Seismic Analysis of Lightweight and Normal Weight Concrete in G+20 High Rise Building: A Comparative Study

Avinash Mishra, Mayank Soni

Assistant Professor Chameli Devi group of Institutions, Indore[1,2]

Abstract

Reinforced concrete multi-story structures are particularly vulnerable to earthquakes. It was discovered that the major cause of RC building collapse is irregularity in its plan size and lateral force resisting system. In this research, an analytical investigation is conducted to determine the reaction of various structures located in severe zone III. ETABS 20.0 was used to do the analysis on a G+20 story structure. In the current study, we are working on multiple models. There are six combinations with three distinct conditions. All of the models are examined, and the outcomes are decided.

Keywords: - Response spectrum, seismic, lightweight concrete

1. Introduction

Engineers developed the idea of a multi-story building to avoid using more land for a building; the natural time period for a high-rise construction is longer than for a low-rise structure, indicating that natural frequency is lower for high-rise structures. The mass and stiffness of a structure affect its natural frequency, which is inversely related to the square root of mass. As a result, if we can significantly lower the mass of a building, the natural frequency of that structure will rise. When compared to steel structures, India's construction costs are reduced since the majority of structures are built of concrete. Using ETABS (Extended three-dimensional analysis of building systems), standard software, the seismic performance of structural lightweight concrete for high-rise buildings is evaluated. (Computers and Structures, INC., 2022). A lightweight aggregate may be used to create structural lightweight concrete, such as expanded clay aggregate, tuff aggregate, pumice aggregate, perlite aggregate, etc. Lightweight aggregate concrete is used in structural applications because it is lightweight and has strong thermal and acoustic insulating qualities. (Murat Emre Dilli, 2015). Utilising scoria lightweight aggregate, it is possible to create lightweight concrete with a density of 1800 kg/m3 and a cylindrical compressive strength of 40 MPa by adding silica fume (Alaettin Kılıc¸, 2003). Similarly, north-eastern Jordan's naturally occurring tuff aggregates can be used to create lightweight concrete with a high strength. The findings demonstrated that using standard methods and a variety of concrete mixtures, it was possible to produce high-quality lightweight concrete that was suitable for use in reinforced and prestressed concrete structures and had a maximum compressive strength of 60 MPa at 90 days. The poison ratio for this type of moist-cured concrete was determined to be 0.21, which is almost identical to the poison ratio of normal weight concrete (Mohammad Smadi, 1991).

The ACI 318 Building Code specifies the mechanical characteristics of lightweight aggregate concrete; nevertheless, as compared to standard weight concrete, the structural lightweight aggregate concrete has a higher modulus of elasticity. Elastic modulus for SLWC depends on the concrete's typical compressive strength and density. The majority of experimental tests concluded that the Poisson's ratio of SLWAC and regular concrete is almost identical. Various experimental tests have determined that the thermal expansion coefficients for regular concrete and lightweight aggregate concrete are $12x10^{-6}$ and $17x10^{-6}$ respectively. For several forms of lightweight concrete, the shear strength reduction factor or modification factor (λ) is provided in ACI 318-14, Table 19.2.4.2 (John P. Ries, 2003).

2. Objectives

1. Seismic Analysis of Normal weight concrete (NC) with area $576m^2$, considering L=B.
2. Seismic Analysis of Normal weight concrete (NC) with area $1152m^2$, considering L=2B.
3. Seismic Analysis of Light weight concrete (LWC) with area $576m^2$, considering L=B.
4. Seismic Analysis of Light weight concrete (LWC) with area $1152m^2$, considering L=2B.
5. Seismic Analysis of composite structure, i.e. Normal and Light weight concrete (NAL) with area $576m^2$, considering L=B.
6. Seismic Analysis of composite structure, i.e. Normal and Light weight concrete (NAL) with area $1152m^2$, considering L=2B.
7. Comparison of Both Light weight concrete (LWC) and Normal weight concrete (NC).

3. Methodology

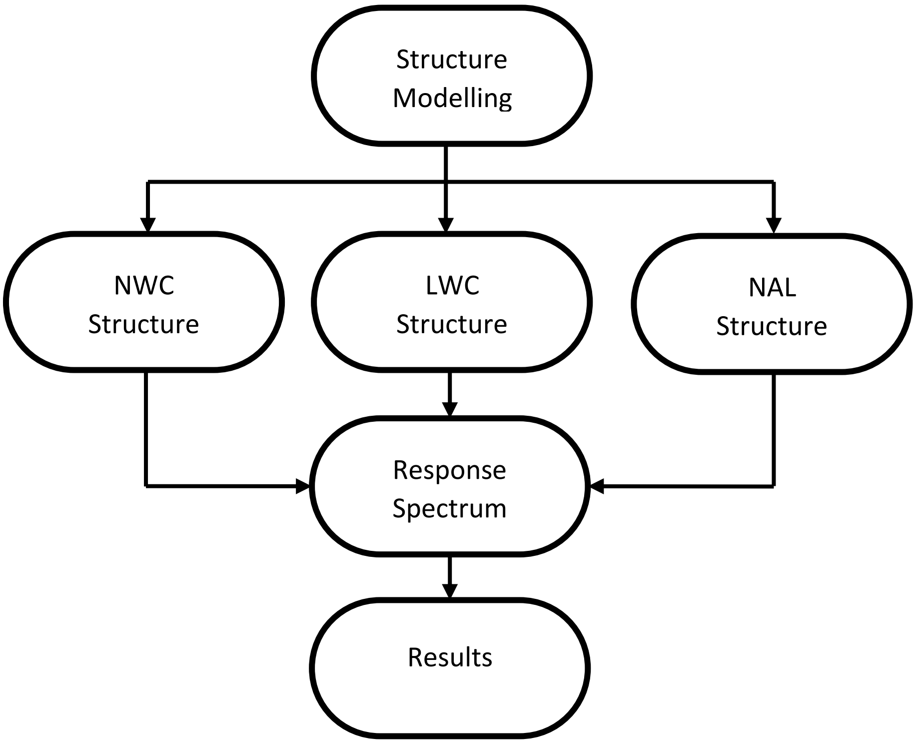

Fig 1: Methodology

4. Study and Results

4.1 Material Properties: -

In ETABS (Extended Three-Dimensional Analysis of Building System), a G+20 high-rise building framed structure is modelled with storey heights of 3.66m, lengths of 24m and width of 24m, a total height of 84.52m, and a variety of member sizes in accordance with design specifications. The thickness of the slab is assumed to be 135 mm and in the same way the thickness of shear wall and staircase waist slab is given as 140mm and 135mm. The model is examined using two distinct material properties: Lightweight concrete (LWC) and normal weight concrete (NWC), both of which were constructed in accordance with IS 456-2000 (Cement andConcrete Sectional Committee, 2005). LWC has a lower elastic modulus than NC. Concrete's density, elastic modulus, poisons ratio, compressive strength, and modification factor are material qualities needed for a construction. Both structural lightweight aggregate concrete and normal weight concrete have densities of 1800 kg/m^3 and 2500 kg/m^3, poisons ratios of 0.20 and 0.15, compressive strengths of 30 to 40 MPa, and elastic moduli of 17986.13 MPa for LWC and 27386.13 MPa for NWC, respectively, according to ACI.

International Journal of Scientific Research in Engineering and Management (IJSREM)
Volume: 07 Issue: 07 | July - 2023 SJIF Rating: 8.176 ISSN: 2582-3930

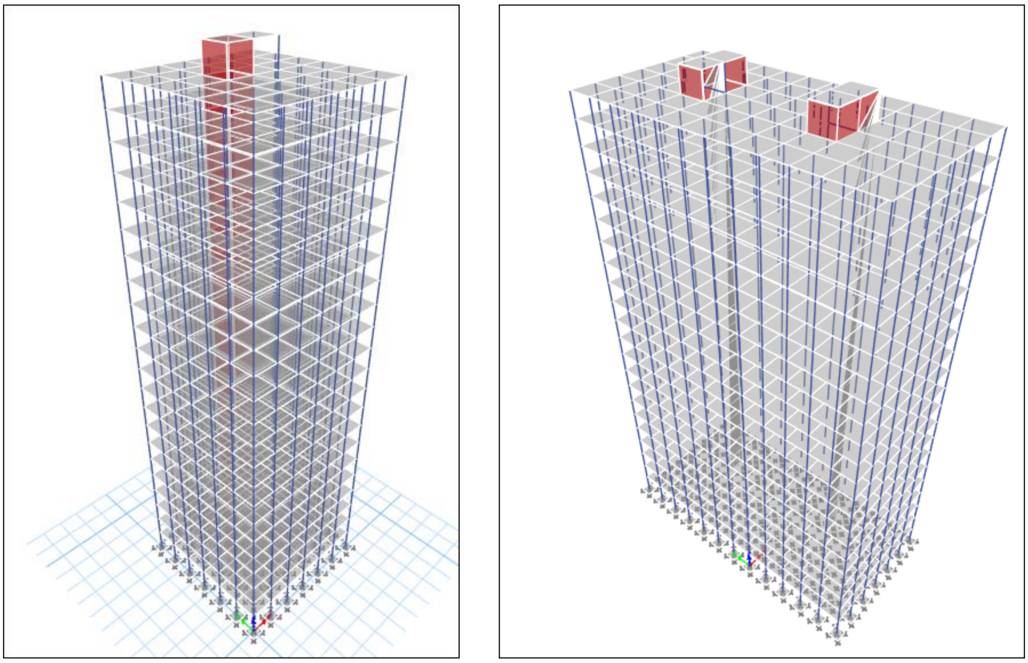

Fig 2: Model of structure (3D view)

4.2 Load details: -

The IS 875 part 1 (1987) for dead loads, the IS 875 part 2 (1987) for live loads, the IS 875 part 3 (1987) for wind loads, and the IS 1893 part 1 (2002) for seismic analyses are the Indian standard codebooks from which the loads are extracted.

Table 1: Load Details

Type of Load	Load Intensity
Live Load	For Floors = 3.2 KN/m^2 For Roof = 0.8 KN/m^2
Water-Proofing	0.508 KN/m^2
Floor Finishing	2.8 KN/m^2
Wall Load	External = 17.12 KN/m Internal = 9.44 KN/m Parapet = 2.58 KN/m
Wind load	As per IS 875 Part 3
Seismic Zone	III
Type of Soil	Medium soil

The structure is analysed for seismic zone III and medium soil condition. Only critical circumstances are accommodated by the structure. The load combinations that ought to be considered during the design of structures in seismic zones according to IS 1893 Part 1(2002) regulation are as follows.

i. $1.2[DL+LL \pm (EL_X \pm 0.3EL_Y)]$ and
$1.2[DL+LL \pm (EL_Y \pm 0.3EL_X)]$;

ii. $1.5[DL \pm (EL_X \pm 0.3EL_Y)]$ and
$1.5[DL \pm (EL_Y \pm 0.3EL_X)]$;

iii. $0.9\ DL \pm 1.5(EL_X \pm 0.3EL_Y)$ and
$0.9\ DL \pm 1.5(EL_Y \pm 0.3EL_X)$.

4.3 Model Details: -

For the analysis of the study we consider residential apartment with different plan areas and different concrete used. The bifurcations are given below:

Table 2: Abbreviation and cases considered

SNo.	Abbreviation	Description of Cases
1	NC1	Residential apartment with plan area 576m^2 using normal concrete
2	NC2	Residential apartment with plan area 1152m^2 using normal concrete
3	LWC1	Residential apartment with plan area 576m^2 using Light weight concrete
4	LWC2	Residential apartment with plan area 1152m^2 using Light weight concrete
5	NAL1	Residential apartment with plan area 576m^2 using normal and lightweight concrete
6	NAL2	Residential apartment with plan area 1152m^2 using normal and lightweight concrete

The properties of the concrete i.e. Normal Concrete and Light weight concrete are given in the following table:

Table 3: Properties of Normal Concrete and Lightweight concrete

Parameters	Normal Concrete	Light Weight Concrete
Density	2500Kg/m3	1800Kg/m3
Poisson's Ratio	0.20	0.20
Characteristic Strength of concrete (f_{ck})	30 MPa	30MPa
Modulus of Elasticity (E)	27386.13 MPa	17956.13MPa
Modification Factor	1	0.75

4.4 Results: -

As per the objectives response Spectrum Analysis has been performed on different models consist of Building Case NC1, NC2, LWC1, LWC2, NAL1 and NAL2 made up of G+20 storey Residential apartment with shear Wall Outrigger. Building Case NC1 and NC2 made up of G+20 storey Residential apartment are made up with normal concrete with plan area 576m^2 and 1152m^2. Building Case LWC1 and LWC2 made up of G+20 storey Residential apartment are made up with Light weight concrete with plan area 576m^2 and 1152m^2. Building Case NAL1 and NAL2 made up of G+20 storey Residential apartment are made up with normal concrete up to 6th floor and with lightweight concrete onwards with plan area 576m^2 and 1152m^2. The reason of implementing lightweight concrete up to only 6th floor is to make the structure strong so that it can withstand the overturning effect. All the cases are situated in Earthquake Zone III.

Since for the analysis of seismic effects, all the cases of the structures have been analysed for seismic shake for longitudinal along with transverse direction. Various loads along with load combinations applied on all the cases and reflective result parameters have been analysed with each other to determine the efficient case.

4.4.1 Maximum Displacement (mm)

displacement refers to the movement or deformation experienced by a structure under the influence of applied loads. The maximum displacements in both x and y directions are shown in table below:

Table 4: Maximum Displacement in X and Y directions

Model Case	Maximum Displacement (mm)	
	For X Direction	For Y Direction
NC1	139.56	135.085
NC2	115.86	200.452
LWC1	168.46	162.692
LWC2	82.308	236.173
NAL1	194.411	187.454
NAL2	138.326	255.357

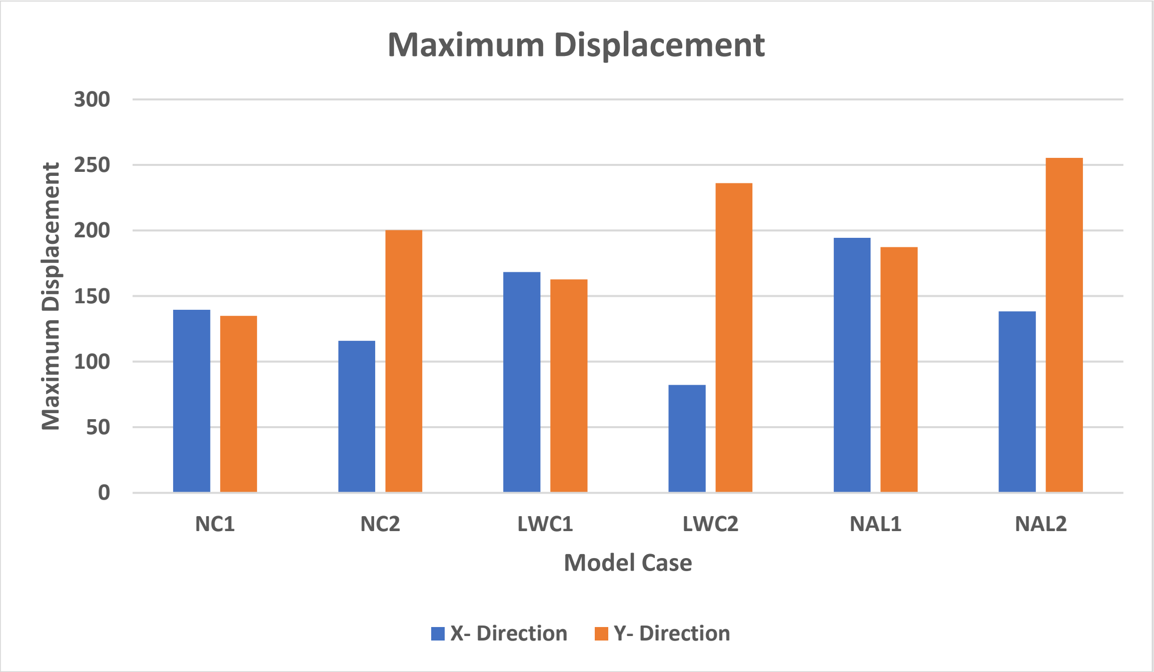

Fig 3: Maximum Displacement for various cases

4.4.2 Base Shear

Base shear is a term commonly used to describe the total lateral force or shear that is transmitted to the foundation of a structure during an earthquake or other lateral loading events. It represents the resistance or counterbalance required to keep the structure stable against the applied lateral forces.

Table 5: Maximum Base Shear in X and Y directions

Model Case	Base Shear (KN)	
	X direction	Y direction
NC1	5623.112	5623.112
NC2	10212	14447.6
LWC1	4424.14	4424.14
LWC2	8107.45	11470.44
NAL1	5623.112	5623.112
NAL2	10212	14447.6

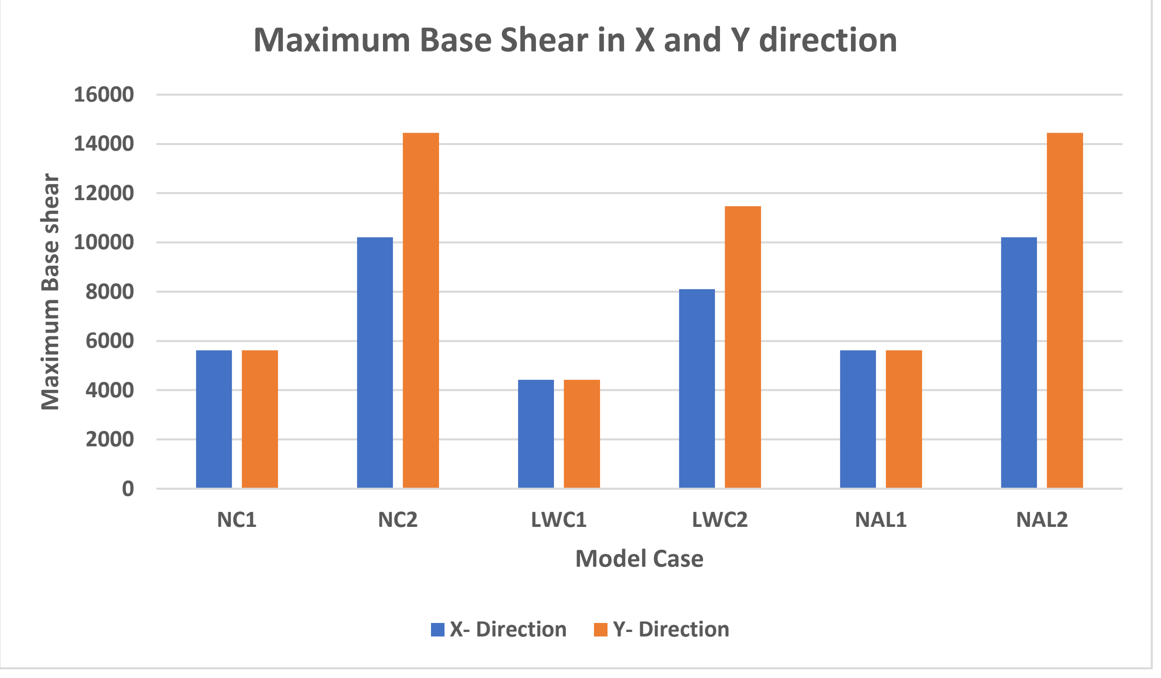

Fig 4: Maximum Base Shear for various cases

4.4.3 Story drift

story drift refers to the horizontal displacement or relative lateral movement between different levels or stories of a building or structure during an earthquake or other lateral loading conditions. It is a measure of the deformation or relative movement between adjacent floors or levels.

Table 6: Maximum Story Drift for Various Cases

Model Case	Story Drift	
	X direction	Y direction
NC1	0.002595	0.002461
NC2	0.001823	0.003278
LWC1	0.003153	0.002983
LWC2	0.001210	0.003844
NAL1	0.00385	0.003621
NAL2	0.002299	0.004529

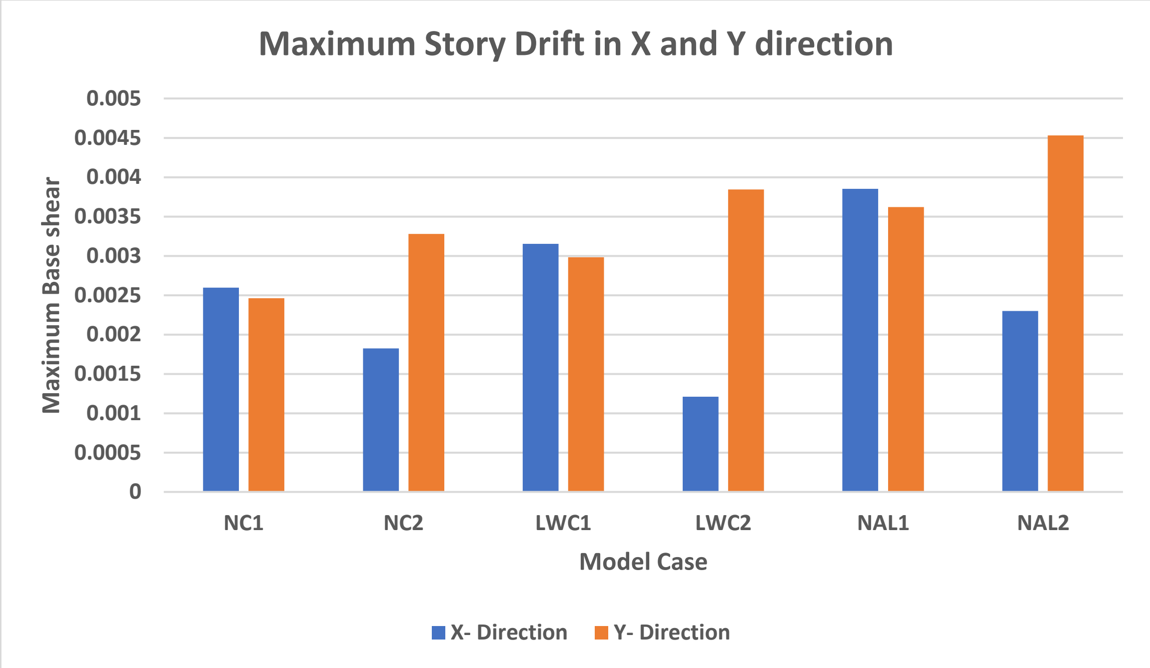

Fig 5: Maximum Story Drift in X and Y direction for various cases

4.4.4 Column Axial Force

Column axial force refers to the amount of axial or vertical force that is applied to a column in a structure. It represents the total load or force that acts along the longitudinal axis of the column. Axial force can be compressive, tensile, or zero, depending on the loading conditions and the structural design.

Table 7: Maximum Column Axial Force for Various Cases

Model Case	Column Axial Force (KN)
NC1	3831.228
NC2	9882.65
LWC1	3310.189
LWC2	11412.38
NAL1	4076.6
NAL2	10628.48

International Journal of Scientific Research in Engineering and Management (IJSREM)
Volume: 07 Issue: 07 | July - 2023 SJIF Rating: 8.176 ISSN: 2582-3930

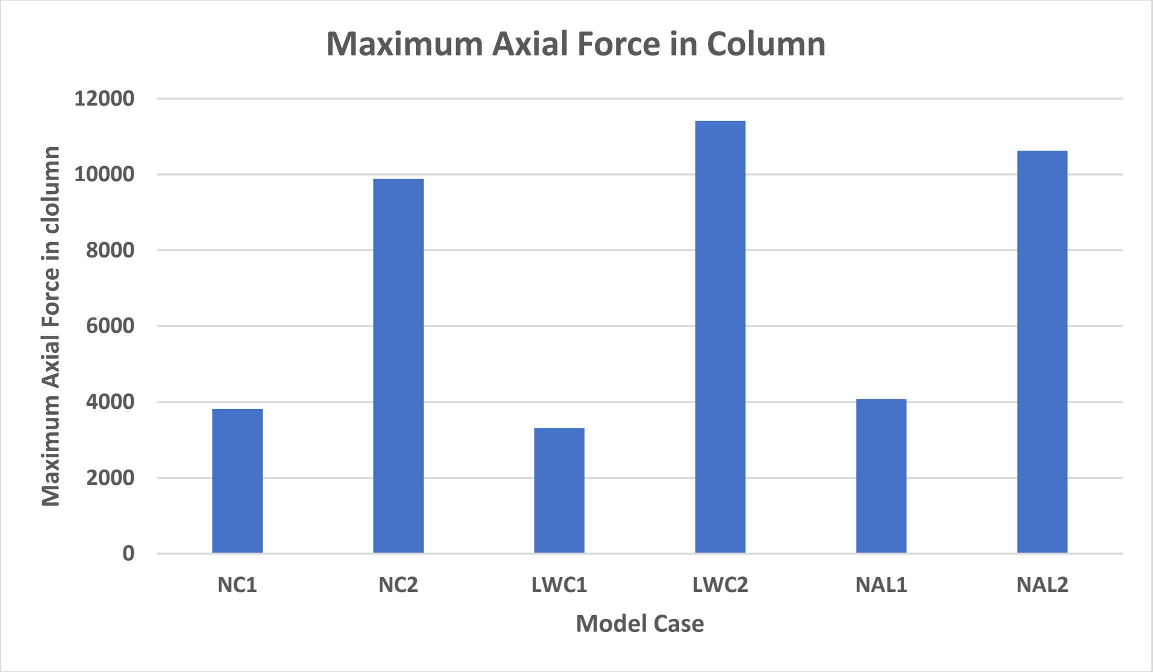

Fig 6: Maximum Axial Force for various cases

4.4.5 Shear force and bending moment in Column

Both column shear force and bending moment are critical factors in the structural design process. They help engineers determine the maximum load capacity of a column and ensure that it can safely support the applied loads without experiencing excessive deformation or failure. By analysing these internal forces and moments, engineers can determine the appropriate column dimensions, reinforcement requirements, and structural connections to ensure the structural integrity and safety of the overall system.

Table 8: Maximum Shear Force and Bending Moment in Column in X and Y directions

Model Case	Column Shear Force (KN)		Column Bending Moment (KN-m)	
	Shear along X	Shear along Y	Moment along X	Moment along Y
NC1	214.68	196.77	588	790.47
NC2	277.01	346.51	897.17	782.42
LWC1	162.78	160.84	430.68	599.03
LWC2	702.46	285.69	695.10	1266.87
NAL1	233.56	183.97	519.82	718.18
NAL2	278.63	401.88	923.50	807.29

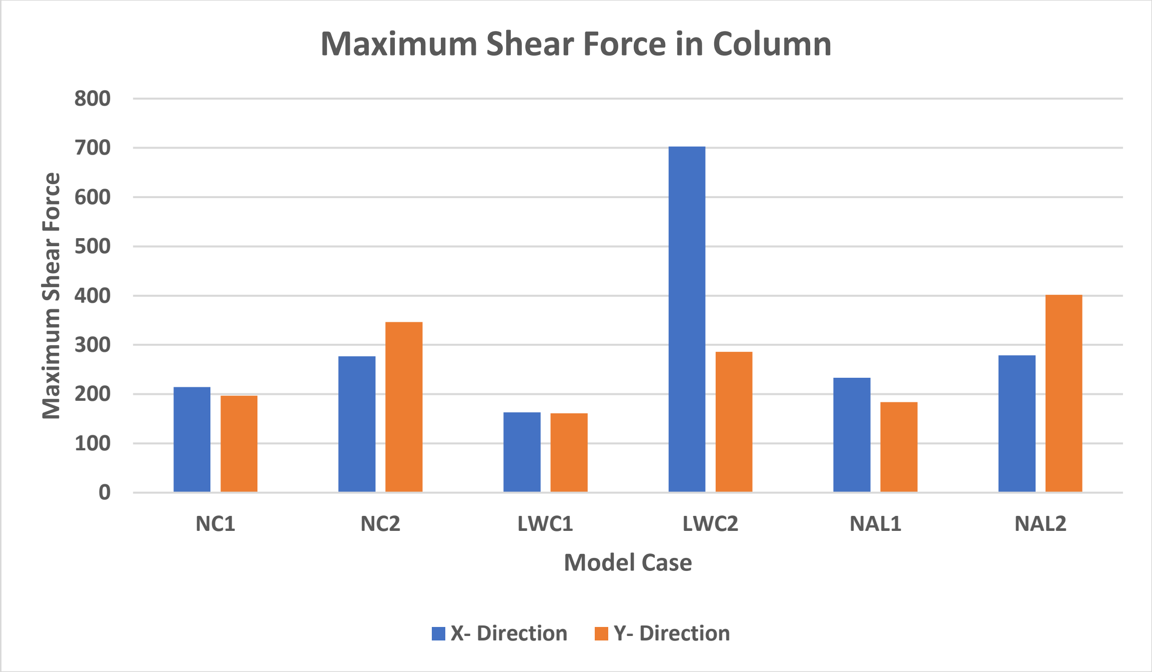

Fig 7: Maximum Shear Force in column for various cases

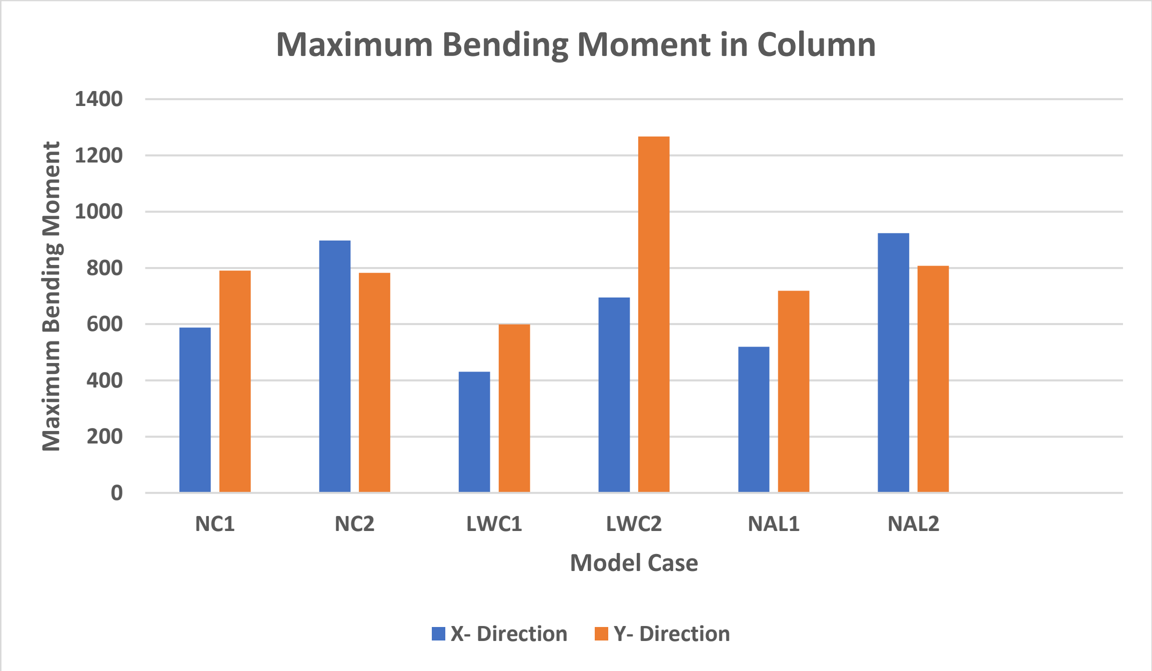

Fig 8: Maximum Bending Moment in column for various cases

4.4.6 Shear force and bending moment in Beam

Both shear force and bending moment are crucial for designing and analysing the structural behaviour of beams. Engineers use shear force and bending moment diagrams to visualize the variation of these internal forces along the length of the beam. These diagrams help determine the maximum stresses and deflections in the beam, which are important considerations for ensuring the beam's structural integrity.

Table 9: Maximum Shear Force and Bending Moment in Beam in X and Y directions

Model Case	Beam Shear Force (KN)		Beam Bending Moment (KN-m)	
	Shear along X	Shear along Y	Moment along X	Moment along Y
NC1	233.94	1.24	2.21	290.24
NC2	377.17	1.52	2.66	503.92
LWC1	190.58	0.91	1.66	232.17
LWC2	310.78	1.84	3.38	409.86
NAL1	239.45	1.07	1.94	298.63
NAL2	413.89	3.04	5.28	566.43

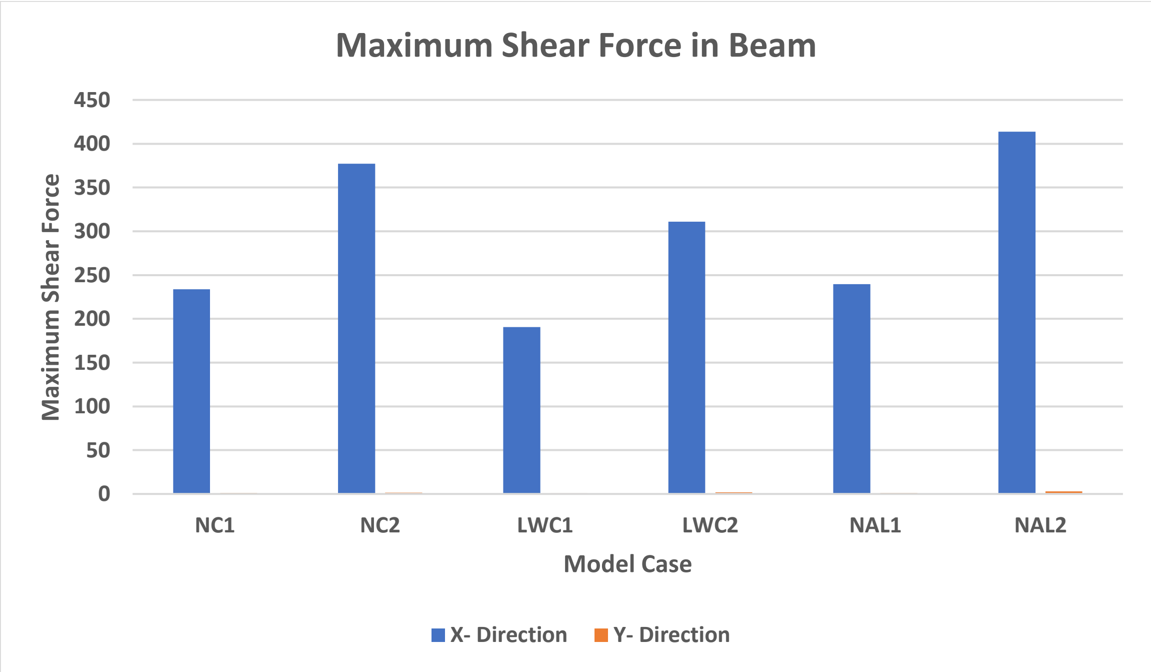

Fig 9: Maximum Shear Force in Beam for various cases

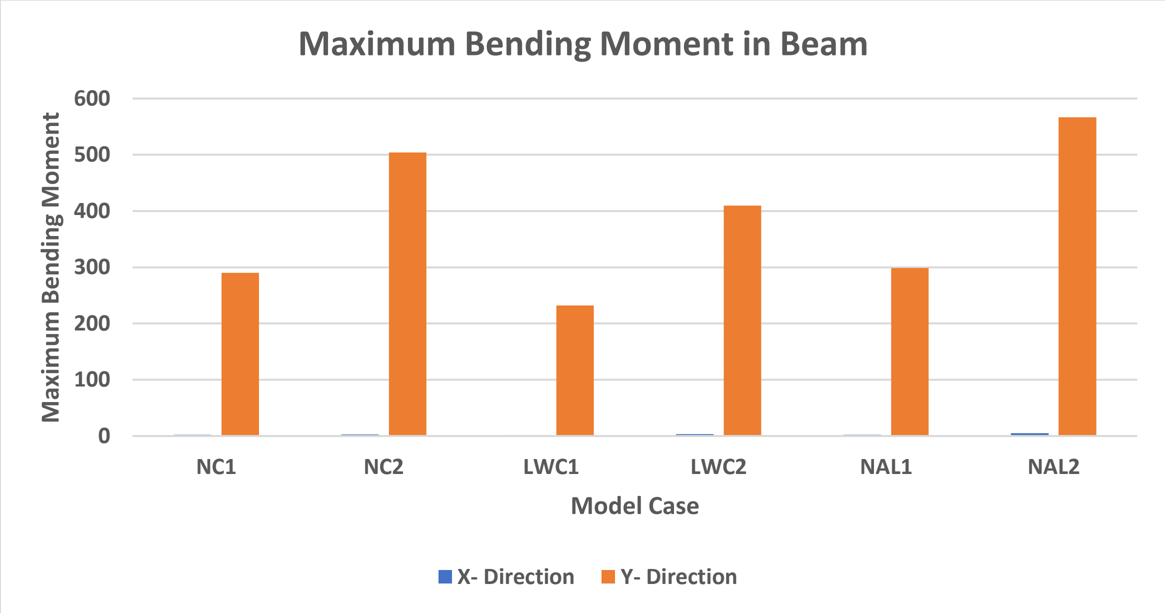

Fig 10: Maximum Bending Moment in Beam for various cases

4.4.7 Maximum Principal Stresses

Maximum principal stresses refer to the highest magnitude of normal stresses experienced by a structure at a particular point. In three-dimensional stress analysis, stresses acting on a point can be resolved into three mutually perpendicular directions. The maximum principal stress is one of these three principal stresses and represents the highest tensile or compressive stress value at that point.

Table 10: Maximum Principal Stresses for various cases

Model Case	Maximum Principal Stresses (Smax Top) N/sq. mm
NC1	3.19
NC2	6.79
LWC1	3.53
LWC2	13.85
NAL1	4.37
NAL2	7.08

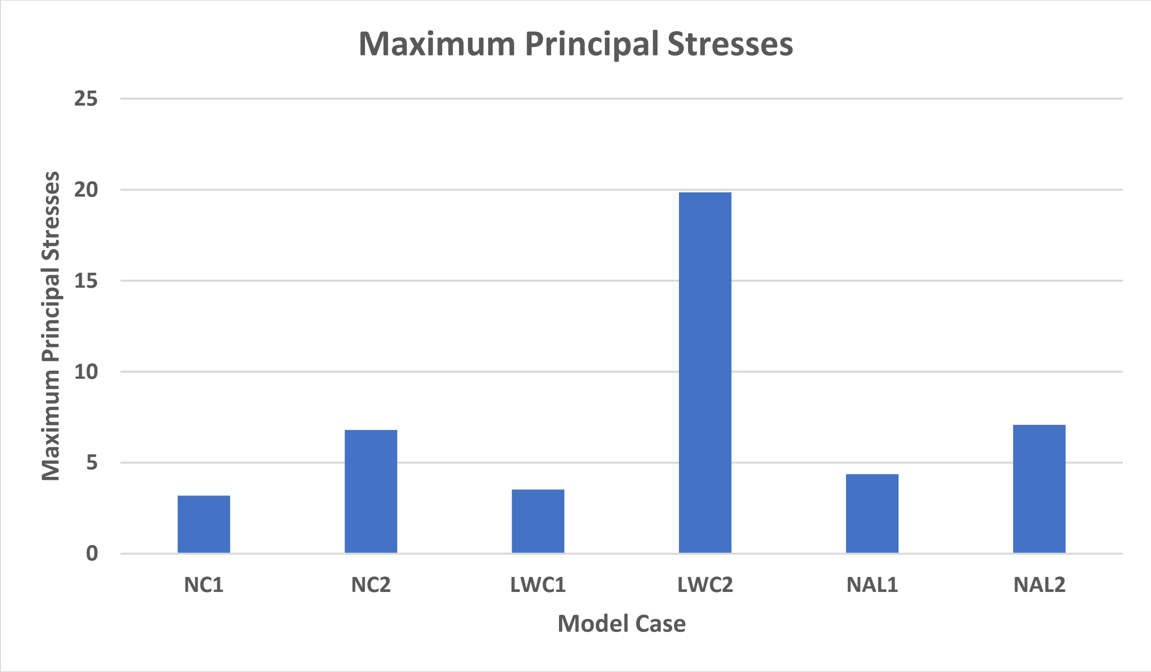

Fig 11: Maximum Principal Stresses for various cases

4.4.8 Maximum Von Mises Stresses

In structural analysis, von Mises stress is commonly used to evaluate the yielding or failure criteria of materials that undergo plastic deformation. It is particularly useful for ductile materials like metals, where plastic deformation occurs before failure.

Table 11: Maximum Von Mises Stresses for various cases

Model Case	Von Mises Stresses (SVM Top) N/sq. mm
NC1	6.73
NC2	9.88
LWC1	7.45
LWC2	13.72
NAL1	8.59
NAL2	9.75

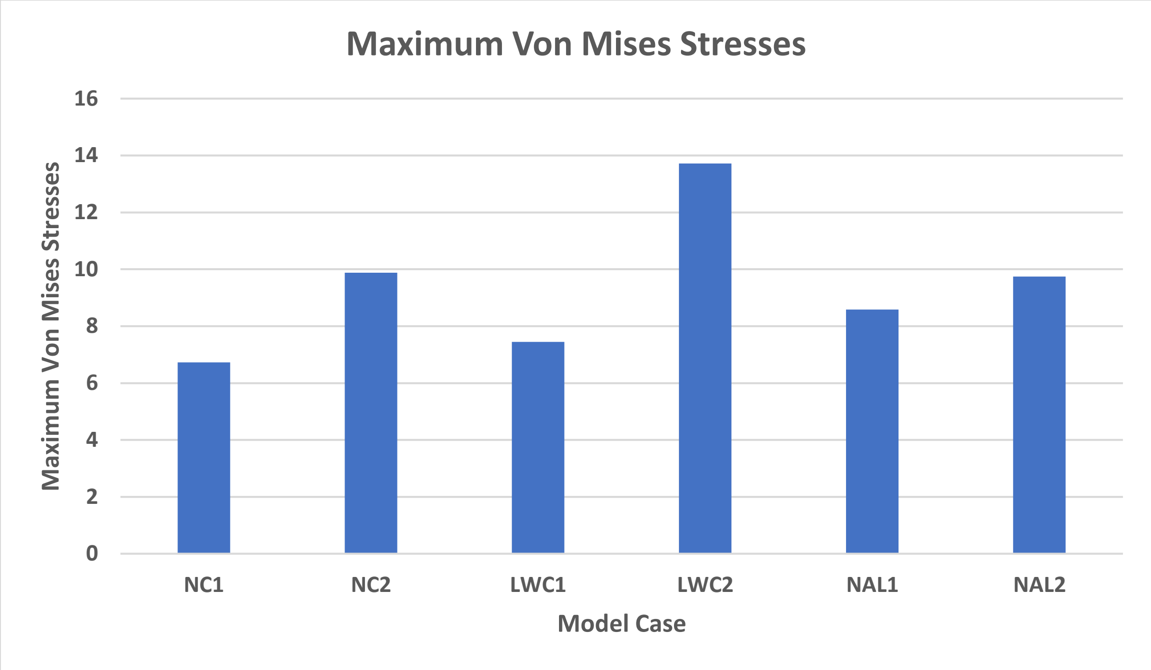

Fig 12: Maximum Von Mises Stresses for various cases

1.1.1 Maximum Shearing Stresses

When a structural element, such as a beam or a column, is subjected to shear forces, the material experiences shearing stresses. These stresses arise due to the internal resistance of the material to the shearing motion.

Table 12: Maximum Shearing Stresses for various cases

Model Case	Shearing Stresses (S12 Top) N/sq. mm
NC1	1.77
NC2	2.40
LWC1	1.63
LWC2	7.2
NAL1	2.09
NAL2	2.45

International Journal of Scientific Research in Engineering and Management (IJSREM)
Volume: 07 Issue: 07 | July - 2023 SJIF Rating: 8.176 ISSN: 2582-3930

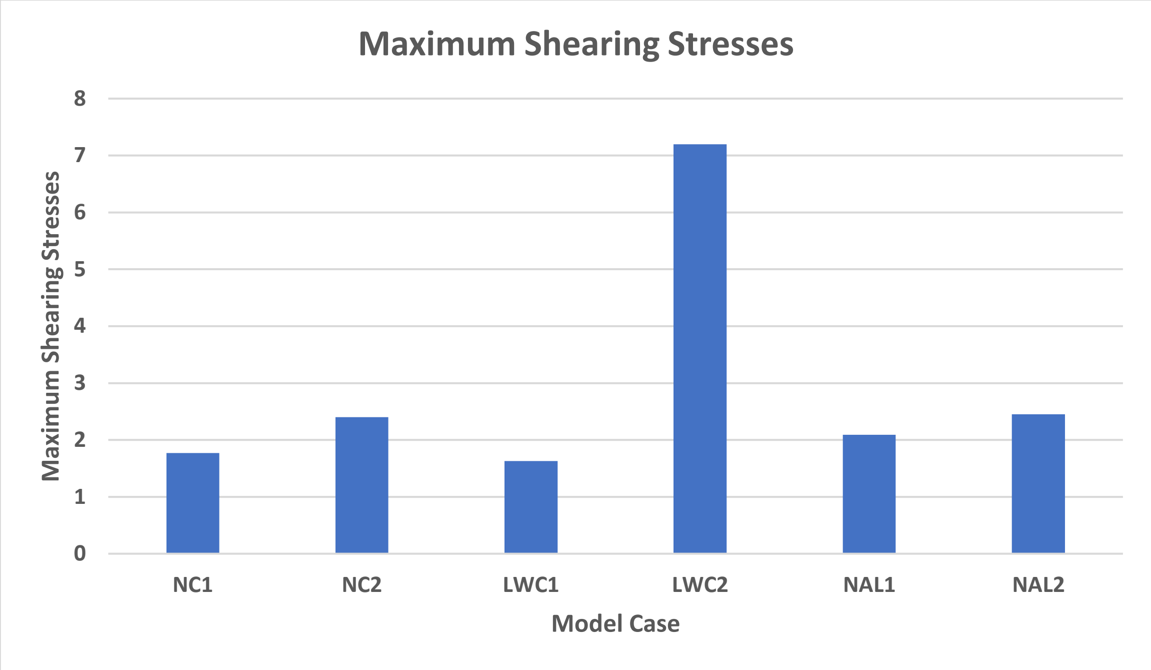

Fig 13: Maximum Shearing Stresses for various cases

5. Conclusion: -

We came across some findings after examining the various models stated in table 2. These findings are as follows:

1. The maximum displacement in x-direction is 194.41mm which is for the case NAL1 i.e Normal and lightweight concrete with length equal to its width, while the minimum displacement is in LWC2 i.e. lightweight concrete with length double of its width, which is found to be 82.308mm in x-direction.so, LWC2 is performing better when comparing with others in terms of displacement.
2. The maximum displacement in y-direction is 255.35mm in the case NAL2, i.e. Normal and light weight concrete with length double of its width, while the minimum displacement in y direction is 135.08mm which is for NC1 condition i.e. Normal concrete with length equal to its width.
3. The story drift in X-direction has maximum value of 0.00385 and minimum value of 0.001210 for the cases NAL1 and LWC2. In the same way the same in Y-direction has maximum value of 0.04529 and minimum value of 0.002461 for the cases NAL2 and NC1.
4. The results hold good for story drift in all the cases only in the case of NAL2 the result is exceeding from 0.004, which is 0.004529. The reason behind this is homogeneity of the structure because of this the values are comparative higher in the cases of NAL i.e. when we consider Normal as well as light weight concrete together.

5. Base shear in X-direction is maximum in case of NC2 and NAL2, which is noted as 10212KN. In the same way the base shear in y-direction is max for Case NC2 and NAL2 which is 14447.6 KN.
6. Axial force in the column is maximum in LWC2, I.e. Light weight concrete with length equals to two times of the width. The maximum axial force is 244% higher than the minimum value obtained.
7. Shear force in X-direction has maximum value of 702.46 KN while in Y-direction maximum shear force is found to be 401.88 KN for the case NAL2, which is normal concrete with light weight concrete and length is double of its width.
8. Bending moment in columns in x-direction is maximum for the case NAL2 with the moment of 923.50KN-m, the min. value for the same direction is found to be 430.68 KN-m for the case LWC2.
9. Bending moment in columns in Y-direction is maximum for the case LWC2 with the moment of 1266.87KN-m, the min. value for the same direction is found to be 599.03 KN-m for the case LWC1.
10. In beams the shear force is maximum in x direction which is 413.89 KN for case NAL2 and the same in Y-direction are very less or negligible.
11. In beams the bending moment is maximum in Y direction which is 566.89 KN-m for case NAL2 and the same in X-direction are very less or negligible.
12. The maximum value of principal stress is 13.85N/sq. mm for the case LWC2, while minimum for the case NC1 which is 3.19 N/sq. mm.
13. Looking into von-mises stresses we get to know that NC1 is performing best with the value of 6.73 N/Sq. mm, while LWC2 is not performing as desired with the value of 13.72 N/Sq. mm.
14. Looking into shearing stresses we get to know that LWC1 and NC1 is performing best with almost similar values of 1.77 N/Sq. mm and 1.63 N/Sq. mm, while LWC2 is not performing as desired with the value of 7.2 N/Sq. mm.

References

1. Abrar ahmad, m. R. (2020). Comparative study on seismic analysis and design of high-rise buildings using static and dynamic analysis by etabs. *Integrating innovation & sustainability in civil engineering*, 1-8.
2. Alaettin kılıc¸, c. D. (2003). High-strength lightweight concrete made with scoria aggregate containing mineral admixtures. *Cement and concrete research*, 1595-1599.
3. Bhuvneshwari. K, d. D. (2017). Experimental study on lightweight concrete using perlite. *International research journal of engineering and technology (irjet)*, 2451-2455.
4. Cement andconcrete sectional committee, c. 2. (2005). Plain and reinforced concrete -code of practice. *Bureau of indian standards*.
5. *Computers and structures, inc.* (2022). Retrieved from https://www.csiamerica.com/: https://www.csiamerica.com/news
6. John p. Ries, g. M. (2003). *Guide for structural lightweight-aggregate concrete.* Aci committee report.
7. Mohammad smadi, e. M. (1991). Properties of high strength tuff lightweight aggregate concrete . *Cement & concrete composites*, 129-135.
8. Murat emre dilli, h. N. (2015). A comparison of strength and elastic properties between conventional and lightweight structural concretes designed with expanded clay aggregates. *Construction and building materials*, 260-267.
9. Vignesh kini k, r. S. (2017). Comparison of response spectrum analysis and construction sequence analysis of rc and steel-concrete composite multi-storey building with floating columns. *Ijret: international journal of research in engineering and technology*, 63-68.
10. Vijay kumar, d. S. (2020). Seismic analysis of high rise building (g+10) using etabs. *International research journal of engineering and technology (irjet)*, 3337-3344.
11. Werasak raongjant, m. J. (2009). Analysis modelling of seismic behaviour of lightweight concrete shear walls. *Proceedings of the international multiconference of engineers and computer scientists*, 1-6.
12. Zhidong gao, m. Z. (2021). A generalized response spectrum method for seismic response analysis of underground structure combined with viscous-spring artificial boundary. *Soil dynamics and earthquake engineering*, 1-12.