iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH
IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 9 Issue: VIII Month of publication: August 2021

DOI: https://doi.org/10.22214/ijraset.2021.37750

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International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.429
Volume 9 Issue VIII Aug 2021- Available at www.ijraset.com

Analysis & Designing of Multistorey Building with Steel Plate Shear Wall

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Abstract: Structural design and analysis produces the capability of resisting all the applied loads without failure during its intended life. Lateral loads mainly due to earthquake govern the design of high-rise buildings. The interior structural system or exterior structural system provides the resistance to lateral loads in the structure. The present paper describes the analysis and design of high-rise buildings with Steel Plate Shear Wall (SPSW) for (G+20) stories. The properties of Steel plate shear wall system include the stiffness for control of structural displacement, ductile failure mechanism and high-energy absorption. The design and analysis of the composite building with steel plate shear wall is carried out using software ETABS. The present study is to carry out the response spectrum analysis of a high-rise composite building by optimizing the thickness of steel plate shear wall and to compare the results of displacement, story drift, overturning moment and story shear. The models are analyzed by Response Spectrum analysis as per IS 1893:2002. All structural members are designed as per IS 456:2002 & IS 800:2007 considering all load combinations.

Keywords: Seismic; Composite; Shear Wall; Earthquake; Reinforced concrete.

I. INTRODUCTION

In the last few decades, shear walls have been used extensively in countries especially where high seismic risk is observed. The major factors for inclusion of shear walls are ability to minimize lateral drifts, inter storey displacement and excellent performance in past earthquake record. Shear walls are designed not only to resist gravity loads but also can take care overturning moments as well as shear forces. They have very large in plane stiffness that limit the amount of lateral displacement of the building under lateral loadings. Shear walls are intended to behave elastically during moderate or low seismic loading to prevent non-structural damage in the building. However, it is expected that the walls will be exposed to inelastic deformation during less or frequent earthquakes. Thus, shear walls must be designed to withstand forces that cause inelastic deformations while maintaining their ability to carry load and dissipate energy. The Investigations of strong ground motions revealed that properly designed and detailed shear wall buildings performed well in past earthquakes. Shear walls built in high seismic regions should be in compliance with special detailing requirements. However, prior observations indicated that even buildings that have high shear walls area to floor area ratios with walls that do not have special seismic detailing survived high magnitude earthquakes. encourage use of shear walls for earthquake-resistant design.

Fig. Steel Plated shear wall.

A. Shear wall and Effect of Shear wall

The wall in a building which resists lateral loads originating from wind or earthquakes are known as shear walls. Reinforced concrete walls are strength and portent elements frequently used in constructions in seismic areas because they have a high lateral stiffness and Resistance to external horizontal loads, these shear walls may be added solely to resist horizontal forces or concrete walls enclosing stairways elevated shafts and utility cores may serve as shear walls. shear walls not only have a very large in plane stiffness and therefore resist lateral load and control deflection very efficiently but they also helps in reductions of structural & non-structural damage. The building incorporated with shear wall sufficiently ductile will be much away from seismic vulnerability and building failure in the earthquake sensitive zones thus resulting in increased life safety & low property loss

B. Behaviour of Shear wall

Shear wall constructed in the high rise buildings, generally behave as vertical cantilever beam with their Strength controlled by flexure as shown in fig(1.3) rather than by shear such walls are subjected to bending moments and Shears originating from lateral loads ,and to axial compression caused by gravity these may therefore be designed in same manner as regular flexural element .when acting as a vertical cantilever beam the behaviour of a shear wall which is properly reinforced for shear, will be governed by the yielding of the tension reinforcement located at the vertical edge of the wall and, to some degree, by the vertical reinforcement distributed along the central portion of wall. It is thus evident that the shear is critical for the Wall with relatively low height-to-length ratio, and tall shear walls are controlled mainly by flexural Requirements. Since the ductility of flexural member such as tall shear wall can be significantly affected by the maximum usable strain in compression zone of concrete. Confinement of concrete that the ends of Shear wall section would improve the performance of such shear wall. Tall shear walls in multi-storey buildings the shear walls are slender enough and are idealized as cantilever fixed at base their seismic response is dominated by flexure. Because of load reversals, shear walls sections necessarily contains substantial quantity of compression reinforcement. The figure below shows the diagonal tension cracks in tall shear wall and the formation of plastic hinges in the axial compression.

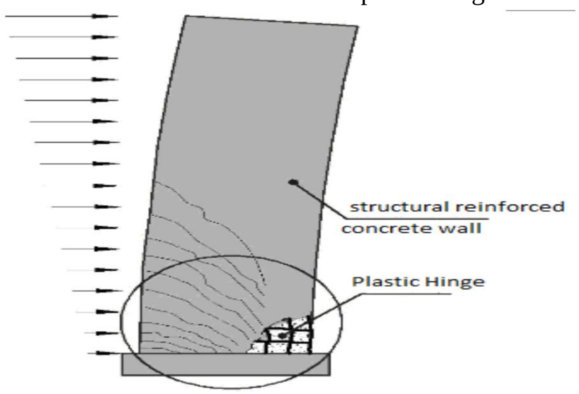

Fig. Behaviour of shear wall under flexure & formation of Plastic hinges

C. Advantages of steel-plate shear walls

1) For the same shear capacity, a CSW will have a smaller thickness, less weight and most likely larger shear stiffness than a RCSW.
2) The smaller footprint of the CSW is attractive architecturally as more floor space is used.
3) The lesser the weight of CSW leads to lower seismic forces and smaller foundations

The RC wall of the CSW can be either cast-in-place or precast.

II. OBJECTIVES

Following are the main objectives of the work:
1) To analyze and design the high rise building with steel plate shear wall-using ETABS.
2) Comparison of behavior of different structures of reinforced concrete with different heights, with and without shear walls.
3) Coupled shear walls have also been studied to understand the comparative merit or demerit of framed structures with shear wall structures.
4) To compare the displacement, story drift, overturning moment and story shear by varying the thickness of steel plate shear wall.

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
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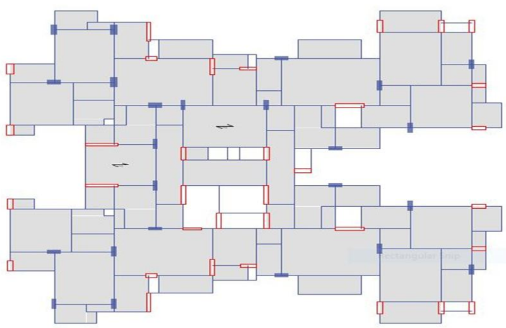
III. SCOPE OF WORK

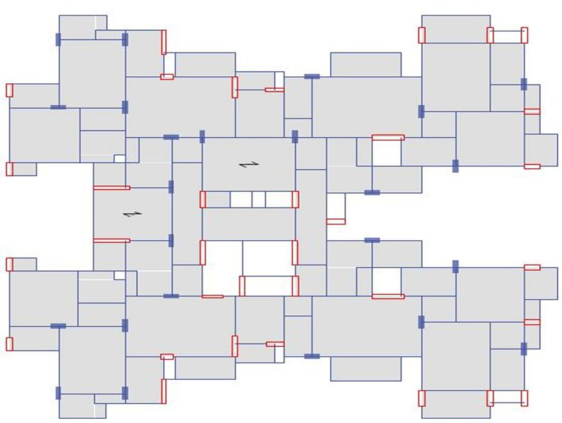
A. Detailed study of shear wall and framed structures under seismic loading.
B. Selection of sample structures.
C. Generation of Analytical model of sample structures.
D. Analysis of above structures.
E. Static analysis.
F. Dynamic Analysis.
G. Diaphragm center of mass displacement.
H. Diaphragm Drift.
I. Storey Acceleration.
J. Storey Drift.
K. Storey Displacement.
L. Base Reaction.
M. Response Spectrum Modal Information.
N. Tabulation, Plotting and Comparison of Key parameters.
O. Results and Discussions.

IV. MODELS CONSIDERED FOR ANALYSIS

Following two types of models have been considered for analysis. It was attempted to choose models that are representative of actual building types that are being constructed nowadays. Type A hybrid framed structure with RCC shear wall in center and columns. Type B is hybrid framed structure with Composite shear wall in center and columns.



Type A: hybrid framed structure with RCC shear wall in center and columns



Type B: hybrid framed structure with Composite shear wall in center and columns.

Models Considered for Analysis

V. METHOD OF ANALYSIS

A. *Static Analysis*

The static method is the simplest one-it requires less computational effort and is based on the formulae given in the code. First, the design base shear is computed for the whole building and it is then distributed along the height of the building. The lateral forces at each floor level thus obtained are distributed to individual lateral load resisting elements.

B. *Dynamic Analysis*

Dynamic analysis shall be performed to obtain the design seismic forces and its distribution to different levels along the height of building and to the various lateral load resisting elements in following cases:

1) *Regular Building:* Greater than 40 m height in zone IV and V and those greater than 90 m in height in zone II and III.
2) *Irregular Building:* All framed buildings higher than 12 m in zone IV and V, and those greater than 40 m height in zone II and III.
3) For irregular building lesser than 40 m in height in zone II and III, dynamic analysis even though not mandatory, is recommended.

C. *Response Spectrum Method*

Response spectrum method is simply a plot of peak or steady state response (displacement, velocity or acceleration of a series of oscillators of varying natural frequency that are forced into motion by same base vibration or shock.

D. *Pushover Analysis (Non-linear Static Method)*

Pushover method of analysis is a technique in which a structural is modeled with non-linear properties (such as steel yield, plastic hinges) and permanent gravity load is subjected to an incremental load applied laterally from ‘0’ value to prescribed ultimate displacement or until the structure become unstable to withstand the further forces

E. *Non- linear time History Analysis*

It is an analysis of dynamic response of structure at each increment of time, when its base is subjected to any specific ground motion time history (compatible time history for medium soil IS-1893:2002-Part 1)

VI. ETABS

ETABS is a sophisticated, yet easy to use, special purpose analysis and design program developed specifically for building systems. ETABS features an intuitive and powerful graphical interface coupled with unmatched modeling, analytical, design, and detailing procedures, all integrated using a common database. Although quick and easy for simple structures, ETABS can also handle the largest and most complex building models, including a wide range of nonlinear behaviors, making it the tool of choice for structural engineers in the building industry.

A. Most buildings are of straightforward geometry with horizontal beams and vertical columns. Although any building configuration is possible with ETABS, in most cases, a simple grid system defined by horizontal floors and vertical column lines can establish building geometry with minimal effort.
B. Many of the floor levels in buildings are similar. This commonality can be used to dramatically reduce modeling and design time.
C. The input and output conventions used correspond to common building terminology. With ETABS, the models are defined logically floor-by-floor, column-by-column, bay-by-bay and wall-by-wall and not as a stream of non-descript nodes and elements as in general purpose programs. Thus, the structural definition is simple, concise and meaningful.
D. In most buildings, the dimensions of the members are large in relation to the bay widths and story heights. Those dimensions have a significant effect on the stiffness of the frame. ETABS corrects for such effects in the formulation of the member stiffness, unlike most general-purpose programs that work on centerline- to center line dimensions.

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VII. DESIGN BASIS

A. Design Philosophy

Limit State Method of design has been used throughout unless specified. In any method of design, the following are the common steps to be followed:

1) To assess the dead loads and other external loads and forces likely to be applied on the structure,
2) To determine the design loads from different combinations of loads
3) To estimate structural responses (bending moment, shear force, axial thrust etc.) due to the design loads,
4) To determine the cross-sectional areas of concrete sections and amounts of reinforcement needed.

Many of the above steps have lot of uncertainties. Estimation of loads and evaluation of material properties are to name a few. Hence, some suitable factors of safety should be taken into consideration depending on the degrees of such uncertainties.

B. Analysis and Design

The basic analysis of the structure starts with the gravity load combinations applied to the structure. This includes Dead Load due to weight of different components of the building structure itself (beams, columns, slabs, stairs etc.), Live Load due to miscellaneous movable components in the floors (furniture, electrical appliances etc).

The presence of occupants also adds to the Live Load of the structure.

Here we have analysed the structure for two load combinations.

1) (Dead Load + Live Load)
2) 1.5 x (Dead Load + Live Load)

The beams and columns have been designed on the basis of responses obtained in the preliminary analysis for gravity loads using STAAD Pro. Software. However, the slab panels have been designed manually for one floor of the building. A model calculation for the slab panels and staircase has also been discussed.

C. Analysis of Gravity Loads

The following are Loads Considered in Analysis.

D. Dead Loads and Live Loads

Different building elements and assumptions that are used for the calculation of dead loads based on architectural plans and as per IS;875-Part 1 is given below.

Densities used in dead load calculations are taken as per Table given below.

E. Overview of Design Philosophy adopted in IS1893:2002

IS1893:2002 clearly states its design philosophy in clause 6.1.3.

Clause 6.1.3 The design approach adopted in this standard is to ensure that structures possess at least a minimum strength to withstand minor earthquakes (<DBE), which occur frequently, without damage; resist moderate earthquakes (DBE) without significant structural damage though some non-structural damage may occur and aims that structures withstand a major earthquake (MCE) without collapse.

In order to achieve that goal, the Code primarily suggests response spectrum analysis. A simplified method based on the Seismic Coefficient Method have been given, popularly referred as Static Analysis Method to be carried out for regular and moderately irregular, low rise buildings. The Code also suggests a rigorous Dynamic Analysis Method based on response spectrum to be carried out for irregular and high rise structures. However, the Code does suggest a Time History analysis method for Dynamic analysis, but it has not been covered in detail in the Code.

F. Static Analysis

The design horizontal seismic coefficient A_h for a structure shall be determined by the following expression:

$$A_h = \frac{ZISa}{2Rg}$$

Where,

Z = Zone factor given in Table 2, is for the Maximum Considered Earthquake (MCE) and service life of structure in a zone. The factor 2 in the denominator of Z is used so as to reduce the Maximum Considered Earthquake (MCE) zone factor to the factor for Design Basis Earthquake (DBE).

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I = Importance factor, depending upon the functional use of the structures, characterised by hazardous consequences of its failure, post-earthquake functional needs, historical value, or economic importance (Table 6).
R = Response reduction factor, depending on the perceived seismic damage performance of the structure, characterised by ductile or brittle deformations. However, the ratio (I/R) shall not be greater than 1.0(Table 7). The values of R for buildings are given in Table 7.
$\frac{Sa}{g}$ Average response acceleration coefficient for rock or soil sites as given by Fig. 2
and Table 3 based on appropriate natural periods and damping of the structure. These curves represent free field ground motion.
The total design lateral force or design seismic base shear (V_B) along any principal direction shall be determined by the following expression:

$$V_B = A_h W \tag{10}$$

For various loading classes as specified in IS 875(Part 2), the earthquake force shall be calculated for the full dead load plus the percentage of imposed load as given in Table 8. For calculating the design seismic forces of the structure, the imposed load on roof need not be considered. The seismic weight of each floor is its full dead load plus appropriate amount of imposed load, as specified in 7.3.1 and 7.3.2. While computing the seismic weight of each floor, the weight of columns and walls in any storey shall be equally distributed to the floors above and below the storey. The seismic weight of the whole building is the sum of the seismic weights of all the floors.
The approximate fundamental natural period of vibration (T_a), in seconds, of a moment-resisting frame building without brick in-filled panels may be estimated by the empirical expression:

$$T_a = 0.075\, h^{0.75} \text{ for RC frame building}$$

$$= 0.085\, h^{0.75} \text{ for steel frame building}$$

The approximate fundamental natural period of vibration (T_a), in seconds, of all other buildings, including moment-resisting frame buildings with brick infill panels, may be estimated by the empirical expression:

$$T_a = 0.09h/\sqrt{d} \tag{11}$$

The design base shear (V_B) computed in 7.5.3 shall be distributed along the height of the building as per the following expression:

$$Qi = VBWihi2/\sum Wjhj2 \tag{12}$$

G. Dynamic Analysis

Dynamic analysis shall be performed to obtain the design seismic forces and its distribution to different levels along the height of building and to the various lateral load resisting elements in following cases:

1) Regular Building – Greater than 40 m height in zone IV and V and those greater than 90 m in height in zone II and III.
2) Irregular building – All framed buildings higher than 12 m in zone IV and V, and those greater than 40 m height in zone II and III.
3) For irregular building lesser than 40 m in height in zone II and III, dynamic analysis even though not mandatory, is recommended.

H. Static and Dynamic Parameters

1) *Design Parameters:* Here the Analysis is being done for the building by computer software using ETABS.
2) *Design Characteristics:* The following design characteristics are considered for Multistorey rigid jointed frames

VIII. ANALYSIS FOR SEISMIC LOADS

As per IS: 1893, Noida is located in Seismic Zone IV.
Design base shear, V = Z I W Sa/2 R g
The values of the salient coefficients are tabulated below:

Table. Seismic parameters

SI.	Description	Value	Reference
1	Seismic Factor for Zone: IV	0.24	IS-1893
2	Structure importance	1.0	IS-1893
3	Response reduction factor, R	5.00	IS-1893
4	Damping	5%	IS-1893
5	Time period	Variable	IS-1893

A. Wind Load Parameters

The basic wind speed $V_{b,\ for}$ any site shall be obtained as per IS 875 (Part 3) and shall be modified to include the following effects to get design wind speed V_z , at any height z, for the chosen structure;

$V_Z=V_B\ K_1\ K_2\ K_3\ K_4$

The wind velocity at Gurgaon is 47m/s. The other parameter of wind load as per IS: 875 (Part-3) is summarized below:

Table .Wind parameters

Sl.	Description	Value	Reference
01	Terrain category.	3	IS-875
02	Class of structure.	C	IS-875
03	Probability factor, k1.	1.0	IS-875
04	Terrain, height and structure size factor, k2.	As/Height	IS-875
05	Topography factor, k3.	1.0	IS-875
06	Importance factor, k4 for the cyclonic region	1.0	IS-875

B. Load Cases

Table. Load case

Load case	Description
Dead	Dead Load
Finish	Floor Finish Load
Services	Service load on floor
Wall	Wall Load
Live	Live Load
Roof Live	Roof Level Live Load
EQX	Static Earthquake Load In X Direction
EQX	Static Earthquake Load In X Direction
SPECX	Dynamic Earthquake Load In X Direction
SPECY	Dynamic Earthquake Load In Y Direction
Wind X	Along Wind Load In X Direction
Wind Y	Along Wind Load In Y Direction

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C. Load Combinations

Table. Load combination

S No.	Load combination
1	1.5 (DL + LL)
2	1.2 (DL + LL + EQX)
3	1.2 (DL + LL – EQX)
4	1.2 (DL + LL + EQY)
5	1.2 (DL + LL – EQY)
6	1.5 (DL + EQX)
7	1.5 (DL – EQX)
8	1.5 (DL + EQY)
9	1.5 (DL - EQY)
10	1.2 (DL + LL + WLX)
11	1.2 (DL + LL -WLX)
12	1.2 (DL + LL + WLY)
13	1.2 (DL + LL-WLY)

IX. ANALYSIS

The analysis of different models of varying heights produced a large set of data. Microsoft excel was used for tabulation plotting and analysis of results obtained by ETABS analysis. The first objective was to figure out the key parameters that affected the building. Tabulation was done for different key parameters for all the models. A sample tabulation has been shown below for Type A structures having 20 storeys.

A. Computational Modelling

To study the effects, three dimensional (3D) geometric models of the buildings were developed in ETABS-2017. Initial dimensions of the structural elements were assumed on the basis of gravity loads and imposed loads. Since, the buildings were assumed as residential buildings, imposed load of 2 KN/m2 and load due to floor finish plus partition were taken as 1.5 KN/m2 as per Indian Standard, IS 875 (part2): 1987. Lateral loads due to earthquake (EL) were calculated considering full dead load (DL) plus 25% of imposed load (IL), using seismic coefficient method given in IS 1893 (Part 1): 2016. In which, imposed load on roof was not considered. Total base shear (VB) was
calculated by:

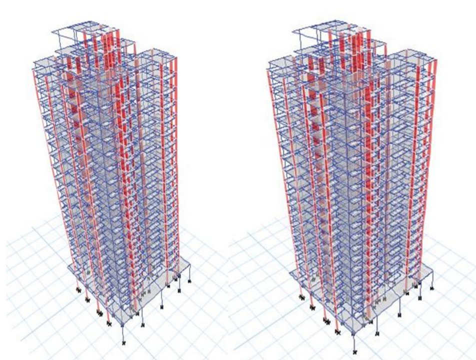
Vb= Ah *W

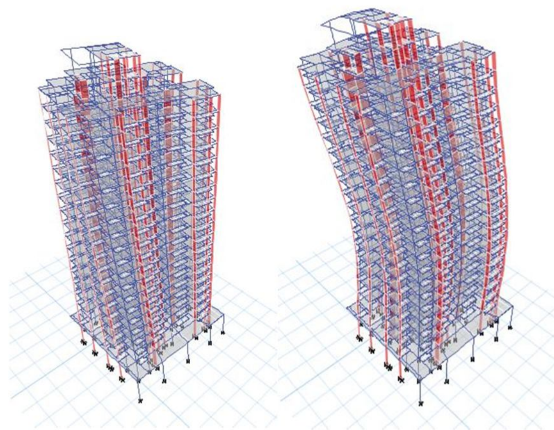
where,
W = seismic weight of the building .
Ah = the design horizontal seismic coefficient which is determined by using
the following expression:

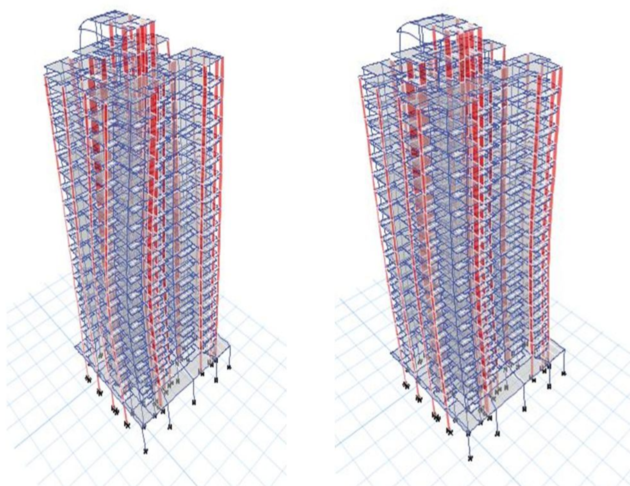
$$A = \frac{Z*I*Sa}{2*R*G}$$

X. MODE SHAPE

Mode 1 to 6 Respectively







The same above parameters have been tabulated for all other types, Type A- reinforced concrete shear walls (RCSW) and Type B-steel-plate shear walls (SPSW). for 20 storeys. The results were tabulated and plotted as below

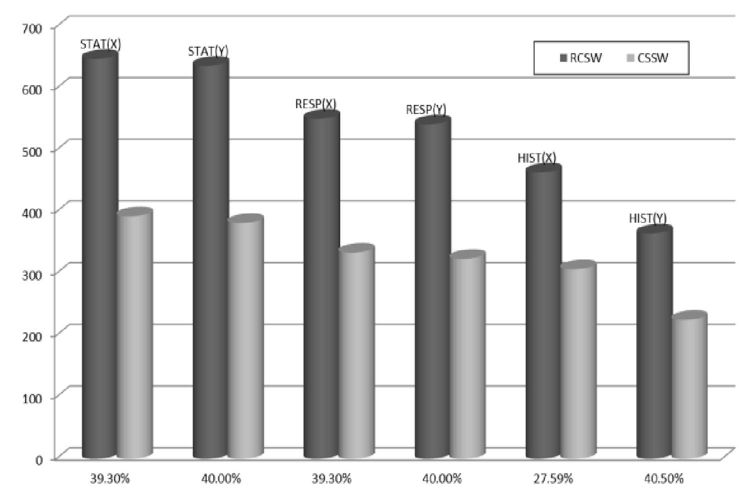


Fig. Comparison of Base Shear for 20-Story Buildings

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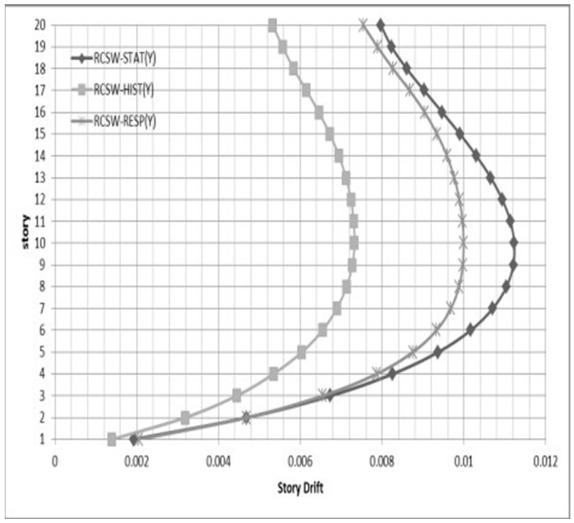
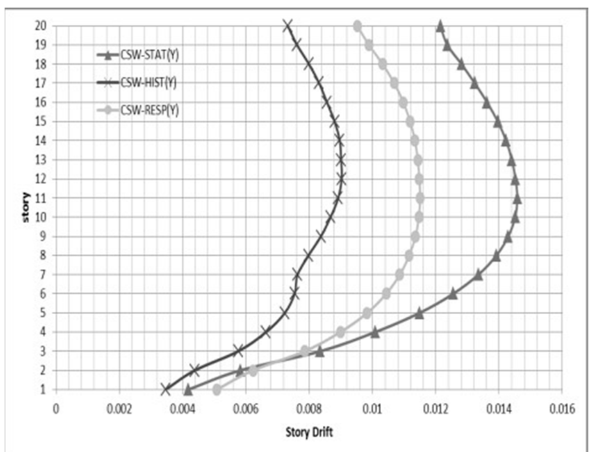
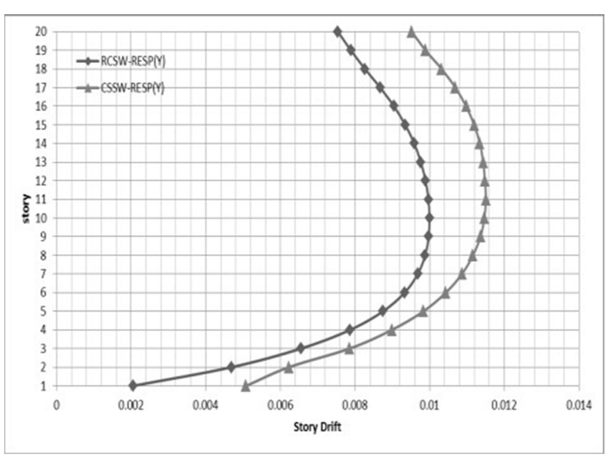


A.RCSW

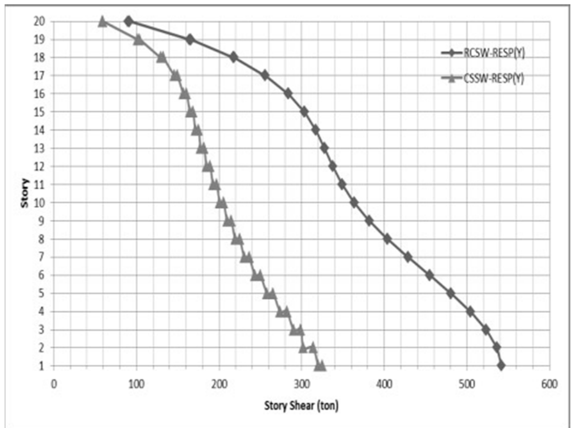


B. CSSW

Fig.Story Drifts for the 20-Story Buildings.



A.RCSW



B. CSSW

Story Shear and Drift for the 20-Story Buildings.

XI. CONCLUSIONS

Providing RC buildings with composite shear walls (Steel Plated) instead of RC shear walls is a very efficient and attractive structural decision to be implemented in regions vulnerable to earthquakes, due to the following advantages:

A significant reduction in the total dead load of the building due to less thickness of the steel wall compared to the RC shear wall. Consequently, the story-shear forces and base shear are reduced by 46% in the eight-story buildings, and 38% in the twenty-story buildings.

The inelastic drifts in the buildings with composite shear walls are higher than those in the buildings with RC shear walls by 26% in the twenty-story buildings.

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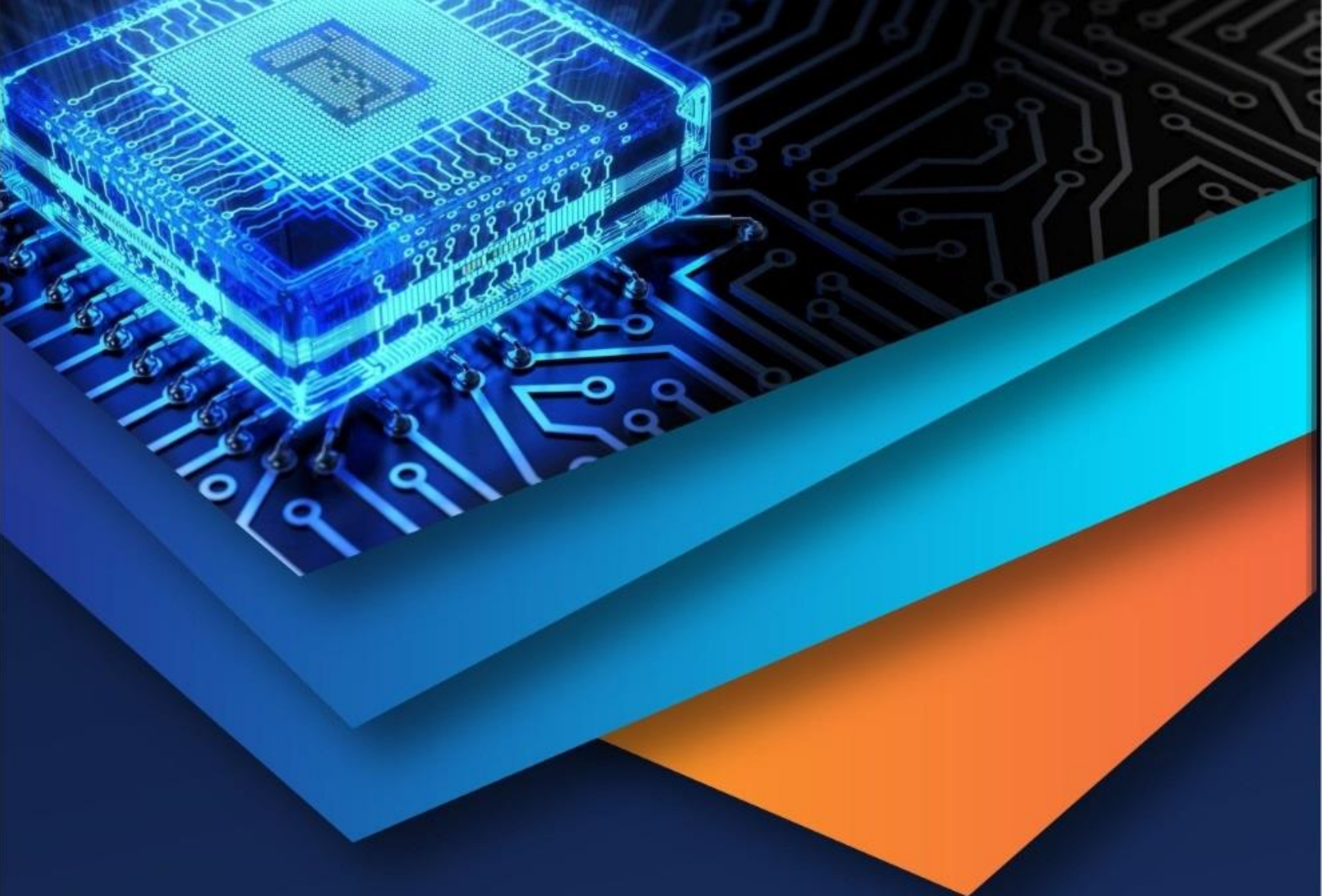

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