Seismic Vulnerability Assessment of Building For Retrofitting Strategies: Simplified Vulnerability Assessment

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Abstract

In India, 85% of existing buildings are unreinforced masonry and 5-7% are reinforced concrete and 5-7% are traditional buildings. And most buildings do not qualify to resist earthquakes, technically it can be said that they would not be able to resist earthquake loads. In the past, it is seen at the time of the earthquake, millions of lives and the economy of that region is affected. Demolition of ageing building mass is not only harmful to the environment but also it is not viable economically to rebuild all vulnerable buildings. Such buildings are recommended to be retrofitted. Recent earthquakes have demonstrated the need to identify and improve the performance of the existing seismic deficient buildings. For this reason, Seismic vulnerability assessment is considered a part of a better strategy to mitigate the risk and improve the resiliency of the country and its infrastructure. Due to the high volume of building archetypes in our country, for Seismic Vulnerability Assessment at a huge scale, a rapid, simplified method is being adopted that can facilitate the assessment procedure in a lesser computational time period.

This paper was primarily engrossed in the analysis of some simplified methods proposed in the literature for assessing the simplified seismic vulnerability. A hypothetical building is analyzed using structural software (Etabs) by Nonlinear Dynamic Analysis Procedure. Using Etabs software, various structural parameters like Story Response Drift, Displacement (max) and Base Shear are considered and discussed. By proper interpretation of the result, a suitable measure to minimize vulnerability and ensure sustainability and cost-effectiveness, retrofitting strategies is recommended.

Keywords: *Seismic vulnerability, Existing Building, Simplified Analytical Method, Rapid Visual Screening, Detailed vulnerability assessment, Etabs, Non-linear Dynamic Analysis, Retrofitting Strategies.*

1. Introduction:

India is one of the world's fastest developing countries, and its economic stability is heavily reliant on its infrastructure and people. In India, unreinforced masonry accounts for 85 per cent of existing buildings, reinforced concrete accounts for 5-7 per cent, and traditional buildings account for 5-7 per cent. And most buildings do not qualify for earthquake resistance; technically, we can say they would be unable to withstand earthquake loads.

Structure needs to be sustainable and efficient in resisting any future Seismic hazard. The existing wisdom on the earthquake-resistant structure is to identify and improve the performance of the existing seismic deficient buildings. For this reason, Seismic vulnerability assessment is considered a part of a better strategy to mitigate the risk and improve the resiliency of the country and its infrastructure during such adversities. It is in the interest of a fast-developing country like India, which is the world's most populated country where most people still live in such vulnerable structures.

Vulnerability

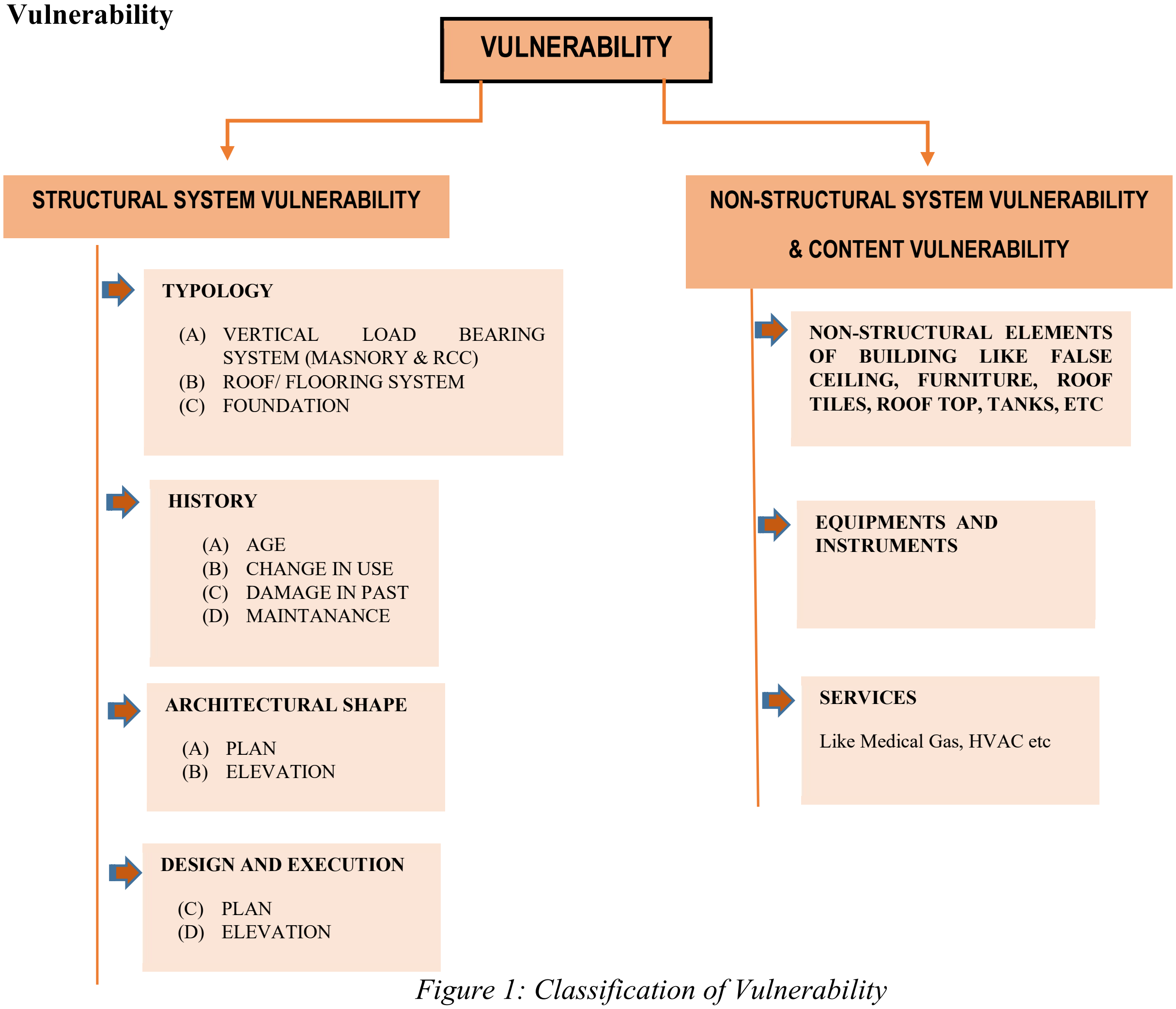


Figure 1: Classification of Vulnerability

1. Methodology:

Building Sample Data for SVA

(1) Building Type: Residential
(2) Occupancy: Around 250 People
(3) Total Area: 10,506.24 m^2
(4) No. of Story: G + 8
(5) Stilt Parking at Base (H=2.8 m)
(6) Height of Building: 30.80 m
(7) Each Storey Height: 3.50 m
(8) Location of Building: Tifra, Bilaspur (C.G.)
(9) Soil Type: Type II (Medium Soil)
(10) Seismic Zone: Zone II
(11) Wind Speed: 39 m/s
(12) Concrete: M20

Figure 2: 3D Exterior Elevation of the Building

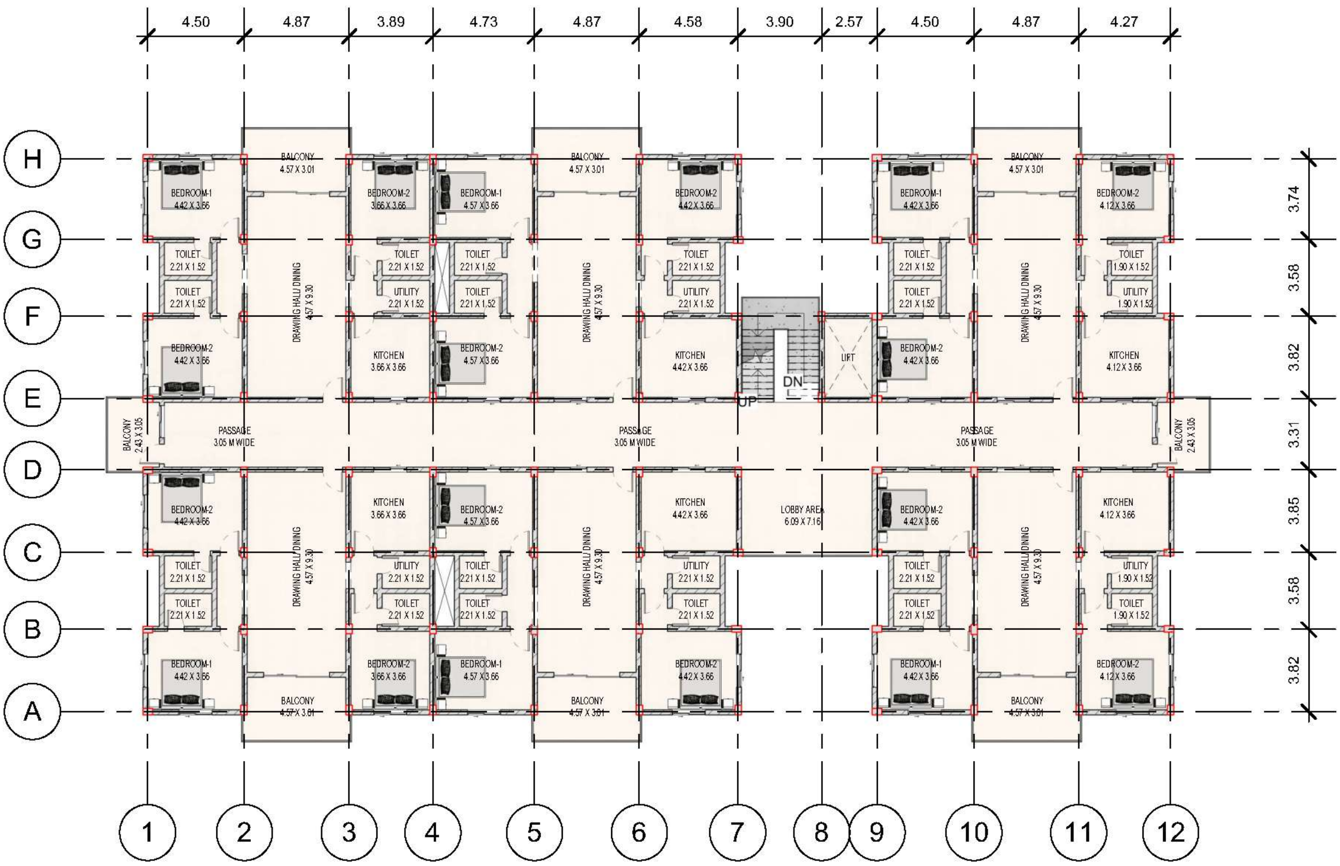


Figure 3: Architectural Floor Plan

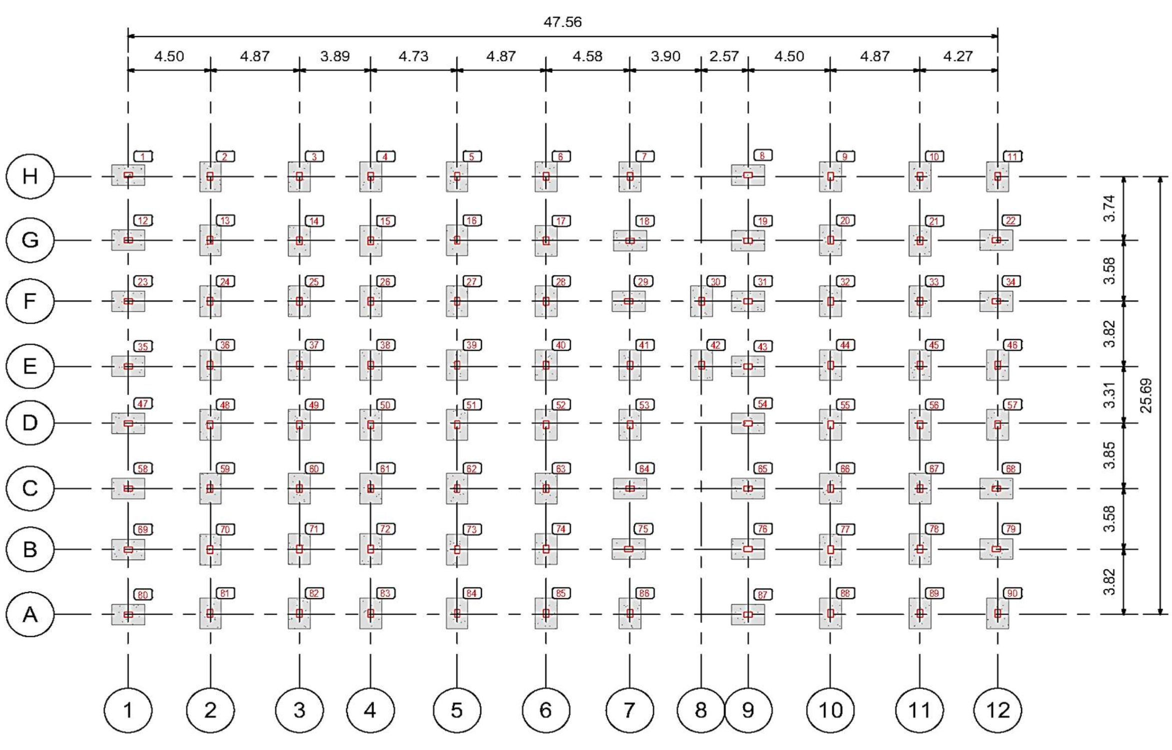


Figure 4: Column Centerline Plan

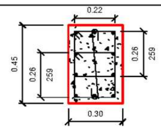
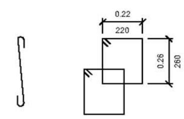
COLUMN NUMBERS		COL. 1-90
PCC M10	Thickness : 100 mm	2700 X 2100
RCC FOOTING	Size : L_f x B_f	2400 X 1800
	Depth : D_f x $D_{f,min}$	D_f=450
	Steel: Bottom L_f & B_f	Y10 @5" C/C
	Steel: Top L_f & B_f	Y10 @5" C/C
COULMN BETWEEN FOOTING TO PLINTH	Size : b x D	300 X 450
	Steel : N-#	10 - Y16
PLINTH TO 1st FLOOR	Size : b x D	300 X 450
	Steel : N-#	10 - Y16
1st FLOOR TO 8TH FLOOR	Size : b x D	300 X 450
	Steel : N-#	10 - Y16
Member Type:		 0.22, 0.45, 0.26, 259, 0.26, 259, 0.30
STIRRUPS		 0.22, 220, 0.26, 260; 260 mm (Link); 220 x 260 mm (Double Overlap Ring)
STIRRUPS SPACING (NOMINAL)		150 mm c/c

Figure 5: Column Schedule

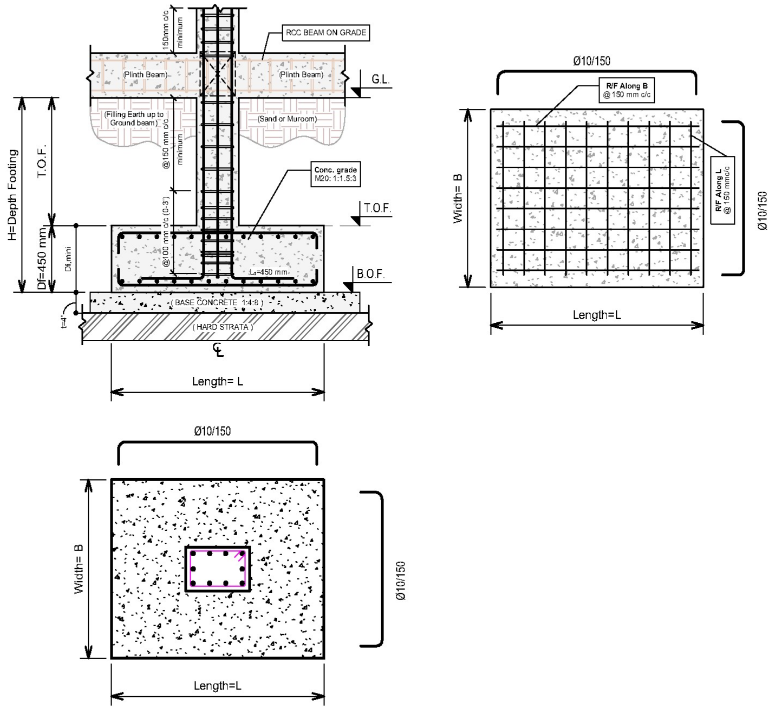


Figure 6: Isolated Footing of Column

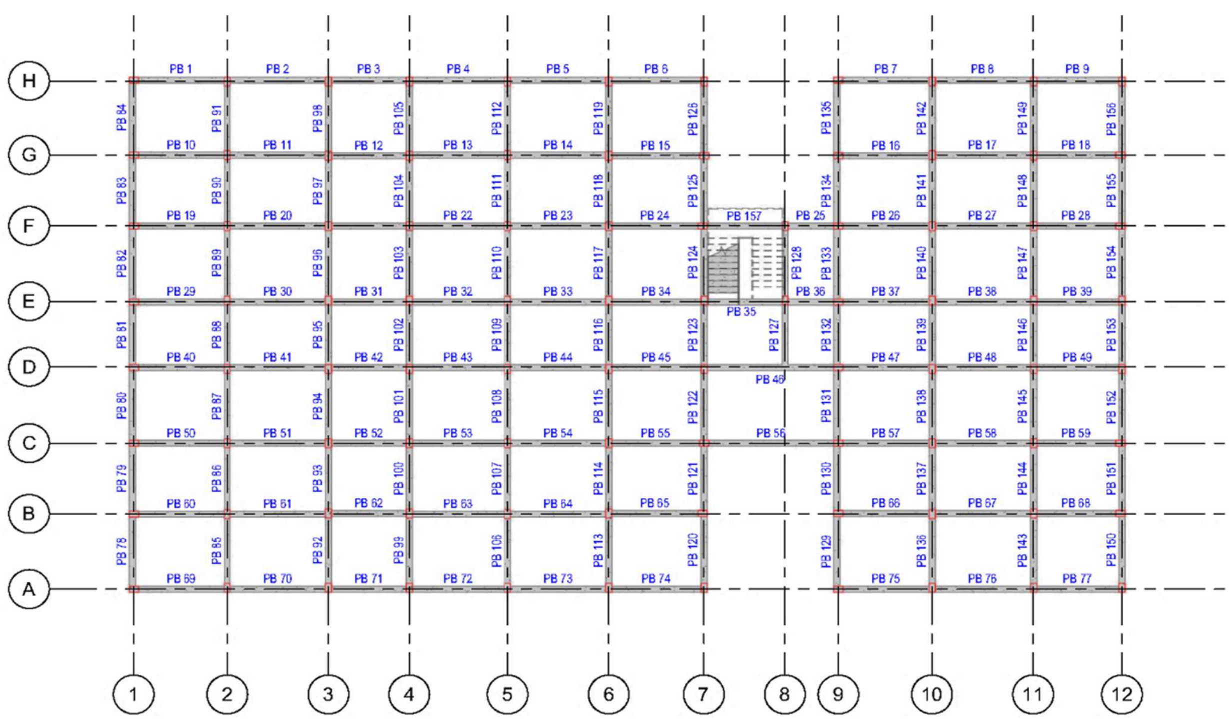


Figure 7: Plinth Beam Plan

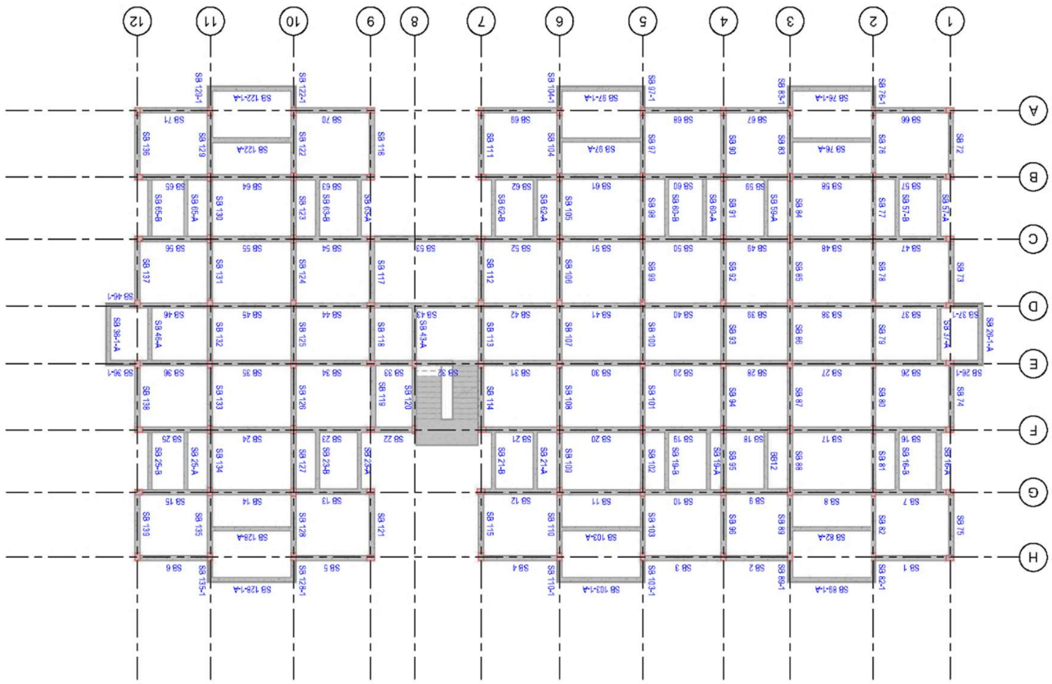


Figure 8: Floor Beam Plan

BEAM NUMBERS	SIZE B mm D mm	TOP REINF. STRAIGHT (TH.)	CRANK BENT (EX.)	BOTTOM REINF. STRAIGHT (TH.)	STIRRUPS (NOMINAL)
(A) **PLINTH BEAM**					
PB 1 TO PB 77	230 X 350	2-Y16	2-Y12	3-Y16	Y8 @150 C/C
PB 78 TO PB 78-156	230 X 350	2-Y12	2-Y12	3-Y12	Y8 @150 C/C
(B) **SLAB BEAM FLOOR BEAMS**					
SB 8, SB 17, SB 27, SB 38, SB 48, SB 58, SB 11, SB 20,SB 30, SB 41, SB 51, SB 61,SB 14, SB 24, SB 35, SB 45, SB 55, SB 64	230 X 400	2-Y16	2-Y16	3-Y16	Y8 @150 C/C
SB 3, SB 10, SB 19, SB 29, SB 40, SB 50, SB 60, SB 68, SB 5, SB 13, SB 23, SB 34, SB 44, SB 54, SB 63, SB 70, SB 1, SB 7, SB 16, SB 26, SB 37, SB 47, SB 57, SB 66	230 X 400	2-Y16	2-Y12	2-Y16	Y8 @150 C/C
SB 2, SB 9, SB 18, SB 28, SB 39, SB 49, SB 59, SB 67, SB 4, SB 12, SB 21, SB 31, SB 42, SB 52, SB 62, SB 69, SB 6, SB 15, SB 25, SB 36, SB 46, SB 56, SB 65, SB 71	230 X 400	2-Y12	2-Y12	3-Y12	Y8 @150 C/C
SB 72, SB 73, SB 74, SB 75, SB 76, SB 78, SB79, SB 80, SB 81, SB 82, SB 83, SB 84, SB 85, SB 86, SB 87, SB 88, SB 89, SB 90, SB 91, SB 92, SB 93, SB 94, SB 95, SB 96, SB 97, SB 98, SB 99, SB 100, SB 101, SB 102, SB 103, SB 104, SB 105, SB 106, SB 107, SB 108, SB 109, SB 110, SB 111, SB 112, SB 113, SB 114, SB 115, SB 116, SB 117, SB 118, SB 119, SB 120, SB 121, SB 122, SB 123, SB 124, SB 125, SB 126, SB 127, SB 128, SB 129, SB 130, SB 131, SB 132, SB 133, SB 134, SB 135, SB 136, SB 137, SB 138, SB 139	230 X 400	2-Y16	2-Y12	2-Y16	Y8 @150 C/C
SB 76-1-A, SB 97-1, SB 97-1-A, SB 122-1-A, SB 122-A, SB 89-1-A, SB 82-A, SB 19-A, SB 19-B, SB 103-1-A, SB 103-A, SB-21-A, SB 62-A, SB 62-B, SB 21-B, SB 63-A, SB 63-B, SB 25-B, SB 25-A, SB 65-B, SB 65-A, SB 122-A, SB 128-A, SB 16-B, SB 57-B	230 X 300	2-Y12	2-Y12	2-Y12	Y8 @150 C/C

Figure 9: Floor Beam Schedule

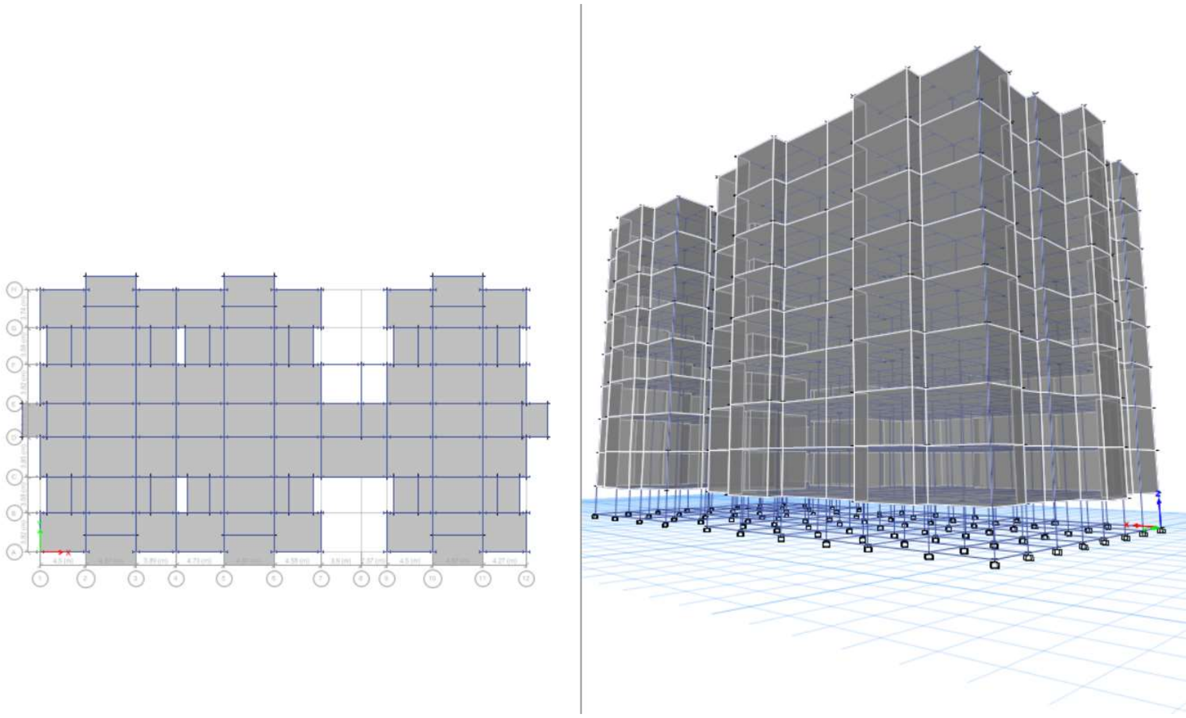


Figure 10: Analytical View 3D View in Etabs

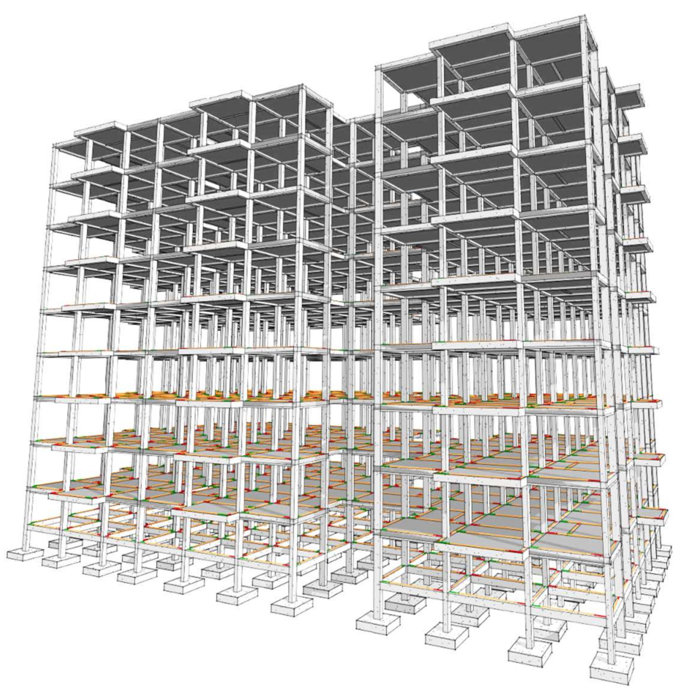


Figure 11: Structural 3D View

2. RESULT AND DISCUSSION

Using Etabs Software Story Response for Displacement, Story Drift, Overturning of building and Base Shear has been given and elaborated below.

2.1. Analytical Result and Diagrams

We have analysed the building in Etabs (Non-Linear Dynamic Analysis) and Story Response to Displacement, Drift and shear etc

(1) Maximum Story Drift Plot is given below:

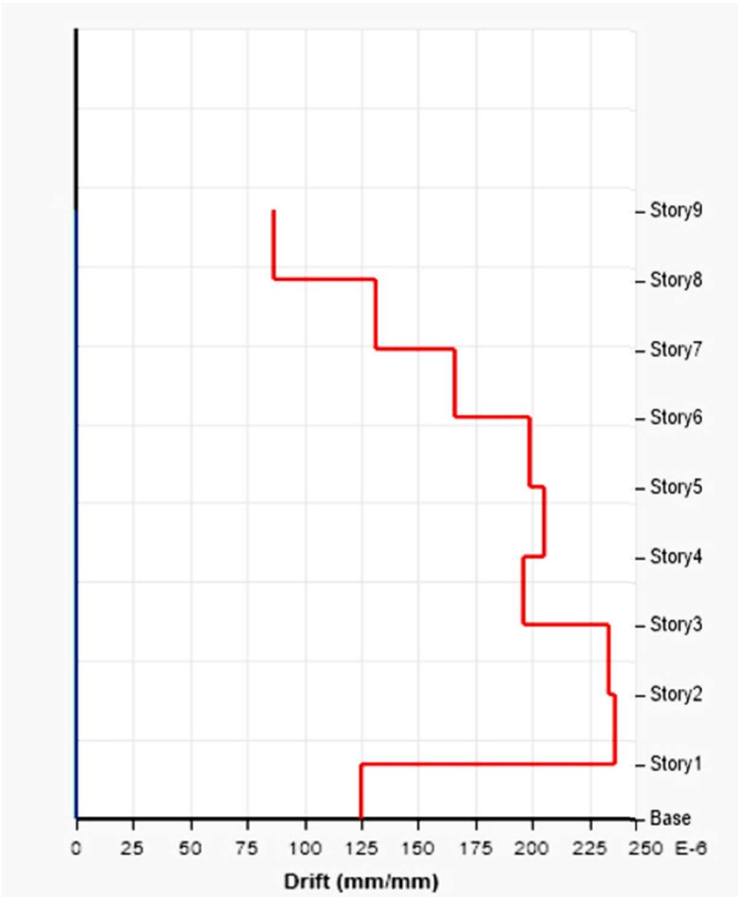


Figure 12: Story Drift

(1) Story drift is the lateral displacement of a floor relative to the floor below, and the story drift ratio is the storey drift divided by the storey height.

(2) The larger the drift, the less stiff the structure is. If the drift is greater on the X-direction than that of the Y-direction, the Y direction may be stiffer.

(3) Story 1st to story 5th faces higher drift value and top story exposed to lowest drift.

(4) The story drift can be considerably reduced by proposing shear walls along the peripheral grids symmetrically and increasing the column size with an increase in the area of rebars up to 3%.

(5) Hence, to ensure that the ultimate moment capacity of columns at column beam junctions of peripheral grids is 1.50 times the ultimate moment of beam shared by the upper and lower columns.

(2) Story Shear and Overturning Plots are given below:

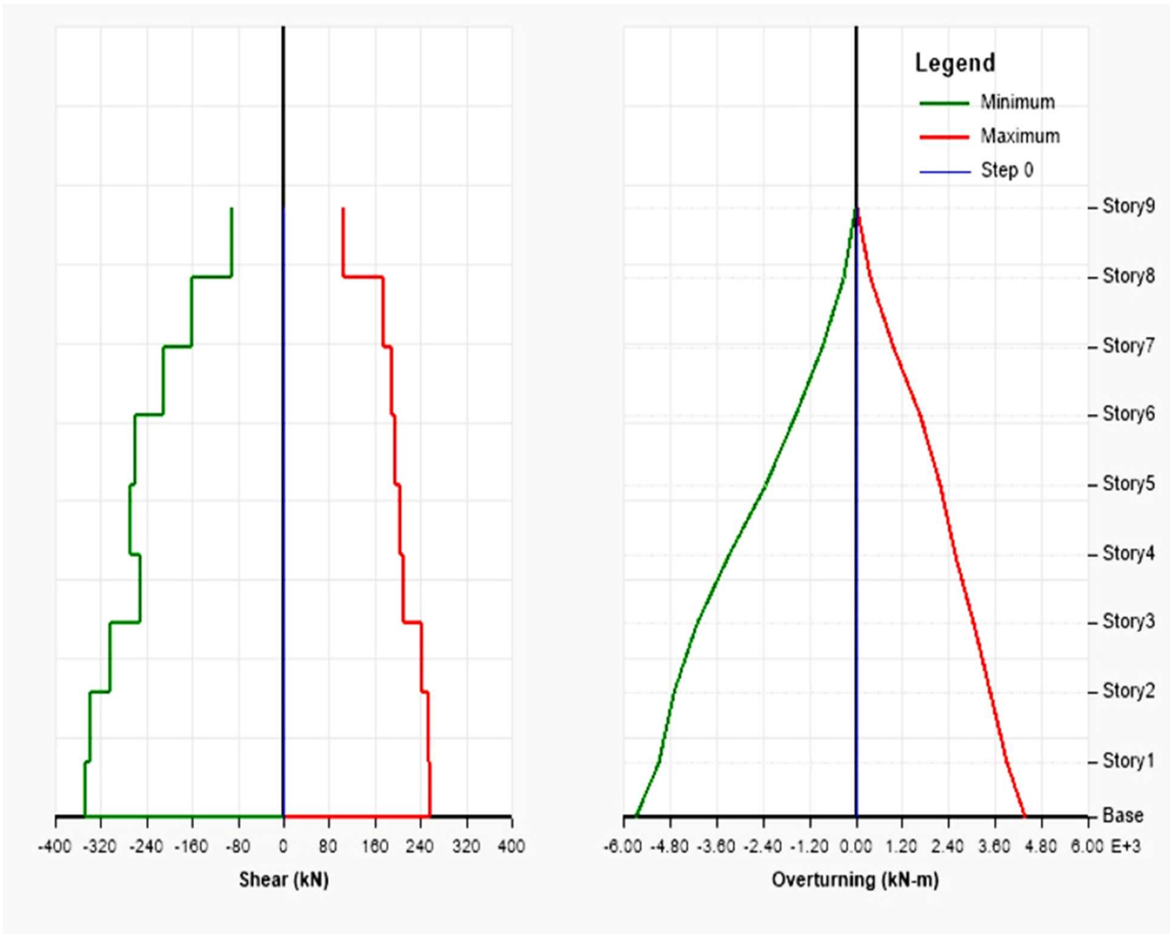


Figure 13: Story Shear and Overturning

(1) Story shear is the graph showing how much lateral load, be it wind or seismic, is acting per story.
(2) The story lower it goes, the greater the shear becomes.
(3) The story shear and story drift plots aid the understanding of a building's behaviour when subjected to lateral loads.
(4) It can be seen from the above diagram the lower story is exposed to higher shear forces.
(5) Higher Story exposed to lower shear force.
(6) Story 1st experiences a greater Overturning moment in comparison to the topmost story.
(7) When a structure is subjected to lateral forces such as wind or seismic forces, it will experience lateral deflection and lateral sway in one direction. As a result, the structure undergoes an overturning effect.

(8) Hence, it is recommended to design columns with higher stiffness in lower stories (Ground to 5th story)

(9) Also, infill shear walls can be provided to increase shear and overturning resistance.

(3) Seismic Acceleration:

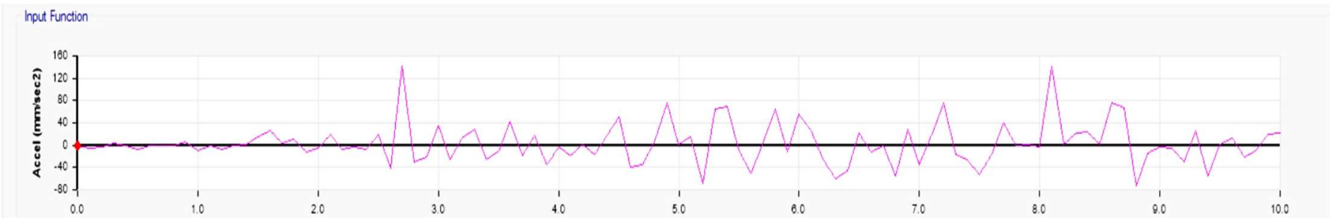


Figure 14: Seismic Acceleration Input (Time-History)

(1) The acceleration is the amount that the velocity varies in a unit of time.

(2) When the ground shakes during an earthquake, it also accelerates.

(3) Acceleration is at its peak between period 2.0-3.0 sec and 8.0-8.5

(4) Base Shear:

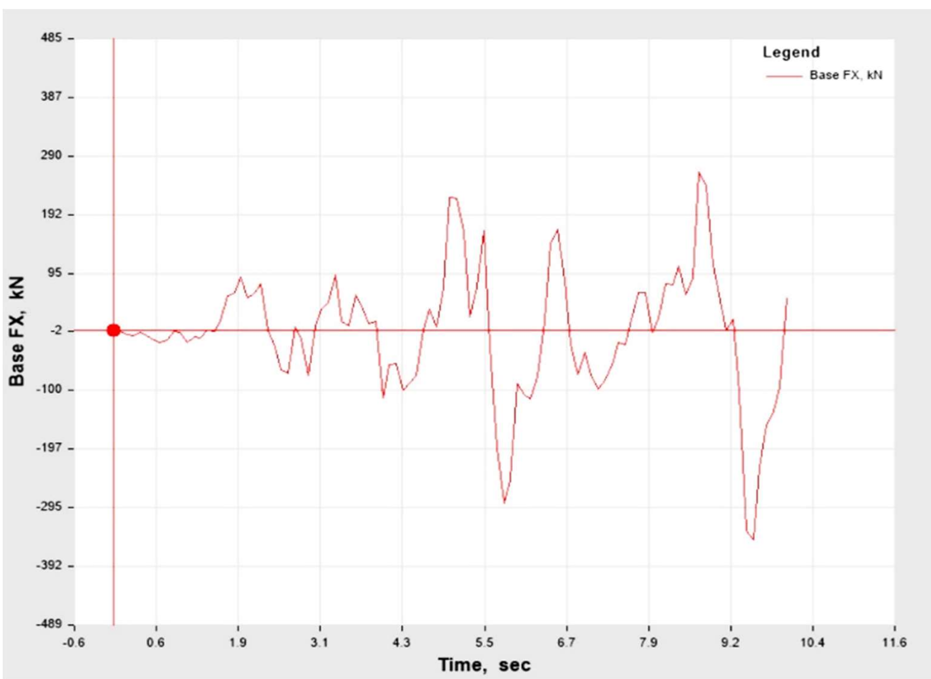


Figure 15: Base Shear Diagram

(1) Base shear is an estimate of the maximum expected lateral force that will occur due to seismic ground motion at the base of a structure.

(2) Seismic forces in the building are greatest at the base of the building. The seismic force at the base of the building is called the base shear.

(3) Peak values are 225 KN at 8.5 sec and -350 KN at 9.8 sec.

(4) Base Shear is largely controlled with the use of the shear wall at the bottom story.

(5) Shear walls are structural elements that can withstand or resist massive horizontal forces (wind loads or seismic forces) without encroaching on usable building space.

(5) Maximum Story Displacement:

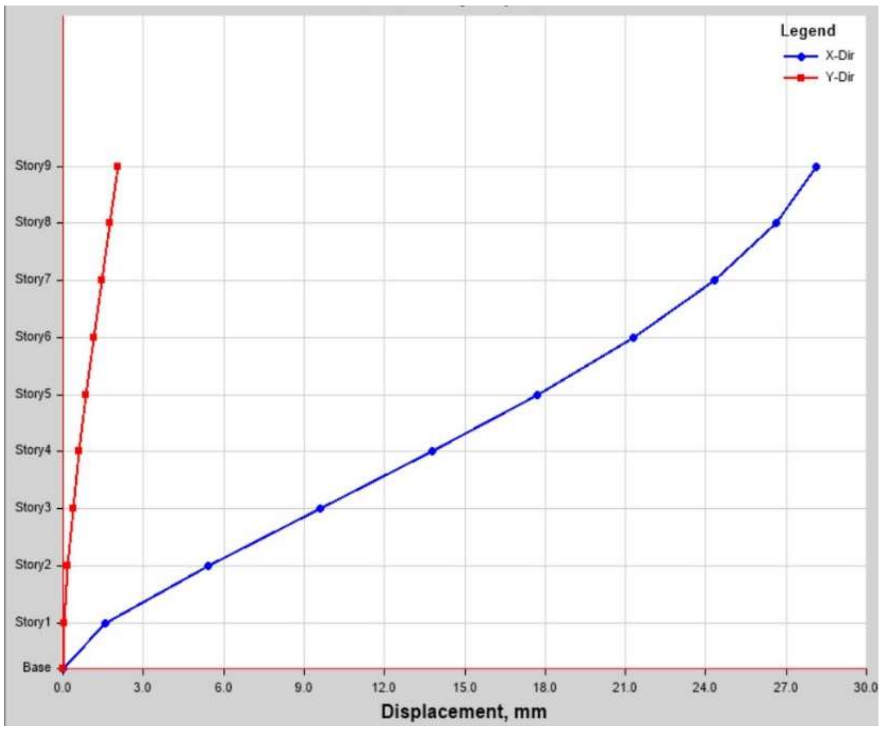


Figure 16: Maximum Story Displacement

(1) It is seen above that the lower story experiences lower displacement and the higher story experiences greater displacement.

(2) In the graph 8th Story experiences 28.5mm while 1st Story experiences near 1.5 mm (x-direction)

(3) While in Y-Direction, the 8th story is 1.5 mm and for the 1st story it's near zero.

(4) Increasing stiffness in the near upper story's story displacement can be restricted to some extent.

(5) As per IS: 456-2000. The lateral sway at the top of the building shall not exceed H/500 for transient wind loads, where H is the total height of the building.

(6) As per IS 1893, the lateral sway at the top should not be greater than H/250 (120 mm) when subjected to seismic loading.

2.2. Detailing of Structural Members

(1) Area of Steel in Beam Member (For 2nd and 9th Story)

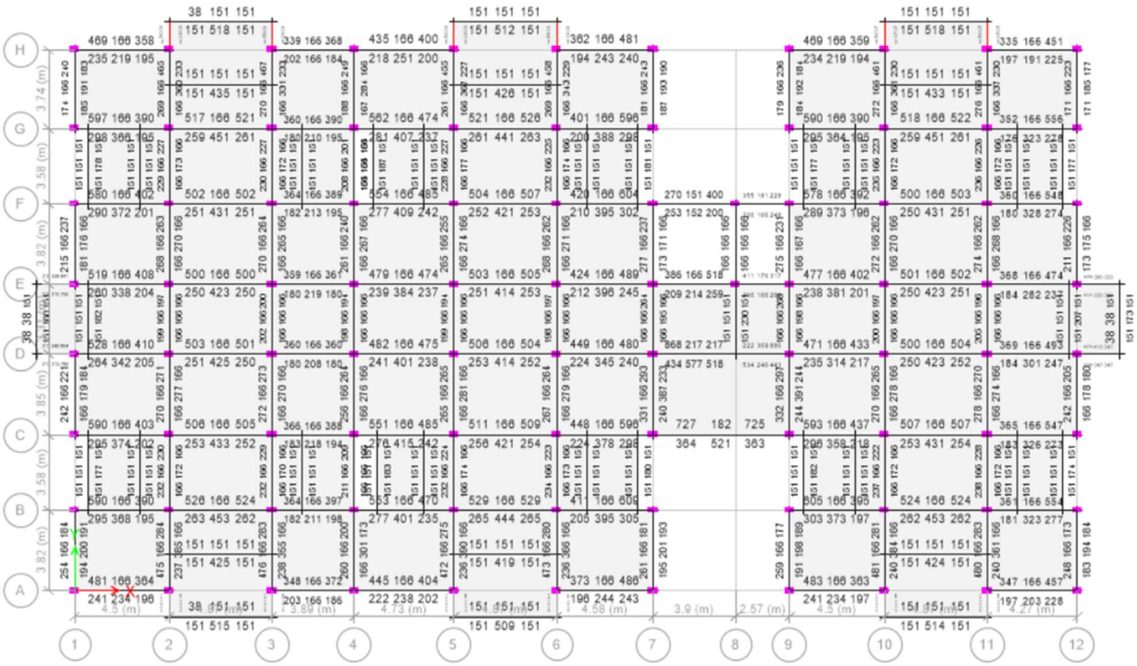
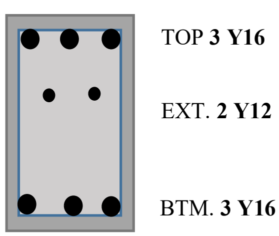


Figure 17: Area of Steel Required in Floor Beams (For Story 2)

- It can be seen above the cantilever beam (balcony) along grid H and {(2-3), (5-6) and (10-11)} failed to be failed with section deficiency and required a higher area of reinforcement (A_{st}= 1200 mm^2 & A_{sc}=1000 mm^2)
- Primary Beam along grid [c] and [7-9] requires higher reinforcement than it was provided with. (Main Top: 3-Y16, Main Bottom: 3-Y16, Ext. 2-Y12) (Beam # SB 53)



Various other beams are to be refitted according to the seismic design reinforcement and must be detailed in the above manner.

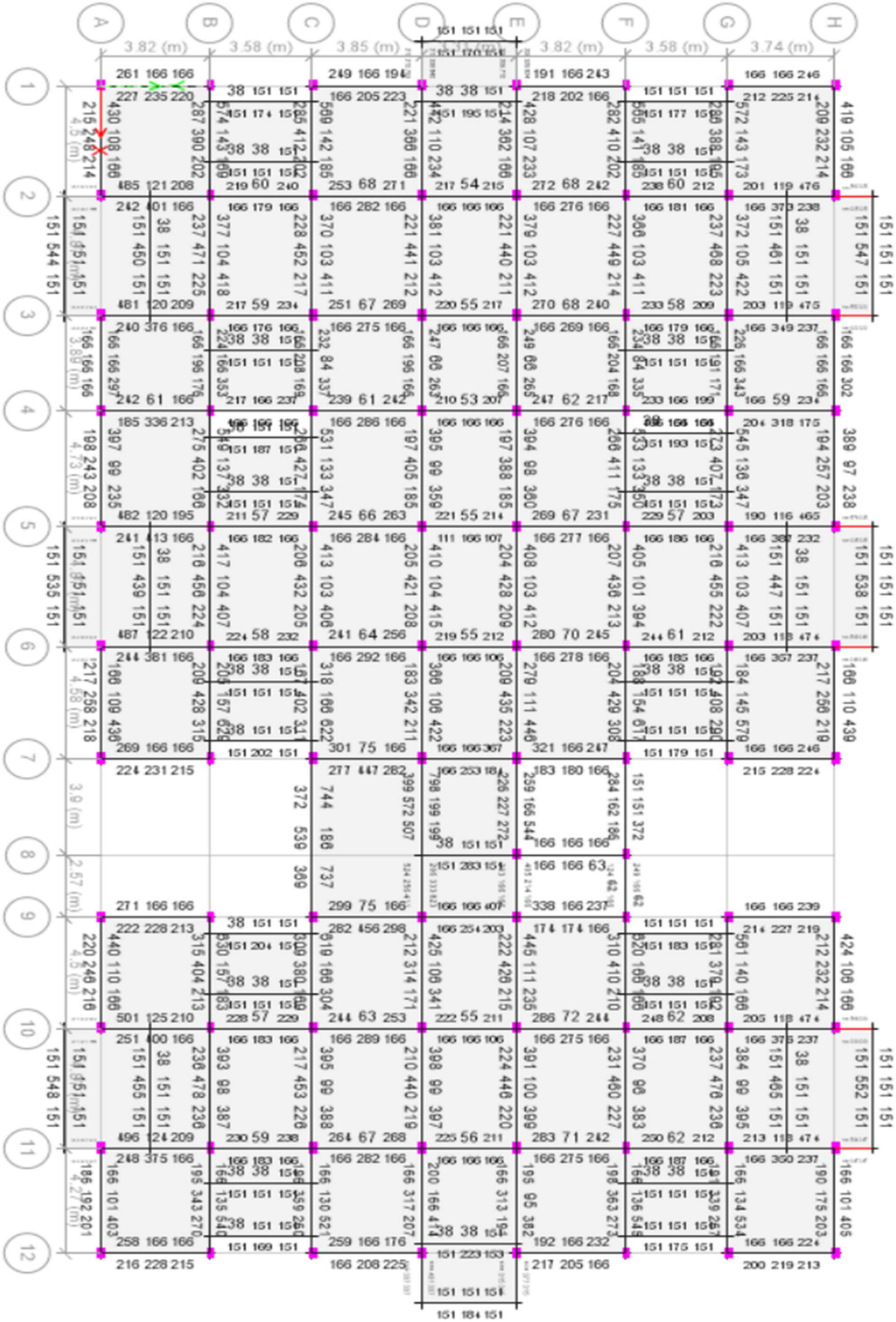


Figure 18: Area of Steel Required in Floor Beams (For Story 9)

(2) Areas of reinforcement required for all the members (Col. & Beams) for the building are given below:

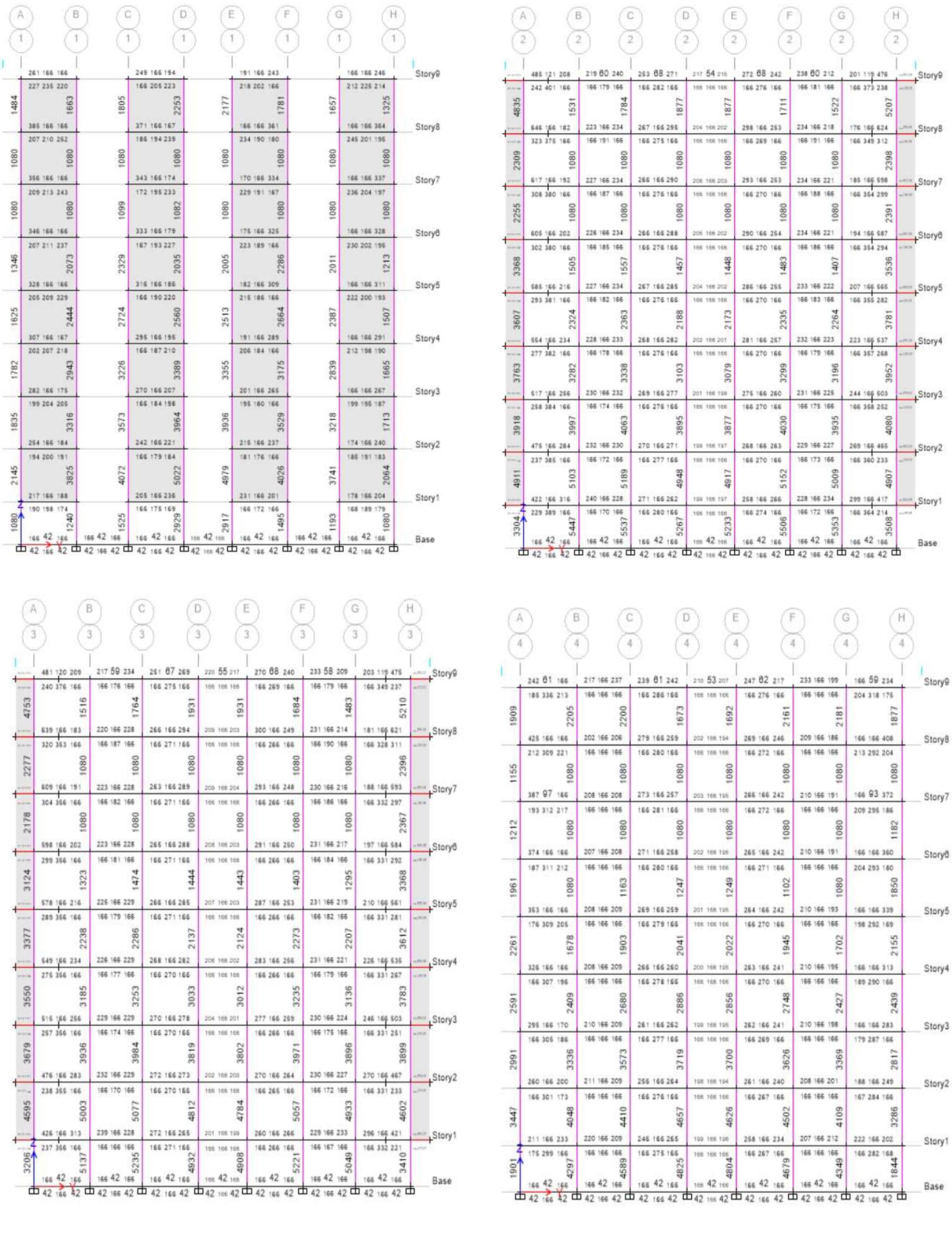


Figure 19: Area of Steel Required in Column and Beams (Along Grid [1-4])

2.3. Retrofitting Strategies

(1) Retroffitng Strategy for Column Deficiency

Their many columns in the building were found to be under-reinforced up to stories 4 &5. These columns are listed below:

Table 1: Retrofitting Strategy Recommendation for Columns

Column Number	**Required Additional Reinforcement (Rebar)**	**Up to Story Level**	**Recommended Retrofitting Strategy**
Along Grid 1 (B-G)	1200 mm^2 (Y16-6N)	Up to 4^{th} Story	R.C. Jacketing
Along Grid 2 (A-H)	1200 mm^2 (Y16-6N)	Up to 4^{th} Story	R.C. Jacketing
Along Grid 3 (A-H)	2400 mm^2 (Y16-12N)	Up to 4^{th} Story	R.C. Jacketing
Along Grid 4 (A-H)	2400 mm^2 (Y16-12N)	Up to 4^{th} Story	R.C. Jacketing
Along Grid 5 (A-H)	1400 mm^2 (Y16-8N)	Up to 5^{th} Story	R.C. Jacketing
Along Grid 6 (A-H)	1400 mm^2 (Y16-8N)	Up to 5^{th} Story	R.C. Jacketing
Along Grid 7 (A-H)	1400 mm^2 (Y16-8N)	Up to 5^{th} Story	R.C. Jacketing
Along Grid 9 (A-H)	1800 mm^2 (Y16-8N)	Up to 4^{th} Story	R.C. Jacketing
Along Grid 10 (A-H)	2800 mm^2 (Y16-14N)	Up to 5^{th} Story	R.C. Jacketing
Along Grid 11 (A-H)	2800 mm^2 (Y16-14N)	Up to 5^{th} Story	R.C. Jacketing
Along Grid 12 (B-G)	1600 mm^2 (Y16-8N)	Up to 5^{th} Story	R.C. Jacketing

Figure 20: Column Jacketing

(2) There are beams whose typical section fails to resist seismic load as per the analysis:

Table 2: Retrofitting Strategy Recommendation for Beams

Beam Mark	**Required Steel Area**	**Story**	**Recommended Retrofitting**
SB 37-1	1500 mm^2[Top]/ 1200 mm^2[Btm]	All Floor	External Plate Bonding
SB 26-1	1500 mm^2[Top]/ 1200 mm^2[Btm]	All Floor	External Plate Bonding
SB 76-1	1200 mm^2[Top]/ 1000 mm^2[Btm]	All Floor	External Plate Bonding
SB 83-1	1200 mm^2[Top]/ 1000 mm^2[Btm]	All Floor	External Plate Bonding
SB 82-1	1200 mm^2[Top]/ 1000 mm^2[Btm]	All Floor	External Plate Bonding
SB 89-1	1200 mm^2[Top]/ 1000 mm^2[Btm]	All Floor	External Plate Bonding
SB 97-1	1200 mm^2[Top]/ 1000 mm^2[Btm]	All Floor	External Plate Bonding
SB 104-1	1200 mm^2[Top]/ 1000 mm^2[Btm]	All Floor	External Plate Bonding
SB 110-1	1200 mm^2[Top]/ 1000 mm^2[Btm]	All Floor	External Plate Bonding
SB 122-1	1200 mm^2[Top]/ 1000 mm^2[Btm]	All Floor	External Plate Bonding
SB 129-1	1200 mm^2[Top]/ 1000 mm^2[Btm]	All Floor	External Plate Bonding
SB 128-1	1200 mm^2[Top]/ 1000 mm^2[Btm]	All Floor	External Plate Bonding
SB 135-1	1200 mm^2[Top]/ 1000 mm^2[Btm]	All Floor	External Plate Bonding
SB 46-1	1500 mm^2[Top]/ 1200 mm^2[Btm]	All Floor	External Plate Bonding
SB 36-1	1500 mm^2[Top]/ 1200 mm^2[Btm]	All Floor	External Plate Bonding

(3) Retrofitting Recommendation for other Structural Elements:

Table 3: Retrofitting Strategy Recommendation for Other Structural Members

Structural Element	**Recommended Retrofitting**
Slab/ Shell	External Plate Bonding
Foundation	Base Isolation Technique

(4) Following Technique/ Method Can be useful for Seismic Retrofitting:
Adding Steel Bracing, Jacketing Method, External Plate Bonding, Base Isolation Technique, Mass Reduction Technique, Wall Thickening Technique, Fibre Reinforced Polymer, Adding Shear Wall, Epoxy Injection Method, Section Enlarging Reinforcing Method.

3. CONCLUSION

1. Story 1st to story 5th encounters a higher drift value and the top story is exposed to the lowest drift.
2. The story drift can be considerably reduced by proposing shear walls along the peripheral grids symmetrically and increasing the column size with an increase in the area of rebars up to 3%.
3. Hence, to ensure that the ultimate moment capacity of columns at column beam junctions of peripheral grids is 1.50 times the ultimate moment of beam shared by the upper and lower columns.
4. Ground story experiences a greater overturning moment in comparison to the topmost story.
5. In the base shear plot, peak values are 225 KN at 8.5 sec and -350 KN at 9.8 sec.
6. Base Shear can be largely normalized with the use of the shear wall at the bottom story.
7. Infill shear walls can be provided to increase shear and overturning resistance.
8. Columns of the lower stories are needed higher stiffness to counter the response to Story Drift, Overturning, Story Shear and Base Shear.
9. Higher stories/ Top Stories column requires a lesser amount of stiffness. Hence, Requires a lesser Column size and area of steel.
10. As per the adequate retrofitting strategy, it is recommended to design columns with higher stiffness in lower stories (Ground to 5th story).
11. Also, to ensure safety during any seismic event, overhanging beams are found to be vulnerable and deficient in top reinforcement rebar, it is recommended to retrofit them using the External Plate Bonding retrofitting method
12. R.C. Jacketing and Steel jacketing methods are recommended to improve its section size and increase the area of the reinforcement of columns. Its implemented easily and in a quite cost-effective manner.
13. As it can be seen, the SVA method is very reliable. It is recommended to use the RVS score in the large Building stock, to identify vulnerable structures and further evaluate it in the SVA method to get reliable results.
14. In India, a large volume of buildings are quite vulnerable to any seismic activity. Efficient and economical retrofitting strategies are needed.
15. As people can’t replace the existing buildings with new seismic-resistant buildings at once. It is required for the government to promote and encourage the country about retrofitting the existing vulnerable buildings to counter any future seismic activity.
16. For developing nations all over the world, new cost-efficient retrofitting techniques should be further researched to help the poor existing building to overcome their various deficient member for future sustainability.
17. Retrofitting of existing structures supports the economy and helps reduce the carbon footprint of a country.

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