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DYNAMIC ANALYSIS OF HYBRID FRAME STRUCTURES IN DIFFERENT SEISMIC ZONES USING RESPONSE SPECTRUM METHOD

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ABSTRACT: *From the history of human civilization, uncountable deaths were befallen due to unintended social system, as lesson erudite from Bhuj earthquake where thousands of people pass away and lakhs were incapacitated, that ground reality scenario of suffered people due to disasters finally demands engineered solutions. This research work is concerned with the dynamic analysis of HYBRID frame buildings. Under HYBRID frame structure dissimilar study cases are considered that is CASE 1 Bare RC Frame structure, CASE 2 Frame with various composite bracings, CASE 3 Frame with different RC shear walls, CASE 4 Frame with altered combinations of composite bracing and RC shear walls, CASE 5 Building with outer Frame System incorporated with composite bracing included Mega bracing with core RC shear wall at middle of the building. All above mentioned cases are analysed in ETABS through Response Spectrum method on the basis of features i.e. Displacement, Storey drift and Base shear as per IS 1893 (part 1):2002. Finally, concluded that Tall Hybrid frame buildings performed better than Conventional Tall building as it significantly reduces seismic vulnerability and enhance redundancy of the structure.*

Keywords: Tall Hybrid Building, Composite Bracing, RC Shear Wall, Outer Frame System, Linear Dynamic Analysis, ETABS.

1. INTRODUCTION

History shows the evidence of unplanned social structure as major lesson learnt from disaster of Bhuj earthquake with magnitude of 7.9 which shaken the Gujarat on 26th Jan of 2001, that time period Indian were planning to revel their 52nd republic day, as a result 20,000 people were recounted dead and about 1.7 lakhs were injured [7], consequently makes the major turning point in India towards the campaign of revised Indian standard codes and seismic risk reduction [8]. When seismic shakes arrive, structure reacts to the acceleration transmitted by ground surface through structure's foundation. The inertial forces develops causes shearing of structures correspondingly concentrated stresses on the weak portions (wall, column- beam joints etc.) culminating in failure or total collapse. Most of the deaths due to earthquake are caused by collapse of the structure and wrong construction practices adopted throughout venture as deliberately said "earthquakes do not kill people but it is the structure build by them that do so". The suffering of people due to disasters stresses towards advance engineered solutions, with its implementation. So it is the necessity of following and implementation of IS codes including National Building Code, structural analysis and design strictly through structural designers only, so that our structures must acts as a seismic resistant structure and transfers loads effectively and alongside should be capable enough to provide serviceable conditions to their users.

1.1. Tall buildings

Building whose total height greater than 45m not more than 250m, normally referred as Tall Building. These buildings becomes very popular worldwide for their multipurpose facilities as under one unit or place we live, shop, commerce etc. as per our needs.

ISSN (online): 2250-141X
Vol. 8 Issue 2, June 2018

1.1.1. Reasons for construction of Tall buildings

1. Rapid growth of population in urban areas.
2. Issues of land usage or restriction due to agricultural land or lack of land for use.
3. Representing a symbol of developed and modern era civilisation.
4. High land prices.
5. Sometimes due to geological conditions and specific terrain parameters such as type of subgrade.
6. Utilization of area by high vertical expansion construction on less ground area.

1.1.2. Aspects related to Tall building construction

1. **Architectural aspects**: - It includes all those factors which are responsible for the aesthetics, open city view and spatial requirements by depending upon the usage of concerned area.
2. **Structural design aspects**: - Tall buildings are highly susceptible to wind loads induce oscillations in it. As height of the building goes on increasing, its stiffness decreases and mass increases simultaneously causes low natural frequency responsible for resonance condition. So tall buildings reasonably incorporated with structural members that resist lateral loads and reduce vulnerability.
3. **Safety aspects**: - It includes ease of access to all parts of the building, availability of services like fire fighting equipment, fire escape staircase that must connect to outside of the building and also includes proper implementation of guidelines by various expert bodies.
4. **Economic aspects**: - This is the major element of success in investment projects. Tall building requires huge amount for investment so it is necessary to consider everything precisely at the time of planning period. Following points effects economy are: -

a. Location of building
b. Type of building
c. Height of building
d. Construction material source
e. Construction methods
f. Source of funding

5. **Management aspects**: - A Tall building requires detailed management for keeping it in under serviceable condition. It includes periodic inspections deals with operations like safety checking, funds, maintenance, security arrangements, audits, handling environmental issues etc.

1.2. Dynamic Analysis

Dynamic analysis is performed to evaluate the vibrational effects on the structures. Effect of inertia forces are taken into consideration as loads are applied to the sample. In this analysis, loads are time varying and the corresponding fallouts are also time varying. It includes complex computational process requires deep knowledge of dynamics of structures.

1.2.1. Why dynamic analysis is necessary?

In the majority of analysis performed by an engineers or structure designers are static that forces changes at such an accelerated way that its almost considered as constant, succeeding no dynamic effects are taken up by them. But if the forces experienced by the structure is changes in such a way that inertial forces impart noteworthy effect on the stability of the concerned structure, then dynamic analysis is necessary to evaluate its actual performance under dynamic excitation so that analyst come to know that what is essential to make the structure safe and economic. Dynamic analysis is usually done for earthquake and wind load.

1.2.2. Linear Dynamic Analysis

Response spectrum analysis is linear dynamic method of analysis used for SDOF systems. For seismic analysis, one requires time history of the particular location of consideration, but this is not possible to achieve it for every specific site and seismic analysis does not based only on peak values of ground acceleration as it also depends upon frequency of the response of ground motion by keeping in mind the concept of natural frequency and

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Vol. 8 Issue 2, June 2018

resonance. To pass through above mentioned hurdles response spectrum method is the best tool used ever for the seismic evaluation of the structures. This response spectrum method defines response spectrum of the system under consideration is then followed by the study of characteristics of earthquake response spectrum, which leads into design spectra for the design of prototype and safety assessment of existed structure as well as for future earthquakes also. In this method, no of modes are developed carrying responses at different time instants. Then all these modes are combined together to get global response of the structure.

1.3. What is Hybrid Frame Structure?

Hybrid structures or building is one which comprises combination of two or added horizontal Load resisting systems [9]. In other words, building or structures whose structural elements is built partially in reinforced concrete, structural steel and/or reinforced concrete structural steel composite. Hence, such type of building contains primary elements resisting vertical and lateral loads that are composite elements. As compare to the conventional frame structures, Hybrid frame structures carry more redundancy hence provides more stability and less vulnerability in extreme seismic excitations.

In this venture of research, various RC Shear Wall and composite Bracing systems are used as lateral load relocation mechanisms for dynamic analysis of Hybrid frame buildings.

2. RELATED LITERATURE

Jun et al [1]**,** examined the Design of Super High Rise Hybrid structure for seismic application. Structure consists of concrete shear wall and different composite structure elements. They used linear elastic, static nonlinear elastic-plastic and dynamic nonlinear analysis for seismic evaluation of structural aspects of concerned building. Here results showed that the Hybrid structure performed under acceptable behaviour and data collected for elastic time history and response spectra were found parallel.

Madan et al [2]**,** examined seismic valuation of shear walls and braces for buildings. Dynamic analysis of 10, 15 and 20 story frames with and without lateral load resisting elements with dissimilar configurations were carried out on 3D modeling in STAAD-pro software. Study resulted that Lateral deflection reduced better by shear walls than bracings and combination of shear wall and braces in a detailed planning (SB-A) covering shear wall in the middle bay and braces in outer bays presented most operative fallouts for resistance to lateral loads in the elastic range.

Kasliwal et al [3]**,** studied seismic analysis of reinforced concrete building with unrelated positions and numbers of shear wall. The reinforced concrete building having (G+9) stories with seismic zone V is analysed by using response spectrum method as per IS 1892 (PART 1):2002. In this research, they concluded that building with complete shear wall shows lesser lateral displacement as compared to other frames.

Nassani et al [4]**,** compared effect of different bracings on steel frame under seismic loading. Various bracing systems like X, V, inverted V, Knee and zipper were used and corresponding structural response were studied on the basis of capacity curve, drift ratio, GDI, base shear, displacement, roof displacement time history and plastification in ETABS. Results revealed that bracing incorporated frames performed well and results of time history and pushover analysis were similar to each other.

Anes Babu [5]**,** reported with effect of steel bracings on RC framed structures. Steel braced building significantly decreases the lateral drift when associated with shear wall building using ETABS 2015. As per conclusion, Reinforced concrete building (G+9) was shaped and analysed in three parts comprising model sans steel bracing and shear wall, with dissimilar bracing systems, with shear wall.

Can Balkaya [6**],** performed seismic retrofitting by exterior steel brace Structural Jacketing System. Three dimensional 1/3rd scaled RC models were

ISSN (online): 2250-141X
Vol. 8 Issue 2, June 2018

prepared in the lab with and without jacketing system under static cyclic loading and then outcomes of both analytical and experimental models were verified. Pushover and dynamic analysis were performed and outcomes from experimental and analytical studies were similar. From an economic point of view building with outer frame becomes more serviceable hence cost of maintenance got reduced.

3. OBJECTIVES OF STUDY

1. To standardize the Dynamic response of Tall conventional RC frame building and dissimilar Tall Hybrid frame buildings for seismic zones IV and Zone V under Linear dynamic analysis.
2. To equate the performance of unlike composite bracing types and RC shear walls along with their altered combinations with each other.
3. To identify Dynamic behaviour of Tall frame structures integrated with Outer Frame System with composite bracing included Mega bracing and RC core shear wall at middle of the building.

4. RESEARCH METHODOLOGY

In this venture of research, key emphasis is to do dynamic analysis of Hybrid frame structures in different seismic zones using Response spectrum method as per IS 1893 (part 1):2002 [10]. A (G+25) Tall RC building is modelled for study which are divided into five study cases covering conventional bare RC frame structure, RC frame structure integrated with composite bracings, RC frame structure integrated with RC shear walls, RC frame structure with dissimilar combinations of composite bracing and RC shear walls and RC frame structure with outer frame of composite members comprising of bracing and Mega bracing. All these study cases are created and analysed in ETABS through linear dynamic analysis that is response spectrum method. All study cases are validated for dynamic behaviour on the basis of permissible values of parameters i.e. lateral displacement, storey drift and base shear for seismic zones IV and V as per IS 1893 (part 1):2002 [10].

4.1. Planning of study cases

The following study cases for research work are taken into consideration to evaluate dynamic performance of Tall Hybrid frame structures with respect to Tall conventional building along with individual cases of RC shear walls and composite bracings. Total 5 study cases are deliberated that are modelled and analysed in ETABS software are given below:-

Case 1: Bare RC Frame structure.

Case 2: RC Frame Structure with different RC Shear wall Systems.

Types of RC shear walls considered under study: - L-type, Core, H-type, U-type, T-type and North-South.

Case 3: RC Frame Structure with different composite Bracing Systems.

Types of bracings considered under study: - X-type, Inverted V, Diagonal, K-type, Diamond braced and Eccentric V.

Where each bracing type is evaluated for four different composite sections: - Case (i) Square concrete filled steel tube (SCFST); Case (ii) Rectangular concrete filled steel tube (RCFST); Case (iii) Circular concrete filled steel tube (CCFST) and Case (iv) Concrete encased I section (CEIB) (ISMB350). In this SCFST, RCFST and CCFST are in filled with M20 concrete and CEIB is encased with M30 concrete with minimum cover of 30mm.

Case 4: RC Frame Structure with Combinations of Hybrid Structural Components having different RC Shear wall systems and composite bracing, here composite section (CCFST) for best performed bracing (Inverted V) is preferred on the basis of performance, applicability and economy from the above mentioned composite sections in case 3.

Case 5: RC frame structure with numerous Hybrid Outer frame systems integrated with composite bracing (Inverted V) including Mega bracing and RC core shear wall at middle of the building.

ISSN (online): 2250-141X
Vol. 8 Issue 2, June 2018

4.2. Data used for Modelling and Analysis of Models Studied

Table no 1: - Data for modelling and analysis of models

S.no	Structural Parameters	Properties
1.	No. of floors	G+25
2.	Seismic zones	IV and V
3.	Height of floor	3m
4.	Structure elevation	78m
5.	Plan area	21m*21m
6.	Inner and corner Column Sizes	0.406m*0.406m
7.	Beam Size	0.406m*0.304m
8.	Periphery Column size	0.600m*0.304m
9.	Shear wall Width	0.200m
10.	SCFST	0.220mm*0.220mm*0.008mm
11.	RCFST	0.300mm*0.150mm*0.008mm
12.	CCFST	0.273mm*0.008mm
13.	Damping ratio	5%
14.	Soil type	Type –II as per IS 1893 (part 1):2002
15.	Dead Load	Masonry load = 11.93KN/m
16.	Live Load	2 KN/m^2
17.	Floor Finish load	1.00 KN/m^2
18.	Materials used	M-30, M-20 and HYSD 415
19.	Dynamic study	Response spectrum technique
20.	Software	ETABS
21.	Time period	$Ta= 0.075h^{0.75}$, Where h= elevation/height of building
22.	Zone Factor (Z)	As per IS1893 (part 1):2002
23.	Response Reduction Factor (R)	5
24.	Importance Factor (I)	1.5

4.3. Nomenclature

1. Ecc. IV - Eccentric inverted V
2. CCswCCFST IV – Combination of core shear wall with CCFST Inverted V composite bracing
3. CCOswCCFST IV - Combination of coupled shear wall with CCFST Inverted V composite bracing
4. CHswCCFST IV - Combination of H-type shear wall with CCFST Inverted V composite bracing
5. CLswCCFST IV - Combination of L-type shear wall with CCFST Inverted V composite bracing
6. CN-SswCCFST IV - Combination of North-South shear wall with CCFST Inverted V composite bracing
7. CTswCCFST IV - Combination of T-type shear wall with CCFST Inverted V composite bracing
8. CUswCCFST IV - Combination of U-type shear wall with CCFST Inverted V composite bracing
9. CswBwOFwLB1 - Cored Shear wall building with outer frame with L-type composite bracing 1
10. CswBwOFwLB2 - Cored Shear wall building with outer frame with L-type composite bracing 2
11. CswBwOFwMB1 - Cored Shear wall building with outer frame with Mega composite bracing 1
12. CswBwOFwMB2 - Cored Shear wall building with outer frame with Mega composite bracing 2
13. CswBwOFwMB3 - Cored Shear wall building with outer frame with Mega composite bracing 3
14. CswBwOFwMB4 - Cored Shear wall building with outer frame with Mega composite bracing 4

ISSN (online): 2250-141X
Vol. 8 Issue 2, June 2018

4.4. Models for Five Study Cases

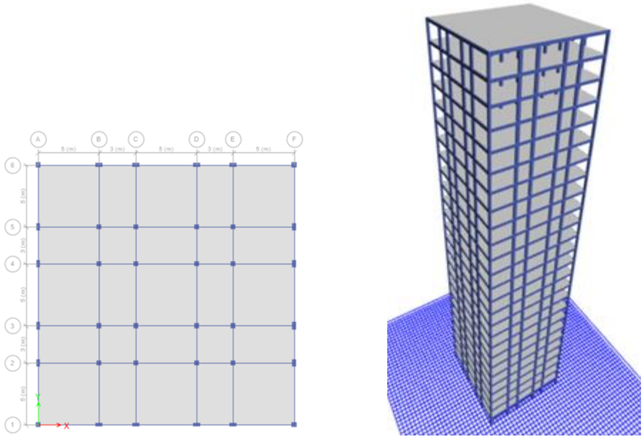
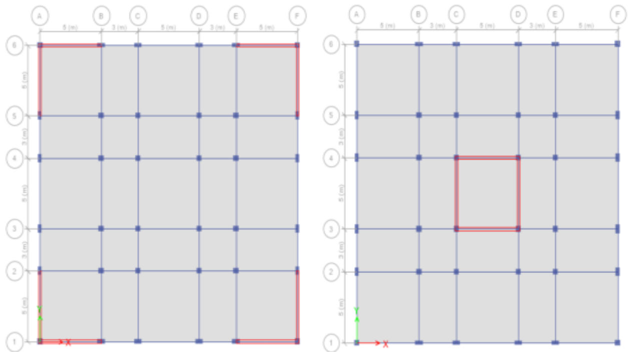
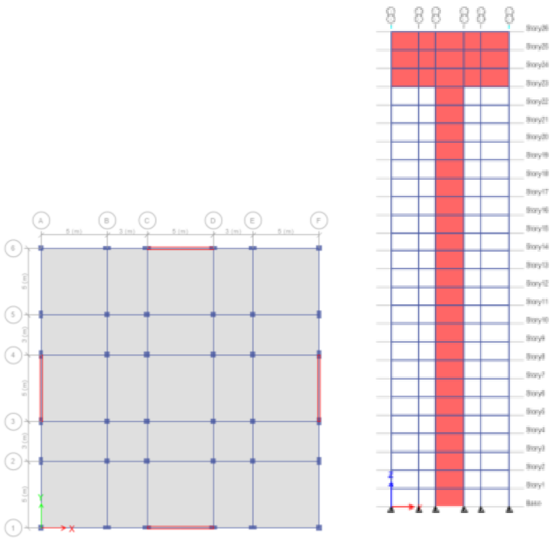


Fig. 1 Plan and elevation of Case 1



(a) (b)

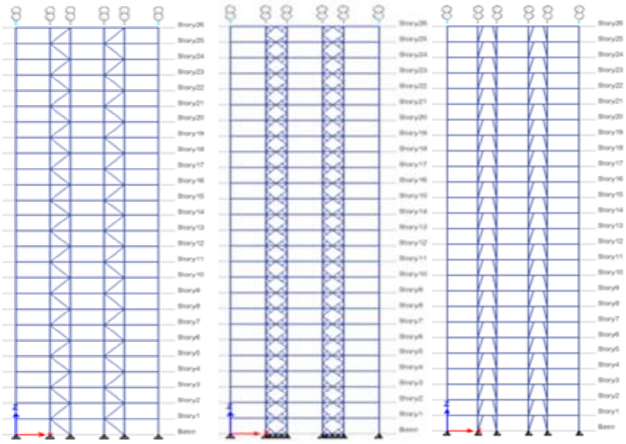


(c) (d)

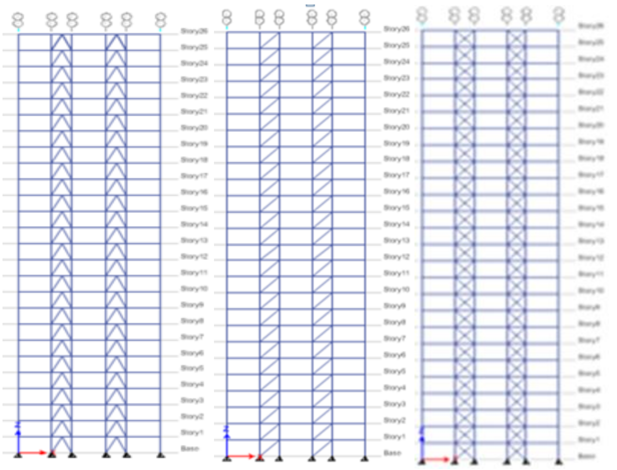
(e) (f)

(a) L-Type (b) Core (c) North-South
(d) T-type (e) U-type (f) H-type

Fig. 2 Plans and elevations of Case 2



(g) (h) (i)

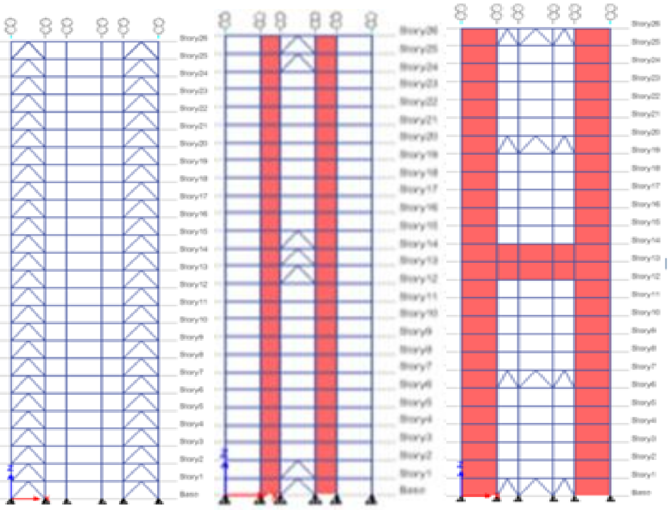


(j) (k) (l)

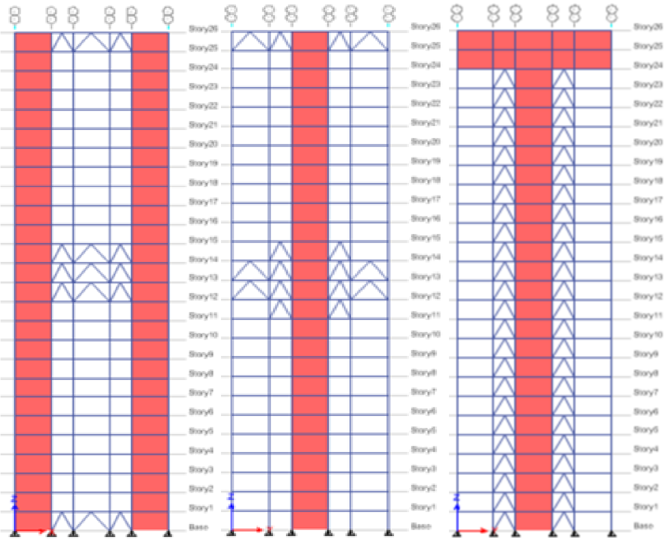
(g) K-type (h) Diamond braced (i) Ecc. IV
(j) Inverted V (k) Diagonal (l) X-type

ISSN (online): 2250-141X
Vol. 8 Issue 2, June 2018

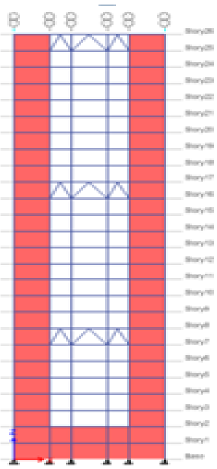
Fig. 3 Elevations of Case 3



(m) (n) (o)



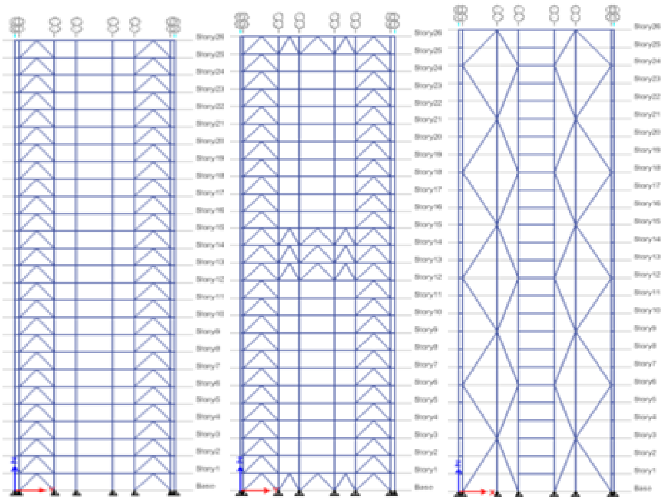
(p) (q) (r)



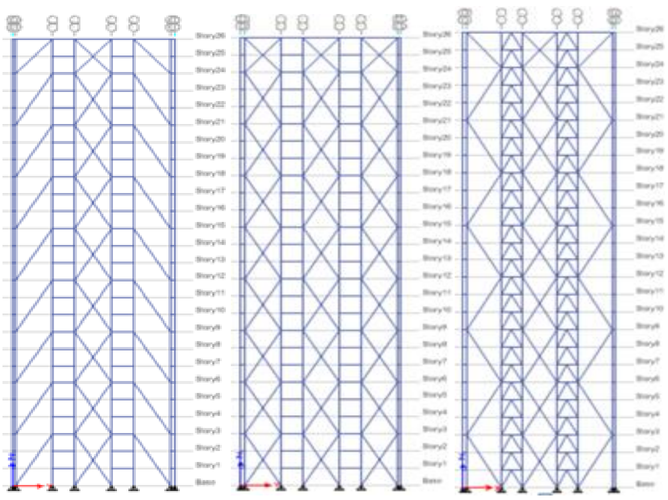
(s)

(m) CCswCCFST IV (n) CCOswCCFST IV
(o) CHswCCFST IV (p) CLswCCFST IV
(q) CN-SswCCFST IV (r) CTswCCFST IV
(s) CUswCCFST IV

Fig. 4 Elevations of Case 4



(t) (u) (v)



(w) (x) (y)

(t) CswBwOFwLB1 (u) CswBwOFwLB2
(v) CswBwOFwMB1 (w) CswBwOFwMB2
(x) CswBwOFwMB3 (y) CswBwOFwMB4

Fig. 5 Elevations of Case 5

5. RESULTS AND DISCUSSION

The dynamic response for different hybrid frame structures and reinforced concrete frame structure are found out using linear dynamic response spectrum technique of analysis. Results covered in terms of displacement, storey drift and base shear followed by comparison between them for different study cases considered.

ISSN (online): 2250-141X
Vol. 8 Issue 2, June 2018

Case 1: Bare RC Frame Structure

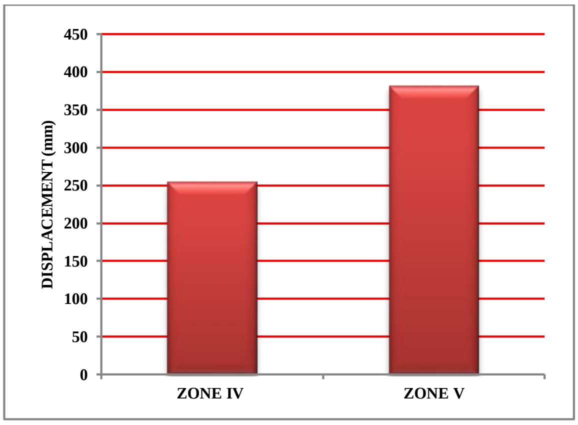


Fig.6 Graph of displacement for RC frame structure for seismic zone IV and V

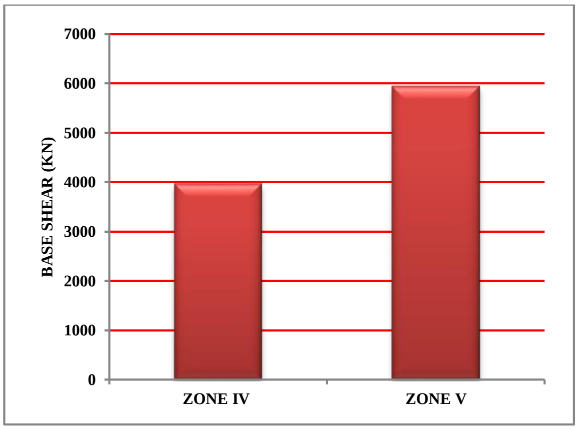


Fig.7 Graph of base shear for RC frame structure for seismic zone IV and V

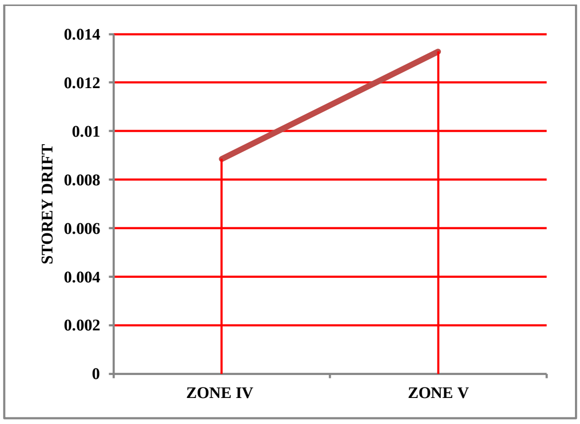


Fig.8 Graph of storey drift for RC frame structure for seismic zone IV and V

Bare RC fame structure is analyzed for dynamic response for seismic zones IV and V in ETABS. It is found that there is great significance variation in results corresponding to seismic zones IV and V as displacement for zone IV is 254.184mm and zone V is 381.276mm, storey drift for zone IV is 0.008853 and zone V is 0.013279 and base shear for zone IV is 3963.684 KN and zone V is 5945.526 KN as shown in fig. 6, where permissible values for displacement as per IS 1893(part 1):2002 is 312mm, story drift is 0.012000 and base shear is already set to permissible value as prescribed by IS 1893(part 1):2002. It shows that bare frame is highly vulnerable in seismic conditions.

Case 2: RC Frame Structure with Different RC Shear Wall Systems

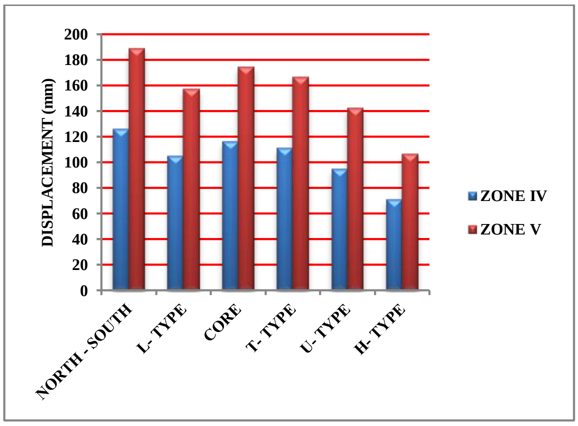


Fig.9 Graph of displacement for RC shear walls for seismic zone IV and V

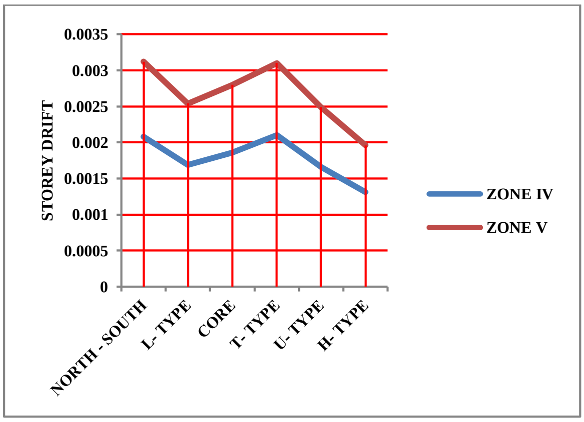


Fig.10 Graph of storey drift for RC shear walls for seismic zone IV and V

ISSN (online): 2250-141X
Vol. 8 Issue 2, June 2018

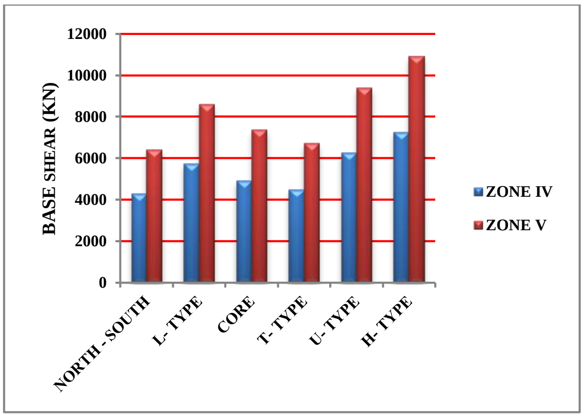


Fig.11 Graph of base shear for RC shear walls for seismic zone IV and V

In this case different RC shear walls are studied. After evaluation of the results, it is estimated that H- type shear wall is best performed with displacement 71.010mm and storey drift is 0.00131 for zone IV and 106.516mm, 0.00196 for zone V, 83.161% increment in base shear over bare RC frame structure. North-south shear wall is least performed case among all with 50.473%, 76.505% reduction in displacement and storey drift, 7.553% increment in base shear for zone IV and V. Also it is observed that RC shear wall works well both for reduction in displacement as well as increase in base shear, hence provides better resistance to vulnerability against seismic forces.

Case 3: RC Frame Structure with Different Composite Bracing Systems

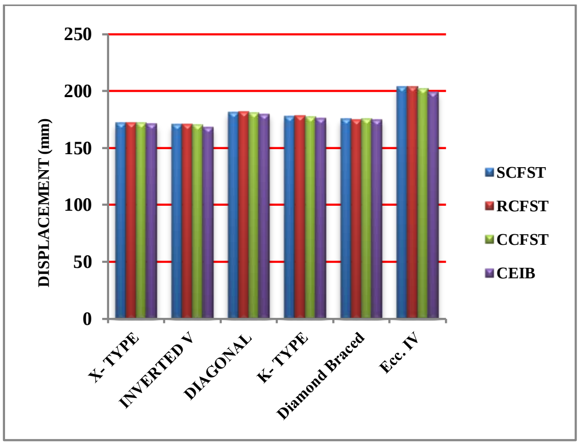


Fig.12 Graph of displacement for composite bracings for seismic zone IV

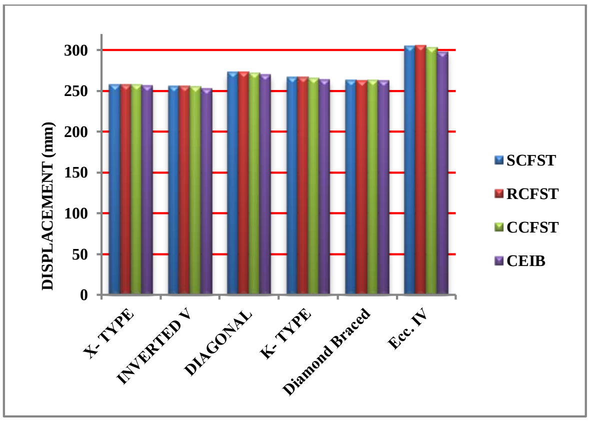


Fig.13 Graph of displacement for composite bracings for seismic zone V

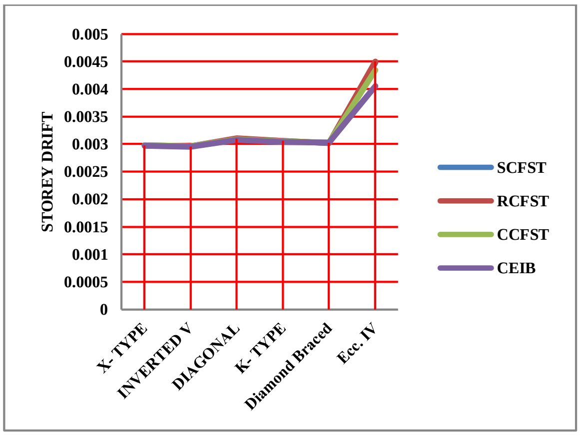


Fig.14 Graph of storey drift for composite bracings for seismic zone IV

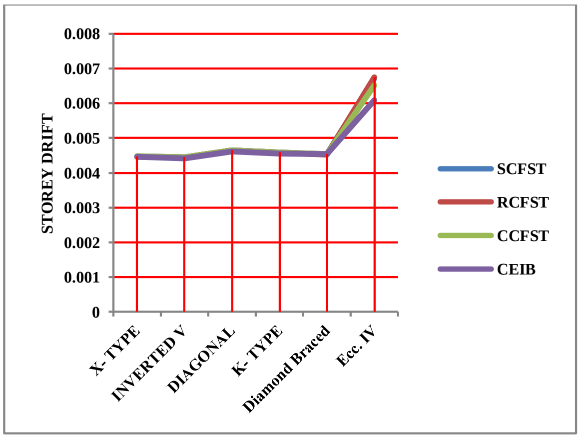


Fig.15 Graph of storey drift for composite bracings for seismic zone V

ISSN (online): 2250-141X
Vol. 8 Issue 2, June 2018

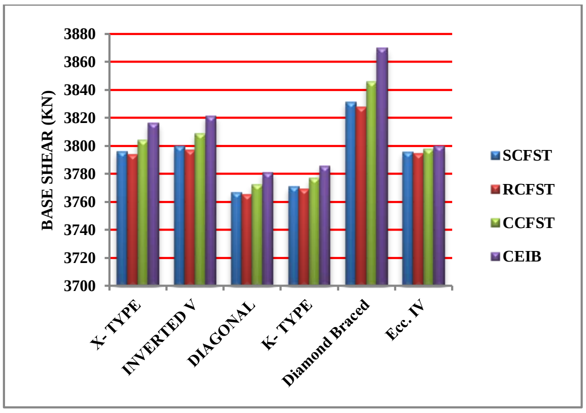


Fig.16 Graph of base shear for composite bracings for seismic zone IV

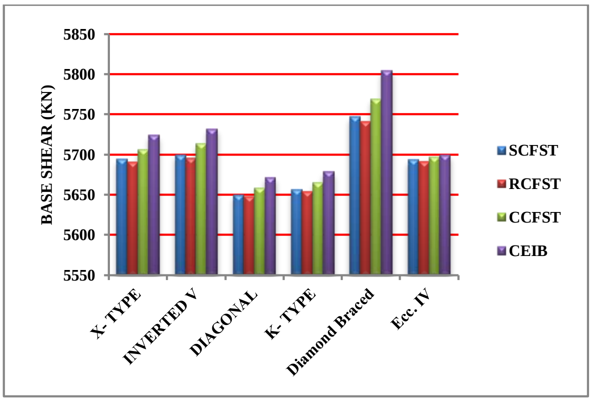


Fig.17 Graph of base shear for composite bracings for seismic zone V

Here dissimilar types of composite bracing types are studied where each bracing type is replaced one by one with SCFST, RCFST, CCFST and CEIB and it is identified that inverted V bracing performed best with displacement 168.575mm and 252.863mm, storey drift 0.00295 and 0.00442 with 33.679%, 66.714% reduction in displacement and storey drift but base shear 3869.732KN and 5804.599KN for zone IV and V is best achieved by diamond braced bracing with 2.370% decrement in base shear. However among SCFST, RCFST, CCFST and CEIB, CEIB is best performed. Out of three CFST's, CCSFT gives maximum reduction in displacement and storey drift. For base shear it is observed that bracing incorporated building shows reduction in base shear than RC frame structure.

Case 4: RC Frame Structure with Combinations of Hybrid Structural Components Having Different RC Shear Wall Systems and Composite Bracing Systems

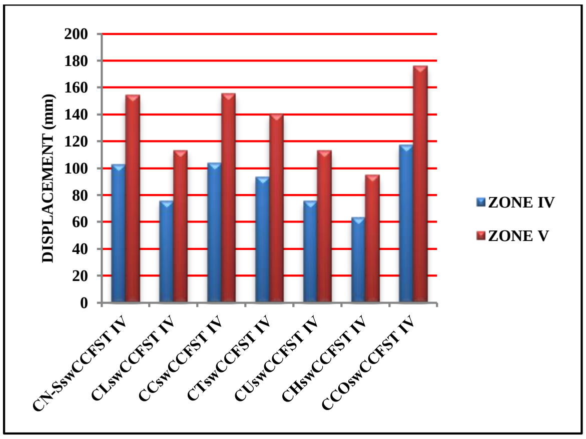


Fig.18 Graph of displacement for combinations of composite bracing and shear wall for seismic zone IV and V

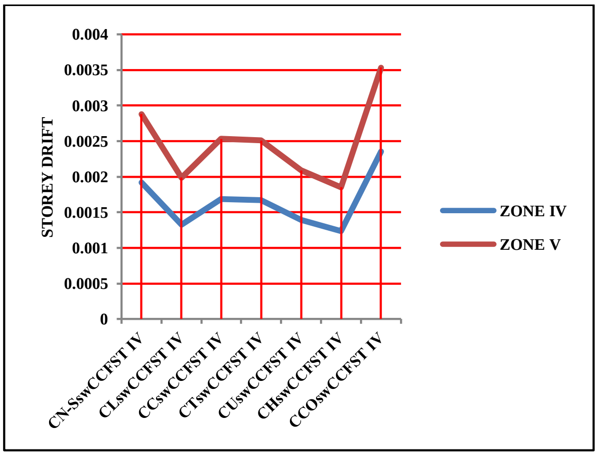


Fig.19 Graph of storey drift for combinations of composite bracing and shear wall for seismic zone IV and V

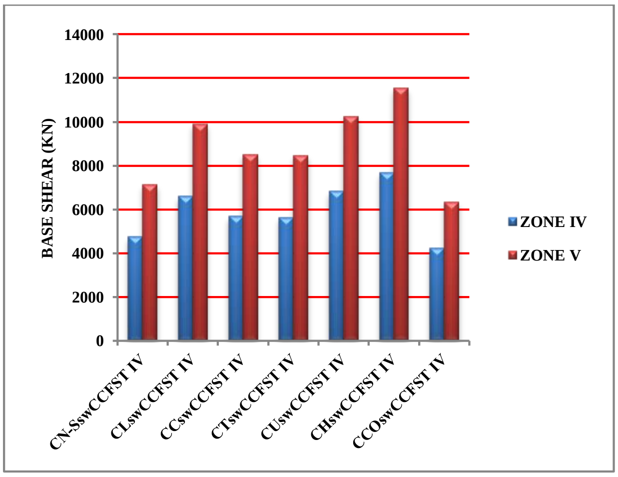


Fig.20 Graph of base shear for combinations of composite bracing and shear wall for seismic zone IV and V

In this case, various study Cases of combinations of RC shear walls and CCFST inverted V composite

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Vol. 8 Issue 2, June 2018

bracing are studied. After assessment it is observed that combination of H shear wall with CCFST bracing CHswCCFST IV performed better with maximum reduction in displacement and storey drift with75.160%, 86.049 % and increment of 94.129% in base shear. It is found that combinations significantly reduce vulnerability of the building better than case 2 and case 3. Here all combinations are made on the basis that it provides less obstruction to viewers, usage of less material, fast application and good aesthetics to concerned building.

Case 5: RC Frame Structure with Numerous Hybrid Outer Frame Systems Integrated with Composite Bracing Including Mega Bracing and RC Core at Middle of the Building

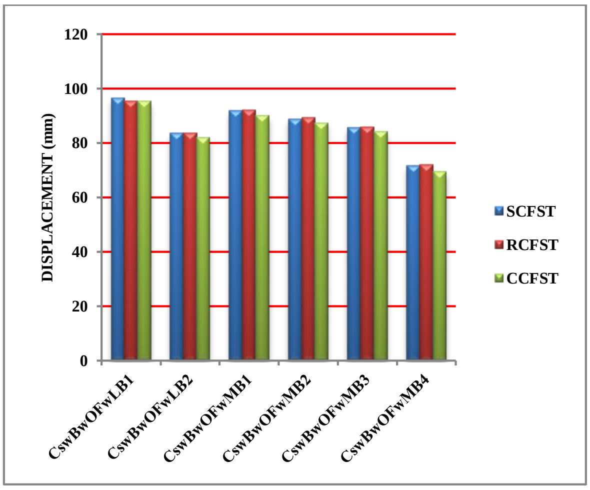

Fig.21 Graph of displacement for hybrid outer frame system for seismic zone IV

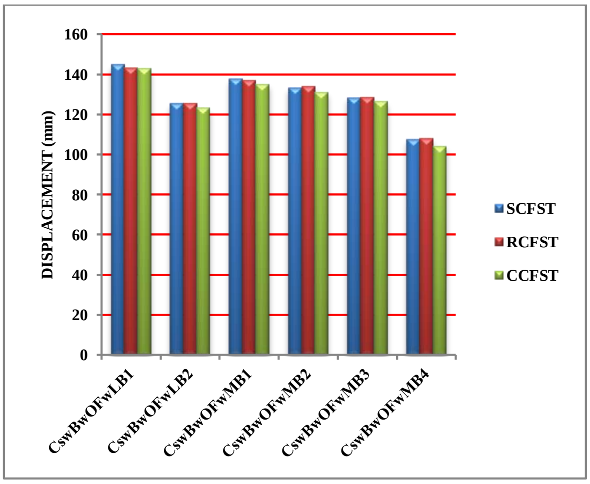

Fig.22 Graph of displacement for hybrid outer frame system for seismic zone V

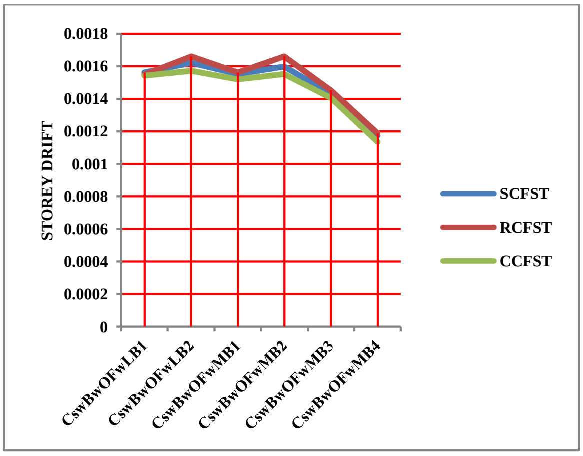

Fig.23 Graph of storey drift for hybrid outer frame system for seismic zone IV

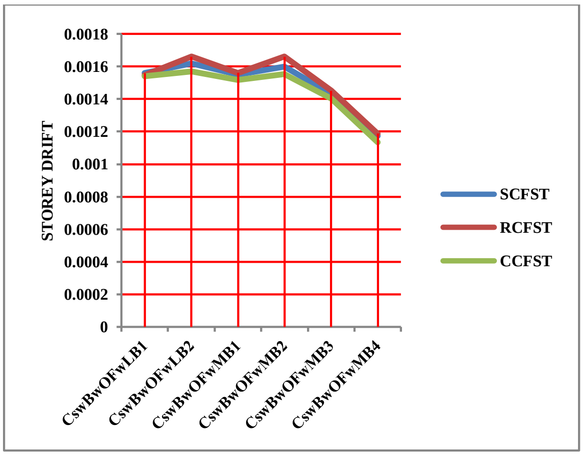

Fig.24 Graph of storey drift for hybrid outer frame system for seismic zone V

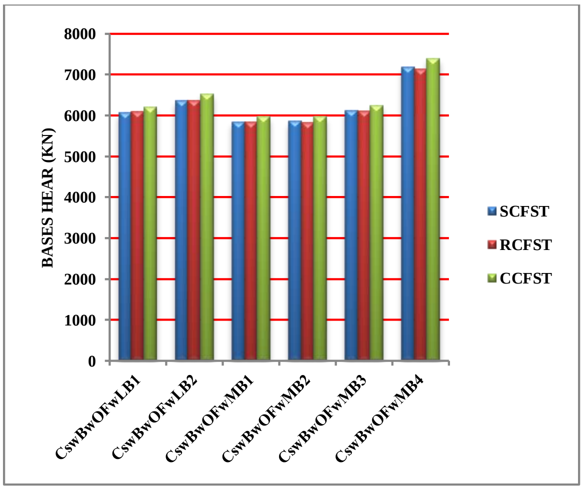

Fig.25 Graph of base shear for hybrid outer frame system for seismic zone IV

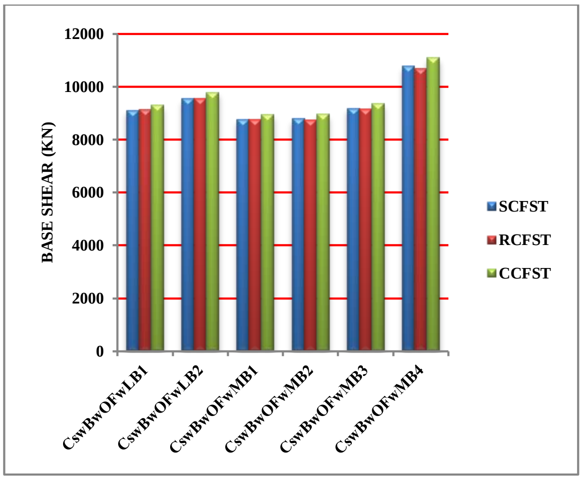

Fig.26 Graph of base shear for hybrid outer frame system for seismic zone V

In this case whole RC structure is jacketed with SCFST, RCFST and CCFST outer frame integrated with bracing and Mega bracing comprising of different study cases. As dynamic is carried out it is observed that CswBwOFwMB4 performed better for reduction in displacement with 72.686%, storey drift 87.168% and increment in base shear with 86.510%. Also it is observed that Mega bracing is also effective in reducing displacement and storey drift, increment in base shear. Out of three CFST's outer frame with CCFST performed better for reduction in displacement, storey drift and in base shear increment for seismic zone IV and V.

6. CONCLUSIONS

As per fallouts of this research, following conclusions and recommendations are set up for five study cases considered are as given below: -

1. Bare RC frame structure shows vulnerability to seismic forces for zone IV and V.
2. Bracing incorporated Tall building significantly reduces displacement and storey drift where maximum reduction in displacement and storey drift is observed with Inverted V bracing type that is 33.679% and 66.677% for seismic zone IV and V.
3. It is concluded that bracing reduces base shear of the existed building where diamond braced reduces minimum with 2.370% among all other types of bracings used in this research.
4. As per results amid four composite sections for bracings, CEIB performed better of all with only 0.5%to 2% better than three CFST's. So we recommend CCFST, SCFST and RCFST over CEIB on the basis of construction ability, workability, cost and time.
5. Among all RC shear walls, H-type performed best with 72.063%, 85.203% reduction in displacement and storey drift, 83.161% increase in base shear for zone IV and V.
6. From the result of H-type RC shear wall that if mid height of the building is stiffened along with overall height of the building then there is a drastic enhancement in the performance of the building is observed.
7. In comparison to composite bracings, RC shear walls performed better in all aspects but in case if there is no possibility to provide RC shear walls then composite bracings is also capable in itself to overcome seismic vulnerability of Tall buildings. We can provide it at the time of construction or for retrofitting purposes too.
8. In case 4, CHswCCFST IV performed best with 75.160%, 86.049% reduction in displacement and storey drift, 94.129% increase in base shear of Tall building for seismic zone IV and V.
9. When combinations of composite bracing and RC shear walls are resulted, it is identified that base shear is increasing at a rate i.e. 11% to 30% than reduction in displacement and storey drift 5% to 13% than Case 2.
10. As seen in Case 5, CCFST Hybrid Outer Frame System with Inverted V composite bracing and mega bracing also shows substantial reduction in vulnerability of the Tall buildings as maximum 72.686%, 87.168% reduction in displacement and storey drift, 86.510% increase in base shear is observed in CswBwOFwMB4.
11. There is no increase in dead load of the building with the application of Hybrid Outer Frame System hence less inertial forces are developed

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in the building succeeding to significant reduction in the overall cost of building.

12. We can also practice Hybrid Outer Frame System for global retrofitting purposes efficiently.
13. It is notified that identical pattern of percentage changes in results is observed for seismic zone IV and V.

7. FUTURE ENHANCEMENT

As this research venture was concentrated on linear dynamic analysis for seismic excitations so further one can do nonlinear dynamic analysis for more precise evaluation of this research work. Also one can go for performance based design that is nonlinear pushover analysis as well as wind load analysis.

8. ACKNOWLEDGEMENT

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