Analysis & Design of an Earthquake Resistant Multistory Apartment Building in all Seismic Zones to Obtain the Increment in the Required Percentage of Weight of Steel-Reinforcement

Shaik Anchala Mohammad Ghouse, Maddikera Lokanath Reddy

Abstract*: For designing of an earthquake-resistant structure we follow Indian Seismic design codes are exclusive to a particular country or region. Moreover these seismic codes considered all the criteria such as building typologies, accepted level of seismic risk, local seismology. IS 1893 is an Indian seismic code that provides the seismic zone map and specifies seismic design force. The Bureau of Indian Standard (IS: 1893 (Part-1) 2002) classified India into 4 seismic zones (i.e. Zone II, Zone III, Zone IV & Zone V) and the code allocates 4 levels of seismic intensities as zone factors. But this code does not provide any information regarding how much of required percentage of steel-reinforcement has been increased from zone to zone. The main objective for presenting this project is to obtain the increment in the required percentage of steel-reinforcement for various zones by analyzing a multistory Apartment Building with Stilt + G + 3 Floors as per Indian Standard Codes IS 456 : 2000 and IS 1893 (Part – 1) 2002 using STAAD-Pro Software.

Keywords*: Earthquake Analysis and Design using STAAD-Pro V8i SS6 software, Seismic Zones-II, III, IV & V, IS 456: 2000, IS 1893 (Part-1) 2002.

I. INTRODUCTION

Earthquake is nothing but the shaking of Earth's surface which is a common phenomenon which results from a sudden release of the energy in the Earth's lithosphere that creates earthquake waves. The amount of shaking of the earth surface can be estimated based on the observed effects that are categorized on various seismic intensity scales. Earthquakes are caused due to the motion of earth's tectonic plates. Some of the Human activities such as construction of building reservoirs, injecting fluids in the earth's crust for Waste Disposal, extracting resources such as coal, diesel, oil, etc. may leads to earthquakes . Earthquake causes many disastrous that results in the destruction of structures, personal injuries and loss of life, loss of property and financial resources. Some of the main effects of earthquakes are:

- Shaking and Ground rupture, due to earthquakes, may cause harsh damage to buildings and other civil structures.
- Soil liquefaction may results in tilting or sinking of the rigid structures such as buildings and bridges. Soil liquefaction will occur when water-saturated granular material (such as sand) which will temporarily lose the strength of the sand.
- An earthquake may cause destabilization of buildings, road and bridge, damage of the properties and loss of life. Further it may bring disease, lack of fundamental requirements, and depression to living beings, mental effects such as panic attacks etc.

A. Role of a Structural Engineer in Earthquake Engineering

A Structural Engineer plays a key role for providing & ensuring the safety, durability and serviceability of the structure. They also involve in the improvement of structural integrity of existing buildings [6]. Seismic design is an essential process of structural analysis while designing the buildings that are subjected to ground motions of the earth due to earthquake, such that the buildings will continue to function and sustain for its intended purpose even after the Earthquake [7].

Structural Engineer has to investigate the post-earthquake causes that may results in structural damage, failure, or collapse; which includes recognition, quantification, and lessening of risk through most favorable repair strategies, performance-based upgrades, and adapted solutions [8][9]. The complexity of analysis has now been computerized with tools like STAAD-Pro, ETABS, and TEKLA etc. These tools results in the designing of the structures in an effective manner so that the structure will sustain for its assigned purpose.

B. Importance of Design Codes

Seismic design codes are exclusive to a particular country or region. All Countries have their own procedures in seismic codes that help to structural engineers in planning, designing, detailing and constructions of the structures.

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Seismic codes helps to improve the performance of structures so that they can withstand the effects due to the earthquakes without significant loss of life and property. For designing of an earthquake-resistant structure one should follow the seismic codes. Moreover, these seismic codes considered all the criteria such as building typologies, accepted level of seismic risk, local seismology, materials and methods used in construction. Furthermore, the seismic codes are indicative to the level of progress of a region or country that has made in the field of earthquake engineering. In India first seismic code IS 1893 was published in the year 1962. Recommendations for Earthquake Resistant Design of Structures was published in 1966 and also revised. As a result of additional knowledge and experience gained on earthquakes, more seismic data was collected in India, therefore fifth Revision was brought out by the Bureau of Indian Standards (BIS). In fifth Revision the seismic zone map has been revised five seismic zones to only four zones. Zone-I have been merged to Zone-II. Hence Zone-I do not appear in the new zoning.

C. Objective of the Study

- The main idea of this study-oriented project is to carry-out a detailed analysis on the increment of steel-percentage for various seismic zones in India.
- This study is focused on bringing out the information about the increase in the usage of steel reinforcement for Zone II, Zone III, Zone IV & Zone V that is not provided in Indian Standard code book IS 1893 (Part – 1) 2002.
- Modeling a multistory apartment building with Stilt + G + 3 floors to estimate & check the seismic response of building and to analyze & design it on that basis using STAAD-Pro V8i SS6 software.

II. METHODOLOGY

In this project a multistory apartment building with Stilt+G+3 floors has been analyzed & designed as per Indian Standard Codes IS 456: 2000 and IS 1893 (Part – 1) 2002 using STAAD-Pro Software by means of Equivalent Static Lateral Force Method of analysis [2]. This method defines a series of forces acting on the building so that it can exhibit the effect of earthquake vibrations. As per this condition, the building must not twist when the ground moves. The Bureau of Indian Standard (IS: 1893, Part 1-2002) classified India into 4 seismic zones (i.e. Zone II, Zone III, Zone IV & Zone V) and allocates 4 levels of seismic intensities as zone factors and in this project the building is analyzed & designed accordingly [3][4].

A. Calculation of loads as per Indian Standards

There are different types of loads acting on the structure. The loads that will act on the Structure are as follows

- *Dead loads*: The dead load acting on the structure are weights of walls, partitions floor finishes, false floors. Dead loads are calculated from the measurements of the members and their unit weights.
- *Live loads*: Live load is nothing but the loads that are intended to use or occupancy of a building. Live loads may be distributed or concentrated loads that includes the weight of movable partitions, load due to vibration and impact loads etc.
- *Wind loads*: The wind speeds can be obtained with the help of anemometers which are installed at meteorological observatories from the ground level up to a height of 30 meters.
- *Seismic loads*: Seismic load is nothing but the application of a seismic oscillation to a structure. The seismic load may apply in X-direction or may be in Z-direction. To calculate the seismic load acting on the structure, there are different parameters which should be defined at first. In this particular part, those parameters like zone factor, performance factor or the soil type has been defined. On basis of those factors using the standard formula, defined in any standard code, the seismic load is calculated. In IS-1893 the corresponding values are given.

B. Preliminary Data for Example Building

Table- I: Details of the Structure Considered

Description	Structure Details
No. of Stories	Five, Stilt + G + 3
Site Dimensions	23.00 m X 44.00 m
Building Dimensions	15.74 m X 31.89 m
Height of each floor	3.15 m
Grade of Concrete	M25
Grade of Steel	Fe500
Seismic Analysis	Equivalent Static method IS 1893 (Part – 1) 2002
Design Philosophy	Limit state method conforming to IS 456: 2000

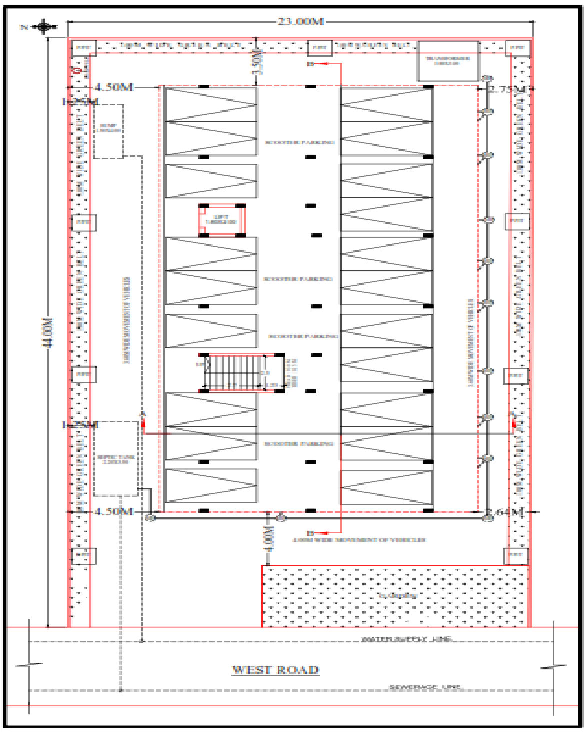

Fig. 1. Stilt Floor Plan.

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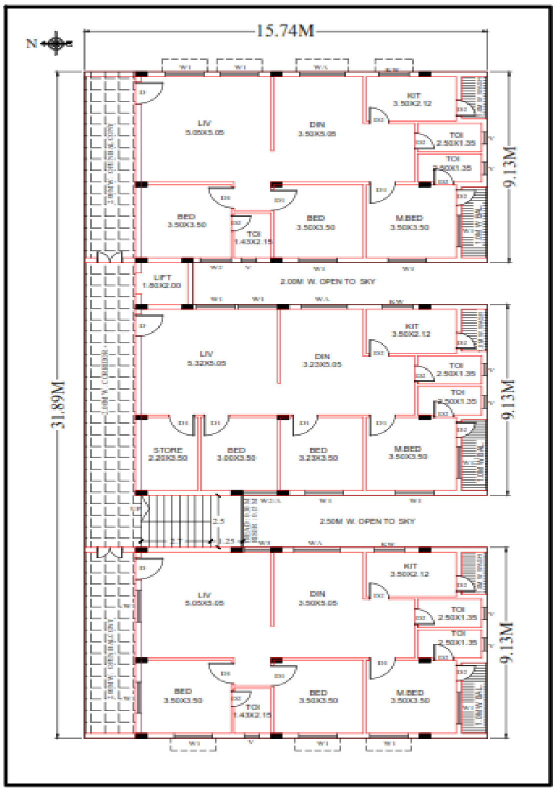

Fig. 2. Typical Ground, First, Second & Third Floor Plan.

III. ANALYSIS & DESIGN USING STAAD-PRO

A. Modeling of the Structure

- *Nodes generation & Modeling of the Structure:* The nodes are to be generated as per the positions of the columns. After nodes are created it will join with the help of line elements by using add beam command and the building is to be modeled and then the supports at the base of the structure are to be assigned as fixed support.

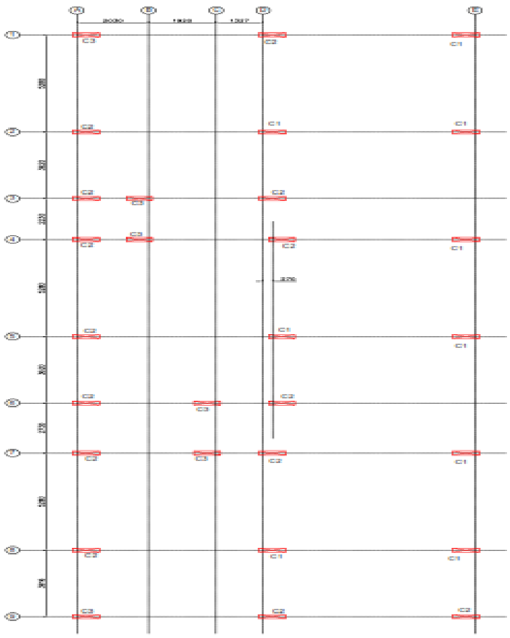

Fig. 3. Column Layout Plan in AutoCAD

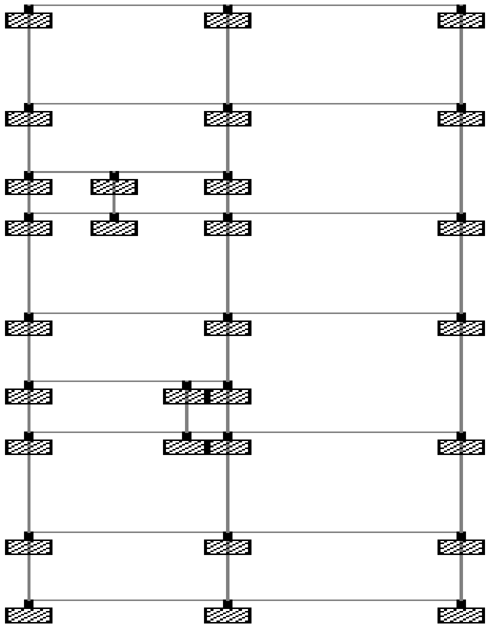

Fig. 4. Column Positions in Staad-Pro.

- *Assigning of Structural Elements:* Structural elements/members such as Beams & Columns are defined and the properties of the section are assigned. Beams are designed for flexure, shear & torsion and Columns are intended to carry axial forces and bi axial moments as per IS 456: 2000 [1].

B. Application of Loads

- *Dead Load:* In STAAD-Pro load section, the dead loads is defined which includes following

a) *Self Weight*: The self weight of the structural elements like beams & columns are be generated by the software itself with the help of self weight command.

b) *Wall Load:* The Main wall, Partition wall & Parapet Wall loads have been assigned to the Structural members. Stair Case Load, Dead Load of Slab, Floor Finishes is to be assigned.

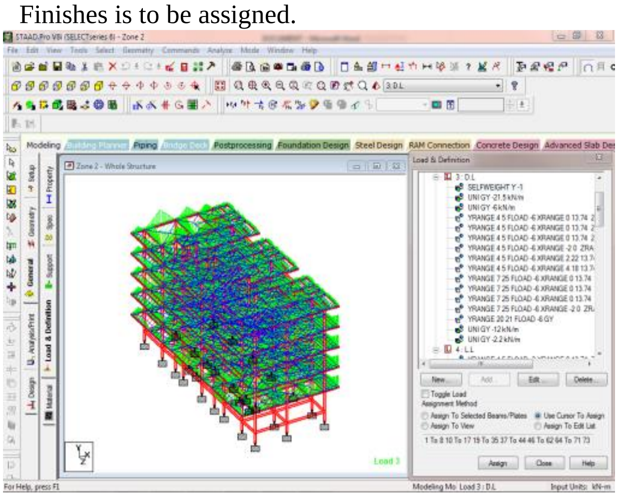

Fig. 5. Dead Load.

- *Live Load:* The live load is to be assigned in the same manner as above case

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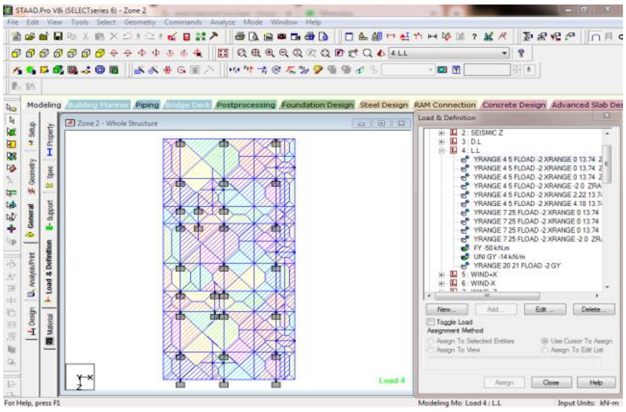

Fig. 6. Live Load.

- *Wind Load:* The Wind Load is assigned in +X, -X, +Z, & -Z directions. This load values are generated by the software itself as per IS 875 (Part-3). Under the defined load tab, the definition of wind load is to be assigned.

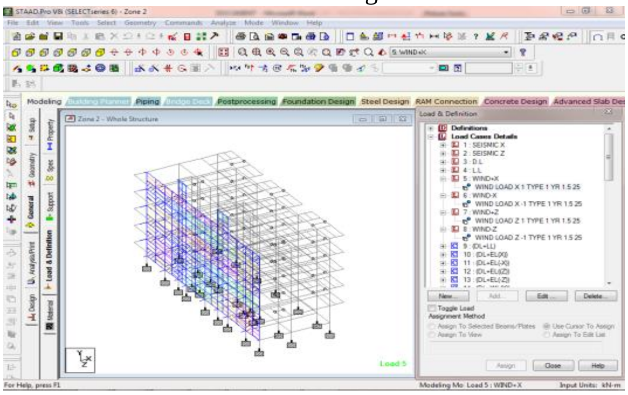

Fig. 7.(a). Wind Load.

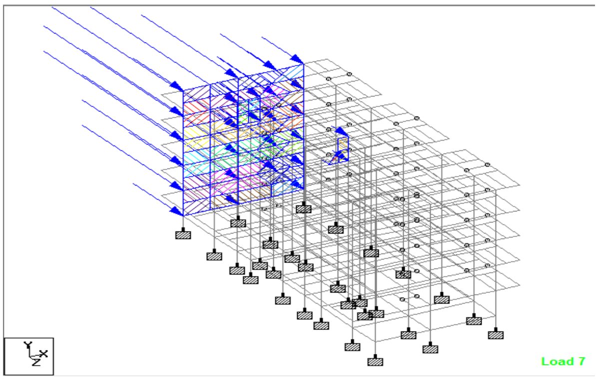

Fig. 7.(b). Wind Load.

- *Seismic Load:* The seismic load values are calculated based on IS 1893-2002. In STAAD-Pro the lateral load due to earthquake in X-direction and Z-direction can be generated with the help of seismic load generator as per the IS code.

The total design seismic base shear (V_b) can be obtained with the help of below formula that is specified in IS 1893 (Part-1) : 2002.

i.e. $V_b = A_h * W$.

Where, A_h = Design Horizontal acceleration spectrum

W = total seismic weight of the building

As per Clause 6.4.2 of IS 1893 2002,

$A_h = (Z/2)*(I/R)*(S_a/g)$

Where,

S_a/g = Average response acceleration coefficient.

Z = Zone Factor.

In this project I have considered the zone factor's in each zones, as per Table 2 of IS 1893 2002, to obtain the variation of steel-percentage in different zones.

Table 2 Zone Factor, Z

(*Clause* 6.4.2)

Seismic Zone	II	III	IV	V
Seismic Intensity	Low	Moderate	Severe	Very Severe
Z	0.10	0.16	0.24	0.36

Fig. 8.(a). Zone Factor Table as per IS 1893 (Part-1) 2002.

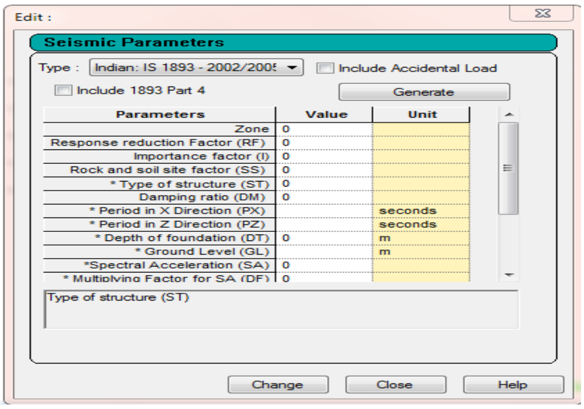

Fig. 8.(b). Seismic Parameters in STAAD-Pro.

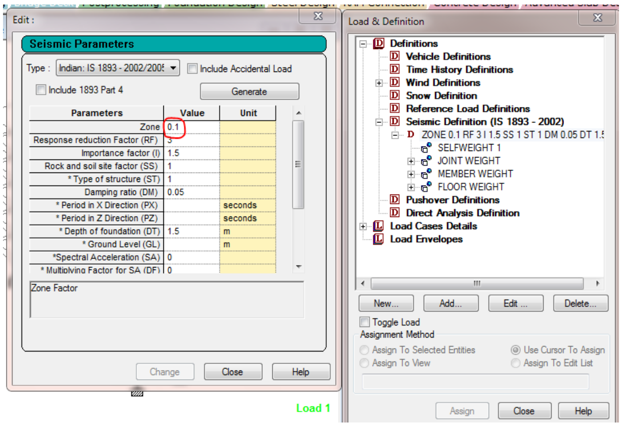

Fig. 8.(c). Zone Factor value in Zone II – 0.1

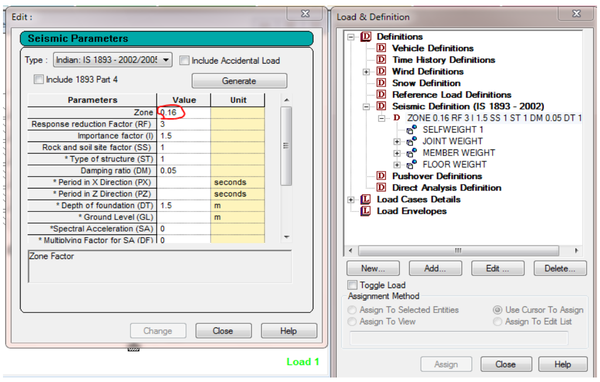

Fig. 8.(d). Zone Factor value in Zone III – 0.16

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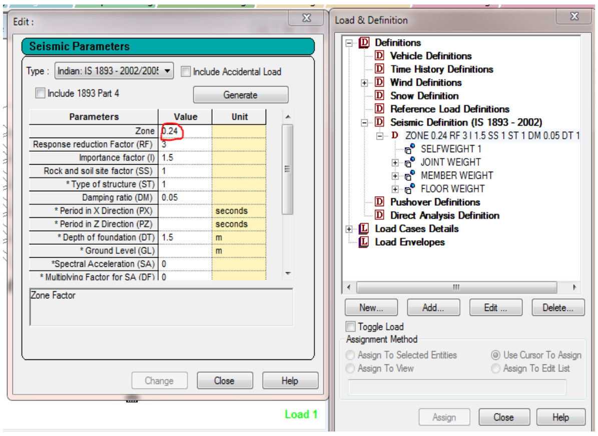

Fig. 8.(e). Zone Factor value in Zone IV – 0.24

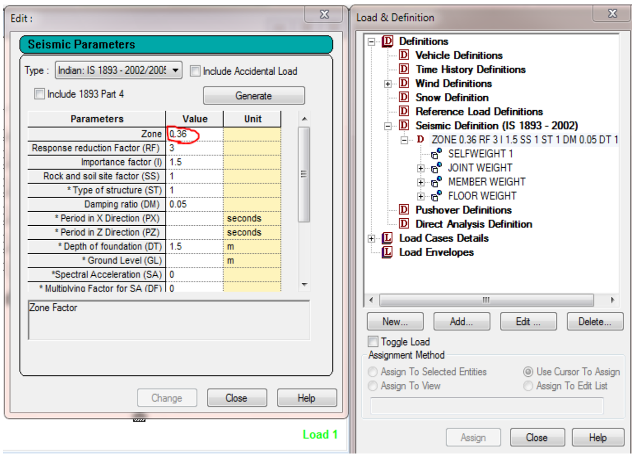

Fig. 8.(f). Zone Factor value in Zone V – 0.36

I = Importance factor.

In this project the importance factor is considered as 1.5 as per Table 6 of IS 1893 2002.

Table 6 Importance Factors, *I*

(*Clause* 6.4.2)

Sl No.	Structure	Importance Factor
(1)	(2)	(3)
i)	Important service and community buildings, such as hospitals; schools; monumental structures; emergency buildings like telephone exchange, television stations, radio stations, railway stations, fire station buildings; large community halls like cinemas, assembly halls and subway stations, power stations	1.5
ii)	All other buildings	1.0

NOTES

1 The design engineer may choose values of importance factor *I* greater than those mentioned above.

2 Buildings not covered in Sl No. (i) and (ii) above may be designed for higher value of *I*, depending on economy, strategy considerations like multi-storey buildings having several residential units.

3 This does not apply to temporary structures like excavations, scaffolding etc of short duration.

Fig. 9.(a). Importance Factor Table as per IS 1893 2002

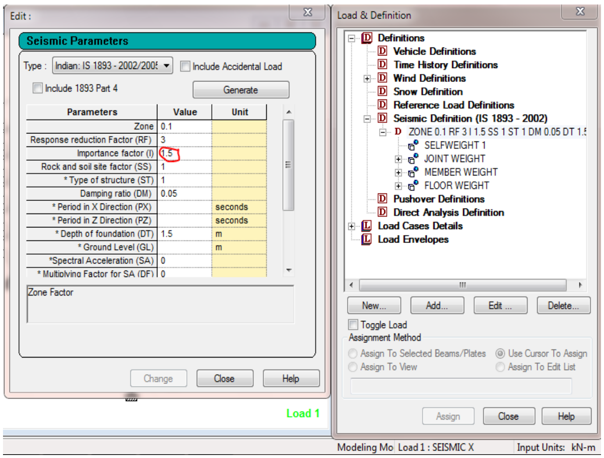

Fig. 9.(b). Importance Factor considered (1.5).

R = Response Reduction Factor.

In this project the response reduction factor is considered as 3 for Special RC Moment –Resisting Frame (SMRF) system as per Table 7 of IS 1893 (Part-1) 2002.

IS 1893 (Part 1) : 2002

Table 7 Response Reduction Factor [1], *R*, for Building Systems

(*Clause* 6.4.2)

Sl No.	Lateral Load Resisting System	*R*
(1)	(2)	(3)
	Building Frame Systems	
i)	Ordinary RC moment-resisting frame (OMRF)[2]	3.0
ii)	Special RC moment-resisting frame (SMRF)[3]	5.0
iii)	Steel frame with	
	a) Concentric braces	4.0
	b) Eccentric braces	5.0
iv)	Steel moment resisting frame designed as per SP 6 (6)	5.0
	Building with Shear Walls[4]	
v)	Load bearing masonry wall buildings[5]	
	a) Unreinforced	1.5
	b) Reinforced with horizontal RC bands	2.5
	c) Reinforced with horizontal RC bands and vertical bars at corners of rooms and jambs of openings	3.0
vi)	Ordinary reinforced concrete shear walls[6]	3.0
vii)	Ductile shear walls[7]	4.0
	Buildings with Dual Systems[8]	
viii)	Ordinary shear wall with OMRF	3.0
ix)	Ordinary shear wall with SMRF	4.0
x)	Ductile shear wall with OMRF	4.5
xi)	Ductile shear wall with SMRF	5.0

Fig. 10.(a). Response Reduction Factor Table as per IS 1893 (Part – 1) 2002.

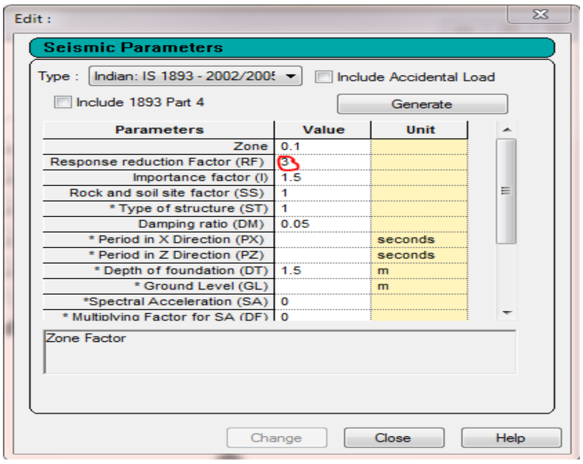

Fig. 10.(b). Response Reduction Factor Considered (3).

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- *Load Combinations:* Now the structure has to be analyzed for the combination of loads by considering all the load cases. In case-1 the load combinations such as such as self-weight, dead & live load and wind load were taken into account. In case-2 the load combinations such as self-weight, dead & live load and seismic load were taken into account.

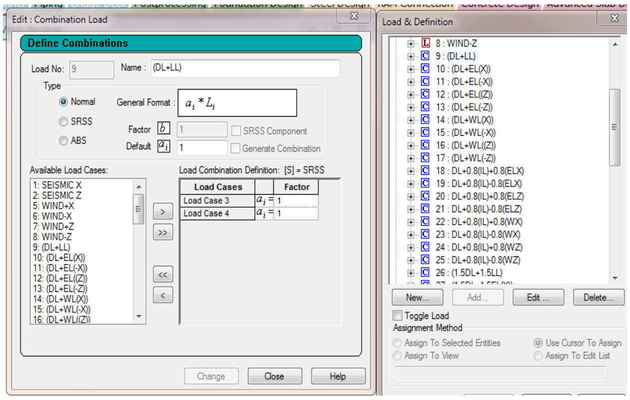


Fig. 11.(a). Load Combinations.

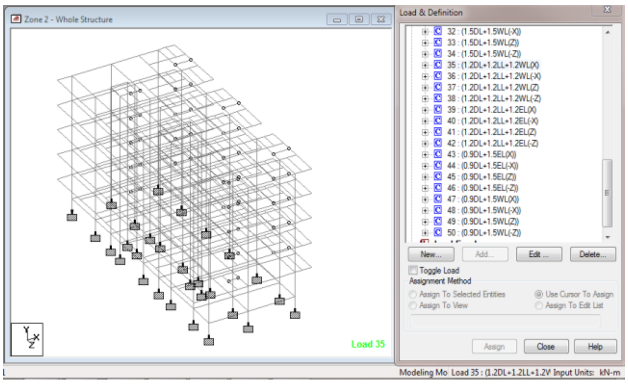


Fig. 11.(b). Load Combinations.

C. Designing of the Structure

The structure has been designed as per IS 456: 2000. The design parameters that are noted below were specified. Here the horizontal members are to be assigned as beams and vertical members are to be assigned as columns.

The following are the design parameters considered in this project.

- FC - 25000 k N/m2
- FY MAIN - 500000 kN/m2
- FY SEC - 500000 kN/m2
- MIN MAIN - 12 mm
- MIN SEC - 8.0 m
- RENSH - 0.5 m
- ENSH - 0.5 m

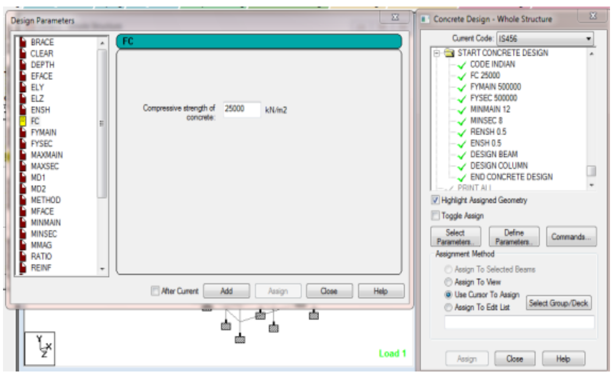


Fig. 12.(a). Design Parameters.

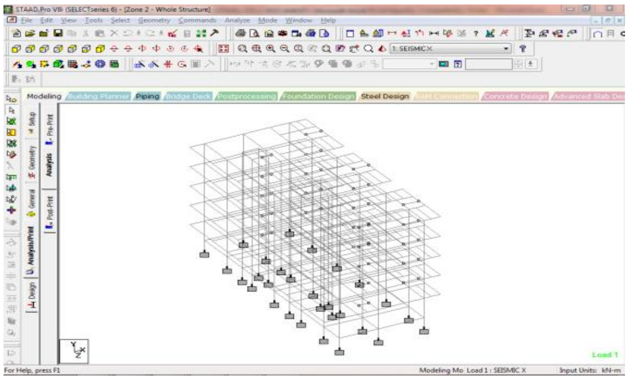


Fig. 12.(b). Model of the Building.

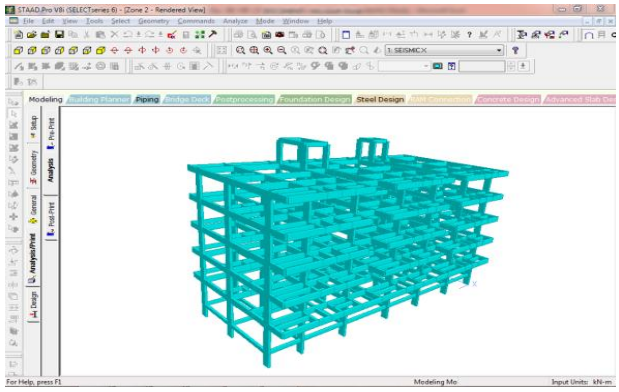


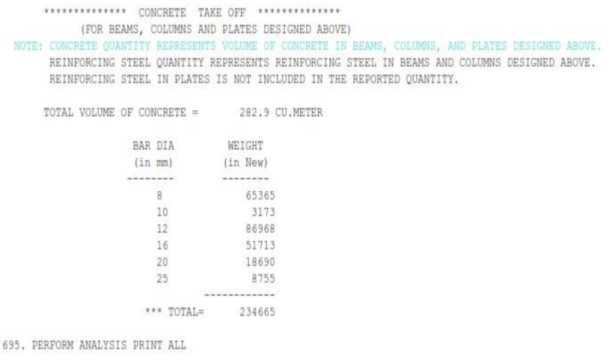
Fig. 12.(b). 3D-Render View of the Model.

D. Run Analysis

After assigning the supports, properties of the members and applying the loads on the member, we have to analyze the structure by clicking the tab Analysis/Print and select the option All. At the ribbon tab, click on analyze and then Run Analysis. After analyzing the structure, the building has to be designed for concrete per the Indian Standard Code IS 456: 2000.

IV. RESULT & DISCUSSION

The analysis and design of a multistory apartment building with Stilt + G + 3 floors has been done using STAAD-Pro V8i (SELECT series 6) by applying all the four seismic zones separately and the required Weight of Steel for different Zones have been represented in the following expressions [5].



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************** CONCRETE TAKE OFF **************
     (FOR BEAMS, COLUMNS AND PLATES DESIGNED ABOVE)
NOTE: CONCRETE QUANTITY REPRESENTS VOLUME OF CONCRETE IN BEAMS, COLUMNS, AND PLATES DESIGNED ABOVE.
      REINFORCING STEEL QUANTITY REPRESENTS REINFORCING STEEL IN BEAMS AND COLUMNS DESIGNED ABOVE.
      REINFORCING STEEL IN PLATES IS NOT INCLUDED IN THE REPORTED QUANTITY.

 TOTAL VOLUME OF CONCRETE =      282.9 CU.METER

            BAR DIA       WEIGHT
            (in mm)       (in New)
            --------      --------
               8           65365
              10            3173
              12           86968
              16           51713
              20           18690
              25            8755
                       ------------
           *** TOTAL=     234665

 695. PERFORM ANALYSIS PRINT ALL
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Fig. 13.(a). Required Weight of Steel in ZONE II.

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 REINFORCING STEEL IN PLATES IS NOT INCLUDED IN THE REPORTED QUANTITY.

TOTAL VOLUME OF CONCRETE =       278.9 CU.METER

            BAR DIA       WEIGHT
            (in mm)      (in New)
            --------     --------
               8            64793
               10            3227
               12           87306
               16           49444
               20           17285
               25           15785
                         ------------
           *** TOTAL=      237840

704. PERFORM ANALYSIS PRINT ALL
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Fig. 13.(b). Required Weight of Steel in ZONE III.

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************** CONCRETE TAKE OFF **************
      (FOR BEAMS, COLUMNS AND PLATES DESIGNED ABOVE)
NOTE: CONCRETE QUANTITY REPRESENTS VOLUME OF CONCRETE IN BEAMS, COLUMNS, AND PLATES DESIGNED ABOVE.
 REINFORCING STEEL QUANTITY REPRESENTS REINFORCING STEEL IN BEAMS AND COLUMNS DESIGNED ABOVE.
 REINFORCING STEEL IN PLATES IS NOT INCLUDED IN THE REPORTED QUANTITY.

TOTAL VOLUME OF CONCRETE =       267.1 CU.METER

            BAR DIA       WEIGHT
            (in mm)      (in New)
            --------     --------
               8            61553
               10            6227
               12           76211
               16           56260
               20           32228
               25           19105
               32            4185
                         ------------
           *** TOTAL=      255768

704. PERFORM ANALYSIS PRINT ALL
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Fig. 13.(c). Required Weight of Steel in ZONE IV.

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************** CONCRETE TAKE OFF **************
      (FOR BEAMS, COLUMNS AND PLATES DESIGNED ABOVE)
NOTE: CONCRETE QUANTITY REPRESENTS VOLUME OF CONCRETE IN BEAMS, COLUMNS, AND PLATES DESIGNED ABOVE.
 REINFORCING STEEL QUANTITY REPRESENTS REINFORCING STEEL IN BEAMS AND COLUMNS DESIGNED ABOVE.
 REINFORCING STEEL IN PLATES IS NOT INCLUDED IN THE REPORTED QUANTITY.

TOTAL VOLUME OF CONCRETE =       254.2 CU.METER

            BAR DIA       WEIGHT
            (in mm)      (in New)
            --------     --------
               8            56232
               10           13076
               12           60585
               16           50572
               20           43848
               25           39911
               32           29425
                         ------------
           *** TOTAL=      293649

704. PERFORM ANALYSIS PRINT ALL
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Fig. 13.(d). Required Weight of Steel in ZONE V.

V. CONCLUSION

From the above results it is observed that the increment in the percentage of weight of steel-reinforcement is very small in between Zone II & Zone III. And the required weight of steel-reinforcement percentage has been increased from Zone III to ZONE V. Hence it is concluded that as the required weight of steel-reinforcement is increased, the cost of construction is also increases and the structure becomes uneconomical. Therefore, a Structural Engineer must have to follow all the design criteria while designing a structure so that the structure should be safe to carry all the design loads as well as it must be economical.

Table- II: Increment in the required percentage of weight of steel-reinforcement

S. NO	ZONES	WEIGHT OF STEEL (in Newton)	Increment in the Weight of Steel (in %)
1.	Zone 2	234665	100 % (If)
2.	Zone 3	237840	101.33 %
3.	Zone 4	255768	108.25 %
4.	Zone 5	293649	120.09 %

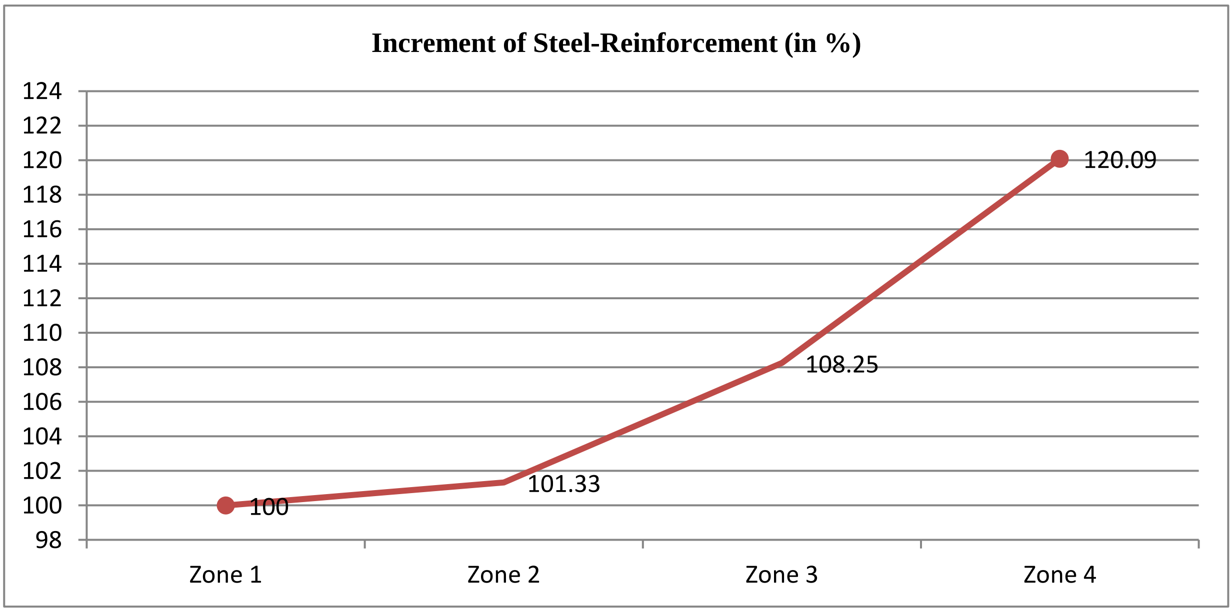

Fig. 14. Graph Showing the Increment In The Required Percentage Of Weight Of Steel-Reinforcement

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