Steel Concrete Composite High-Rise Building with Stepped Architecture for Earthquake Prone Areas

Arup Saha Chaudhuri

Professor, Department of Civil Engineering, Techno Main Salt Lake, Kolkata, India

---***---

Abstract - *In structural engineering, steel-concrete composite structures are those types of structures where we use these two materials efficiently in the construction. They act as a single unit in which steel is effective on tension side and concrete is effective on compression side. In this paper, the proposed G+21 storey high-rise building frame is made of structural steel columns and steel beams with concrete slab composite floors. Stepped Architecture is one of the ideal concepts of construction to stabilize any framed structure. The bottom portion should be much wider than the top portion of the structure in this concept. This concept is very suitable for high-rise buildings in earthquake prone areas. We will discuss about composite construction and stepped architecture concepts in detail and will show how we can apply both of these concepts in high-rise building to work efficiently. Purpose of this paper is to design and analyze a two dimensional building frame under high seismic zone without providing any extra seismic resisting system.*

Key Words: **High-rise steel building, Earthquake prone area, Stepped architecture, Vertical stability bracings, Steel-concrete composite floors**

1. INTRODUCTION

We all know that 71% of earth surface is covered by water and remaining part is covered by land. Population of world is increasing day by day but our land of earth is limited. So it is not possible to built house for each and every individual person. In our modern days of civilization, construction of tall buildings is rapidly increasing where maximum person can live by using minimum space of land. This tall building is constructed not only for residential purpose but also can be used for commercial purpose or both. There is no such definition of tall or high-rise building. But as per IS Code RC buildings of height more than 50 m but less than 250 m can be treated as a tall building but this standard is not applicable for location of building near field of seismic fault.

Composite is that where two or more materials or units of different properties are combined together and these materials or units act as a single unit. Composite construction is widely used method in modern days of constructions. Scientists are doing research on this theory that how to develop more composite construction in different ways. Engineers are also adopting this technique in construction industries. Composite construction is widely used in building construction, aircraft and watercraft. There are some examples of composite construction like – Steel-Concrete composite deck, Wood-Plastic composite deck, Cement-Polymer composite etc. Composite constructions have some advantages like high strength, high stiffness, high seismic resistance, increased load carrying capacity, economic, lightweight and environment sustainability.

Most of the high-rise buildings have more tend to experience prolonged shaking than short buildings because they often have lower damping and body waves from earth rapidly travels through the ground compared to slower, more destructive wave. They are not safe enough to resist vibrations. Hence, tall buildings are not safe against earthquake. It has major chance to damage of properties and lots of life loss. Tall buildings are not safe even in Zone – II. For example, we can say about 2001 Bhuj earthquake where high-rise buildings of Ahmadabad city were damaged epicenter was 300 km away from it. To resist the affects of earthquake we have to apply some modern technologies by installing seismic isolation devices. These devices reduce the energy of structure and reduce forces acting on floors. These devices increase the stiffness of structures and also increase the capacity of structures to resist loads. There are so many devices those can be used as per the design like Synthetic Rubber Bearing or Lead Rubber Bearing, Fluid or Viscous Dampers, Visco-Elastic Damper, Rocker Roller etc. Sometimes we can use some design concept for earthquake resistance building like Shear Wall concept, Braced Frame concept etc.

There is a lot of research on the best shapes for earthquake resistance buildings. Buildings can be irregular or asymmetrical in shape. Some shapes those have been found to perform well in earthquake include Triangular shape, Rectangular shape, Dome shape, Stepped shape etc. In this paper, we will focus on stepped shape with no extra seismic resistant mechanism.

2. STEEL CONCRETE COMPOSITE

Steel-Concrete composite is one of the most widely used among all composite structures. This type of composite slab is generally used in bridges and multi-storey buildings. Because of composite action, it has higher stiffness, higher strength, higher span to depth ratio, lower deflection than traditional steel or concrete. Concrete is strong in compression where steel is strong in tension. Therefore, it is proven that steel-concrete composite enhances the structural performance.

Composite deck is a combination of the compressive strength of concrete with the tensile strength of steel to improve the design efficiency and potentially reduce the volume of material necessary to cover a given area. A profiled sheet of metal supported by steel joist or beam is the shuttering cum reinforcement. Then fresh concrete is poured on top of this sheet and it becomes a composite deck. The advantage of using composite deck is the increased strength of the floor without adding any extra weight.

Due to high load carrying capacity, larger span, high diaphragm action, easy installation process, minimal wastage and good safety for workers composite deck is proposed by the designers now-a-days.

3. EARTHQUAKE RESISTANT BUILDING

Releases of energy due to movement of tectonic plates huge damages occur in the structures like tall buildings, bridges etc. The tall buildings are more flexible than the short buildings so it has more chances to damage by earthquake. This is so destructive that is enough to kill lot of people and massive loss of economy. Hence, seismic analysis is very much needful for tall buildings. In our country, we have all four seismic zones i.e. Zone 2 to Zone 5. This analysis is followed by IS codes and depends on earthquake zones, soil strata, type of structure, seismic weight of building, ground acceleration etc. Effects of design earthquake loads applied on structures can be considered in different analysis method such as equivalent static method, response spectrum method etc. Various methods of earthquake resisting systems are also applied like shear wall, core wall, braced frame, base isolation, different types of dampers etc.

4. OUR CASE STUDY

Only steel or concrete buildings both have drawbacks in wind and earthquake respectively. According to our study to improve the properties of tall building we should use steel concrete composite. A study says that composite systems are over 25% lighter than concrete construction. In high-rise building seismic reaction affects horizontally and tortionally. In general, bracing and shear wall are designed for stiffness because bracing and shear wall aim to dissipate this poor seismic behavior.

The storey displacement is more in symmetrical building, so we propose to design different architectural concept that is horizontally or vertically irregular in shape. Triangular or pyramidal shape is more prominent for earthquake resistant building. So in this case we design a building which is cascade shape or also we can say this type of architecture is stepped architecture. All over the world we can see the concept of stepped architecture. Shenye Tairan Building (Shenzhen City, China) and Aspern J4 (Vienna, Austria) are the examples of among stepped architecture.

STAAD-PRO software is used for seismic analysis of buildings. The results show that bracings are much more efficient than shear wall in reducing lateral displacement of frame as drift and horizontal deflection are much less than shear wall. Column axial forces are more in braced frame than shear wall and column & beam moment is less than shear wall. CCTV Headquaters (Beijing, China) and Hearst Building (New York City, USA) are the best example of tall building with bracing.

4.1 DESCRIPTION OF STRUCTURE

In this paper, a G+21 storey residential two dimensional building frame is considered which is to be designed under seismic loading. The building shape has three steps. The first step is constructed from the Ground floor to 10th floor and also has 11 bays with distance of 5 m each. The second step is designed from 11th floor to 17th floor. We reduce two bays from all sides of the frames of second step and thus 7 no. bays with distance of 5 m each. Similarly, in the third step again we reduce two more bays from all sides of frames. This third step is 18th floor to top of the building frame. Each floor height of this building is 3.25 m.

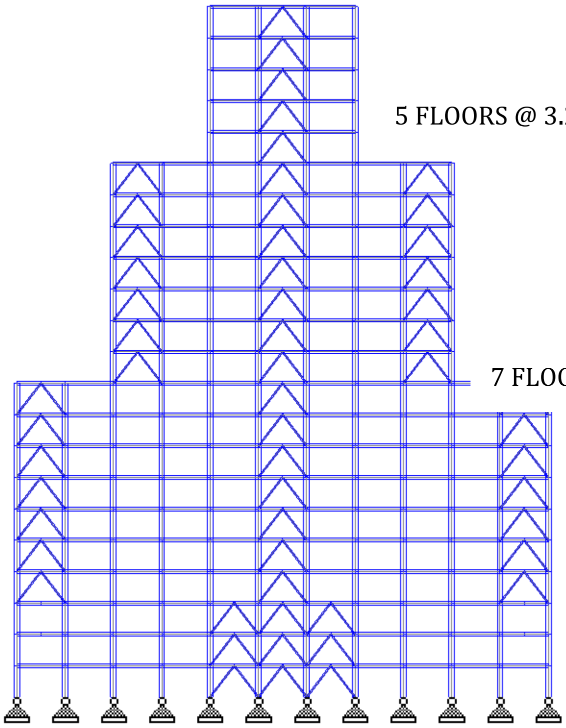


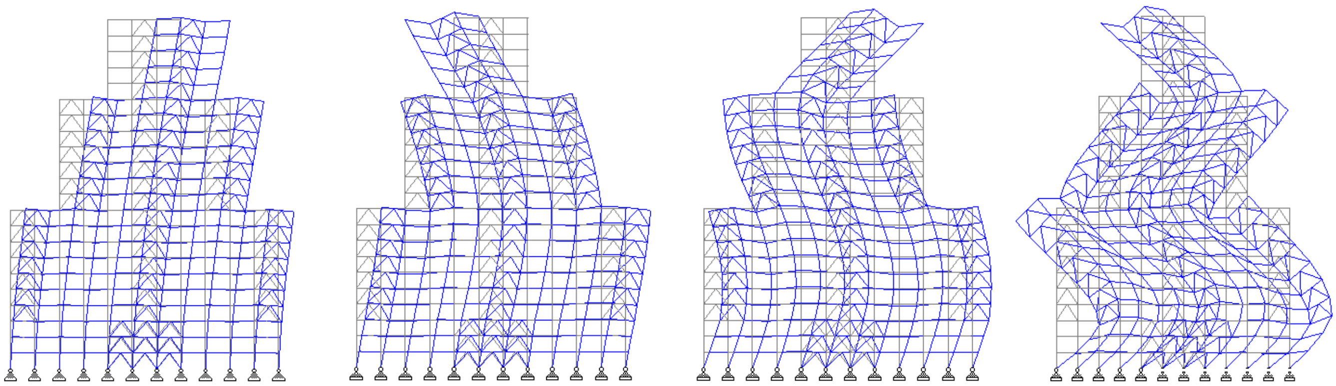
Figure 1 : G+21 storey Building Elevation with Stepped Architecture

The building is made of steel-concrete composite by using wide flange steel beam & column sections (UB/WPB) and steel bracing sections (SHS/RHS). Consider the building is located at Zone IV in India. From IS 1893 (Part-1):2016, Table-3 we get Seismic zone factor Z is 0.24. The response reduction factor R is 4. Importance factor I is 1.2 as per IS code. The soil stratum of construction site is assumed as medium stiff. For this design horizontal seismic co-efficient is calculated A_h as 0.036. We provided damping 5% on this building frame. The dead load is considered as 5 kN/sq.m including its self weight for all floors. The live load is considered as 4 kN/sq.m from 1st floor to 5th floor and 3 kN/sq.m from 6th floor to 10th floor on the first step. On the second and final steps we considered live load 2.5 kN/sq.m. The nodal load is 67.5 kN for all nodes at the edge of the building. Water tank load is considered at the roof of each step. The seismic load is acting towards horizontal direction on the building frame. We have analyzed the model by response spectrum method. The set of load combinations involving seismic effects are as follows:

i) DL + LL
ii) DL + LL + EQL
iii) DL + LL – EQL
iv) 1.5 (DL + LL)
v) 1.2 (DL + LL + EQL)
vi) 1.2 (DL + LL - EQL)

Temperature stress analysis should also be carried out and proper structural arrangements for releasing the temperature stress must be implemented in the main structure.

The building is then suitably designed in STAAD Pro software using response spectrum method.



MODE SHAPE : 1 MODE SHAPE : 2 MODE SHAPE : 3 MODE SHAPE : 4

Figure 2 : Mode Shapes 1, 2, 3 & 4

We can see the mass participation factors of our building frame in the following table:

Table -1: Mass Participation Factors

	MASS PARTICIPATION FACTORS IN PERCENT						BASE SHEAR IN KN		
MODE	X	Y	Z	SUMM-X	SUMM-Y	SUMM-Z	X	Y	Z
1	58.77	0.00	0.00	58.765	0.000	0.000	435.69	0.00	0.00
2	22.67	0.00	0.00	81.434	0.000	0.000	399.63	0.00	0.00
3	7.30	0.00	0.00	88.737	0.000	0.000	241.95	0.00	0.00
4	6.71	0.00	0.00	95.443	0.000	0.000	239.85	0.00	0.00
5	0.00	50.40	0.00	95.443	50.401	0.000	0.00	0.00	0.00
6	0.00	0.02	0.00	95.445	50.420	0.000	0.08	0.00	0.00
					TOTAL SRSS	SHEAR	682.34	0.00	0.00
					TOTAL 10PCT	SHEAR	682.34	0.00	0.00
					TOTAL ABS	SHEAR	1317.19	0.00	0.00
					TOTAL CSM	SHEAR	682.34	0.00	0.00
					TOTAL CQC	SHEAR	694.34	0.00	0.00

Table -2: Fundamental Time Periods and Modal Base Actions

MODAL BASE ACTIONS FORCES IN KN LENGTH IN METE

					MOMENTS ARE ABOUT THE ORIGIN		
MODE	PERIOD	FX	FY	FZ	MX	MY	MZ
1	2.624	435.69	0.11	0.00	0.00	0.00	-19826.53
2	1.104	399.63	-0.36	0.00	0.00	0.00	-4361.20
3	0.587	241.95	-0.35	0.00	0.00	0.00	-1387.85
4	0.411	239.85	1.67	0.00	0.00	0.00	-935.67
5	0.330	0.00	-0.91	0.00	0.00	0.00	-24.92
6	0.302	0.08	-0.23	0.00	0.00	0.00	117.98

Table -3: Lateral Deflection Check

FLOOR LEVELS	TIP HORIZONTAL DEFLECTION (MM)	HEIGHT / 500 (MM)	REMARKS
At 10th floor	25	65	DL+LL+EQL
At 17th floor	46	110	DL+LL+EQL
At 22nd floor	65	143	DL+LL+EQL

4.2 COMPARISON WITH EQUIVALENT TALL BUILDING ANALYSIS

Now we will compare the above responses with the equivalent tall building of same cross sectional area. The building then consists of 6 bays @ 5m each and G+28 floors of 3.25m height each. The loading and analytical procedures are same as the earlier one. After response spectrum analysis the following results are obtained.

It is observed that here the tip horizontal deflection is 213 mm that is too large compared to the stepped building (65mm). However, the natural time periods in both the cases are far away from the resonating zone. It is also observed that the base shear for tall slender building is less due to long time period with very high lateral deflection. Very large tip horizontal deflection is the cause of uncomfortable situation in human perspective. So less amount of horizontal tip deflection is desirable with sufficiently long time periods that is happening with the stepped architecture.

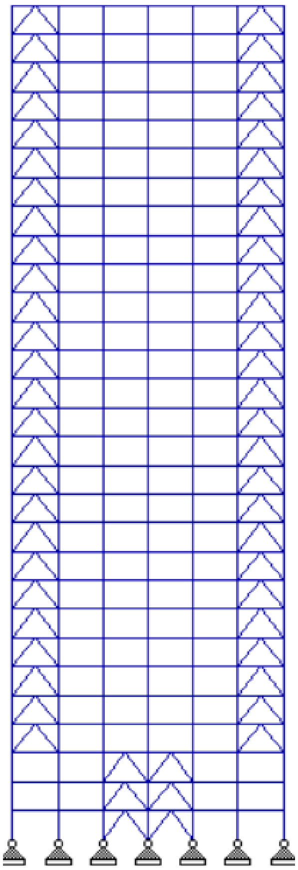


Figure 3 : G+28 storey Tall Building Elevation

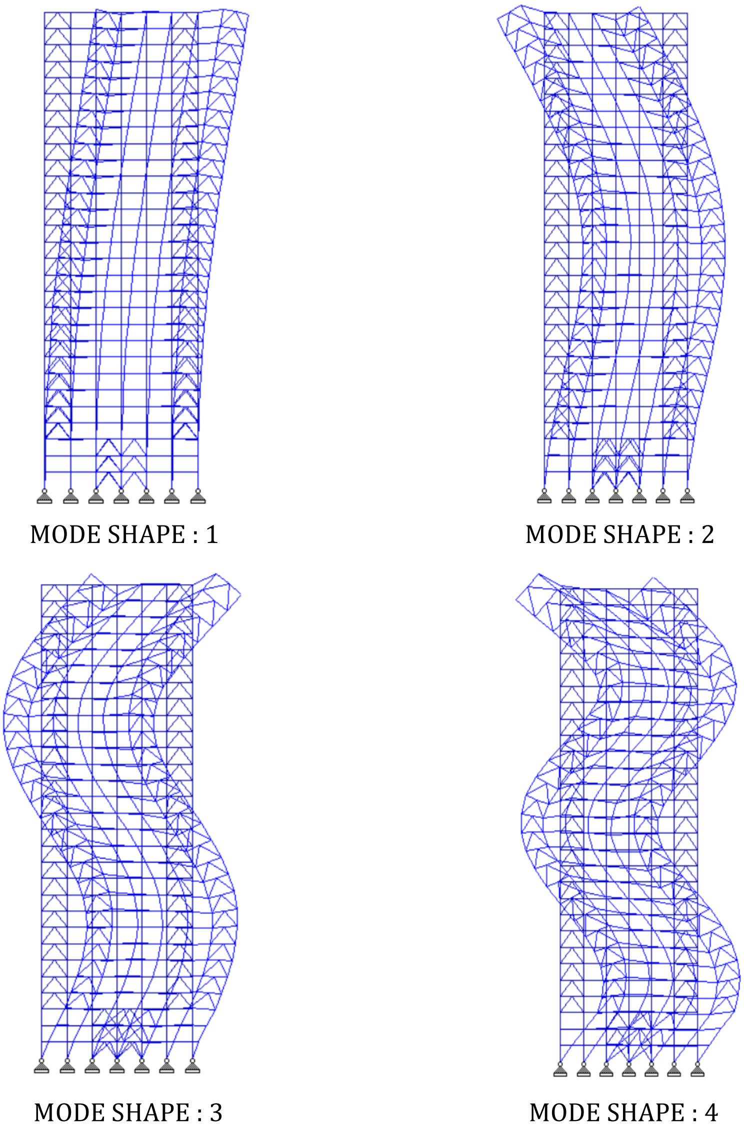


Figure 4 : Mode Shapes 1, 2, 3 and 4

Table -4: Mass Participation Factors

MODE	X	Y	Z	SUMM-X	SUMM-Y	SUMM-Z	BASE SHEAR X (KN)	BASE SHEAR Y (KN)	BASE SHEAR Z (KN)
1	55.96	0.00	0.00	55.956	0.000	0.000	115.44	0.00	0.00
2	23.25	0.00	0.00	79.203	0.000	0.000	222.67	0.00	0.00
3	10.09	0.00	0.00	89.293	0.000	0.000	215.69	0.00	0.00
4	4.56	0.00	0.00	93.853	0.000	0.000	160.29	0.00	0.00
5	0.00	38.92	0.00	93.853	38.925	0.000	0.00	0.00	0.00
6	0.00	0.00	0.00	93.857	38.925	0.000	0.14	0.00	0.00
				TOTAL SRSS SHEAR			367.60	0.00	0.00
				TOTAL 10PCT SHEAR			367.60	0.00	0.00
				TOTAL ABS SHEAR			714.24	0.00	0.00
				TOTAL CSM SHEAR			367.60	0.00	0.00
				TOTAL CQC SHEAR			372.80	0.00	0.00

Table -5: Fundamental Time Periods

CALCULATED FREQUENCIES FOR LOAD CASE 4

MODE	FREQUENCY(CYCLES/SEC)	PERIOD(SEC)	ACCURACY
1	0.106	9.44931	7.533E-16
2	0.491	2.03519	7.455E-16
3	1.097	0.91199	1.154E-09
4	1.803	0.55463	3.561E-07
5	2.145	0.46631	8.110E-08
6	2.145	0.46625	7.507E-08

Table -6: Lateral Deflection Check

TIP DEFLECTION	DEFLECTION (MM)	HT / DEFLECTION (< H/250)	REMARKS
At 10th floor	33	984	PERMISSIBLE
At Top floor	213	443	PERMISSIBLE

5. CONCLUSIONS

We designed and analyzed the two model buildings for seismic zone – IV by response spectrum method. One is following stepped high-rise shape and another is equivalent tall building with same cross sectional area. Responses for both the cases were studied and it was observed that tall slender building exhibited very large amount of horizontal tip deflection causing more human discomfort than stepped building shape. Without any special seismic resistant systems like – Shear wall, Damper bracings etc. this seismic design is very safe implementing the stepped architecture design considerations with stability bracings.

REFERENCES

[1] Tall Building Design – Steel, Concrete and Composite Systems by Bangale S. Taranath.

[2] IS 1893 (Part 1): 2016 Criteria for Earthquake Resistant Design of Structures.

[3] IS 800: 2007 Steel structure design code of practice.

[4] Literature survey on stepped architecture concept in the internet.