Comparative Study on the Lateral Load Resistance of Multi-Storied Structure with Bracing Systems

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Abstract

The vulnerability of seismic forces onto a high rise structure leads to a sudden collapse which is unpredictable. It can also be understood from the provisions of Indian Standards that, it is desired to allow the damage of the structure to certain extent for sudden earthquakes by safeguarding the livelihood. In the present study, a five storied RC building has been modeled and then analyzed considering the combination of gravity and seismic forces. The performance of the same structure has been investigated for different types of bracing system such as cross and diagonal bracings using a concrete section and steel sections respectively. The performance of the same building has been evaluated in terms of lateral displacement of members, storey drift, axial force and bending moment in columns at different critical. The effectiveness of various bracing systems on the structure has also been investigated. More importantly, the reduction in lateral displacement has been found out for different types of bracing system in comparison to building with no bracing for zone-3 and zone-4. From the present study, it has been found that the crossed ‘X’ bracing reduces more lateral displacement and thus significantly contributes to greater structural stiffness to the structure.

Keywords: Bracing Systems, Equivalent Lateral Force Method, Response Modification Factor

1. Introduction

1.1 Background

In today’s world, concrete has become ubiquitous and in fact it is hard to imagine modern world without it. Concrete, in some or other form is used in the construction of structures that we see all around us. However there are a few areas of concern with this material, one of the major being the inability of these concrete structures to withstand vigorous ground motion which is normally accompanied with earthquakes. Thus seismic analysis of these structures and designing these structures keeping for the codal provisions of earthquake design based on the analysis obtained, has become an area of importance. Seismic analysis done over variety of structures without incorporating bracing systems showed up various ill effects. Hence incorporating proper bracing system has to be ensured for the safety of the structure. Therefore a comparative analysis has been made with respect to different bracing systems. The growth of high rise building is one of the reasons for the advances in structural systems, construction technology, analytical methods and materials for analysis and design. Due to wind or earthquake the Lateral loads determine the structural design of the high rise buildings. The interior structural system or exterior structural system provides the lateral load resistance. The interior system comprises of shear wall core, braced frame and combination with frames, where the central located elements resist the lateral load. While lateral loads are resisted by braced tube structural system and by elements provided on periphery of structure of the frame structure. It is a must that the design requirements should be satisfied with the specified structural thereby utilizing the structural elements effectively. In the recent years, tall buildings have been specified according to the diagrid structural system owing to its structural efficiency and flexibility in architectural planning. This particular type of structure has inclined columns on

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the exterior surface whereas, on the other hand, closely spaced vertical columns are in the framed tube structure. The inclined columns assist in the resisting which is due to the axial action of the diagonals which is not the same case in framed tube structure where the bending of vertical columns takes place. The lateral shear is applied on the diagonals of the periphery of the building, so there is no need of core in diagrid structures\(^1\).

Engineers focus on the need to control the horizontal displacements. The horizontal actions, coming from wind and earthquakes become more sensitive with the height of the buildings. Without specific stiffening members, the dimensions of the columns increase to such an extent that they are no longer reasonable. So, the traditional solutions providing vertical bearing capacity tend to be associated with or replaced by innovative structural configuration. From the structural viewpoint, high-rise structures represent a demanding problem which requires adequate structural solutions in terms of stability and rigidity. Indeed, while in the design of low-rise buildings the influence of dead and live loads is the leading factor, increasing height, the attention of the structural systems, which had its origins from tube, rigid frame, and core-outrigger to diagrid structures\(^2\).

### 1.2 Literature Review

In a research, a detail analysis of a 36 storey diagrid building (steel) was done, considering a regular floor plan. IS 800:2007 is used in designing all the structural members. Analysis of load distribution is also done on the diagrid system. 50, 60, 70 and 80 storey diagrid structures’ design and analysis results were also presented. The results conclude that, gravity is resisted by internal columns and diagrid columns on the periphery resist most of the lateral load. There has been an increase in lever arm of peripheral diagonal columns. Therefore, it is effective to use diagrid structural system in lateral load resistance. On the periphery of structure, the axial force in diagonal members resists the gravity and lateral loads. This makes the diagrid structural system more effective. This also facilitate in flexible planning of façade and interior space of a building\(^1\).

There is a need for the assessment of the global displacements and the lateral load distribution of external actions in high-rise buildings. The analytical formulation which examines the structural behavior of tall buildings sustained by any kind of bracings, is reviewed. In particular, it takes into consideration frames and thin-walled shear walls with closed or open section. In addition, curves regarding the lateral load distribution between different structural typologies as well as the internal actions of a generic bracing have been reported in order to highlight the capabilities of the method\(^3\).

A high-frequency force balance technique in a wind tunnel has been used to test all the 15 tall building models which are of different cross-sections and aspect ratios ranging from 4 to 9 to obtain their first-mode generalized dynamic forces across-wind. The important behaviors like aspect ratio, land suitability condition, side ratio of cross section and modified corner of the building models on the across-wind forces are investigated in detail\(^4\).

Three important parameters namely side ratio aspect ratio and elevation were given importance in the typical analyses which consists of spectra, local wind force coefficient and span wise cross-correlation. Side ratio is obtained as 0.6303. Stationary cylinders of certain free-stream turbulence has a critical side ratio value (close to 0.63 here). At this mean, critical side ratio and RMS drag coefficients, crosswind cross-correlation and peak of crosswind spectrum, they attain their maximum. The values can be decreased due to the interaction of shear layer and edge and further reattachment which exceeds the critical side ratio. This variation of interaction along elevation levels causes the fluctuations in crosswind spectra, torsional spectra and span wise cross correlation of these two force components. The torsional spectrum and torsional cross correlation are very much dependent on these three parameters\(^4\).

Diagrid structures have been prevalently used for tall buildings all over the world. The compositional characteristics of diagrids which are unique provide great structural efficiency and aesthetic potential as an accentuating element in any existing urban context composed of orthogonal components in buildings. This paper explains structural performance and constructability issues of diagrid structures employed for complex-shaped tall buildings such as tilted, twisted and freeform towers. Application of diagrid structures for tall buildings is modern. With emergence of tall buildings of different complex shapes in the world, studies are very much required on their potential structural systems and multidisciplinary collaboration to construct built environments of higher performance\(^5\).

In this study, the factors responsible for high inelastic seismic demands and the large difference between
demands obtained from the RS and NLRHA procedures in the high rise RC core wall buildings were identified. A case study building was examined in detail. The effect of some obvious factors such as excitation level, over strength, and different damping ratios is quantitatively estimated using NLRHA procedure. It is observed that there is still considerable difference between the RS demands and NLRHA demands which cannot be explained by performing only NLRHA. To determine the reasons for the considerable difference, modal decomposition of the inelastic demands using UMRHA method is needed. The detail understanding will lead to better design of the high rise RC core wall buildings as well as to design and identify control measure for reduction of the high inelastic seismic demands. Hence the study is of practical importance.

Analyses indicate the CMDB net section may have similar demands to an SCBF. Analytical results indicate that CMDB designs in cyclic analyses may possess a higher low cycle fatigue life than an SCBF, and have the potential for lower seismic demands, in earthquake simulations.

Using UMRAH (Uncoupled Modal Response History Analysis method), a 9-storey RC frame is examined for top 34 strong records of earthquake. The effect of higher modes on nonlinear response was assessed. In planar structure, first mode dominated RC frames even more specifically in inertial forces and accelerations of storey at all floors and shear forces at higher storeys, higher mode effects are important. Displacements and inter storey drifts are less dependent relatively. This higher modes contribution to these inertial forces and shear forces depends on the ground motion characteristics and the flexural over strength associated with each mode. The modal reduction factors that were developed during an earthquake are inversely proportional to each mode order. So, in the current design practice, if a constant R value (found from the response of the first mode) is adopted, storey accelerations and forces are underestimated.

The actual value of R in real life designs is expected to be even lower than what is calculated here, because of various reasons like poor workmanship and lack of control at the time of construction, not giving attention to ductile detailing requirements according to guidelines, torsional effects caused by irregularities in dimensions, etc. The strong-column-weak-beam criterion in design does not make any major difference in terms of R. The conclusions of the study are limited by the facts that only a single plan configuration (without plan-asymmetry) in one single seismic zone has been considered. In addition, the structural behavior is not validated by any nonlinear response-time-history analysis. The different parameters used in the work presented have been considered to be deterministic, although in reality their statistical variations are significant enough requiring a reliability-based framework for this study.

For the determination of periods of vibration of RC MRF buildings, it is important to consider the effect of both the building overall length (H) and the number of stories (N) must be taken together. Using regression analysis of data new formulae of the fundamental period of vibration of RC MRF buildings considering the coefficient as a function of number of stories was developed. From the motions recorded during earthquake, fundamental vibration period of few RC MRF buildings is measured. This data is analyzed and used developing the formulae. Various formulae has been considered to find the higher accurate value of period of RC building and thus equations are recommended. Additionally, the period (from rational analysis) should be considered only if it is less than 1.5 times the value (from recommended equation). Including places where building design practice deviates from that of California, the Regression analysis, on data sets that are large, should be periodically repeated.

After an earthquake Self-Centring Concentrically Braced Frame (SC-CBF) systems have been previously developed to increase the drift capacity of the structure prior to damage and to self-center. Using the developed probabilistic demand models for peak inter-story drift and residual inter-story drift, seismic fragilities are assessed for peak inter-story drift and residual inter-story drift in three performance levels: Immediate Occupancy (IO), Life Safety (LS) and Collapse Prevention (CP). The results of the numerical analysis show that the SC-CBF building has higher roof drift values than the CBF building due to softening behaviour in the SC-CBF.

### 2. Equivalent Lateral Force Method

A static force is applied on the structure and is analysed in Equivalent Lateral Force Procedure. To make the cross-sectional members act like two force members, the forces are applied at the joints. The aggregate of the lateral forces affecting the structure (base shear) is the most significant and important force in the entire procedure. This base shear should be resisted by the capacity or the
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strength of the members. Additionally, storey drift check is also performed to examine if the exact members are selected. Seismic response coefficient, importance factor and response modification factor are few other factors that should be considered during analysis using this procedure. In this method the base shear is the main load and the analysis is static.

2.1 Seismic Response Coefficient
The base shear of the structure is determined by using this Seismic Response Coefficient. The Base shear is calculated by multiplying the effective weight of the structure and the Response Coefficient. The effective weight consists of all loads including dead loads as well as live loads.

2.2 Response Modification Factor
When a structure is designed by engineers, the primary aspect of the building to be considered is its resistance to damage and preserving of human life. In some cases, the best designed buildings are also influenced by inelastic deformation. The structure's ability to absorb energy without collapsing or its energy dissipation capacity is being accounted by Response Modification Factor (R). This factor is dependent upon the type of structure. The ductility of a structure can be considered directly proportional to the modification factor. If a structure is ductile, it changes its shape under stress before it breaks.

2.3 Importance Factor
The Importance Factor (I) contributes reflects the use and importance of a building. Occupancy Categories for buildings from IS codes directly gives the values of Importance Factor. Public facilities such as hospitals and schools have a high Importance Factor and the facilities such as storage buildings are given a lower Importance Factor.

Note: ISA 110 refers to 110’110’12 angle section and ISA 150 refers to 150’150’12 angle section throughout the paper

3. Analyzing a G+5 Structure in STAAD.Pro
Tables 1 and 2 give details of the structure details of the structure and types of bracings used for analysis respectively. Figure 1 gives beams - columns layout and plan view of the structure.

| Table 1. | Details of the structure |
| --- | --- |
| Earthquake zones | Zone-3,zone-4 |
| Type of soil | Loose soil |
| Foundation particulars | Raft foundation, soil structure interaction is ignored |
| No of stories | 5 |
| Height of each storey | 3.3 m |
| Depth of slab | 120 mm |
| Dimensions of beams | 230×420 mm |
| Dimensions of columns | 300×400 mm |
| Imposed load | 4KN/m² |
| Infill walls | Brick masonry 0.23m thick and density 20KN/m³ |
| Unit weight of concrete | 25Kn/m³ |
| Codes considered | IS 1893-2002 |

| Table 2. | Bracings used |
| --- | --- |
| 1 | 150 X 200_cross_concrete |
| 2 | 150 X 200_diagonal_concrete |
| 3 | ISA 110_cross_steel |
| 4 | ISA 110_diagonal_steel |
| 5 | ISA 150_cross_steel |
| 6 | ISA 150_diagonal_steel |

3.1 Theory behind Analysis
The primary requirement of beams and columns is to be compact and non-slender. This is vital for columns sections which may be too slender which may lead to buckling. The sections classification comprises of two categories, namely, Stiffened and Unstiffened elements. A W section or I beam section consists of a central web which is between a top flange and a bottom flange. Compact sections are the general requirement for beams. This can be attributed to the fact that compact beams buckle less and hence, it is a desired trait in beams. On the other hand for columns, since they have vertical loads, they require a non-compact structure. These shapes permit plastic and elastic buckling behavior and are desirable for earthquake resistant frames since the columns may sway.

Compactness of beams can be acquired in the flange and web sections. This paves a way for the minimum buckling of beams. This can be considered as a fortunate situation for beams since floors require minimum buckling. For instance, consider heavy equipment being hauled into the building or a large gathering happening.


4. Observations on Specific Member

In order to understand the behaviour of a particular member we choose a column which is at one of the bottom corners of the structure, which is beam 84 spanning in X direction and has the highest displacement. We know, resistance to lateral forces is provided primarily by rigid frame action i.e., by the development of bending moment and shear force in the frame members and joints. So it is necessary to have the comparative study of moments.

Note: In Figures 2 and 3, the numbers on x axis indicate the type of bracing used. They are according to Table 2. Where 1 – 150’200 Cross Concrete, 2 – 150’200 Diagonal Concrete, 3 – ISA110 Cross Steel, 4 – ISA110 Diagonal Steel, 5 – ISA150 Cross Steel and 6 – ISA150 Diagonal Steel.

We observe from Figure 2 that moment in ‘Z’ and ‘Y’ directions are way higher than that in ‘X’ direction. And in all the three directions moments in zone-3 are smaller than in zone-4. Among all the bracing types in zone-3, bracing type one which is 150 X 200 cross_concrete has the least moment. But in zone-4 the bracing types 3 and 5, ISA 110_cross_steel and ISA 150_cross_steel have almost equal and least moment.

5. Maximum Node Displacements

With the data from Figure 3, we can assess the maximum node displacement for a particular zone. Depending on that we can choose an appropriate bracing system for the building.

6. Analysis of each Bracing type in Zone 3 and 4

A paradigm trend one can expect in ascending order for the storey drift is

- Zone-3 ‘z’ direction.
- Zone-3 ‘x’ direction.
- Zone-3 ‘z’ direction, without braces (not plotted).
- Zone-3 ‘x’ direction, without braces.
- Zone-4 ‘z’ direction.
- Zone-4 ‘x’ direction.
- Zone-4 ‘z’ direction, without braces (not plotted).
- Zone-4 ‘x’ direction, without braces.
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Figure 2. Moment in. (a) X direction. (b) Y direction. (c) Z direction for member 84.

Figure 3. Node displacements in. (a) X direction. (b) Y direction. (c) Z direction.

The same trend is justified with the values we got from STAAD analysis and is shown in all the 6 bracing systems. Here in Figure 4, the graphs are drawn with storey drift in ‘cm’ vs height of the structure. 3.3m is the height of the first floor and so on. We can say a bracing type can show a uniform behavior if all the ends of the curves in a graph are closely spaced and vice versa.
Figure 3. Node displacements in: (a) X direction. (b) Y direction. (c) Z direction.

Figure 4. Storey drift when the structure is braced with: (a) 150*200 cross concrete. (b) 150*200 diagonal concrete. (c) ISA 110 cross steel. (d) ISA 110 diagonal steel. (e) ISA 150 cross steel. (f) ISA 150 diagonal steel.
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Comparison of Drift with different Bracings in X direction for zone 3 and zone 4 is as shown in Figure 5.

7. Observations

From the Figures 4 and 5 it can be observed that the percentage decrement in drift using a

- Concrete cross section of 150x200 ‘X’ bracing system in zone 3 is 61.5%
- Concrete cross section of 150x200 ‘X’ bracing system in zone 4 is 19.5%.

- Concrete cross section of 150x200 diagonal bracing system in zone 3 is 51.5%.
- Concrete cross section of 150x200 diagonal bracing system in zone 4 is 3.5%.
- Steel cross section of ISA 110 ‘X’ bracing system in zone 3 is 16.5%.
- Steel cross section of ISA 110 ‘X’ bracing system in zone 4 is 16.5%.
- Steel cross section of ISA 110 diagonal bracing system in zone 3 is 2.5%.
- Steel cross section of ISA 110 diagonal bracing system in zone 4 is 2.5%.
- Steel cross section of ISA 150 ‘X’ bracing system in zone 3 is 23%.
- Steel cross section of ISA 150 ‘X’ bracing system in zone 4 is 23%.
- Steel cross section of ISA 150 diagonal bracing system in zone 3 is 6.5%.
- Steel cross section of ISA 150 diagonal bracing system in zone 4 is 6.5%.

8. Conclusions

A five storied RC building has been modeled for its lateral resistance with different types of bracing systems. From the obtained results, it can be concluded that

1. Concrete ‘X’ bracing of cross section 150 X 200 was showing better performance in zone-3 as it has the highest percentage decrement in drift.
2. ISA150 ‘X’ bracing steel was showing better performance in zone-4 as it has the highest percentage decrement in drift.
3. When steel bracings are used, it is seen that, there is almost the same percentage decrement in drift in both the earthquake zones. For the proposed structure, choosing of a particular type of bracing system also plays a vital role in the performance of a building subjected to lateral loads.

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