULTS/ DISCUSSIONS

This research is basically comprised of four different models. Moment resisting frames (MRF), building frame system (BFS) i.e. dual frame system, outriggers braced frames with 10 ft depth (OBF10') having 2 full depth outriggers with 10 story interval, and outriggers braced frame with reduced depth outriggers located at 6 story interval, reduced depth varying from 1' to 8' (e.g. OBF4', OBF3' etc.).

Effect of Reduced Depth Outriggers

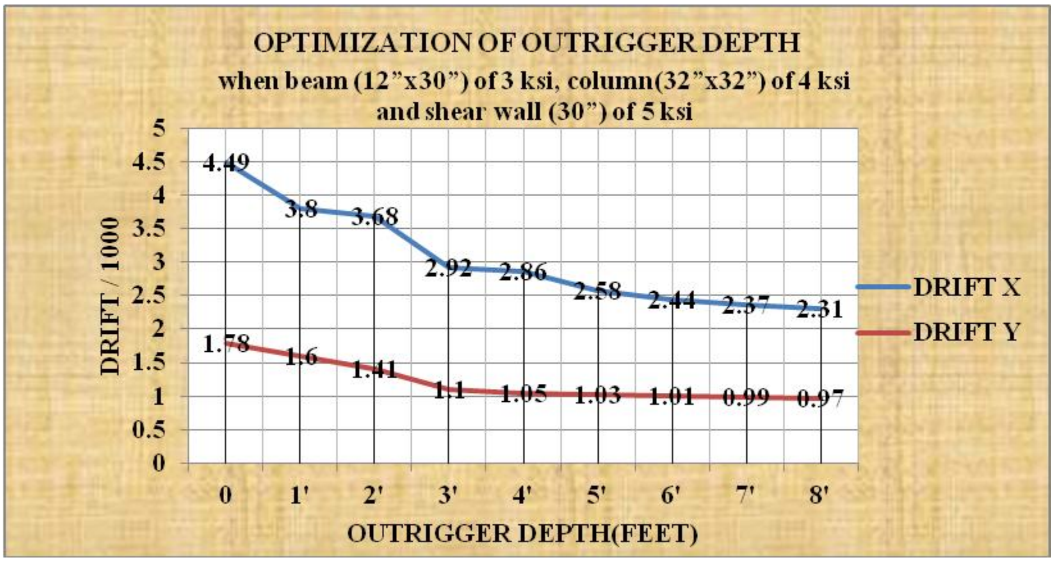


Figure 3: Analytical results of reduced depth outriggers with respect to inter story drift

From Figure 3 it is observed that without outriggers (0 depth) story drift found near to the allowable limit of 0.005 but as the depth of outrigger increases building structure gets more stability in its response and the significant reduction of story drift is seen as the outrigger depth is increased upto 3 ft. However not much further reduction in drift occurs as outrigger depth is increased from 4 ft to 8 ft.

Effect of Member Concrete Strength Variation

The In Figure 4, four different models are compared on the basis of inter story maximum drift while column and shear wall concrete strengths is constant. Varying the concrete strength in beam from 3 ksi to 7 ksi, four model responses are plotted here. The variation in outrigger depth does not affect story drift significantly. Here 10 ft outriggers are located at 10 story intervals and 3 ft outriggers are located at 6 story interval and both the models show almost similar response in lateral stability. Increase in beam concrete strength also reduces the story drift and results in a better stability control.

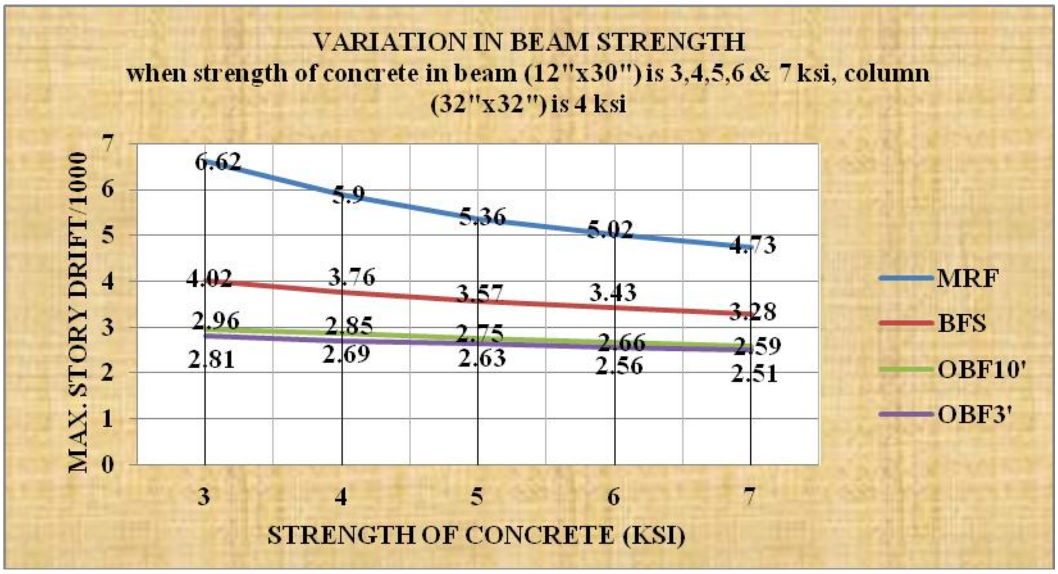


Figure 4: Comparison of drift of frames system by changing beam strength.

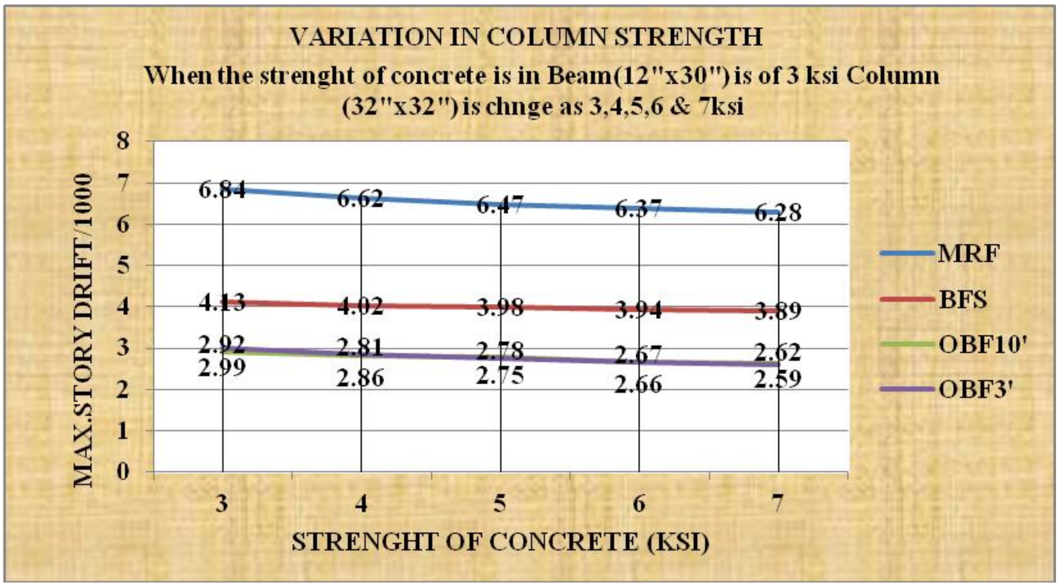


Figure 5: Comparison of drift of frames system by changing column strength.

Similar response is observed in Figure 5 which depicts the stability behavior of four models with respect to story drift when strength of column is changed from 3 ksi to 7 ksi. 5 Outriggers having depth of 3 ft at 6 interval shows almost the same response as that of 2 outriggers with 10 ft depth at 10 story interval. The effect of variation of shear wall concrete strength is plotted for 3 models and shown in Figure 6. Figure 7 shows the variation in model behavior with simultaneous variation in strength of concrete in all structural members and it can be observed that reduced depth outriggers have response similar to that of full depth outriggers. It is noted that rate of reduction in drift is fast as strength of concrete is increased upto 5 ksi. With further increase in strength, rate of reduction of drift gets slower and therefore 5 ksi strength of concrete is selected to give optimum results.

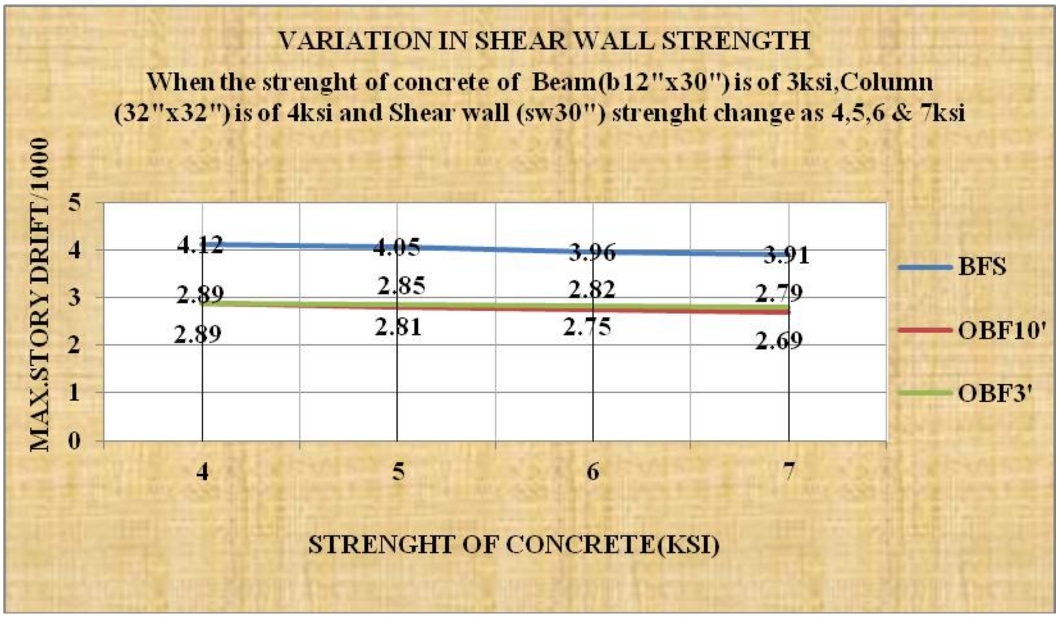


Figure 6: Comparison of drift of frames system by changing shear wall strength.

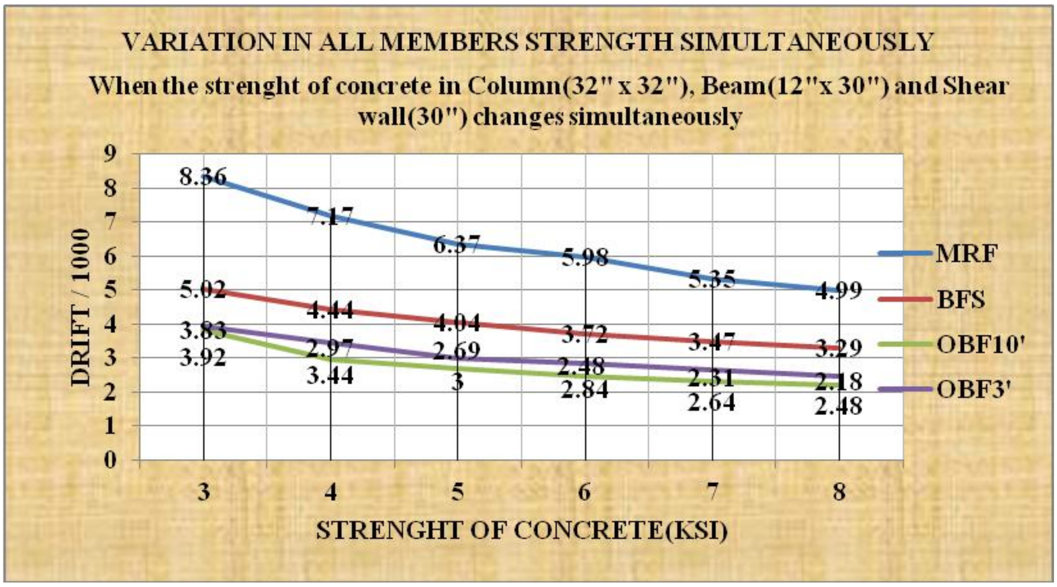


Figure 7: Comparison of drift of frames system by changing member strength simultaneously.

Effect of Earth Structure Properties

For the sake of understanding the complete behavior of reduced outrigger depth, the models is also analyzed against all the seismic zones and all the soil class types as shown in Figures 8 and 9. Here the depth of outrigger is kept 3 ft for this analysis.

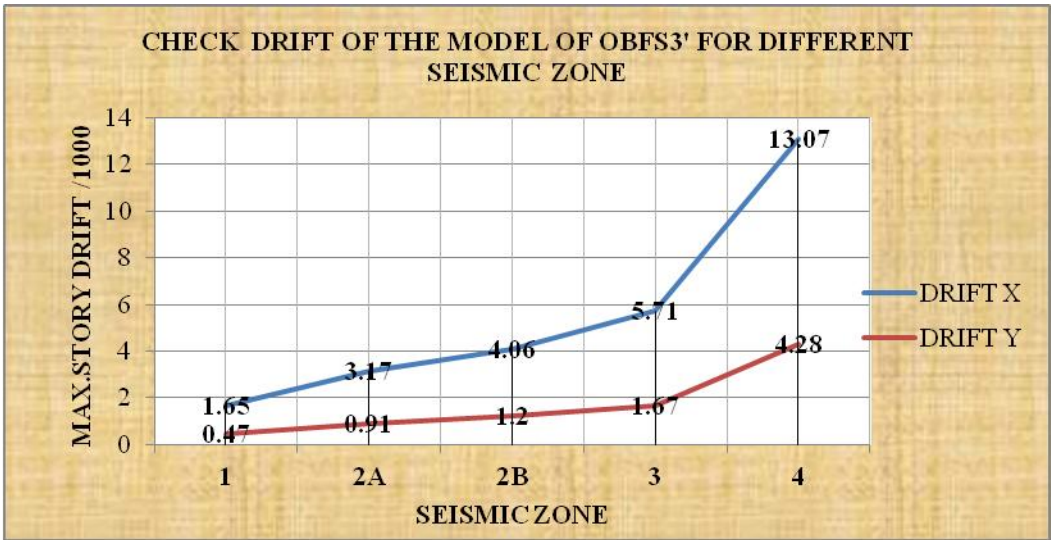


Figure 8: Effect of different seismic zone on reduced depth outriggers

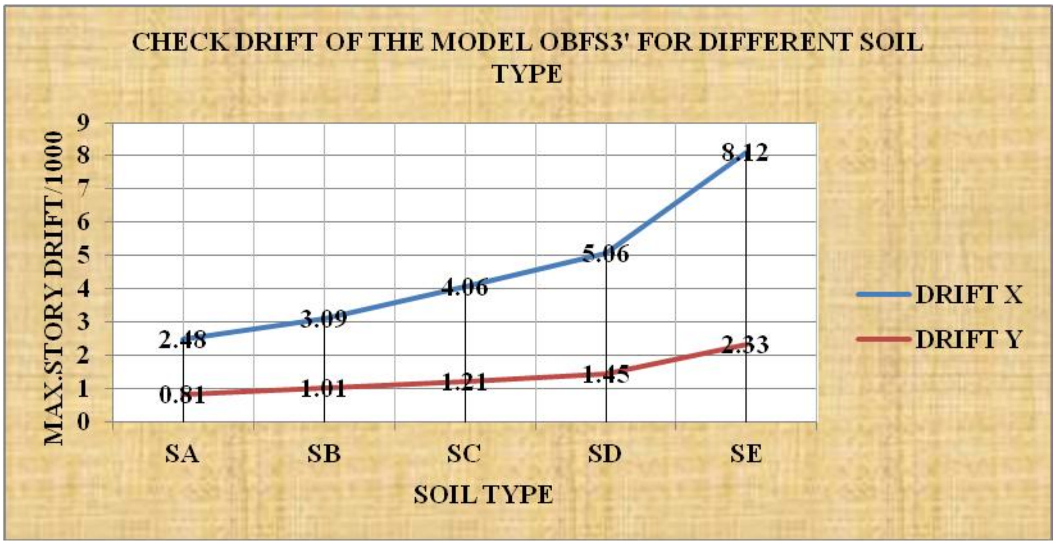


Figure 9: Effect of different soil class profile on reduced depth outriggers

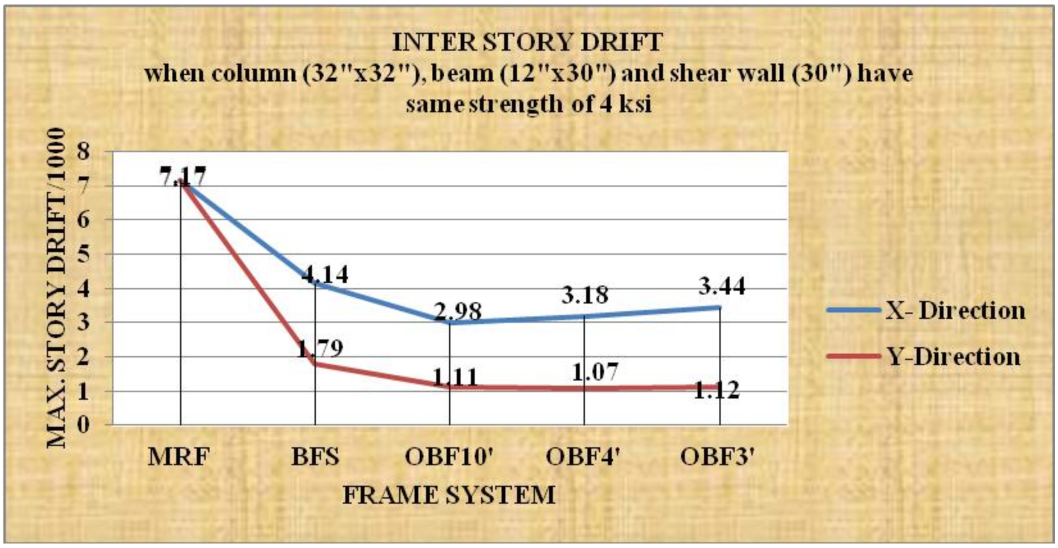


Figure 10: Drift comparison of outriggers with other structural systems

Figure 10 shows the comparative results of reduced depth outriggers with some more commonly used structural systems when all the structural members have the same concrete strength of 4 ksi. Drifts in moment resisting frames and building frame (Dual Frame) system is quite high however full depth outriggers are most stable among all. But it can be observed that reduced depth outriggers of 4 ft and 3 ft also contribute significantly in controlling the story drift. Figure 11 shows the result of same model in terms of structure displacement and 5 outriggers of 3 ft depth with 6 story interval responded in similar way as that of 2 full depth outriggers with 10 story interval.

Table 2: Optimized cross section sizes of members

MEMBER	MRF	BFS	OBF 10’	OBF 3’
Beam	12”X 36”	10” X28”	10” X 18”	10” X 18”
Column	48” X 48”	35” X 35”	32” X 32”	28” X 28”
Shear wall	N/A	34”	34”(story 1-3)	34”(story 1-3)
	N/A	N/A	24”(story 4-30)	24”(story 4-30)
Outriggers	N/A	N/A	ARMS 18” X 10’ BELT 8” X 10’	ARMS 18” X 3’ BELT 8” X 3’
Max. drift	0.00419	0.00433	0.004	0.004063

For optimizing the cross sectional sizes in this study all these models were analyzed. For this purpose all the structural members were assigned the same concrete strength and section sizes were reduced such that the drift and displacement of the considered building structure remained safe under the allowable limit provided by ACI-318-11 code. The design results are summarized in table 2 and optimized members cross sectional sizes for the four models are mentioned above.

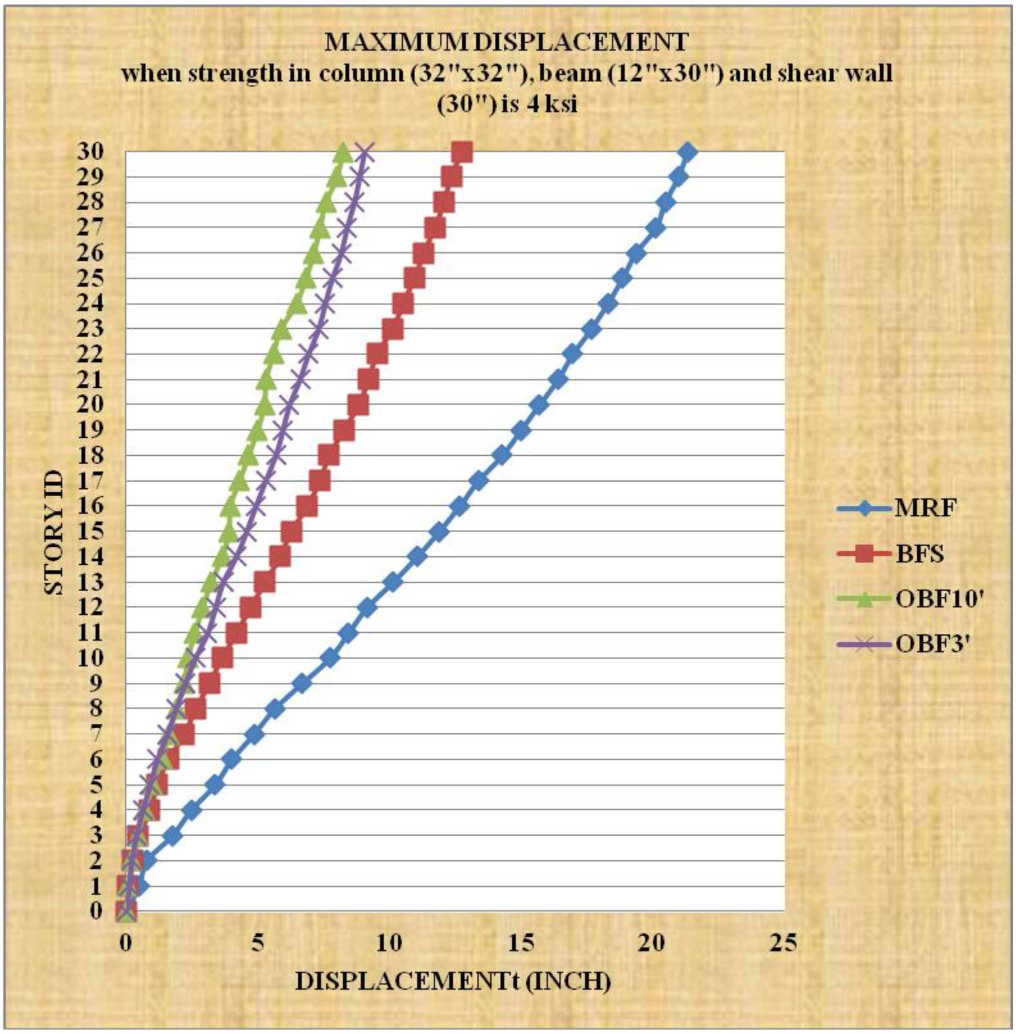
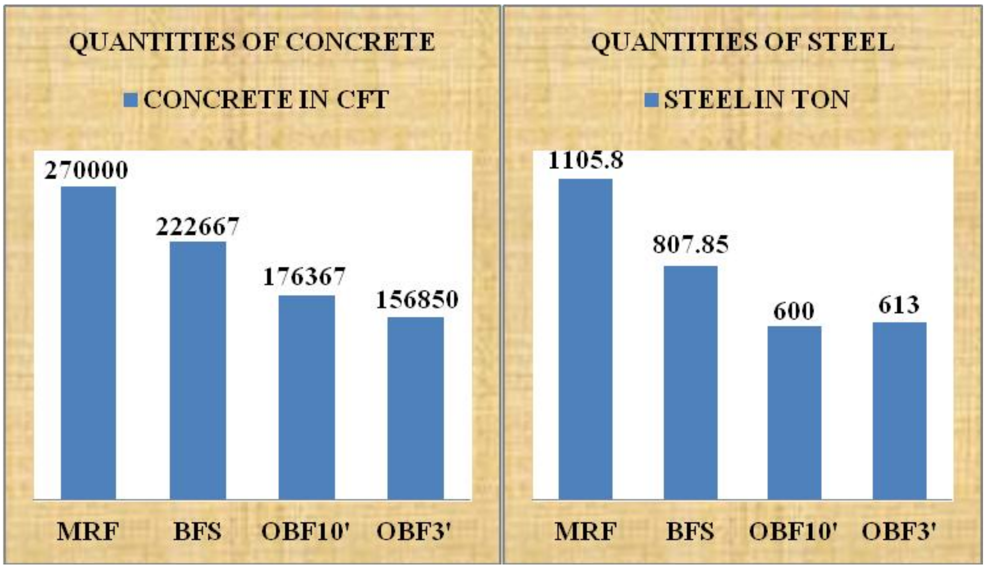


Figure 11: Maximum story displacement comparison

Cost Comparison

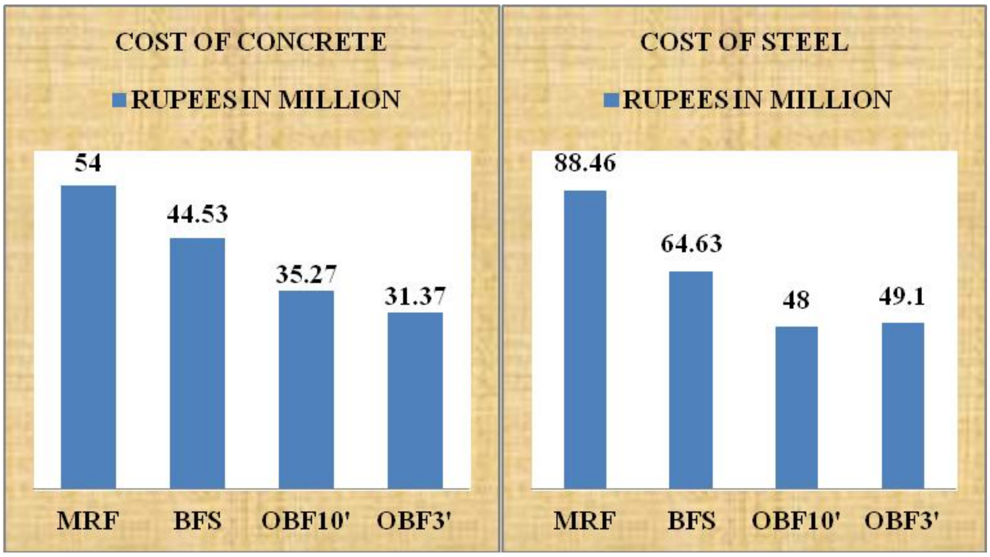
After performing all the analysis, the quantities of steel and concrete in structural members of each structural frame were calculated, in order to make effective cost comparison. For the sake of cost comparison of all the four models, rates of concrete and steel were assumed to be as under (recent average rates in Pakistan):

- Rs.80000/ ton for steel cost calculation
- Rs.200/ cft for concrete cost calculation



(a) (b)

Figure 12: (a) Quantities of concrete (b) Quantities of steel in all structural frames



(a) (b)

Figure 12: (a) Cost of concrete (b) Cost of steel in all structural frames

The quantity estimation of all the four types of analyzed models are estimated on the finally optimized cross sectional design tabulated in table 2, and the results for material quantities are shown in figure 12. Similarly the cost analysis has been made on the basis of rates mentioned earlier and the cost comparison is shown in figure 13. The overall cost comparison is the sum of cost for concrete and steel and the result is shown in figure 14.

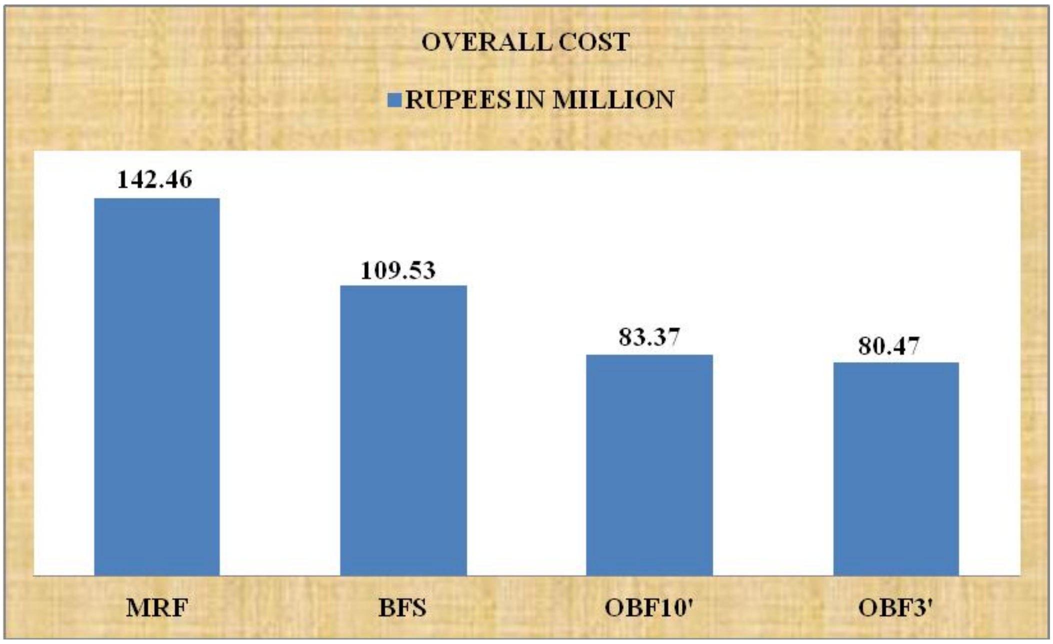


Figure 14: Overall cost comparison of the 4 system in millions

CONCLUSIONS

On the basis of overall analysis of different design models it can be concluded that for a moderate seismic zone upto zone 2B reduced outrigger depth technique is the best optimized model for building analysis. To get the most feasible and optimized results the concrete strength for all the structural members should be taken as 5 ksi. Here the three ft depth of outriggers are suggested since the results of three ft reduced depth outrigger is quite similar to the full depth outriggers but for applying the reduced depth technology the number of outriggers location will be more than that of full depth application. Hence the major conclusions of this research are listed below:

1. Concrete strength of 5 ksi for all structural members is most efficient
2. Five outriggers with reduced depth of 3 ft located at 6 storey interval were found to give optimum results.

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REFERENCES
Building Codes

American Concrete Institute (ACI). (2011). *Building code requirements for structural concrete (ACI 318R-11)*, ACI Committee 318, Detroit, Michigan.
Uniform Building Code (UBC). (1997). *Structural Design Requirements.* Volume-2

Books
Hassoun, M. N., and Al-Manaseer, A. (2008). *Structural Concrete-Theory and Design*, John Wiley &Sons, Inc. USA.

Journals

Siddhaling S. Khanapur, and Visuvasm J. (2016). *Behaviour of Outrigger System for High Rise Slender Building.* Advances in Natural and Applied Sciences 2016(3): 58-62.

Fan, H,Q.S. Li, Tuan Alex Y, Lihua Xu. (2009). *seismic analysis of world's tallest building*. Journal of Constructional steel research Volume 65 Issue 5: 1206-1215

Conferences

Nicoreac, M, J.C.D. Hoenderkamp. (2012) *Periods of vibration of braced frames with outriggers*. Procedia Engineering 40: 298-303.

J.C.D. Hoenderkamp , M.C.M Bakker and H.H.Snijder. (2003). *Preliminary design of high rise outrigger braced shear wall structures on flexible foundations*. Proceedings of the second Structural Engineers World Congress, Volume-42, pp. 81-98

Website

http://onlinelibrary.wiley.com

www.researchgate.net

Study Project Reports

Abdul Latif, Asif Nabi, Fatima Batool, Imam Yar Baig, Khurram Hussain, Kashif Salman, Muhammad Riaz & Noor Zada. (2016). *Structural design of high rise building using the concept of outrigger braced frame system and its comparison with ordinary building frame system.* Final Year Project report submitted to Civil Engineering Department, SSUET

Muhammad Azeem, Zeeshan Haider, Abdur Rehman, Shamsul Alam & Kashif Hussain. (2017). *Design and cost comparison of thirty story RCC building using the concept of Moment Resisting Frame System, Ordinary Building Frame System and Outrigger Braced Frame System.* Final Year Project report submitted to Civil Engineering Department, SSUET