Control of Earthquake Resistant High Rise Steel Frame Structures

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Abstract**—** This paper concerns studies on control buildings in industrial plants that may be subjected to harmonically varying severe earthquake loads and their parametric responses over a range of applied frequencies and amplitudes. Investigations have been carried out in respect of design philosophy, structural concepts and dynamic stability properties of a model system. Eigen-buckling responses for possible structural concepts subjected to earthquake forces for different height to plan areas as well as aspect ratios are derived by finite element approach using general purpose software (STAAD Pro.). Finally structural concepts are explained in explicit form based on the results of numerical investigations of economical viewpoints.
Key Words : Control Buildings, Earthquake Resistance, Stability, dynamic analysis, drift index.

1. Introduction

In a design process, a thorough knowledge of high rise structural components and their modes of behavior is a prerequisite to devise an appropriate load resisting system. Such a system must be efficient, economic and should minimize the structural penalty for height while maximizing the satisfaction of basic serviceability requirements. Structural engineers are concerned with the stability of motion in response of high rise structures against random loading from seismic events. Comparatively little literature exists on the dynamic stability of structures subjected to time-varying random loads.

Stability criteria in buckling of structure were explained by Iyenger [1] through equilibrium (Euler) approach, energy approach and vibration (dynamic) approach. Numerical methods and their closed form equations, which include the rotational stiffness at the web-flange connection, were reported by him. Kenny et al [2] developed empirical relationships to characterize dynamic plastic response of slender beams by experimental investigations. Variations in effective slenderness ratio and material properties for slender beams subjected to axial impact were introduced for experimental investigations by them [2]. Further they established an empirical basis for validation of parallel numerical analysis based on finite element method. Datta [3] performed a series of detailed numerical analysis of stiffened plates subjected to in plane longitudinal compressive load for different aspect ratios in a recent paper. Three different numerical integration procedures had been considered for determining response of model structure due complex nature of applied loads and nonlinearity governing equilibrium equation.

The provision of adequate stiffness, particularly lateral stiffness is a major consideration in the design of tall building. As far as the ultimate limit state is concerned, lateral deflection must be limited to prevent second-order P-Delta effects. In terms of the serviceability limit state, deflections must first be maintained at sufficiently low level to allow the proper functioning of nonstructural components, to avoid distress in structure, to prevent excessive cracking and consequence loss of stiffness and to avoid any redistribution of load. The structure must be sufficiently stiff to prevent dynamic motions becoming large enough. Parameter that controls later stiffness of a building is the drift index. Drift index is defined as the ratio of the maximum deflection at the top of the building to the total height. Assessment of drift index limit is a major decision. Unfortunately there are no unambiguous or well defined guidance to decide an appropriate value of drift index. As the height of the building increases, drift index coefficients should be decreased to the lower end to keep the top storey deflection to a suitably low level. The present study aims at minimization of the drift index from modal analysis of high rise steel frame structures for a specified earthquake loading. The numerical value of layout plan area of control building is kept constant while the variation has been made in geometric configuration. This is to look into the possible optimal zones between aspect ratio and increasing heights for high rise industrial structures.

2. Static and Dynamic Equilibrium

The basic equation of static equilibrium under displacement method of analysis is given by:

$$F(ext) = ky \quad (1)$$

Where,
F(ext) = external applied static force
k = stiffness resistance
y = resulting displacement

The equation of dynamic equilibrium with time varying force is given by,

$$F(t) = m\ddot{y} + c\dot{y} + ky \quad (2)$$

Thus dynamic equilibrium equation includes two additional forces called inertia force ($m\ddot{y}$) and damping force $(c\dot{y})$ resulting from induced acceleration and velocities in the structure respectively

An earthquake force is a dynamic force resulting from rapid movement along the plane of faults within the earth crust. This sudden movement of faults releases great energies in the form of seismic waves. These are transmitted to the structures through their foundations and causes motions in the structures. These motions are complex in nature and induce abrupt horizontal and vertical oscillations in structures resulting in accelerations, velocities and displacements in structures. The energy produced in the structures by the ground motion is dissipated through internal friction within the structural and nonstructural members. This dissipation of energy is called damping. The structures always possess some intrinsic damping, which diminishes with time once the seismic excitation stops.
Therefore, the equation of dynamic equilibrium for earthquake force has the form in which, inertia, damping and restoring forces balance the applied force,

$$F(t) = m\ddot{y}(t) + c\dot{y}(t) + k(t)y(t) \quad (3)$$

Where,
$m\ddot{y}(t)$ = inertia forces acting in the direction opposite to that of seismic motion applied to the base of structure. m is the mass in Kg and $\ddot{y}(t)$ the acceleration (m/sec^2).

$c\dot{y}(t)$ = damping forces acting in the direction opposite to that of seismic motion applied to the base of structure. C is the damping coefficient (N-sec/m) and $\dot{y}(t)$ the velocity(m/sec). The value of the damping in structure depends on its components, connections, materials etc. In practice this damping effect is expressed as a percentage of the critical damping which is the greatest damping value that allows the vibratory moment to develop.
$k(t)y(t)$ is the restoring force
$F(t)$ is the externally applied force (N).

3. Model High Rise Steel Frame Structure

The constraints in the present study are geometric constraints, imposing limits on the layout plan area of high rise steel frame structure, and also on bracing arrangements. Case studies are made for determining drift indexes and mode shapes of steel frame structure with different ranges of heights. A series of detailed numerical analysis of high rise steel frame structure are performed to describe the static and dynamic responses of three different layout plan areas and heights. The layout plan areas are with same area content. The frame structures are subjected to a typical earthquake load. Steel columns, floor beams and lateral bracings are defined with three different types of steel sections respectively. All the frame structures are selected with similar steel sections for columns, floor beams and lateral bracings. The solution technique makes use of interaction between ground acceleration and structural systems through response spectrum. The aim of this work is the modification of the dynamic interaction between the structure and the earthquake ground motion, in order to minimize the structural damage and to control structural response. The control ids based on modification of the dynamic characteristics in which the structural period is shifted away from the predominant periods of seismic input, thus avoiding the risk of resonance occurrence. All purpose software STAAD Pro. 2005 has been applied for the modal analysis in order to assess the response history of high rise steel frame structures to a specified ground motion in conjunction with a response spectrum. Finally drift indexes are expressed in explicit form based on aspect ratios from layout plan areas from the results of numerical investigations of the non-linear behavior of steel frame structures.

Table 1: Time History Earthquake Load

Time (sec)	Fraction of Ground Acceleration
0.0000	0.006300
0.0200	0.003640
0.0400	0.000990
0.0600	0.004280
0.0800	0.007580
0.1000	0.010870

Table 2 Flow stress values of steel in uniaxial isothermal compression

True Strain	True Stress (MPa)
0.003	205.79
0.007	341.43
0.03	430.13
0.10	584.65
0.2	758.56
0.35	959.19
0.46	1063
0.49	1072.58
0.51	939.27

Table 3 Properties of structural steel at room temperature

Elastic Modulus (GPa)	193
Rigidity Modulus(GPa)	65.6
Melting point in Celsius	1560
Co-efficient of friction	0.47
Poisson's ratio	0.28
Density (gm/cc)	7.85

Table 4: Parameters for High Rise Frame Structures

Plan Area	Plan Area (M^2)	Height of Structures (M)	Storey Height (M)
Circular (5M radius)	78.54	40	5
		70	5
		100	5
Square 8.85 x 8.85 M^2	78.32	40	5
		70	5
		100	5
Rectangular 15.7 x 5 M^2	78.50	40	5
		70	5
		100	5

Table 5: Assigned Steel Frame Sections

Structural Member	Steel Section	Area (cm^2)	Moment of Inertia cm^4
All Columns	W 500400x01	223	21347
All Floor Beams	W 400350x01	171	14127
All Inclined Barces	ISMC 250	39	219

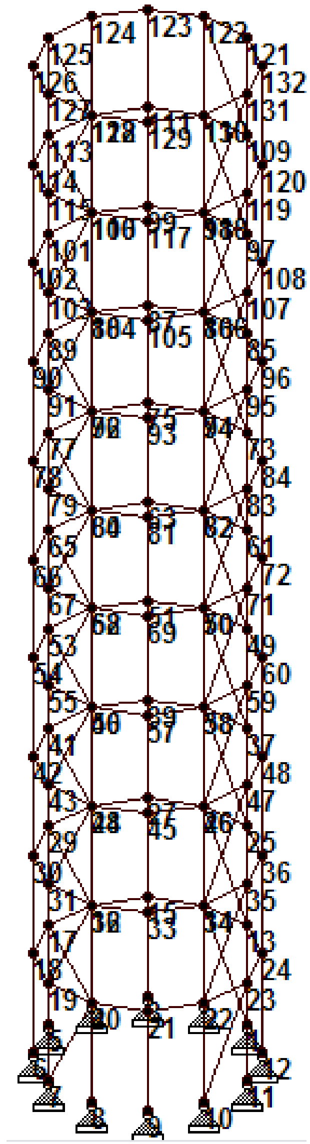

Figure 1: Model 10 Storey Circular Frame Structure with Generated Node Numbers

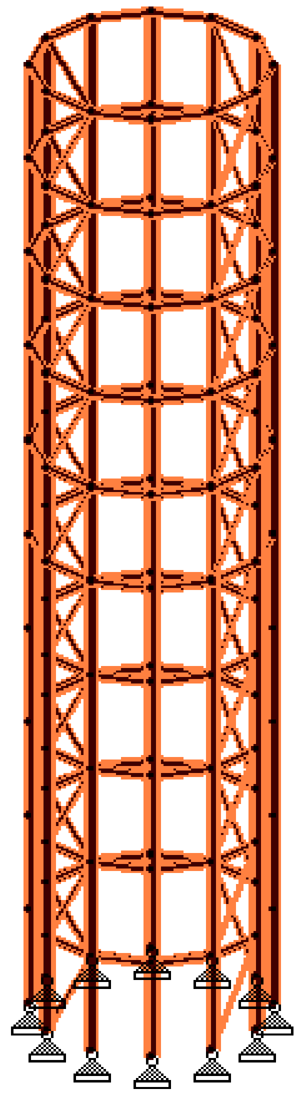

Figure 2: Model 10 Storey Circular Frame Structure with Assigned Steel Sections

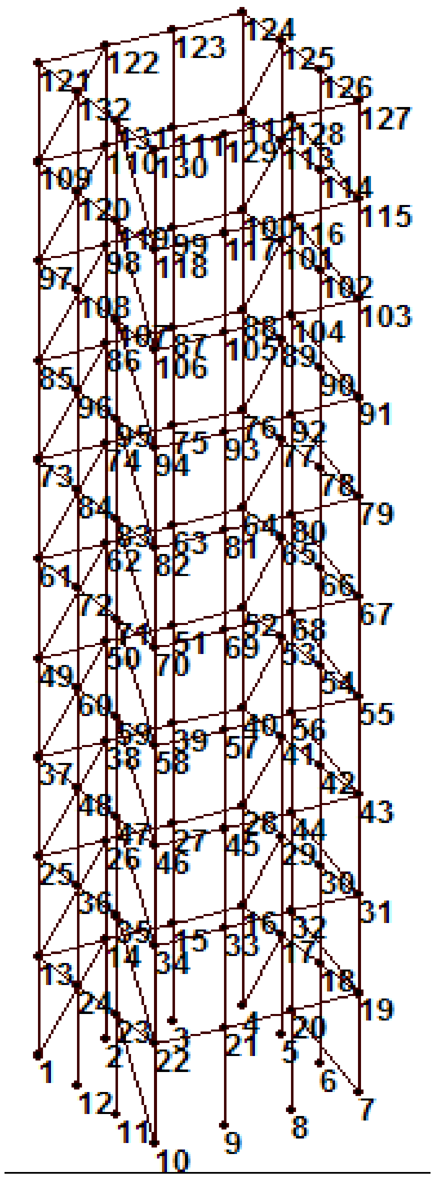

Figure 3: Model 10 Storey Square Frame Structure with Generated Node Numbers

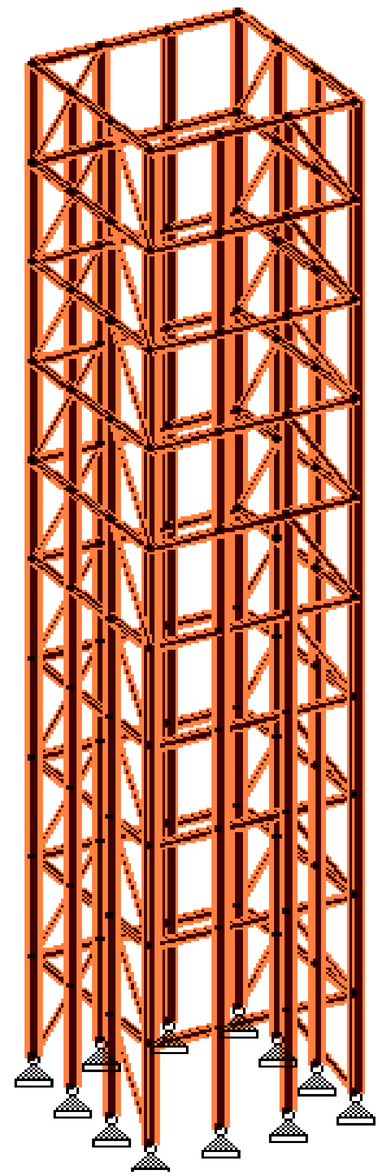

Figure 4: Model 10 Storey Square Frame Structure with Assigned Steel Sections

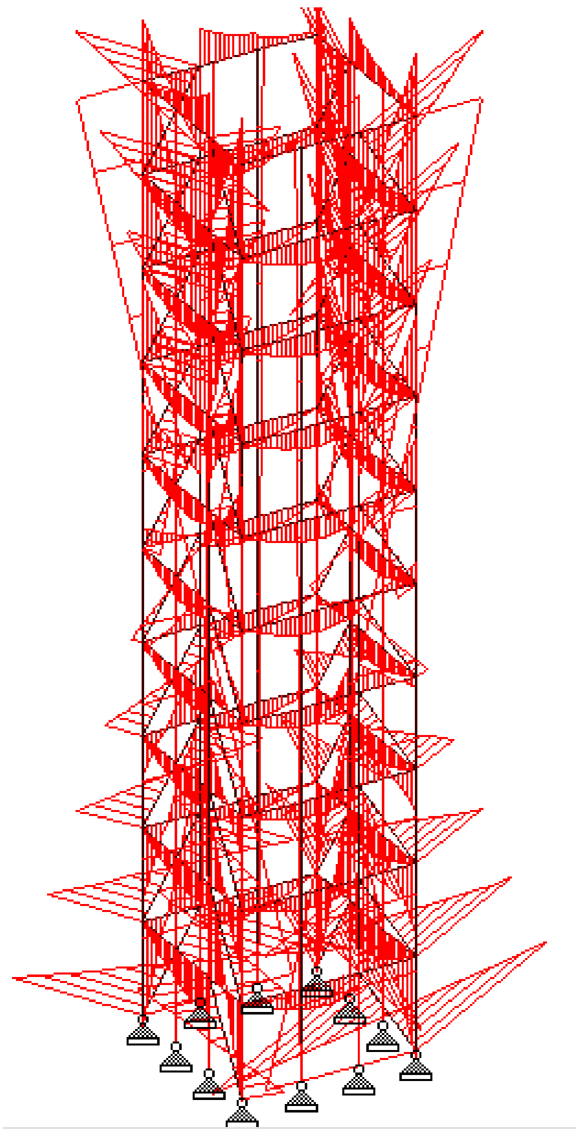

Figure 5: Model 10 Storey Square Frame Structure with Assigned Steel Sections

4. Output from Numerical Analysis

Modal analysis has been carried out for high rise frame structures subjected to time-history earthquake loads on model frames. . Output from STAAD Pro. in respect of lateral drifts and mode shapes for different models are presented in Table 6.

Table 6 : Drift responses of frame structures series

	Height of Frame Structure (M)	Drift Index
Circular Plan Area	40	0.378
Circular Plan Area	70	1
Circular Plan Area	100	1.57
Square Plan Area	40	0.13
Square Plan Area	70	0.18
Square Plan Area	100	0.203
Rectangular Plan Area	40	0.43
Rectangular Plan Area	70	1.154
Rectangular Plan Area	100	2.061

5. Drift Optimization of Frame Structures for Stability

Drift Index responses for varying plan geometries and heights for steel frame structures with different bracing arrangements are shown in Table 6 above. The net layout areas for all the cases are kept constant, The drift responses exhibit monotonic increase in the values of drift indexes with increase storey heights for circular and rectangular layout areas. However the values of drift indexes are remarkably constants even the storey height increase for frame structures with square layout area[Fig.6]. This is unique finding from this study and it ensures that there is certainly optimized zone for a plan layout where there will be minimum drift for high rise structures.

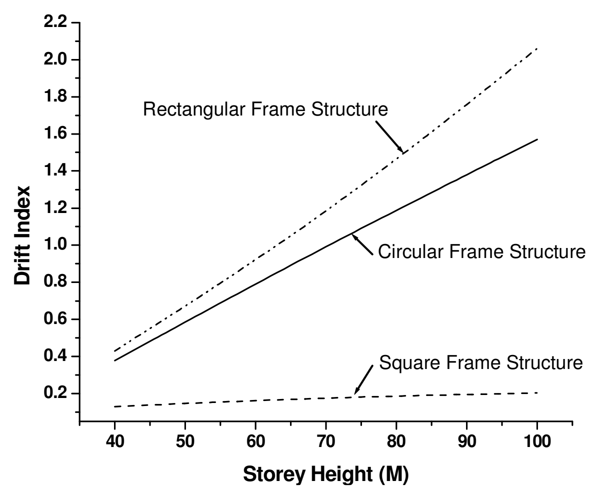

Figure 6: Drift Index Responses for High Rise Frame Structures with different Plan Layouts

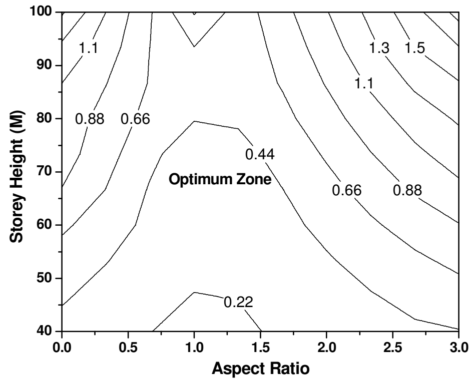

Figure 7: Drift Index Responses for Storey Heights and Aspect Ratio Layouts

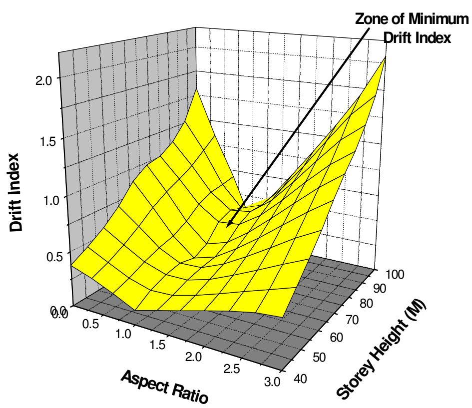

Figure 8: Optimum Drift Index Responses for Storey Heights and Aspect Ratio Layouts

As the height of the building increases, drift index coefficients are found to be at their minimum around aspect ratios 1.0 to 2.0 [Fig 7 & 8]. Height may be increased upto desired levels within this zone ensuring stability for a particular brace arrangement to keep the top storey deflection to a suitably low level. Thus excessive drift of a structure can be reduced by changing the geometric configuration to alter the mode of lateral resistance.

6. CONCLUSION

The control of lateral deflection is of particular importance for modern tall buildings. In view of the importance of improving overall stability of high rise steel frame structures, an appropriate optimization model has been formulated by considering appropriate geometric configuration of layout plan area without compromising increase in heights. General purpose software STAAD Pro. provides an approximate numerical analysis for the formation of concise and properly representative model of tall building analysis. Based on this fact, drift indexes are obtained for any geometry and height against earthquake loads for high rise structures. The unique finding of this work ensures excessive drift of a structure can be reduced by changing the geometric configuration to alter the mode of lateral resistance to a great extent for arbitrary increase in heights within the optimal zones of aspect ratios.

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