Analysis and Design of an Earthquake Resistant Structure using STADD. Pro

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Abstract - *With the advent of advanced technology, civil structures such as high-rise buildings and long span bridges are designed with increased flexibility, increasing their susceptibility to external excitation. Therefore, these structures are vulnerable to excessive modes of vibration under the effect of a strong wind and earthquake. To protect such civil structures from significant structural damage, the seismic response of these structures is analyzed along with wind force calculation and forces such as support reactions and joint displacement are calculated and included in the structural design for a vibration resistant structure. The primary objective of this paper is to create an earthquake resistant structure by undertaking seismic study of the structure by static equivalent method of analysis and carry out the analysis and design of the building using STADD. Pro software. For this purpose, a G+11 residential building plan in Mumbai is considered. Seismic calculations are conducted for earthquake zone 3, Response reduction factor 3, for ordinary moment resistant frame and Importance factor 1. The structural safety of the building is ensured by calculating all acting loads on the structure, including the lateral loads caused due to wind and seismic excitation.*

Key Words: **STADD. Pro, analysis, seismic force, ordinary moment resisting frame, fundamental period, inter-story drift, equivalent static analysis, IS code.**

1. INTRODUCTION

Structural design is the science of analyzing and designing any structure with ultimate strength, safety, serviceability and economy. It not only requires conceptual thinking and imagination but also the discipline to maintain design standards specified by the respective country design code, for example IS Code. Any building project initiates from the planning stage to meet the specified requirement of the client. Although the client may be unaware of the impracticable conditions existing within the site and have unprecedented expectations, it is the sole responsibility of the structural engineer to undertake

The challenge and meet the design requirements for strength, durability, economy and safety.

The existing shortage of land due to the human population out-burst is constantly demanding the construction of high-rise structures. As the floor count of these multi-story buildings increase, the structure gets vulnerable to external lateral forces subjected by earthquake excitation and wind pressure, thus leading to structural instability and subsequently complete failure of the structure. To enable tall structures resistant to such lateral forces, analysis of the forces due to earthquake and wind must be undertaken and included in the ultimate design of the building.

1.1 Stages in Structural Design

Every structure follows a specific path from its initiation to ultimate design as follows:

- Structural planning of the building.
- Calculation of applied loads.
- Structural analysis of the building
- Design of the building as per analysis.
- Drawing and detailing of the structural members.
- Preparation of schedule.

It is the sole responsibility of the design engineer to construct the building structurally sound, considering all the loads acting on the building. There are multiple methods of conducting these design procedures, one of which is the use of STADD. Pro software.

1.2 Introduction to STADD. Pro

STADD. Pro provides the design engineer with excellent user interface and tools required to impose dead load and imposed load along with external acting loads on the structure. It has a powerful engine to undergo advanced dynamic analysis considering multiple loading combinations and generate an appropriate design of the structure. The software gives easy access to view reaction forces, joint displacement, shear force and bending moment acting on different beams and columns in the post-processing mode due to the applied loading condition on the structure.

STADD. Pro provides a vast interface to carry out timber, aluminum and concrete design of building, bridge and water tank. From model generation to ultimate design, the software provides accurate results and submits the final output which contains the structural design of every individual beam and column within the building.

1.3 Getting Started

This paper contains detailed information on the methodology to analyze and design a structure on STADD. Pro from model generation, fixation of supports, load analysis and finally building design. Step by step procedure has been explained with the help of diagrams. Further, load calculations have been explained in depth and manual seismic and wind calculations have also been undertaken.

2. OBJECTIVES

The primary objective of this paper is to undergo lateral load analysis and design an earthquake resistant structure on STADD. Pro. The objectives have been specified as follows:

- Generation of building model on STADD. Pro.
- Load calculation due to different loading conditions.
- Application of loads on STADD. Pro model.
- Analysis of the structure on STAD. Pro.
- Study of the reaction forces, shear force, bending moment and node displacement.
- Design of the building.

3. METHODOLOGY TO UNDERTAKE ANALYSIS AND DESIGN OF G+11 BUILDING ON STADD. PRO

Step-1: Nodal point generation.

With respect to the positioning of the column on the building plan we, respective nodal points have been entered on the STADD model.

Step-2: Beam and column representation.

Based on the nodal points, with the help of add beam command on STADD. Pro, beam and columns have been generated.

Step-3: Assign support and member property.

After column generation, supports have been provided below every column as fixed supports.
Subsequently, based on load calculations, the beam and column cross-sections have been assigned.

Step-4: 3D View.

After assigning the member property, the 3D view of the structure can be shown.

Step-5: Dead Load assignment.

According IS: 875 (Part 1) – 1987, the dead loads have been assigned based on member load, floor load and self-weight of the beams.

Step-6: Live Load assignment.

According to IS: 875 (Part 2) – 1987**,** live load of 2KN/m2 has been assigned to the members.

Step-7: Seismic load assignment.

After creating suitable seismic definition as per the requirement of IS 1893 (Part 1) : 2002**,** the seismic load has been assigned with respect to +X, -X, +Z and -Z directions with appropriate seismic factor.

Step-8: Wind load assignment.

After entering the wind intensity and creating the wind definition as per IS: 875 (Part 3) – 1987**,** the wind loads have been assigned with respect to +X, -X, +Z and -Z directions.

Step-9: Load combination assignment.

Different load combination cases have been assigned to the model based on specified loading combinations provided in the IS CODES that are also available in STADD. Pro.

Step-10: Analysis of the structure on STADD. Pro.

With the help of the Run Analysis Command, the structure is analyzed and detailed study of forces and bending moment is undertaken through the Postprocessing mode.

Step-11: Structural Design on STADD. Pro and Output Generation.

The design is undertaken as per IS 456:2000. M25 concrete and FE415 is used as design parameters. Percentage steel of 4% has been specified as per IS Code standards and the design parameters have been assigned to respective beam and column. After the final design of the structure, the output file is generated containing the structural design of every individual beam and column member.

4. ANALYSIS OF G+11 BUILDING

Equivalent static coefficient method of analysis is chosen for the following structure. This approach defines a series of forces acting on the building to represent the effect of earthquake ground motion, typically defined by a seismic design response spectrum. It considers that the building vibrates in its fundamental mode. For this to be true, the building must be low-rise and must not twist significantly when the ground moves. The seismic zoning map of India is given below categorizing every zone as zone I, II, III and IV.

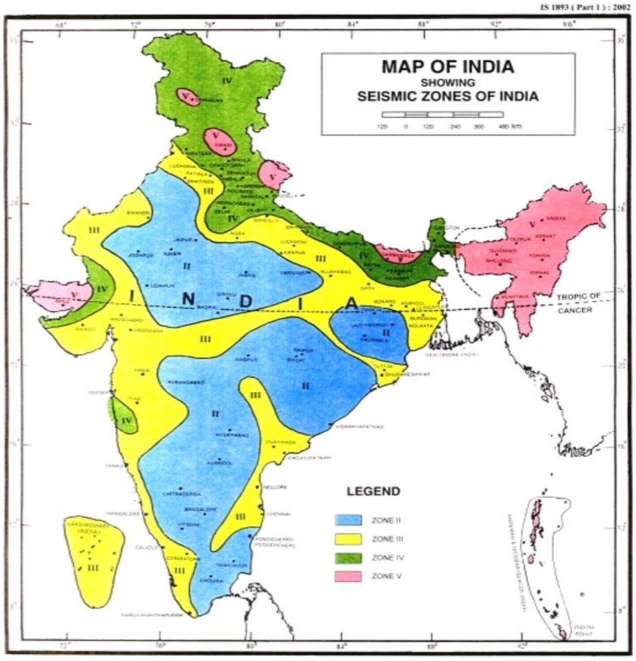


Fig – 1: Seismic zoning map of India

4.1 Response Spectrum

The response spectrum coefficient considered as per Indian Standards for design, is shown in the figure for different soil type based on suitable natural periods and damping ratio of the structure. The spectral acceleration coefficient (Sa/g) considered as per IS 1893 (Part 1): 2002 is as follows.

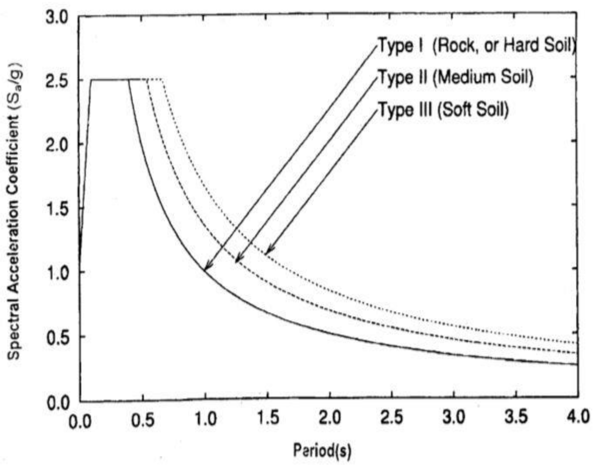


Fig – 2: Response spectra for 5% damping

The response reduction factor for different building systems is considered as per the table below.

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 – 3: Response reduction factor

The building is designed as an ordinary moment resisting frame (OMRC) for the considered residential structure without ductile detailing and hence a response reduction factor of 3 is considered.

4.2 Project Statement

The building is designed for the following parameters:

- Site location: Mumbai in Seismic Zone – III
- Type of the soil: Medium soil.
- Allowable bearing pressure: 150KN/m^2
- Response Reduction factor(R) – 3 for OMRC.
- Number of Floors: 11
- Floor Height: 3.3m
- External thickness of wall: 230mm
- Internal thickness of wall: 150mm
- Beam Size: - 230x250 mm
  - 230x300 mm
  - 230x350 mm
  - 230x400 mm

- Column Size: - 230x400 mm
  - 230x500 mm
  - 250x600 mm
  - 300x1000 mm (staircase).
- Slab Thickness: 120
- Live Load: 2KN/m^2
- Wind Load: IS: 875-(Part-3).
- Earthquake Load: IS: 1893-2002(Part-1).
- Grade of Concrete: M25
- Grade of Steel: FE415

The STADD. Pro plan and model for the considered G+11 building is shown below.

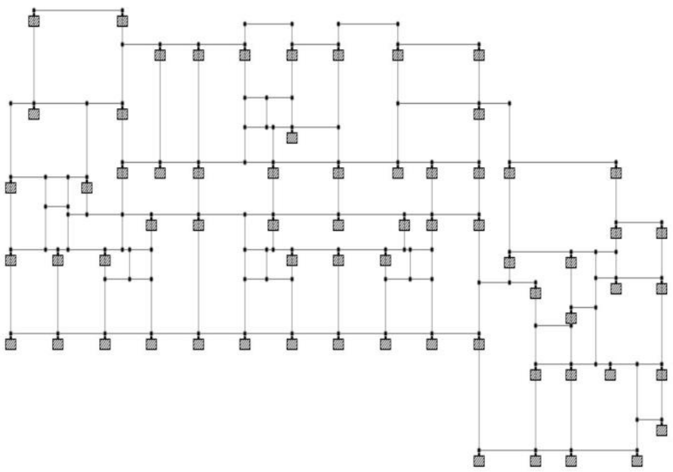


Fig – 4: STADD. Pro Line Plan

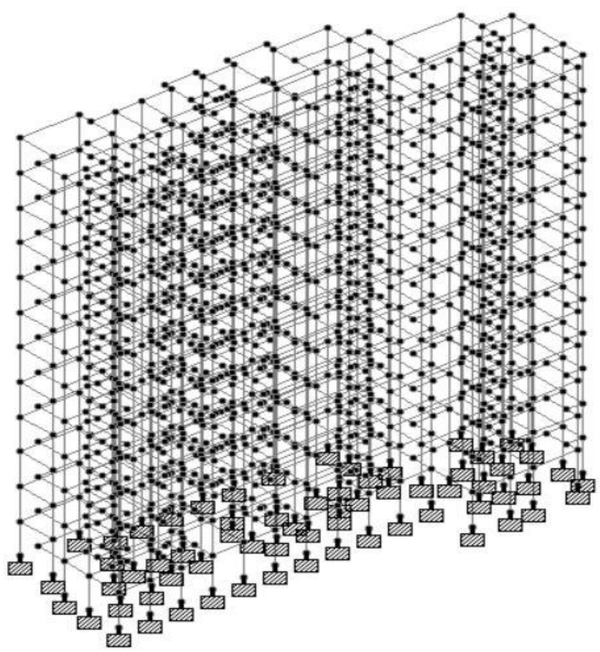


Fig – 5: STADD. Pro model

4.3 Load Calculation

Dead load, Live load, Seismic load and Wind load are calculated and entered into STADD. Pro model as give below.

4.3.1 Deal Load

Type 1: Floor load.

Reinforced concrete unit weight – 25KN/m^3

Slab thickness -120mm

Deal load due to Slab = 25 x B X D

= 25 x 1 x 0.12

= 3.0 KN/m

Floor finish = 1 KN/m^2 x 1m = 1KN/m

Total Floor Load = 4 KN/m

Factored Floor Load = 4x1.5

= 6KN/m

Type 2: Member load.

1. External wall load:

Unit weight of brick masonry – 20KN/m^3

Thickness of wall – 230 mm

Height of wall – 3.3m

Load of wall on the beam = 20 x 3.3 x 0.23 x 1.5 Factored wall load on beam = 22.8 KN/m

2. Internal wall load:

Unit weight of brick masonry – 20KN/m^3

Thickness of wall – 150mm

Height of wall – 3.3m

Load of wall on the beam = 20 x 3.3 x 0.15 x 1.5 Factored wall load on beam = 14.8 KN/m

Type 3: Self-weight of the Beam.

Reinforced concrete unit weight – 25KN/m^3

Depth of the beam – 300mm

Width of the beam – 230mm

Slab depth – 120mm

Self-weight of beam = 25 x 0.23 x 0.3 = 1.73KN/m

Factored beam weight = 1.73 x 1.5 = 2.6KN/m

Fig – 6: Dead Load on STADD. Pro

4.3.2 Imposed Load (Live Load)

The load produced by the occupancy of the building, movable partition load, concentrated and distributed load, load due to vibration and impact, people occupying the floor but excluding all external loads caused by snow, wind and earthquake or temperature changes such as shrinkage, differential settlement, creep etc. is termed as imposed load.

The imposed loads have been considered in the design as per IS: 875 (Part 2) - 1987, clause 3.1, 3.1.1 and 4.1.1. Some of the values specified by the IS code have been mentioned below:

Residential Building	**UDL (KN/m²)**
All rooms and kitchens	2
Toilet and bath rooms	2
Corridors, passage and staircase	3
Balconies	3

IS : 875 (Part 2) - 1987

TABLE 1 IMPOSED FLOOR LOADS FOR DIFFERENT OCCUPANCIES

(Clauses 3.1, 3.1.1 and4.1.1)

SL No.	Occupancy Classification	Uniformly Distributed Load (UDL)	Concentrated Load
(1)	(2)	(3)	(4)
		kN/m²	kN
i)	RESIDENTIAL BUILDINS		
	a) Dwelling houses:		
	1) All rooms and kitchens	2'0	1'8
	2) Toilet and bath rooms	2'0	—
	3) Corridors, passages, staircases including tire escapes and store rooms	3'0	4.5
	4) Balconies	3.0	1'5 per metre run concentrated at the outer edge

Fig – 7: Live Load

4.3.3 Wind Load

The lateral forces acting on the structure due to wind have been calculated as per (IS: 875 (Part 3) – 1987).

Design Wind Speed $V_Z = V_B K_1 K_2 K_3 K_4$ (Section 5.3, IS: 875 (Part 3) – 1987).

Design Wind Pressure $P_Z = 0.6 \times V_Z^2$ (Section 5.4, IS: 875 (Part 3) – 1987).

Where,

P_Z – Wind speed pressure (KN/m²).
V_Z - Wind speed design (m/s).

V_B – Basic Wind Speed at any height in m/s.

K_1 - Probability factor.

K_2 - Terrain roughness.

K_3 - Topography Factor.

K_4 – Importance factor in cyclonic region.

Exposure factor - 1.0 (As per IS Code).

For Mumbai,

Wind category - 4,

Wind Speed (V_B) = 44m/s

K_1 = 1 (Table 1, IS: 875 (Part 3) – 1987).

K_2 = 1.04 (Table 2, IS: 875 (Part 3) – 1987).

K_3 = 1 (Clause 5.3.3.1, IS: 875 (Part 3) – 1987).

K_4 = 1 (Clause 5.3.4, IS: 875 (Part 3) – 1987).

With respect to the values of K_1, K_2, K_3 and K_4 listed above, the wind speed design V_Z is calculated by the formula listed above. The square of the design wind speed is multiplied by a factor of 0.6 and the value of design wind pressure is calculated. The below calculated wind pressure values (P_Z) at each floor are provided as input to wind definition in STADD. Pro and the wind force acting on the structure is displayed below.

Table - 1: Lateral wind force

Height	VB	K1	K2	K3	K4	VZ	PZ
39.6	44	1	1.03	1	1	45.32	1.23
36.3	44	1	1.01	1	1	44.44	1.18
33.0	44	1	0.99	1	1	43.56	1.14
29.7	44	1	0.97	1	1	42.68	1.09
26.4	44	1	0.91	1	1	40.04	0.96
23.1	44	1	0.85	1	1	37.40	0.84
19.8	44	1	0.8	1	1	35.2	0.74
16.5	44	1	0.8	1	1	35.2	0.74
13.2	44	1	0.8	1	1	35.2	0.74
9.9	44	1	0.8	1	1	35.2	0.74
6.6	44	1	0.8	1	1	35.2	0.74
3.3	44	1	0.8	1	1	35.2	0.74

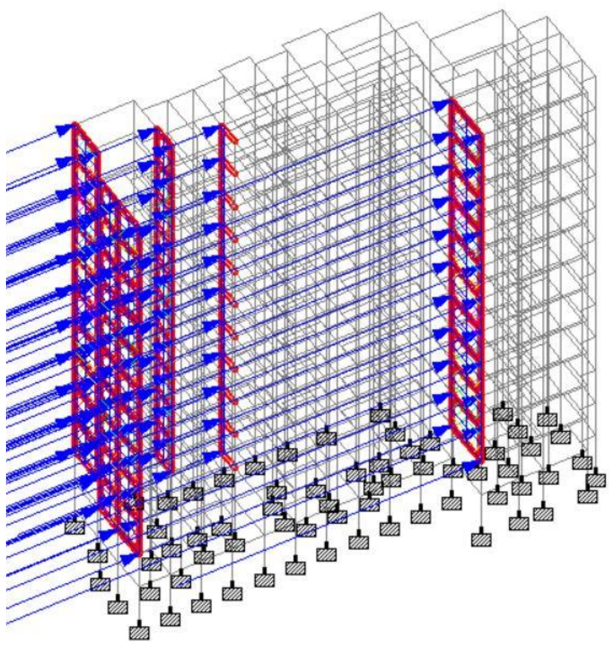


Fig – 8: Wind Force acting on STADD model

4.3.4 Seismic Load

To make the structure earthquake resistant, the fundamental period of the building while vibration should be calculated and provided as input to STADD. Pro for seismic analysis. The considered building is in Mumbai.

Seismic parameters as per (IS 1893 (Part 1) : 2002) are stated below:

Seismic Zone – III (IS 1893 (Part 1) : 2002)

Zone Factor (Z) – 0.16 (Table 2, IS 1893 (Part 1) : 2002)

Importance factor – 1 (Table 6, IS 1893 (Part 1) : 2002)

Response Reduction Factor – 3 (Table 7, IS 1893 (Part 1) : 2002)

Fundamental Period (Ta):

The formula for calculating the fundamental natural period of vibration for moment resisting framed building provided with brick infill panel is given in IS:1893 Part 1 as follows,

Fundamental period = $0.09h/(d)^{1/2}$ (Clause 7.6.2, IS 1893 (Part 1) : 2002).

The building plan is of size 37.8 x 19.7 m.

Height of the building (h) = 39.6 m

Width of the building (dx) = 37.8 m

Width of the building (dz) = 19.7 m

Period in X direction (P_X) = $0.09 \times 39.6 / (37.8)^{1/2}$

= 0.58 sec

Period in Z direction (P_Z) = $0.09 \times 39.6 / (19.7)^{1/2}$

= 0.8 sec

These values are provided as input to the seismic definition in STADD. Pro and seismic forces are calculated. The earthquake force acting on the structure is displayed below.

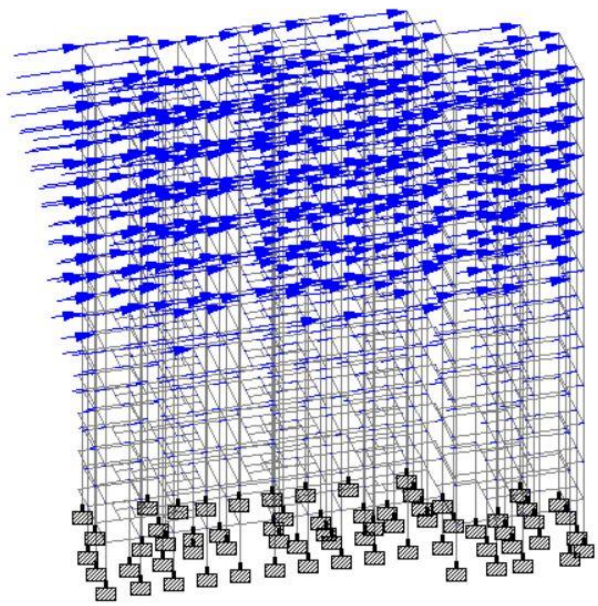


Fig – 9: Seismic Force on STADD model

5. CONCLUSION

The G+11 residential building has been analyzed and deigned using STADD. Pro. Seismic and wind forces have been considered and the structure is designed as an earthquake resistant structure. Earthquake and wind oriented deflections must be limited for multiple reasons and hence abundant structural stiffness is important. As a result, the inter-story drift must be obtained within the specified limits. For minimum specified lateral force with partial load factor of 1.0, the inter-story drift should be under 0.04 x Hs, where (Hs) is the story height (Clause 7.11.1, IS 1893 (Part 1) : 2002). For 3300 mm floor height, inter-story drift = 0.04 x 3300 = 13.2 mm. The actual relative displacement between every story in the structure is below the inter-story drift limit and hence safe.

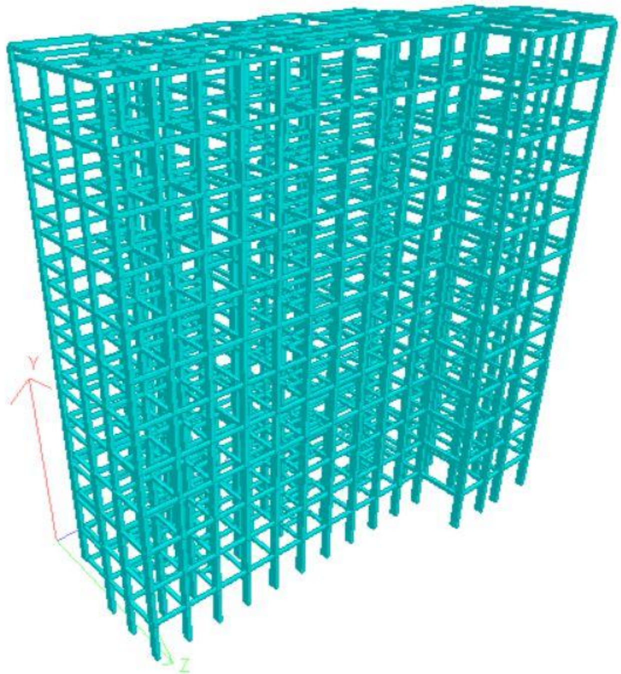
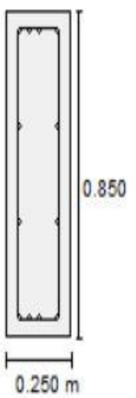


Fig – 10: STADD. Pro 3D Rendered Model



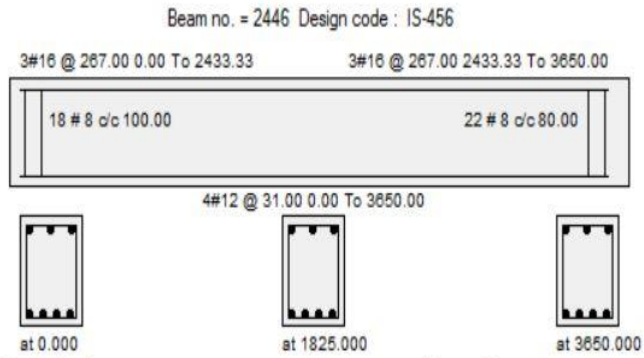
Design Load

Load	30
Location	Long Col
Pu(Kns)	2142.26
Mz(Kns-Mt)	9.4
My(Kns-Mt)	196.12

Design Parameter

Fy(Mpa)	415
Fc(Mpa)	25
As Reqd(mm²)	2767
As (%)	1.77
Bar Size	20
Bar No	12

Fig – 11: Column Output



Design Load

Mz Kn Met	Dist. Met	Load
12.56	1.8	35
-23.39	0	29
-12.07	3.7	33

Design Parameter

Fy(Mpa)	415
Fc(Mpa)	20
Depth(m)	0.300000011
Width(m)	0.230000004
Length(m)	3.649999618

Fig – 12: Beam Output

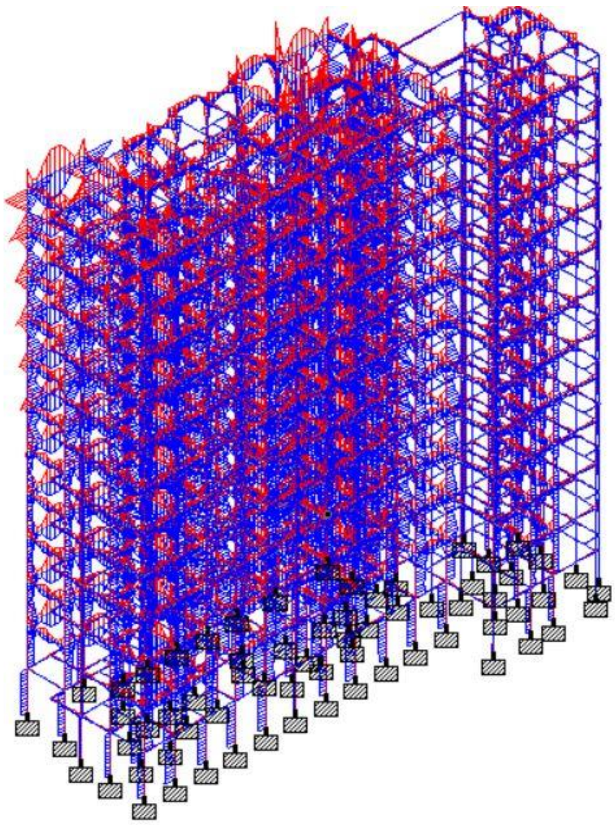


Fig -13: Shear Forces acting on the structure

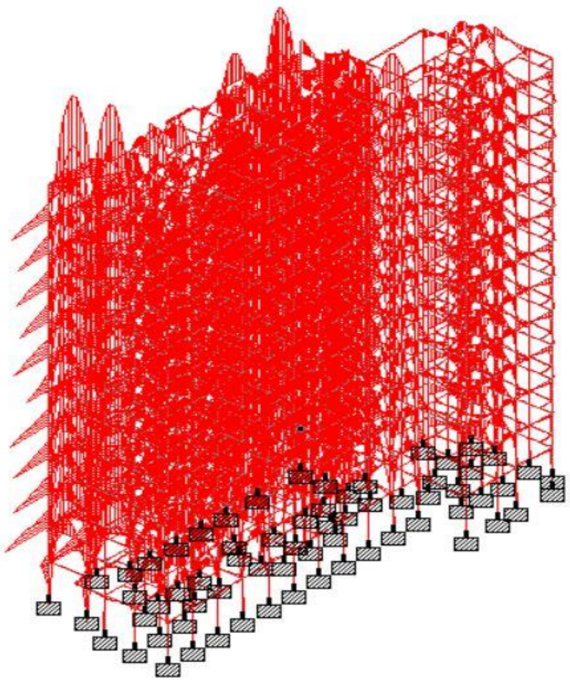


Fig -14: Bending Moment acting on the structure

To conclude, STADD. Pro is a user friendly versatile software having the capacity to determine the reinforcement required for any concrete section based on its loading and determine the nodal deflections against lateral forces. It undergoes static as well as dynamic analysis of the structure and gives accurate results. The following points have been derived at the end of the design.

- The values of bending moment and shear force for every individual member has been studied.
- The short-term deflection for all horizontal members is within safe limits.
- With the consideration of wind and seismic forces, the steel percentage has increased to 2%, but is still below the permissible limits.
- Proposed structural size of the members can be used for practical design consideration.
- The final output for beams and columns has been generated and reinforcement details have been studied.

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