COMPARATIVE STUDY OF LATERAL LOADS AND ITS COST EFFECT ON RC MOMENT FRAME AND WALL-FRAME BUILDING ACCORDING TO BNBC 2020 IN DIFFERENT ZONES OF BANGLADESH

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Abstract: With the advancement in material science, construction technology and structural analysis, a new building code was essential to keep pace with technological advantages. Recently introduced BNBC 2020 bridges the gap largely. A very basic change in lateral loading provision has occurred in the new code, which accounts for several newly defined parameters. For wind analysis, the new code introduces 3-second gust velocity as basic wind speed, wind pressure application in four cases that accounts for eccentricity. It considers topographic and internal pressure effect. A new seismic zoning is introduced in BNBC 2020 with revised PGA values and spectral acceleration. The code also introduces seismic design category and revised response reduction factor. All these changes will affect the design practice. To understand and compare lateral loading in different zones, a FEA of 20 storied RC building with and without core shear wall was analyzed using ETABS V18. The comparison shows that Rajshahi (Zone I) has lowest wind and seismic loading, Chattogram (Zone III) has highest seismic and wind loading while, Dhaka (Zone II) has moderate seismic and wind loading. Wall frame building has slightly larger seismic base shear while shear wall resists major portion of base shear and reduces top story displacement and story drift greatly. The cost of construction in zone III is significantly larger than in zone I and II. In all zones shear wall building imparts economic structural solution compared to bare frame against lateral loading for 20 storied buildings and the margin of economy increases with increasing lateral loading.

Keywords: Base Shear; Shear Wall; Wall-Frame interaction; Story Drift; Earthquake Load; Wind Load.

1. INTRODUCTION

A structure needs to withstand extreme natural events like earthquake, storm, tsunami throughout its lifetime. For keeping infrastructure's performance optimum, engineers need to design considering extreme event loading, including seismic and wind load. A well-established building code acts like a safeguard against failure during extreme events. Bangladesh National Building Code BNBC 1993 was the first official code of the country. BNBC 1993 was being followed for a long period of tine till 11th February, 2021. As BNBC 1993 underestimates lateral loads in comparison of IBC, ASCE and other building codes, an update was a crying need for the nation. The new BNBC 2020, which is a regional modification for ASCE 7-05, has reasonably more appropriate loading provision for ensuring safety and ductility. A significant change is occurring in building design, detailing, and construction practice. This will profoundly affect the nation's housing sector, infrastructure industry, and materials supply chain vendors. Moreover, demand for high strength materials, alternate economic materials and lightweight materials will increase. The change in entire ecosystem will form a new balance which is influenced by updated lateral loading, according to BNBC 2020. This study aims to compare lateral loads and relative cost of construction in three zones of Bangladesh- Rajshahi, Dhaka and Chattogram. For this, a 20-storied reinforced concrete residential building of symmetric plan is considered for two different lateral load resisting systems: moment resisting frame and dual system. A relative comparison for these two cases in different regions was done parametrically.

2. LITERATURE REVIEW

Because of the utilization of lightweight, high-strength, and high-performance materials, modern buildings are becoming more flexible, slender, and irregular in shape. This decreases the lateral loading safety margins supplied by non-structural components. Shear wall structures have less nodal displacement, both translational and rotational, and higher base reactions than Moment resistant frame structures, according to Owais at el. [1]. Using BNBC 2015, Barua at el. [2] investigated the impact of a core wall in a frame structure under seismic load and discovered that frame structures with a core wall have much lower story drift, column reactions, shear forces, base shear, and overturning moments than frame structures without a shear wall. Ahamad at el. [3] used ETABS 2015 to perform a dynamic analysis on soft soil of an irregular multi-story building in all of India's seismic zones as defined by IS 1893 (Part-1) 2016, and found that the structure with shear walls placed symmetrically will perform better in terms of all seismic parameters than the structures without shear walls and with shear wall at one end. Buddika at el. [4] investigated the multilevel seismic response of post-tensioned hybrid precast wall-frame (PWF) buildings using nonlinear response history analysis and compared it to the response of shear wall-frame (SWF) buildings under unidirectional excitation, finding that PWF buildings outperform SWF buildings to limit structural damage at the design earthquake level and the risk-targeted maximum considered earthquake. Tarigan at el. [5] used the response spectrum method to investigate the seismic performance of shear walls in various positions in structures, and found that placing a shear wall at the structure's core symmetrically gives the best performance to reduce displacement and story-drift, as opposed to placing a shear wall at the structure's periphery symmetrically and asymmetrically. We used BNBC 2020 to perform a comparative lateral load analysis on an RC moment frame and a wall frame construction in four seismic zones in Bangladesh [6].

3. FORMULATION

A. Wind Load Calculation

Calculation for wind loading according to BNBC 2020 following simplified procedure expresses velocity pressure,

$$q_z = 0.000613 K_z K_{zt} K_d V^2 I \qquad (1)$$

Where,

K_z = Velocity pressure exposure coefficient
K_{zt} = Topographic factor
K_d = Wind directionality factor
V = Basic wind speed, m/s
I = Importance factor

Design wind pressure for main wind load resisting system of buildings of all height is,

$$p = qGC_p - q_i(GC_{pi}) \text{ ; KN/m}^2 \qquad (2)$$

Where,

$q = q_z$ = Velocity pressure
G = Gust factor
C_p = External pressure coefficient
q_i = Internal pressure
GC_{pi} = Internal pressure coefficient

For flexible or dynamically sensitive structure where natural period greater than 1.0 second, gust factor should be calculated using this formula.

$$Gf = 0.925 \left(\frac{1+1.7I\bar{z}\sqrt{g_Q^2Q^2+g_R^2R^2}}{1+1.7g_vI\bar{z}}\right) \qquad (3)$$

B. Earthquake Load Calculation

Seismic base shear according to equivalent static analysis according to BNBC 2020 in a given direction is determined from following relation

$$V = S_a W \qquad (4)$$

Where,

S_a = Design spectral acceleration corresponding to the building period T
W = Total seismic weight of building.
Design response spectrum,

The spectral acceleration for the design earthquake is,

$$S_a = \frac{2ZI}{3R} Cs \qquad (5)$$

Where,

Z = Seismic zone coefficient
I = Structure importance factor
R = Response reduction factor
Cs = Normalized acceleration response spectrum

The Fundamental natural period of a building,

$$T = C_t (hn)^m \qquad (6)$$

Where,

hn = Height of building in meters from foundation of from top of rigid basement.
C_t and m depend on structure type.

4. MODELING

For comparing lateral load and structure response among different zones a symmetric plan of a residential building is considered. Two different lateral load resisting system was examined. One is bare frame-Case 1 and another is wall-frame-Case 2. The finite element analysis was carried out using ETABS V.18 software.

A Model Configurations

A residential A2 building of 20 story having a plan dimension 25mX25m for all story with typical story height 3.6m was considered. Reinforced concrete column is positioned at each grid point while reinforced concrete beams run along the grid line maintaining continuity. The columns are fixed supported at the base. A monolithic slab exists covering the total plan area in every story except ground floor. The material property and structural elements configuration are shown in the **TABLE I.** and **Table II.**

TABLE I. MATERIAL PROPERTIES OF BUILDING

Material	Strength

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Grade of concrete	27.5 MPa (column and SW)
	24 MPa (beam and slab)
Grade of steel	413.79 MPa
Poisons ratio of concrete	0.2

TABLE II. DIMENSIONS OF STRUCTURAL MEMBERS

Member	Dimensions
Column	600mmX600mm
Beam	300mmX600mm
Slab thickness	125mm
Stair slab thickness	225mm
Shear wall thickness	300mm

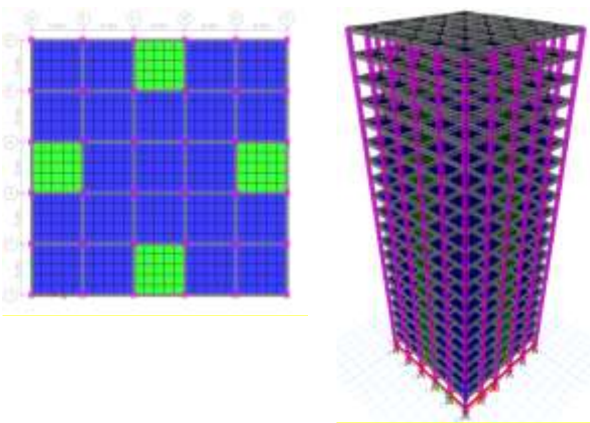

Fig. 1. Plan and three-dimensional view for Case 1

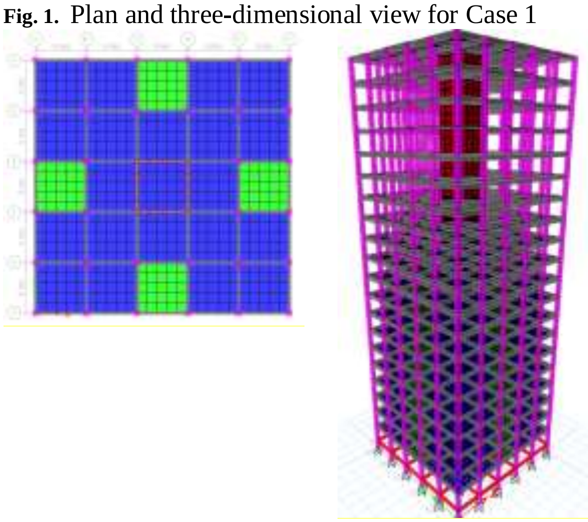

Fig. 2. Plan and three-dimensional view for Case 2

B. Gravity Loading

The vertical forces acting on a structure are known as gravity loads. The structure's self-weight comes from the self-weight multiplication factor as a built-in option. Live load from occupancy was applied as a uniform sell load on the slab. Superimposed dead loads were also applied on the slab as uniform shell load. After application of all gravity loading the slab was meshed auto mesh command. The gravity loading as per BNBC 2020 [7],[8] is shown in **Table III.**

TABLE III. GRAVITY LOADING ACCORDING TO BNBC 2020

Load Pattern	Magnitude
LL	3 KN/m2
LL (For stair slab)	4.79 KN/m2
PW	2.5KN/m2
FF	1.5KN/m2

C. Wind Design Parameters

A rigid floor diaphragm was defined and assigned to all the horizontal shell member. Basic wind speed and wind pressure coefficient was used as per BNBC 2020. Wind pressure exists from ground floor to top floor. Basic wind speed for Dhaka, Rajshahi and Chittagong velocity are 65.7m/s, 49.2m/s and 80m/s respectively. The major wind loading parameters are escribes in **Table IV.**

TABLE IV. WIND LOADING PARAMETERS

Wind Design parameter	Category/Value
Exposure type	B
Topographical Factor, k_{zt}	1
Directionality Factor, k_d	0.85
Gust factor, G_f	0.89 (Dhaka)
	0.867(Rajshahi)
	0.92 (Chittagong)

C. Seismic Design Parameters

Three building model was developed for three zones having different zone coefficient. Seismic mass was defined as per BNBC 2020 including 25% of live load as live load does not exceed 3 KN/m^2 [7]. Site classification was also done as per the code. from seismic zone and site class seismic design category SDC was determined. Other parameters were assigned using Appendix C, Part VI of BNBC 2020. A list of seismic design parameters is shown in **Table V.**

TABLE V. SEISMIC LOADING PARAMETERS

Seismic Design Parameter	Category/Value
Seismic zone	II (Dhaka)
	I (Rajshahi)
	III (Chattogram)
Zone coefficient	0.20 (Dhaka)
	0.12 (Rajshahi)
	0.28(Chattogram)
	8 (Dhaka)

Response reduction factor (R)	5 (Rajshahi)
	8 (Chattogram)
Importance factor	I
Site coefficient for Dhaka	F_a=1.35, F_v=2.7
Site coefficient for Rajshahi	F_a=1.15 F_v=1.725
Site coefficient for Chattogram	F_a=1.3 F_v=2.7
Site class	SD
Seismic design category	D (Dhaka)
	C (Rajshahi)
	D(Chattogram)
Lateral load resisting system	Dual System
Damping ratio	5%
System overstrength factor,	3
Deflection amplification factor, C_d	5.5 (Dhaka, Chattogram)
	4.5 (Rajshahi)

D. Cost Estimation

As BNBC 2020 accounts several newly defined parameters in lateral loading provisions, the cost impact of BNBC 2020 in different zones is of great interest for design engineers as well as other stake holders. For determining this, the models were designed keeping structural member's dimension same for all zones. As the lateral load varies in different zone the reinforcement requirement also varies with it. Then the sections were detailed maintaining ACI detailing provision. Then, Both longitudinal and transverse rebar quantity was estimated for Case1 and Case 2 in different zones.

5. RESULTS AND DISCUSSION

A. Wind Base Shear

Wind base shear is the resultant generated at base of a building due to wind pressure application on the surface of the building. As we considered enclosed structure with same surface area, wind base shear in case 1 and case 2 was found same (fig. 3.). It depicts building mass has nothing to do with wind base shear. Fig. 1. Also shows that, wind base shear is greatest in zone III, which is a high wind zone Chattogram (Vb= 80 m/s) and lowest for zone I which is a low wind zone Rajshahi (Vb= 49.2 m/s). The moderate wind zone, zone II, Dhaka (Vb= 65.7 m/s) lies in between. That's represents wind base shear increases with increased basic wind speed. In comparison of zone I, wind base shear in zone II increases 84.7% and wind base shear in zone III increases 183% as per BNBC 2020.

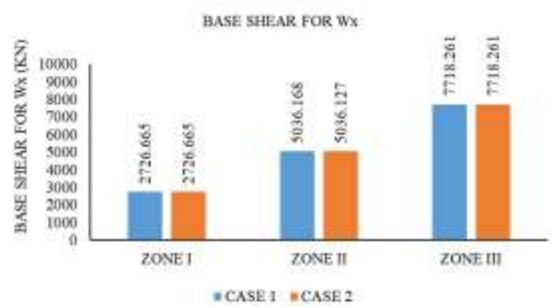

Fig. 3. Base shear for wind load (KN)

B. Seismic Base Shear

Seismic base shear is the resultant generated at base of a building due to ground movement during earthquake occurrence. As we considered case 1 is bare frame and case 2 is wall frame, the total seismic mass increases for case 2. As seismic base shear is a fraction of seismic mass, base shear in case 2 is slightly larger in all zones. (fig. 4.). It depicts higher building mass results in high magnitude of seismic base shear. Fig. 1. Also shows that, seismic base shear is greatest in zone III, which is a high seismic zone Chattogram (Z = 0.28) and lowest for zone I which is a low seismic zone Rajshahi (Z = 0.12). The moderate seismic zone, zone II, Dhaka (Z = 0.20) lies in between. That's represents seismic base shear increases with increased seismic zone coefficient. In comparison of zone I, seismic base shear in zone II increases 84.24% and seismic base shear in zone III increases 157.94% as per BNBC 2020.

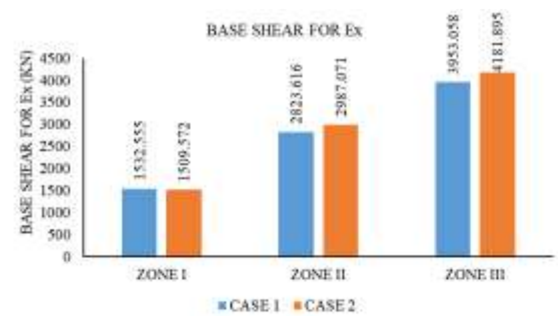

Fig. 4. Base shear for seismic load (KN)

C. Top Story Displacement

Top story displacement is very important parameter to consider for analyzing building response due to lateral loads. Large top story displacement can introduce p-Δ effect and can gradually increase overturning moment. From Analysis, we found that, shear wall in the optimum location greatly reduces top story displacement for both seismic and wind loading

(Fig. 5. & Fig. 6.) The top story displacement for wind load is larger than top story displacement for seismic load in every zone. That's justify an upper limit restriction of top story displacement for wind loading by BNBC 2020. Fig. 3. & Fig. 4. also shows that top story displacement is greater for zone III as it has greater seismic and wind forces and lowest for zone I as it has the lowest lateral forces. Also, the moderate seismic and wind zone lies in between.

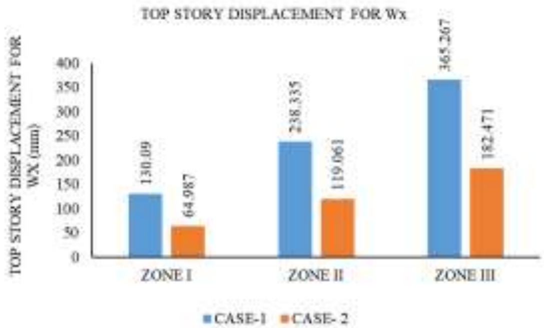

Fig. 5. Top story displacement for wind load (mm)

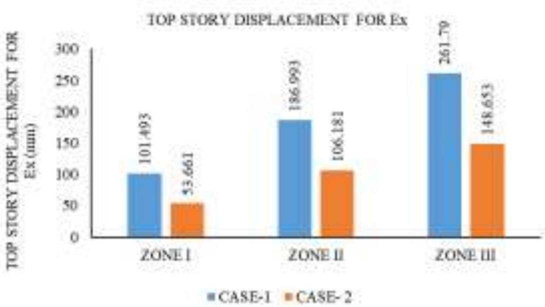

Fig. 6. Top story displacement for seismic load (mm)

D. Story Drift

Story drift is the displacement of one story with respect to another story. Larger story drift indicates more flexible framing, can be crucial for both nonstructural member and structural member. From comparing story drift for both wind and seismic loading it was found that shear wall greatly reduces the magnitude of story drift. That's why in case 2 story drift is smaller (Fig. 7-10.). It was also found that maximum story drift in bare frame occurs at one forth height of the building while inclusion of shear wall moves the position of max story drift almost mid height of the building. The figures also show that story drift is greater for zone III as it has greater seismic and wind forces and lowest for zone I as it has lowest lateral forces. Also, the story drift in moderate seismic and wind zone lies in between.

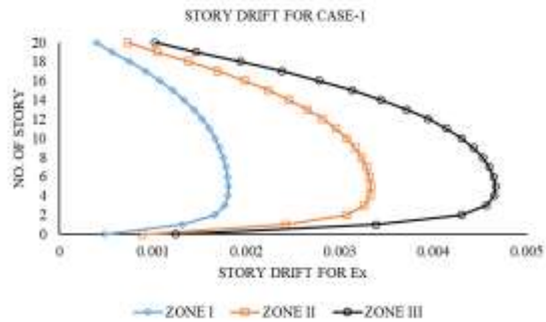

Fig. 7. Story drift for seismic load: case-1

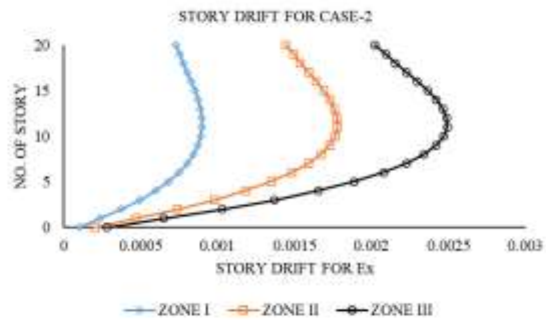

Fig. 8. Story drift for seismic load: case-2

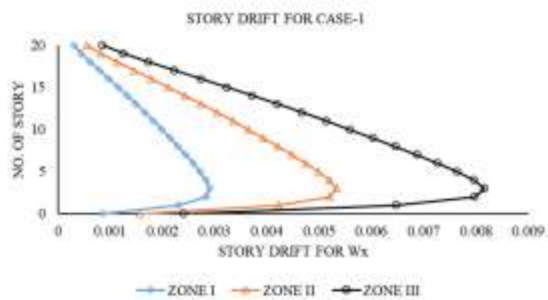

Fig. 9. Story drift for wind load: case-1

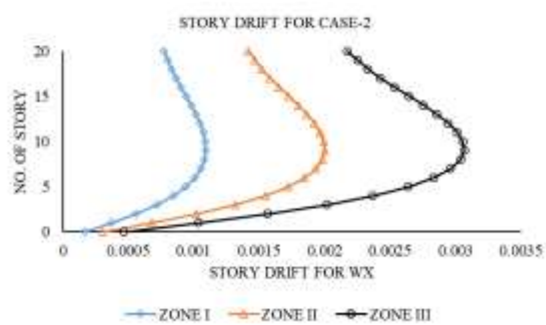

Fig. 10. Story drift for wind load: case-2

E. Shear Wall Contribution Against Lateral Loads.

Shear wall attracts most of the lateral load by bending and shear action as it has high in plane stiffness. Analyzing lateral load distribution according to BNBC 2020, we found that, almost 85.55% of wind base shear is transferred to shear wall at base for this model configuration. This ratio is same for all zones (Fig. 11.). Similar pattern is also found for seismic base shear. 84.27% of total seismic base shear transfers to shear wall for all the zones (Fig. 12.).

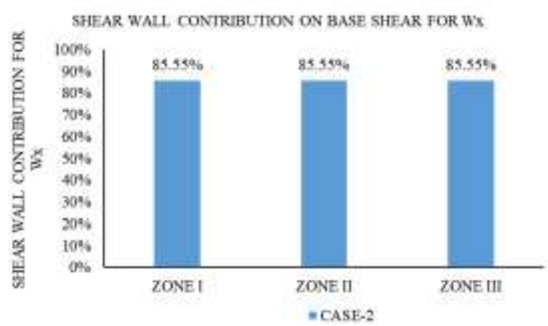

Fig. 11. Shear wall contribution of base shear for Wind load.

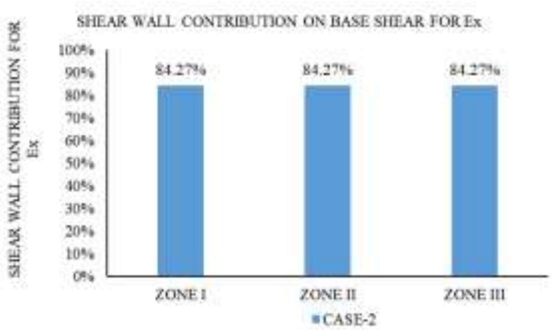

Fig. 12. Shear wall contribution of base shear for seismic load.

F. Cost Impact in Different Zones

The cost of construction of a structure is of great significance. From the detailed estimate we found that, reinforcement required in beam increases with increase of lateral load. The rate of increase of beam reinforcement is greater for wall framed building (Fig. 13. & Fig. 14.). This is due to wall frame interaction in case 2 where link beams attracts more lateral force from shear wall. Column reinforcement also increases with increasing lateral forces but the rate of increase is milder than beams. This is because the number of column having minimum reinforcements increases with decreasing lateral loads (Fig. 13. & Fig. 14.). The calculated total reinforcement shows that bare frame reinforcement is 32.79% higher for zone II and 65.69% higher for zone III compared to Zone I. Similarly Wall frame reinforcement is 19.59% higher for zone II and 46.93% higher for zone III compared to Zone I (Fig. 15.) It also shown that inclusion of core shear wall imparts more economic design for this building height according to BNBC 2020. The margin of economy increases with increasing lateral loading. In zone I shear wall frame building costs 1.38% less, in zone II it is 11.18% and in zone III it costs 12.55% less compared to bare frame building.

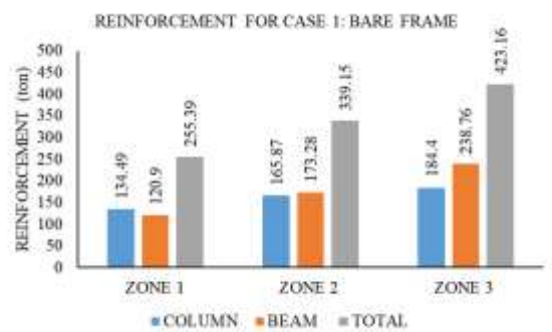

Fig. 13. Frame Reinforcement Requirement for Case 1 According to BNBC 2020.

Fig. 14. Wall and Frame Reinforcement Requirement for Case 2 According to BNBC 2020.

Fig. 15. Comparison of required reinforcement in Different Zones According to BNBC 2020.

6. CONCLUSION

Concrete buildings with moment resisting frame and dual system covers the major portion of infrastructure in Bangladesh. Implication of new building code, BNBC 2020 is going to change design practice greatly. Which will affect the infrastructure industry in upcoming days. Our study aims comparing lateral loads and its cost effect among different zones of Bangladesh. The research found that wind base shear is 2.83 times and seismic base shear is 2.58 times greater in zone III in comparison to zone I. Whereas, wind base shear is 1.85 times and seismic base shear is 1.84 times greater in zone II in comparison to zone I. In bare frame this lateral loads are distributed among all columns but in wall frame structure 85.55% wind base shear and 84.27% of seismic base shear is transferred to shear wall. Which improves structure's response to lateral loads. For high-rise building wall frame structure imparts more economic solution for all zones, while construction in zone III is 65.69% costlier and in zone II is 32.79% costlier compared to construction cost in zone I.

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