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CHARACTERIZATION AND DRIFT MINIMIZATION OF TALL BUILDING FRAMES

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ABSTRACT: Drift is a dominant feature in tall building design. Lateral loads (i.e., wind or earthquake loads) are mainly responsible for drift, which very often dictates the selection of structural systems for high rise building. To bring the maximum drift down to allowable limits, cross sectional dimensions of beams and columns have to be increased in many cases. For buildings having small number of storey, lateral loads rarely affect the design. But when the height of the building increases, the increase in size of structural members and the possible rearrangements of the structure to account for lateral loads incurs a cost premium. Thus if it is possible to introduce certain techniques to utilize the full capacities of the structural elements, savings in materials and cost can be achieved. This paper presents the results of an investigation into characterization of tall building frames under lateral loads, drift and its minimization. The 'Displacement Participation Factor (DPF)' approach is used to identify the members, which contribute significantly to drift. A computer program has been developed to compute the deflection, strain energy and DPF of the members. Through the investigation, DPF of beams and columns, which contribute to maximum lateral sway, have been identified. It has been shown that considerable reduction in drift can be achieved by increasing the moment of inertia (stiffness) of 2nd to 5th floor beams, for up to 30 storey frames.

KEYWORDS: Tall building, drift, DPF, top deflection, drift index, lateral loads, bay width.

INTRODUCTION

Tallness is a relative matter and tall buildings cannot be defined just in terms of height or the number of floors. The tallness of a building is often related to the perception of an individual or a community. Thus a measurable definition of a tall building cannot be universally applied. The Council of Tall Buildings and Urban Habitat considers building having 9 or more stories as high-rise structures (CTBUH, 1980). There is no consensus on what constitutes a tall building. Perhaps the dividing line should be drawn where the design of the structure moves from the field of statics into the field of structural dynamics. From a structural engineer's point of view, however, a tall building may be defined as one that, because of its height, is affected by lateral forces due to wind or earthquake actions to an extent that they play an important role in the structural design.

In tall building design drift is a dominant feature. Drift may be defined as the displacement of one level relative to the level

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above or below due to the lateral forces. Lateral loads (i.e., wind and earthquake) are responsible for the drift, which is an important consideration for structural engineers. This drift often dictates the selection of structural system. To bring the drift down to allowable limits, cross sectional dimension of beams and columns have to be increased. So the structural characterization and drift minimization of tall building frames under lateral load is very important (Ahmed and Choudhury, 1993).

Sound engineering judgement is required when deciding on the drift index to be imposed. Drift index is the ratio of the maximum deflection at the top of building to the total height. Design drift index limits that have been used in different countries range from 0.001 to 0.005. To put this in perspective, a maximum horizontal top deflection between 0.1 and 0.5m (6 to 20 inches) would be allowed in a 33-storey building. Generally, lower values should be used for hotels or apartment buildings than for office buildings, since noise and movement tend to be more disturbing in the former. Consideration may be given to whether the stiffness effects of any internal partitions, infills, or claddings are included in the deflection calculations.

ANALYSIS APPROACH

For the analysis of tall planar frames, deformation arising from flexural, axial and shear distortion occurring within the beams, columns and beam-column joints can be computed by displacement participation factor approach (Smith and Coull, 1991; Charney, 1990; Taranath, 1988). A displacement participation factor is a numeric value, which represents the contribution of a structural member to the displacement occurring at a specific point and in a specific direction. For example, if it is known that the lateral displacement at the roof of a 40-storey tube is 500 mm, and the displacement participation factor for a column at the base of the structure is calculated to be 2.5 mm, that member is responsible for 2.5/500 or 0.5% of the total drift. The sum of the displacement participation factors for all the members of the structure is equal to the displacement at the specified location.

The principle of virtual work constitutes the most versatile method available for evaluating elastic deflections of structures. Through this method, not only it is possible to determine the deflections resulting from loads of any type, causing any kind of strains in a structure, but it is also possible to compute deflections resulting from temperature changes, errors in fabrication, or shrinkage of the structural material (Brebbia and Ferrente, 1988; Sazzad and Kamruzzaman, 2000).

According to the principle of the virtual work,

External work = Internal

Or, $P^{*}\Delta/2 = U$

Or, $\Delta = (2/P)*U$ (1)

where, Δ = displacement, P = applied load, U = strain energy

For whole structure, with m number of members,

$$\Delta \sum_{i=1}^{m} U \bullet 2/P \qquad (2)$$

It can be easily seen that each of the products in the summation on Eq. (2) represents the contribution of that member to the overall displacement. Hence equation (2) may be written as:

$$\Delta \sum_{i=1}^{m} DPF_i \qquad (3)$$

where, DPF_i= Displacement Participation Factor

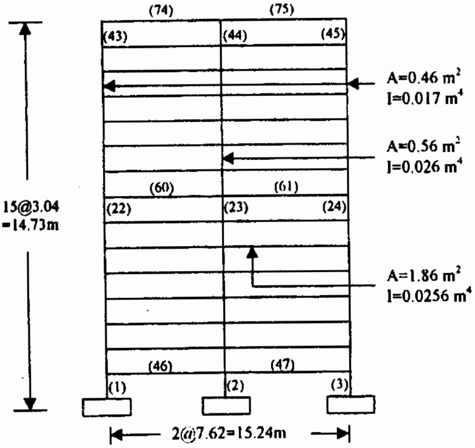
The analysis of rigid frame buildings is accomplished most efficiently by using stiffness analysis programs. A computer program in FORTRAN VISUAL WORKBENCH has been developed to compute the deflection, strain energy and displacement participation factor (DPF) of the members.

ANALYSIS

Tall buildings can be analyzed by idealizing the structure into simple two-dimensional or more refined three-dimensional continuums. In the present study, a total of 5 structures were analyzed, with the parameters varied being number of bays, bay width, load case and number of stories and stiffness (e.g., dimensions of beams and columns). Storey height is varied from 10 to 30-storey, as drift reduction above this height is narrowest. The parameter values used for each of these variables are shown in Table 1. A typical 15-storey frame is shown in Fig. 1.

Table 1. Summary of Frame Analysis

Storey	No of Bay	Bay Width (m)	Load Case	Stiffness Variation	Location of Floor Beam
10, 15, 20, 25, and 30	2	7.62	Point Load	2I, 3I, 4I, (I+2I), (I+2I+3I) (I+2I+3I+4I)	Top, 1st, 2nd, 3rd, 4th, (1st +2nd), (1st +2nd+3rd) floor beam
			UDL		
			Triangular Load		
		9.14	Point Load		
			UDL		
			Triangular Load		
	3	7.62	Point Load		
			UDL		
			Triangular Load		
		9.14	Point Load		
			UDL		
			Triangular Load		



[Numbers in the parenthesis indicate number of the member]

Fig 1. 15-Storey Frame

Lateral load cases like UDL for wind load, triangular load for earthquake load and point loads subjected from shear wall are implied on different frames. In this study, the DPF (%) values of different stories are calculated. The 1st, 2nd, and 3rd maximum DPF (%) contribution of different floor beams along with their values are tabulated and given in Table-2, Table-3 and Table-4.

Table 2. The DPF (%) values for point Loading

No of Storey	DPF(%) contribution with position of floor beam					
	1st position		2nd position		3rd position	
	Floor position	DPF(%)	Floor position	DPF(%)	Floor position	DPF(%)
10	5th	3.56	6th	3.55	4th	3.54
15	5th	2.04	6th	2.04	4th	2.00
20	5th	1.31	6th	1.30	4th	1.29
25	5th	0.88	6th	0.087	4th	0.87
30	5th	0.61	6th	0.06	4th	0.59

Table 3. The DPF (%) values for UDL

No of Storey	DPF(%) contribution with position of floor beam					
	1st position		2nd position		3rd position	
	Floor position	DPF(%)	Floor position	DPF(%)	Floor position	DPF(%)
10	2nd	7.33	1st	6.58	3rd	5.95
15	2nd	5.13	3rd	4.62	1st	4.27
20	2nd	3.74	3rd	3.51	4th	3.14
25	2nd	2.80	3rd	2.70	4th	2.48
30	2nd	2.15	3rd	2.10	4th	1.97

Table 4. The DPF (%) values for triangular Loading

No of Storey	DPF(%) contribution with position of floor beam					
	1st position		2nd position		3rd position	
	Floor position	DPF(%)	Floor position	DPF(%)	Floor position	DPF(%)
10	2nd	6.16	3rd	5.81	4th	4.99
15	3rd	3.87	2nd	3.86	4th	3.65
20	3rd	2.68	4th	2.62	4th	2.61
25	3rd	1.93	4th	1.90	2nd	1.87
30	3rd	1.42	4th	1.41	5th	1.39

From the results presented in Tables 2, 3 and 4, it is obvious that with the increase of height maximum DPF (%) contribution of different floor beams as well as their position changes. The DPF (%) contribution with respect to different storey height is shown graphically in Fig. 2.

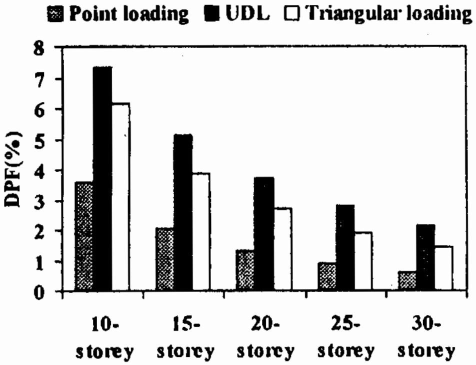


Fig 2. Effect of drift reduction on storey height

EFFECT OF NUMBER OF BAYS ON DRIFT REDUCTION

The variation in the number of bay also affects the top deflection. In this study, it has been found that that considerable reduction in top deflection can be attained by increasing the bay number. The reduction in top deflection for different types of loading is shown in Tables 5 through 7.

Table 5. Reduction in top deflection for point Loading

Storey height	Top deflection		Percentage reduction
	2-Bay	3-Bay	
10 Storey	0.1089	0.0073	6.7
15 Storey	0.1883	0.013	6.9
20 Storey	0.2950	0.0182	6.17

Table 6. Reduction in top deflection for UDL

Storey height	Top deflection		Percentage reduction
	2-Bay	3-Bay	
10 Storey	0.0512	0.0035	6.84
15 Storey	0.1315	0.0087	6.62
20 Storey	0.2683	0.017	6.37

Table 7. Reduction in top deflection for triangular Loading

Storey height	Top deflection		Percentage reduction
	2-Bay	3-Bay	
10 Storey	0.3607	0.024	6.65
15 Storey	1.3565	0.089	6.56
20 Storey	3.7068	0.2327	6.28

REDUCTION IN DRIFT

From Tables 2, 3, and 4, it is observed that maximum DPF contribution goes to 2nd and 3rd floor. The 4th and 5th also contribute significantly to drift. So it is obvious that by increasing the moment of inertia (stiffness) of 2nd to 5th floor beam, considerable amount of drift reduction may be achieved. Figures 3 through 5 show the reduction in top drift by increasing the moment of inertia by 2, 3 and 4 times of the1st, 2nd 3rd floor beams.

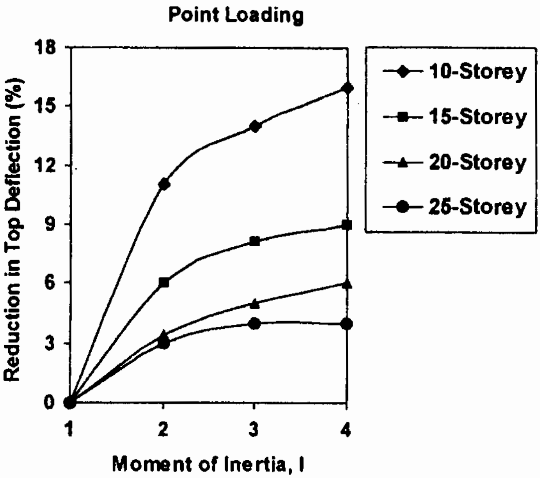


Fig 3. Reduction in top deflection vs moment of inertia for point loading

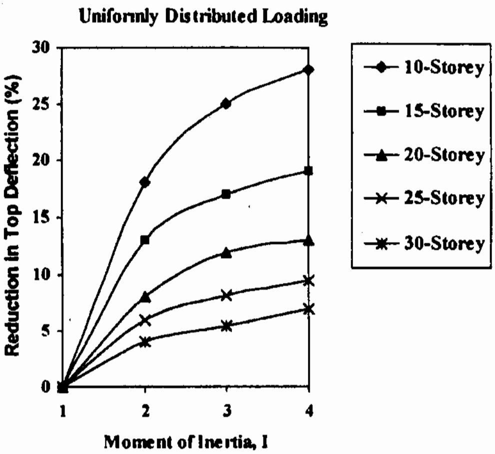


Fig 4. Reduction in top drift vs moment of inertia for UDL

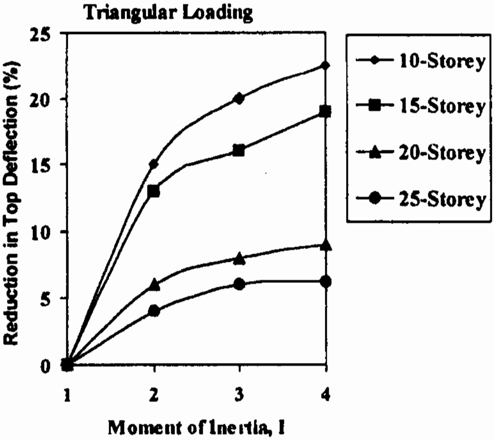


Fig 5. Reduction in top drift vs moment of inertia for triangular loading

CONCLUSIONS

The results of the study can be summarized as follows: (1) The 'Displacement Participation Factor' approach is a convenient method for identifying the members that contribute significantly to drift; (2) By increasing the moment of inertia of 2nd to 5th floor beams, significant amount of top drift reduction can be achieved; (3) By increasing the moment of inertia of top beam, no significant reduction in drift is achieved; (4) The DPF of 2nd floor beam is maximum for UDL for any storey height and the DPF of 3rd floor beam is maximum for triangular loading for any storey height except 10-storey; (5) Above 30 storey, drift reduction is narrowest and is not economical by increasing the moment of inertia of 2nd to 5th floor beams, as the DPF contribution of columns are much greater than beams; (6) Increasing the moment of inertia of 2nd 3rd of any floor beam having a DPF very close to the floor having maximum DPF can lead to significant reduction of top drift.

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