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Optimization of Outrigger Braced Structures Using Regression Analysis

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Abstract - *Tall buildings are subjected to various lateral loads, especially wind and earthquake loads that become judgmental in the design of these buildings. Various lateral load resisting structural systems were introduced for the analysis and design of these high-rise buildings which mainly include tubular structures, core supported outriggers with bracings, diagrid structures, etc. The core supported outrigger with bracings is one of the most commonly used structural systems to control the risk of structural and nonstructural damage due to lateral load, so that, during small or medium lateral load due to either earthquake or wind load, the risk of structural and nonstructural damage can be minimized. The main aspect of the design of outriggers is to fix the position of outriggers. In this paper, the optimization of the outrigger is done on the basis of the depth of outrigger in addition to the position of the outrigger. First, a study of the existing approximate methods to calculate the top deflection in an outrigger braced structure is done. A statistical method called Regression analysis is then used to find out the relationship between variables that affect the top deflection in an outrigger braced structure is also used. Results from the regression based equation showed produced favorable results with a factor of safety of 0.88 and 0.99.*

Key Words: **outrigger; lateral load; Regression, earthquake, structural system.**

1.INTRODUCTION

A 'high-rise building' is a building in which the height of the building plays an important role in the design of the design, construction, and use than the existing common buildings of certain region and period. The tallness of a building is the matter of a person's or community's circumstances and their consequent perception. Tall building structure requires special structural arrangements if they are subjected to lateral loads such as high wind pressures and earthquake loadings. In the modern era, tall buildings structures are in great demands because of the following reasons which are as follows:

- Scarceness of land in urban areas
- Greater demand for business and residential space
- Economical emergence
- Technical advancements
- Innovations in Structural Systems
- Desire for aesthetics in urban areas
- Cultural significance and prestige
- Human ambitions to build higher

Lateral stiffness governs the structural design of tall buildings, and, consequently, structural systems in tall buildings have evolved to produce higher lateral stiffness more efficiently. Among various structural systems developed for tall buildings, perimeter tube type structures with diagonals, such as braced tubes and diagrids, are very efficient in general. This is because they carry lateral loads by their primary structural members' axial actions and the structural depth of the systems is maximized by placing the structural members on the building perimeter. Another very efficient structural system widely used today is the outrigger system. Perimeter mega-columns, connected to shear wall type core structure through outrigger trusses, resist overturning moments very efficiently in outrigger structures.

Outriggers are rigid horizontal structures designed to improve strength and building overturning stiffness by connecting the core or spine to distant columns. An Outrigger system functions by tying together two structural systems- typically a perimeter system and a core system to yield the whole structural behavior that is much better than those of component system. The benefits of an outrigger system lie in the fact that the overturning moments causing building deformations get reduced resulting, on the other hand, greater efficiency is achieved in resisting forces.

2. EVALUATION OF THE OF REGRESSION-BASED EQUATION

Regression analysis is a statistical process for estimating the relationships among variables. It includes many techniques for modeling and analyzing several variables when the focus is on the relationship between a dependent variable and one or more independent variables. The regression equation is formulated on the basis of results obtained from software analysis. Building models are subjected to linear time history analysis, and the top displacement of each analysis is noted. The regression equation is then formulated for the top displacement on the basis of various parameters that affect the top displacement of an outrigger braced structure.

3. MODELLING AND ANALYSIS

The 30 storey and 40 storey building is modelled. The outrigger position and depth of outrigger is varied in each model. The outrigger positioned at 1/3rd height of the building, middle of the building, 2/3rd height of the building and top of the building. The depth of outrigger is varied between 3m,3.5m,4m and 4.5m. The Plan area of the Structure is 38.50 x 38.50m with columns spaced at 5.5m from center to center. All wall piers have a uniform wall thickness of 350mm over their height. The outrigger beams and all other beams are 230mm wide and 600mm deep, Grade 40 concrete is considered throughout the height of the building. The number of stories considered for all the cases is 30 stories, and roof height is considered as 90 m and storey to storey height is 3.0 M. And the outer and inner columns sizes are considered as 600 x 600 mm and shear wall thickness is considered as 350 mm. Analysis of the building was done in ETABS. The building is assumed to be a office building live load is considered as 3 kN/m^2. Earthquake load in this study is established in accordance with IS 1893(part 1)-2002.The building is assumed to be in "zone 4" (Z=0.36). The importance factor (I) of the building is taken as 1.5. The site is assumed to be hard/rocky site (Type III). The response reduction factor R is taken as 5.0.

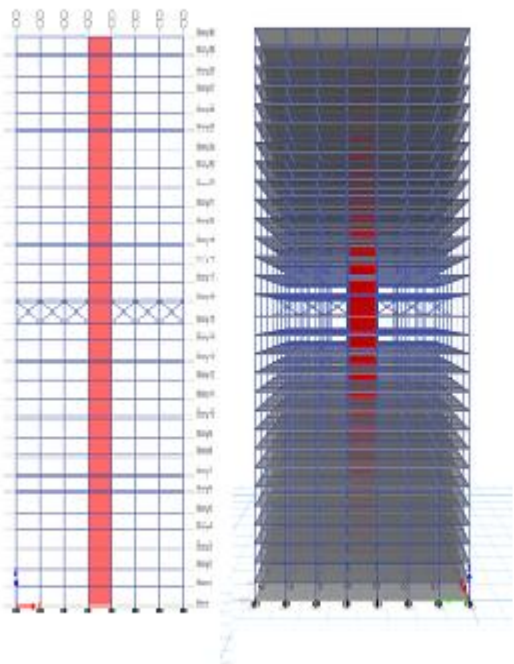

Fig -1: Elevation and 3D model of an outrigger braced structure

4. REGRESSION ANALYSIS

Regression analysis is a statistical process for estimating the relationships among variables. It includes many techniques for modeling and analyzing several variables, when the focus is on the relationship between a dependent variable and one or more independent variables. More specifically, regression analysis helps one understand how the typical value of the dependent variable changes when any one of the independent variables is varied, while the other independent variables are held fixed.
The formulation of regression equation is done for the top deflection of the building. The data samples for the formulation of regression equation are obtained from the model analysis results.

There are many parameters that affect the top deflection of an outrigger braced structure. The type of loading, dimensions of the structure, dimensions of the structural members and material properties of the structural members are the main parameters that contribute to the top deflection of the structure. Since the primary concern is to find the optimum configuration of the outrigger in terms of position and depth, parameters like loading and material properties of the structural elements are kept constant during the analysis. The various parameters considered are:

- I_o= Moment of inertia of the outrigger
- A_o= Area of column
- h = depth of outrigger (equal to the height of bay/storey)
- d = distance between external columns
- x= position of outrigger measured from top

5. RESULTS

The results for the dynamic structural analysis of the building models for the regression analysis are:

Table -1: Data for regression analysis

H	x	Acolumn	Io	d	displacement
90	30	12.96	3147.448	27.5	2595
90	45	12.96	3147.448	27.5	2369
90	60	12.96	3147.448	27.5	2377
90	90	12.96	3147.448	27.5	2536.5
90	30	12.96	3598.19	27.5	2580
90	45	12.96	3598.19	27.5	2355
90	60	12.96	3598.19	27.5	2366.6
90	90	12.96	9863.175	38.5	2536
90	30	12.96	4079.837	27.5	2572
90	45	12.96	4079.837	27.5	2347
90	60	12.96	4079.837	27.5	2362
90	90	12.96	4079.837	27.5	2541
90	30	12.96	4592.094	27.5	2568
90	45	12.96	4592.094	27.5	2345
90	60	12.96	4592.094	27.5	2362.6
90	90	12.96	4592.094	27.5	2548
120	40	12.96	3147.448	27.5	4560.5
120	60	12.96	3147.448	27.5	4433.2
120	80	12.96	3147.448	27.5	4477.1
120	120	12.96	3147.448	27.5	4622
120	40	12.96	3598.19	27.5	4561.3

120	60	12.96	3598.19	27.5	4421.8
120	80	12.96	3598.19	27.5	4473.2
120	120	12.96	3598.19	27.5	4628.5
120	40	12.96	4079.837	27.5	4562.8
120	60	12.96	11209.84	38.5	4417
120	80	12.96	4079.837	27.5	4475.2
120	120	12.96	4079.837	27.5	4639.1
120	40	12.96	4079.837	27.5	4568.7
120	60	12.96	4592.094	27.5	4420
120	80	12.96	4592.094	27.5	4642.5
120	120	12.96	4592.094	27.5	4482.5
90	30	24.64	8605.768	38.5	2869.5
90	45	24.64	8605.768	38.5	2807.2
90	60	24.64	8605.768	38.5	2835.1
90	90	24.64	8605.768	38.5	3013.4
90	30	24.64	9863.175	38.5	2849.7
90	45	24.64	9863.175	38.5	2784.5
90	60	24.64	9863.175	38.5	2816.4
90	90	24.64	9863.175	38.5	3008.3
90	30	24.64	11209.84	38.5	2834
90	45	24.64	11209.84	38.5	2767.2
90	60	24.64	11209.84	38.5	2803
90	90	24.64	11209.84	38.5	3006
90	30	24.64	12645.32	38.5	2822.1
90	45	24.64	12645.32	38.5	2755.7
90	60	24.64	12645.32	38.5	2795
90	90	24.64	12645.32	38.5	3008.5
120	40	24.64	8605.768	38.5	4448
120	60	24.64	8605.768	38.5	4384
120	80	24.64	8605.768	38.5	4396
120	120	24.64	8605.768	38.5	4580
120	40	24.64	9863.175	38.5	4442
120	60	24.64	9863.175	38.5	4372.7
120	80	24.64	9863.175	38.5	4385.3
120	120	24.64	9863.175	38.5	4582.9
120	40	24.64	11209.84	38.5	4435
120	60	24.64	11209.84	38.5	4363
120	80	24.64	11209.84	38.5	4379
120	120	24.64	11209.84	38.5	4587.5

Regression equation for top displacement,
$\Delta=-2989.66+(1.579337*x) - (0.00575*I_o) + (68.03735*H) + (38.10111 *A_c)-(44.9291*d)$

For the final check for the regression equation, four models were chosen, the final results are as follows:

Table -2: Check for regression

Position	H(m)	X(m)	Top displacement(mm)	
			software analysis	regression analysis
top	90	90	2536	2513.395
2/3rd	90	60	2803	2463.246
middle	120	60	4417	4414.17
1/3rd	120	40	4435	4382.583

6. DISCUSSION

From the results, it can be seen that the optimum position for a single outrigger against dynamic earthquake load is in the middle position. The effect of secondary earthquake waves may account for the optimal position.

The effect of variation in depth in case of 30 storey building was linearly increasing. As the depth of outrigger increased, the top displacement decreased linearly. But in the case of 40 storey building, the performance increase was seen only when placed at the 1/3rd position or middle position. The increase in depth showed only marginal improvement when placed at a 2/3rd height, after variation in the height of 4m to 4.5m. Also, when placed at the top, any increase in outrigger depth brought about a negative impact on its performance. The top drift increased when the depth of outrigger was increased at the top. This is because when the height of outrigger is increased, the storey height also increases. This brings about a negative impact on the structure. When outrigger is introduced into a structure, and when the height of storey is increased, the outrigger has to perform a dual job of counteracting the lateral force and the the effect due to increased storey height. This may be the reason why the increase in outrigger depth brought about an increase in top displacement when placed at the top of the structure.

The results from the regression analysis produced generally favorable results. The results obtained showed very little variation from original data. The results from regression analysis has a factor of safety between 0.88 and 0.99.

7. CONCLUSIONS

The design of an outrigger braced structure is often governed by numerous parameters that may affect the stability of a structure against lateral forces directly or indirectly. In this paper, the position of the outrigger and the depth of outrigger are given predominant importance. The variation of outrigger performance on the basis of top deflection is studied. The following conclusions were made.

- Existing methods for the approximate analysis of outrigger braced structures are based on many assumptions that often do not match real world cases.
- Results from equivalent lateral load showed that the optimum location of the outrigger is at the middle height of the building.
- Variation of the depth of outrigger in the equivalent lateral load analysis showed a linear variation the top displacement.
- The variation of outrigger depth in linear time history analysis showed decreased top displacement except when placed at the top position.
- Results from regression based equation showed produced favorable results with a factor of safety of 0.88 and 0.99.

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