e-ISSN: 2582-5208
International Research Journal of Modernization in Engineering Technology and Science
(Peer-Reviewed, Open Access, Fully Refereed International Journal)
Volume:05/Issue:07/July-2023 Impact Factor- 7.868 www.irjmets.com

FLOOD RESISTANT DESIGN OF THE RC MULTI-STORY BUILDING

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DOI : https://www.doi.org/10.56726/IRJMETS43422

ABSTRACT

Structural analysis and design are the backbone or the crucial aspects in civil engineering. The foremost important requirement in civil engineering is to design all of the members related to a building such as slabs, beams, columns and footings. The residential building is situated in the Sitamarhi district of Bihar state. The model has been prepared for G+5 residential building with shear wall and without shear wall at the basement level which will protect the structure from underground water level and seepage. The work is carried out for flood non- coastal zone A. This is checked for different static and dynamic loads like Hydrostatic, Hydrodynamic, Impact load, Wave loads, etc with the help of SAP2000 software. Structural analysis and designing of the building is carried out according to the relevant IS codes, American codes, SAP2000 software. Taking into account all these constraints proper designing must be done as per IS 456:2000, ASCE 24-14 and ASCE 7-16 codes. The results are compared for earthquake, wind and flood loads with and without shear walls. For the upcoming flood loads, effects at the base are analyzed and the footing are designed accordingly using SAFE 20.0.3.

Keywords: Structural Analysis, SAP2000, SAFE 20.0.3, Flood Resistant Structure, Indian Standard Code, American Codes.

I. INTRODUCTION

Many states in India have large amounts of water in form of rivers and lakes. The melting of ice and increase in population will increase the frequency of floods and the sea level rise also increases the danger to coastal and riverside buildings. When floods occurred in 2018 in Kerala, conventional types of housing structures easily collapsed. The numbers of damaged houses were so high that it became necessary for the government rebuilds the houses for the affected ones.

A flood can be defined as a condition in which that land is submerged in water which is normally used to be dry. It can be attributed to an unusually high stage of a river or other water bodies like lakes, oceans, etc. during which the water spills over the bank and spread to the adjoining land. The low-lying area adjacent to a river bank is called a flood plain, which is formed mainly of the sediments of the river and consists of very fertile soil. In the case of flood, the water spills to the flood plains which are thickly populated due to the advantages of good water availability and fertility of the land for irrigation purposes. The flood condition can occur due to various reasons depending upon the location of the concerned area and the primary cause of the accumulation of water which cannot be accommodated naturally. For flat or low-lying land with infiltration or runoff rate lesser than the rate of precipitation, water can accumulate resulting in a flood situation. Due to different natural phenomena like rainfall lasting for a longer period of time, monsoon season, tropical cyclones or a large amount of rapid snowmelt flood situations can occur in rivers or other drainage.



Fig No 1: Bihar flood

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1.1 Reasons of occurrence of flood

1. Infiltration or run-off rate will be lesser than the rate of precipitation in a flat or low lying land.
2. High water level due to strong storms combines with natural high tide in coastal areas.
3. In urban areas, due to improper drainage systems and high precipitation, water can accumulate in the streets and can backflow into building through sewer pipes when rainfall is higher than drainage capacity.
4. Rainfall, monsoon, and tropical cyclones lasting for a longer period of time than usual.
5. Condition of flood worsens in case of infrastructure failures like dam mismanagement.

1.2 Methods of flood proofing

Dry flood proofing (clause no 6.2 pg.no 21 ASCE 24-14)

Dry flood proofing shall be accomplished through the use of flood damage-resistant material and techniques that render the dry flood proofed portion of a structure substantially impermeable to the passage of floodwater below the elevation.

Dry flood proofing requirements

Walls, floors, and flood shields shall be designed and constructed to resist hydrostatic, hydrodynamic, and other flood-related loads including effects of buoyancy resulting from the flood.

Any soil, fill adjustment to the structure compacted & protected against erosion & local scour. At least one door satisfying building code requirements for exit door or window & other meeting building criteria.

Wet flood proofing (clause no 6.2 pg.no 21 ASCE 24-14)

Limitation on wet flood proofing:

Flood design class 1 structure.

Enclosures used solely for parking vehicles, building access, or storage.

Structure that is functionally dependent on close proximity to water.

Agricultural structures not included in flood design class 1

Wet flood proofing requirements:

Use of techniques that minimize damage to the structure associated with flood loads.

Meeting requirements are depending on the flood hazard area.

1.3 Objective

1. To design the structure to resist earthquake load and flood load with shear wall and without shear wall.
2. To find the effect of flood loads on the structure.
3. To compare the result obtained from the model with shear wall and without shear wall in terms of displacement, etc.
4. To design a raft foundation to resist the coming flood load.

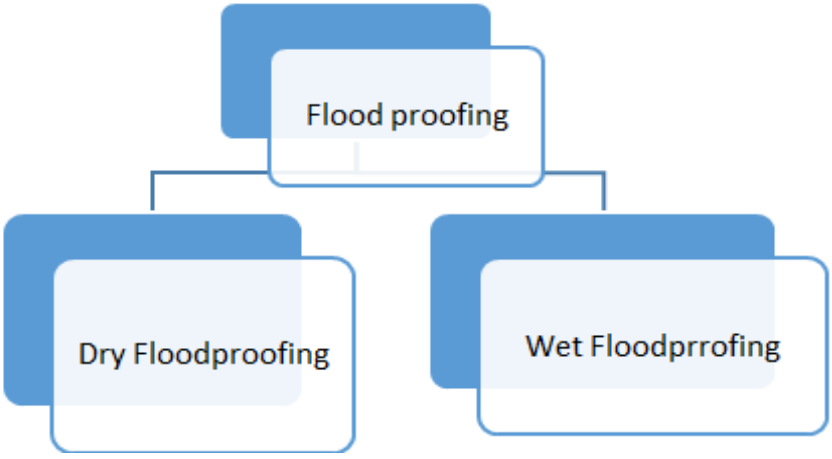


Fig No: 2

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II. RESEARCH METHODOLOGY

2.1 Description of the model

Table No 1: Description of modal

No of bays in X- direction	5
No of bays in Y- direction	5
Width of a single bay in both directions	4 m
No of story	6
Height of each story	3m and 3.1m
Grade of concrete	M40
Grade of steel	HYSD500
Wall thickness	200 mm
Slab thickness	160 mm
Live Load	2 kN/m^2
Floor finish	1.5 kN/m^2
Waterproofing	1 kN/m^2
Plan size	16 x 16 m

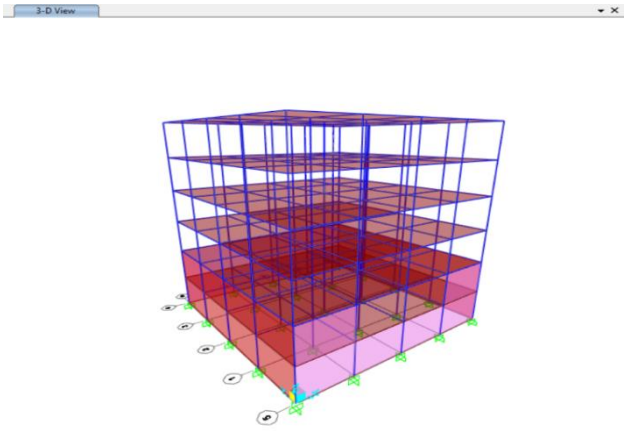


Fig No 3: Plan view with RCC wall

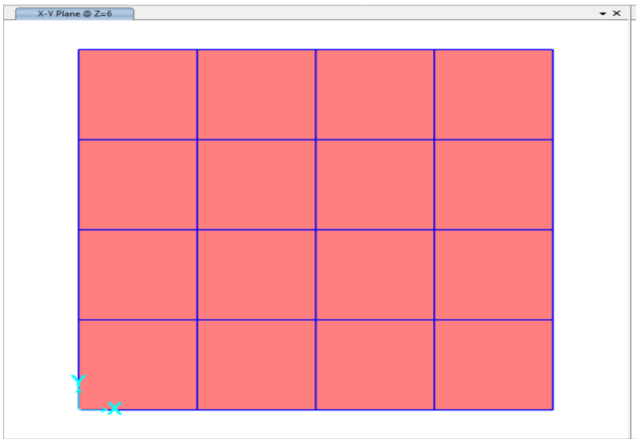


Fig No 4: 3D view with RCC Wall

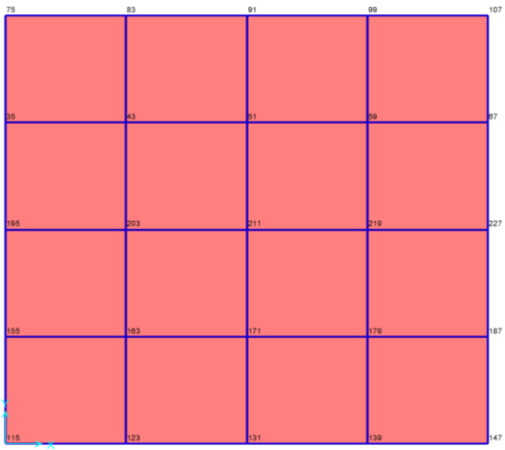


Fig No 5: Plan view with RCC frame structure

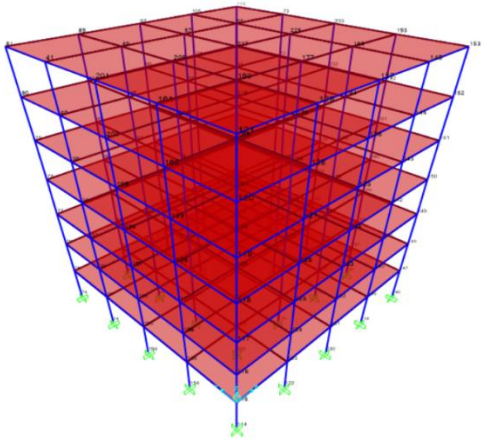


Fig No 6: 3D view with RCC frame structure

2.2 Earthquake Load calculation

- Grade of concrete: M40

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- Grade of steel: HYSD 415 (Confined Bar) and HYSD500 (Longitudinal Bar)
- Seismic zone: V Sitamarhi (Bihar)
- Zone factor : 0.36
- Importance factor: 1.2(as per IS 875 part 3 2015 Cl.7.2.3)
- Response reduction factor: 5 (as per IS 875 part 3 2015 Cl.7.2.6)
- Wall loading

- Outer wall = 0.23x20x(3.1-0.6) = 11.5 kN
- Interior wall= 0.15x20x(3.1-0.6) = 7.5 kN
- Outer wall = 0.23x20x(3-0.6) = 11.04 kN
- Interior wall= 0.15x20x(3-0.6) = 7.2 kN
- Parapet wall = 0.23x20x1.2 = 5.52 kN

$$\text{Time period} = \frac{0.09h}{\sqrt{d}}$$

$$\text{Time period} = \frac{0.09 * 18.4}{\sqrt{16}}$$

$$\text{Time period} = 0.414 \text{ sec}$$

2.3 Wind Load calculation

Location – Sitamarhi (Bihar)
Basic wind speed Vb = 47 m/s (As per Appendix A of IS 875 part 3 2015)
Design life of the structure = 50 years all general building
Risk coefficient (Table no 1 of IS 875 part 3 2015) K1 = 1
Terrain & height factor (Table 2 of IS 875 part 3 2015). For terrain category 2 and for height 18.40 m.

Table No 2: Terrain and roughness and height factor

Height	K2
0 to 10 m	0.91
10 to 15 m	0.97
15 to 20 m	1.01

Topography factor (Clause 6.3.3 of IS 875 part 3 2015) K3 = 1
For slope $3^0 < \theta < 17^0$ (Annex C)
Importance factor for cyclonic region

- Nature of the site = Cyclonic
- Structure type: All other structure (General) K4 = 1 (Cl 6.3.4 of IS 875 part 3 2015)

Design wind speed $V_z = V_b \times K1 \times K2 \times K3 \times K4$

$V_z = 47 \times 1 \times 1 \times 1 \times 1$

$V_z = 47$ m/s

Design wind pressure $P_d = K_a \times K_d \times K_c \times P_z$
P_d = Design wind pressure
K_a = Area of Averaging factor
K_d = wind directionality factor for building as per clause 7.2.1 of IS 875 part 3 2015 K_d = 1
K_c = combination factor as per clause 7.3.3.13 for frames over the building envelope when roof is subjected to pressure and internal pressure is suction or vice-versa 0.90
Wind pressure $P_z = 0.6 \times (V_z)^2$
Wind force $F = C_f \times A_e \times p_d$
C_f – force coefficient (Fig 4 of IS 875 part 3- 2015)
A_e – Effective frontal area A_e for 1m width may be taken as centre to centre of frame x 1m height

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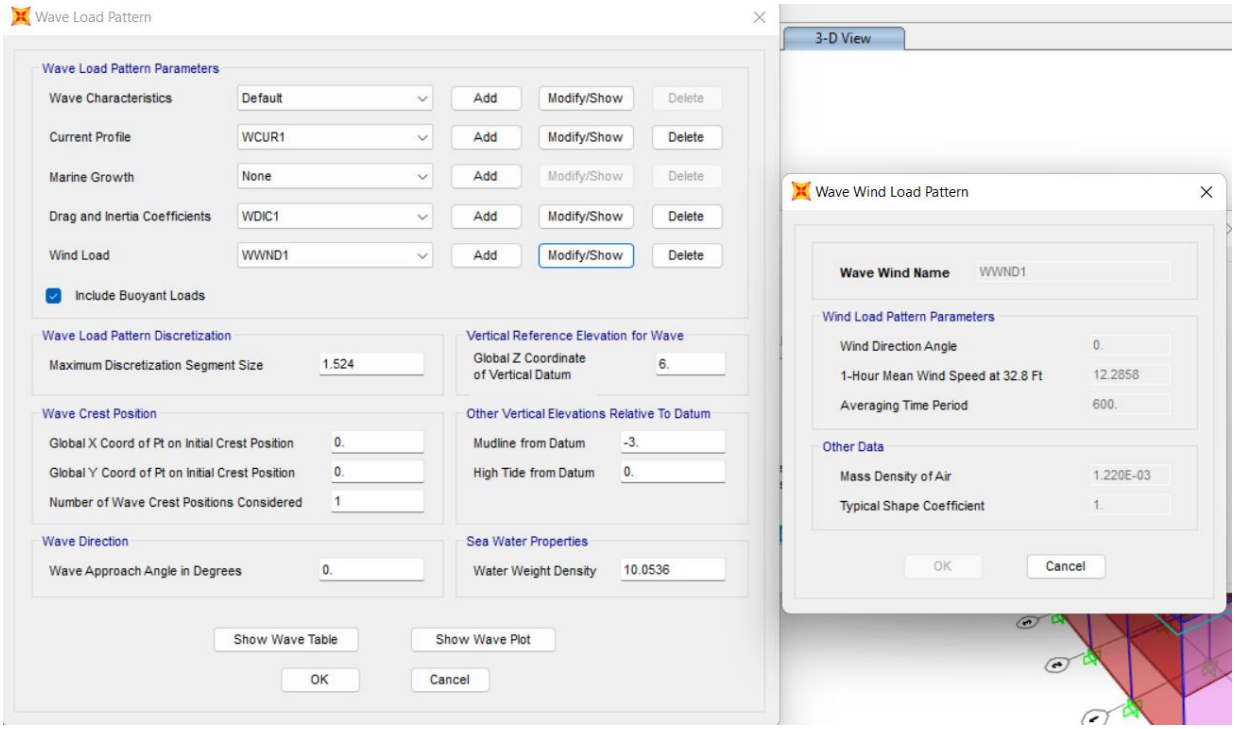


Fig No 7: Details of Wave load

Wave characteristics

The two-dimensional regular wave kinematics from Stream Function or Stokes 5th wave theory do not account for wave directional spreading or irregularity in wave profile shape. These "real world" wave characteristics can be approximately modelled in deterministic wave analyses by multiplying the horizontal velocities and accelerations from the two-dimensional regular wave solution by a wave kinematics factor. Wave kinematics measurements support a factor in the range 0.85 to 0.95 for tropical storms and 0.95 to 1.00 for extra-tropical storms.

Current blockage factor

The current speed in the vicinity of the platform is reduced from the specified "free stream" value by blockage. In other words, the presence of the structure causes the incident flow to diverge; some of the incident flow goes around the structure rather than through it, and the current speed within the structure is reduced. Since global platform loads are determined by summing local loads from Morison's equation, the appropriate local current speed should be used.

Marine growth

All structural members, conductors, risers, and appurtenances should be increased in cross-sectional area to account for marine growth thickness. Also, elements with circular cross-sections should be classified as either "smooth" or "rough" depending on the Amount of marine growth expected to have accumulated on them at the time of the loading event. Specific marine growth profiles are provided for U.S. waters.

Drag and Inertia coefficients

For typical design situations, global platform wave forces can be calculated using the following values for circular and rectangular column:

Cd for square and rectangular column = 2.25

Cd for circular column = 1.75

Inertia = 1.5

Wind loads

One hour min wind speed at 10 m $V2H = Kzi\ x\ Vb$

$$Kzi = 0.1423\left(log\left(\frac{Z}{Zoi}\right)\right)x\ (Zoi)^{0.0706}$$

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$$Kzi = 0.1423\left(log\left(\frac{10}{0.02}\right)\right)x\ (0.02)^{0.0706}$$

$$Kzi = 0.2914$$

$$V2H = 0.2914\ x\ 47$$

$$V2H = 12.2858\ \text{m/s}$$

Wave loads shall be included for both V-Zones and A-Zones. In V-Zones, waves are 3 ft (0.91 m) high, or higher; in coastal floodplains landward of the V-Zone, waves are less than 3 ft high (0.91 m). As per ASCE 7-16 cl.no 5.4.4 pg.no 22.

$Wave\ height = 0.65m$ < 0.91m (considered as A-zone)

>0.91m (considered as V- zone)

$$Flood\ Velocity\ for\ hydrostatic = \frac{ds}{1}$$

$$Flood\ Velocity\ for\ hydrostatic = \frac{3}{1}$$

$$Flood\ Velocity\ for\ hydrostatic = 3\ m/s$$

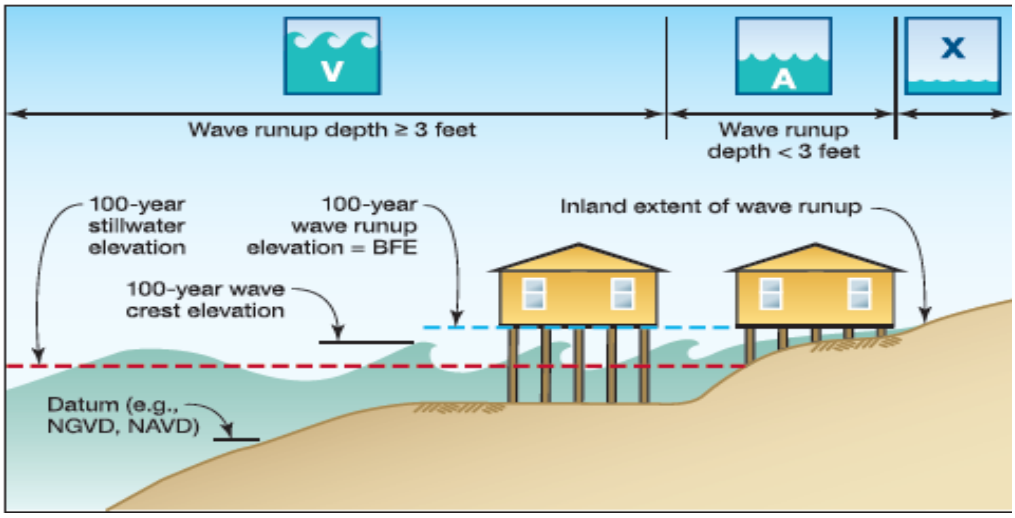


Fig No 8: Flood zones as per ASCE 7-16

Impact Load

Impact loads result from debris, ice, and any object transported by floodwaters striking against buildings and structures, or parts thereof. Impact loads shall be determined using a rational approach as concentrated loads acting horizontally at the most critical location at or below the DFE. There are three types of impact load as per US army crops.

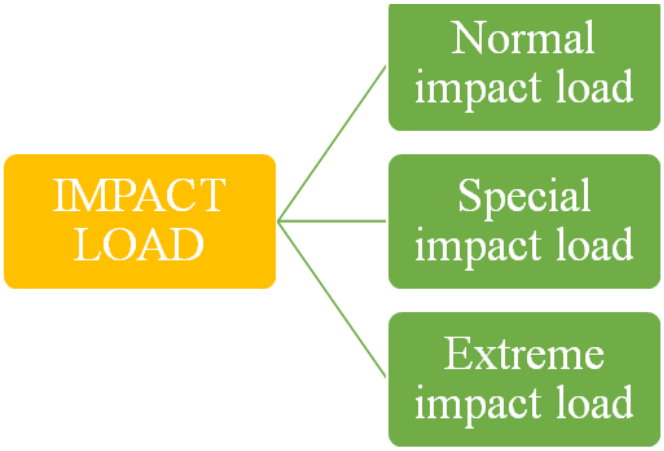


Fig No 9: Types of impact load

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$$Special\ Impact\ load = \left(\frac{1}{2}\right) x\ Cd\ x\ \gamma_w\ x\ V^2$$

$$Special\ Impact\ load = 0.5\ x\ 1\ x\ 10.05\ x\ 5.424^2$$

$$Special\ Impact\ load = 147.83\ kN/m^2$$

Wave load on shear wall:

$Wave\ load\ on\ shear\ wall\ P_{max} = Cp \times \Upsilon_w \times ds + 1.2 \times \Upsilon_w \times ds$

$Wave\ load\ on\ shear\ wall\ P_{max} = 2.8 \times 10.05 \times 3 + 1.2 \times 10.05 \times 3$

$Wave\ load\ on\ shear\ wall\ P_{max} = 120.42\ kN/m^2$

Cp – Risk category of building as per ASCE 7-16 Table no 1.5.1

Υ_w- Density of water

ds – Still water depth

P_{max}- Combined dynamic and static wave pressure

Table 5.4-1 Value of Dynamic Pressure Coefficient, C_p

Risk Category[a]	C_p
I	1.6
II	2.8
III	3.2
IV	3.5

[a]For Risk Category, see Table 1.5-1.

STANDARD ASCE/SEI 7-16

Fig No 10: Dynamic pressure coefficient

Table 1.5-1 Risk Category of Buildings and Other Structures for Flood, Wind, Snow, Earthquake, and Ice Loads

Use or Occupancy of Buildings and Structures	Risk Category
Buildings and other structures that represent low risk to human life in the event of failure	I
All buildings and other structures except those listed in Risk Categories I, III, and IV	II
Buildings and other structures, the failure of which could pose a substantial risk to human life	III
Buildings and other structures, not included in Risk Category IV, with potential to cause a substantial economic impact and/or mass disruption of day-to-day civilian life in the event of failure	
Buildings and other structures not included in Risk Category IV (including, but not limited to, facilities that manufacture, process, handle, store, use, or dispose of such substances as hazardous fuels, hazardous chemicals, hazardous waste, or explosives) containing toxic or explosive substances where the quantity of the material exceeds a threshold quantity established by the Authority Having Jurisdiction and is sufficient to pose a threat to the public if released[a]	
Buildings and other structures designated as essential facilities	IV
Buildings and other structures, the failure of which could pose a substantial hazard to the community Buildings and other structures (including, but not limited to, facilities that manufacture, process, handle, store, use, or dispose of such substances as hazardous fuels, hazardous chemicals, or hazardous waste) containing sufficient quantities of highly toxic substances where the quantity of the material exceeds a threshold quantity established by the Authority Having Jurisdiction and is sufficient to pose a threat to the public if released[a]	
Buildings and other structures required to maintain the functionality of other Risk Category IV structures	

Fig No 11: Risk category of building

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2.5 Flood load combinations

Table No 3: Flood load combinations

FLOOD LOAD COMBINATION	
Load combination as per ASCE 7-16	Convert as per Indian condition
1.4 D	1.5DL+1.5LL
1.2D+1.6L+0.5(Lr Or S Or R)	1.5DL+1.5EQx , EQy
1.2D+1.6(Lr Or S Or R)+(L Or 0.5W)	1.5DL+1.5WLx, WLy
1.2D+1W+L+0.5(Lr Or S Or R)	1.2DL+1.2LL+1.2WL
1.2D-1W+L+0.5(Lr Or S Or R)	1.2DL+1.2LL-1.2WL
1.2D+1E+L+0.2S	1.2DL+1.2LL+1.2EQ
1.2D-1E+L+0.2S	1.2DL+1.2LL-1.2EQ
0.9D+1W	0.9DL+1.5WL
0.9D-1W	0.9DL-1.5WL
0.9D+1E	0.9DL+1.5EQ
0.9D-1E	0.9DL-1.5EQ
LOAD COMBINATION FOR NON-COASTAL FLOOD ZONE A & V	
1.2D+0.5Wx+1Fa+L+0.5(Lr Or S Or R)	1.2DL+1.2LL+0.6Wx+1.2Fa
1.2D+0.5Wy+1Fa+L+0.5(Lr Or S Or R)	1.2DL+1.2LL+0.6Wy+1.2Fa
1.2D-0.5Wx+1Fa+L+0.5(Lr Or S Or R)	1.2DL-1.2LL+0.6Wx+1.2Fa
1.2D-0.5Wy+1Fa+L+0.5(Lr Or S Or R)	1.2DL-1.2LL+0.6Wy+1.2Fa
0.9D+0.5Wx+1Fa	0.9DL+0.75Wx+1.5Fa
0.9D+0.5Wy+1Fa	0.9DL+0.75Wy+1.5Fa
0.9D-0.5Wx+1Fa	0.9DL-0.75Wx+1.5Fa
0.9D-0.5Wy+1Fa	0.9DL-0.75Wy+1.5Fa
LOAD COMBINATION FOR COASTAL FLOOD ZONE A & V	
1.2D+1Wx+2Fa+L+0.5(Lr Or S Or R)	1.2DL+1.2LL+1.2Wx+2.4Fa
1.2D+1Wy+2Fa+L+0.5(Lr Or S Or R)	1.2DL+1.2LL+1.2Wy+2.4Fa
1.2D-1Wx+2Fa+L+0.5(Lr Or S Or R)	1.2DL-1.2LL+1.2Wx+2.4Fa
1.2D-1Wy+2Fa+L+0.5(Lr Or S Or R)	1.2DL-1.2LL+1.2Wy+2.4Fa
0.9D+1Wx+2Fa	0.9DL+1.5Wx+3Fa
0.9D+1Wy+2Fa	0.9DL+1.5Wy+3Fa
0.9D-1Wx+2Fa	0.9DL-1.5Wx+3Fa
0.9D-1Wy+2Fa	0.9DL-1.5Wy+3Fa

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IV. RESULTS AND DISCUSSION

3.1 Comparison of model with SW model

Table No 4: Comparison of displacement with SW

COMPARSION OF STOREY DISPLACEMENT WITH SW MODEL							
Story	**Elevation**	**X-Dir. G+WL**	**X-Dir. Fa+G+WL**	**X-Dir. EQ+G**	**Y-Dir. G+WL**	**Y-Dir. Fa+G+WL**	**Y-Dir. EQ+G**
	m		mm	mm		mm	mm
TERRACE	18.4	24.454507	27.544364	30.98255	0.148951	19.543033	24.41822
FOURTH	15.3	22.523266	25.20756	26.90277	0.083007	17.993331	22.60599
THIRD	12.2	18.789026	20.740929	20.7875	0.070711	14.964992	19.63279
SECOND	9.1	13.281533	16.149327	15.80212	0.027306	10.467559	13.15184
FIRST	6	6.260923	10.691868	11.45767	0.009494	4.748833	5.321713
GROUND	3	0.139341	29.6235	7.140853	0.007515	0.080774	0.372783
BASE	0	0	0	0	0	0	0

As the height of the structure is 18.4m, the overall deflection should not exceed the permissible limit H/500 which is 36.8mm. Maximum displacement observed in earthquake model but in flood model maximum displacement occurred at ground level because to the flood acting on ground level shear wall .The observed deflection is not exceeding the allowable.

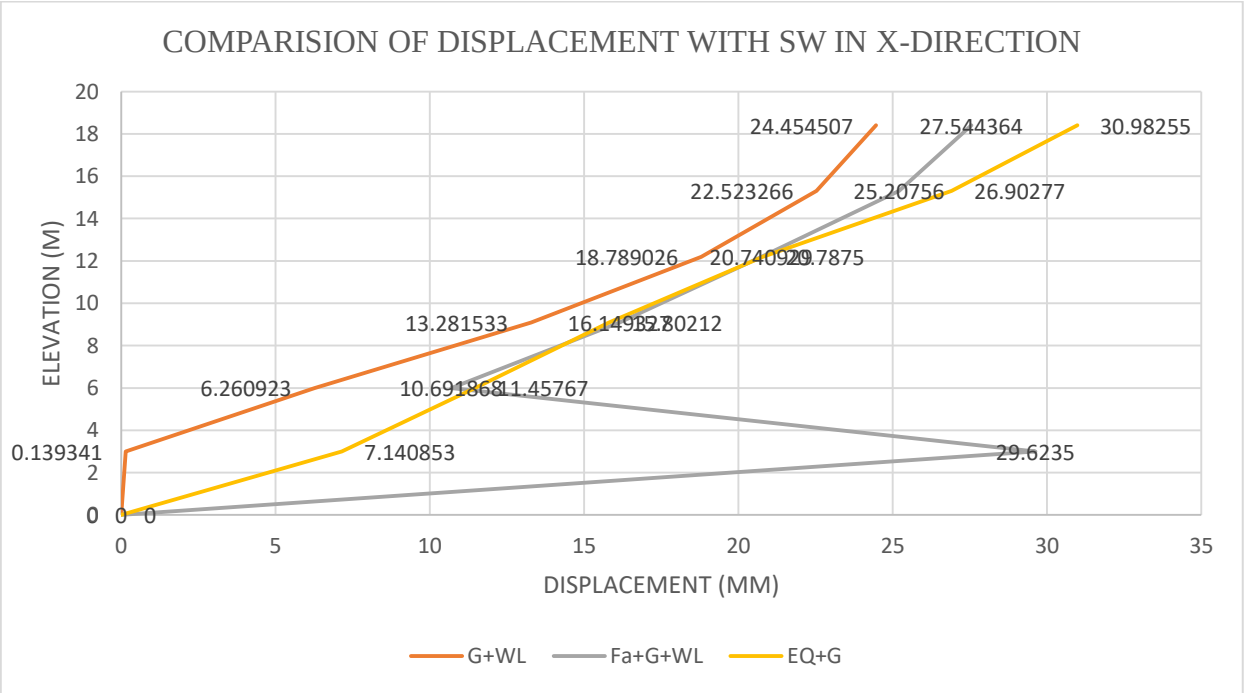


Fig No 12: Comparison of displacement with SW in X-direction

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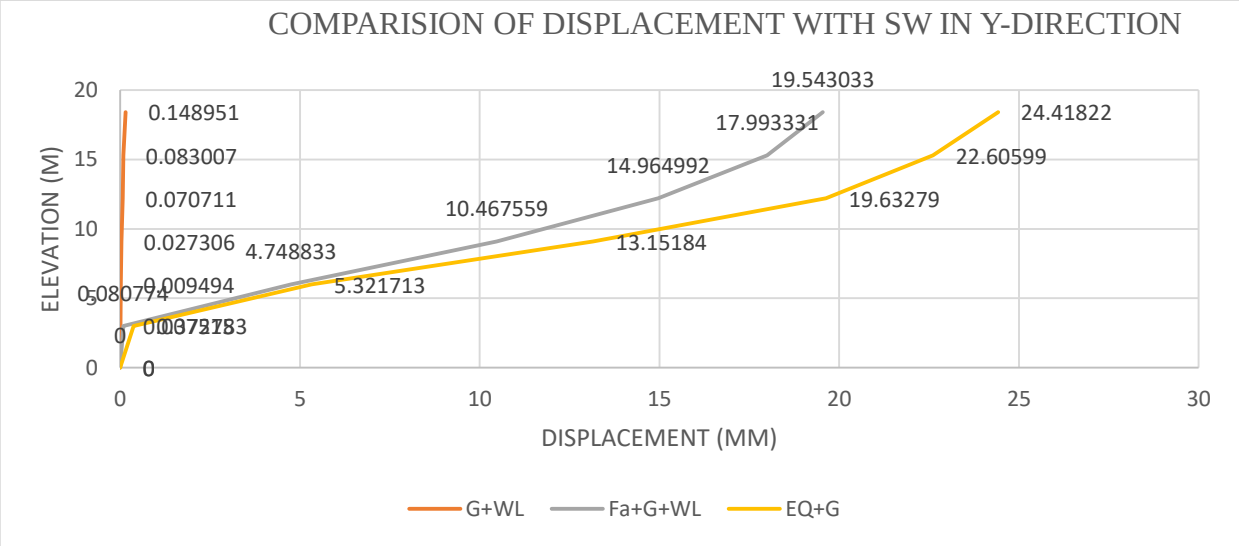


Fig No 13: Comparison of displacement with SW in Y-direction

3.1 Comparison of model without SW model

Table No 5: Comparison of displacement without SW

COMPARISION OF DISPLACEMENT WITHOUT SHEAR WALL MODEL							
Story	**Elevation**	**X-Dir G+WL**	**X-Dir EQ+G**	**X-Dir Fa+G+WL**	**Y-Dir G+WL**	**Y-Dir EQ+G**	**Y-Dir Fa+G+WL**
	m	mm	mm	mm	mm	mm	Mm
TERRACE	18.4	26.244264	35.5189	31.413125	0.194725	31.23218	22.6614
FOURTH	15.3	25.020477	33.3019	31.219093	0.193405	29.00581	21.4273
THIRD	12.2	22.703126	27.53744	30.961403	0.175309	23.26281	17.0559
SECOND	9.1	19.298994	20.8459	30.620127	0.066294	16.42756	15.3962
FIRST	6	14.88397	14.93491	30.051487	0.050123	6.601614	8.6144
GROUND	3	9.856834	9.498316	27.892106	0.046153	0.433216	4.7286
BASE	0	0	0	0	0	0	0

As the height of the structure is 18.4m, the overall deflection should not exceed the permissible limit H/500 which is 36.8mm. Maximum displacement observed in without shear wall model as compared to with shear wall model. The observed deflection is not exceeding the allowable.

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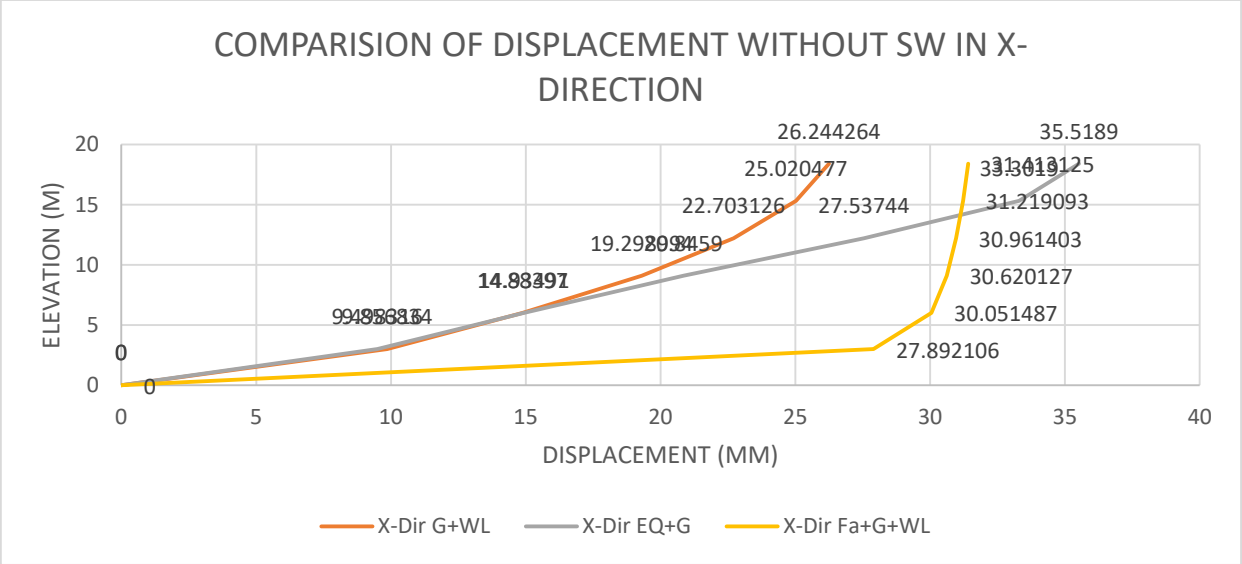


Fig No 14: Comparison of displacement without SW in X-direction

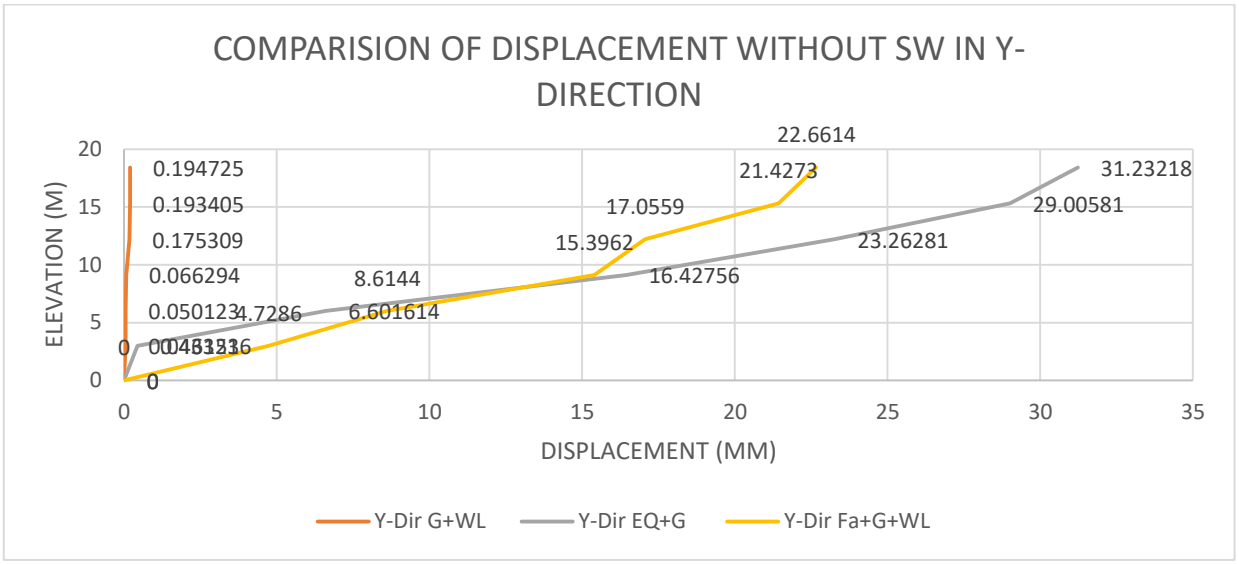


Fig No 15: Comparison of displacement without SW in Y-direction

3.3 Comparison of with & without SW model

Table No 6: Comparison of with & without SW model

DISPLACEMENT FLOOD MODEL WITH AND WITHOUT SHEAR WALL					
Story	**Elevation**	**X-Dir without sw**	**X-Dir with sw**	**Y-Dir without sw**	**Y-Dir with sw**
	M	**mm**	**mm**	**mm**	**mm**
TERRACE	**18.4**	**31.413125**	**27.544364**	**22.6614**	**19.543033**
FOURTH	**15.3**	**31.219093**	**25.20756**	**21.4273**	**17.993331**
THIRD	**12.2**	**30.961403**	**20.740929**	**17.0559**	**14.964992**
SECOND	**9.1**	**30.620127**	**16.149327**	**15.3962**	**10.467559**
FIRST	**6**	**30.051487**	**10.691868**	**8.6144**	**4.748833**
GROUND	**3**	**29.4658**	**29.6235**	**4.7286**	**0.080774**
BASE	**0**	**0**	**0**	**0**	**0**

e-ISSN: 2582-5208
International Research Journal of Modernization in Engineering Technology and Science
(Peer-Reviewed, Open Access, Fully Refereed International Journal)
Volume:05/Issue:07/July-2023 Impact Factor- 7.868 www.irjmets.com

As the height of the structure is 18.4m, the overall deflection should not exceed the permissible limit H/500 which is 36.8mm. Maximum displacement observed in without shear wall model as compared to with shear wall model. The observed deflection is not exceeding the allowable.

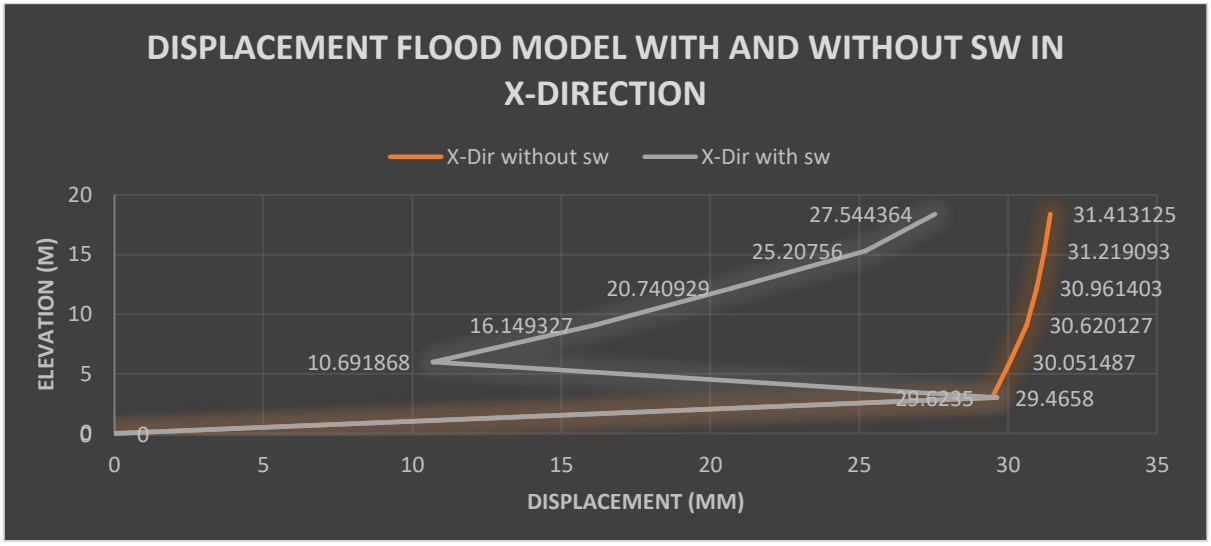


Fig No 16: Displacement of flood model with & without SW in X-direction

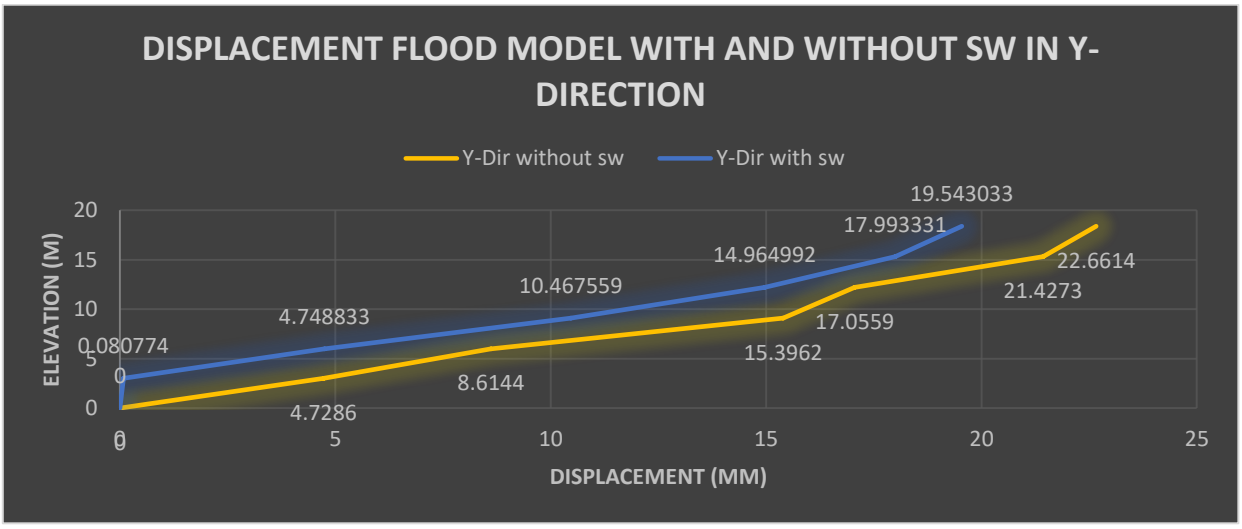


Fig No 17: Displacement of flood model with & without SW in Y-direction

3.4 Footing result with SW model

3.4.1 Soil Pressure

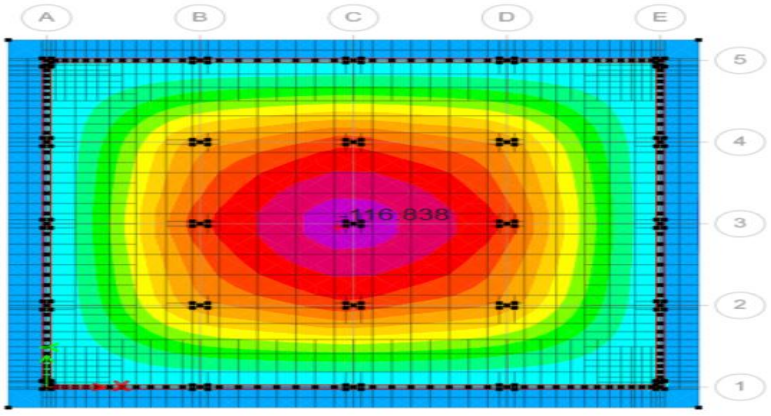


Fig No 18: Soil pressure with SW model

e-ISSN: 2582-5208
International Research Journal of Modernization in Engineering Technology and Science
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Maximum soil pressure exerted due to the building loads is 116.838 kN/m² which is less than the safe bearing capacity of 150kN/m². Hence, the structure is safe and within the limits.

3.4.2 Punching shear



Fig No 19: Punching shear with SW model

Maximum soil pressure exerted due to the building loads is 116.838 kN/m² which is less than the safe bearing capacity of 150kN/m². Hence, the structure is safe and within the limits.

3.4.3 Crack width

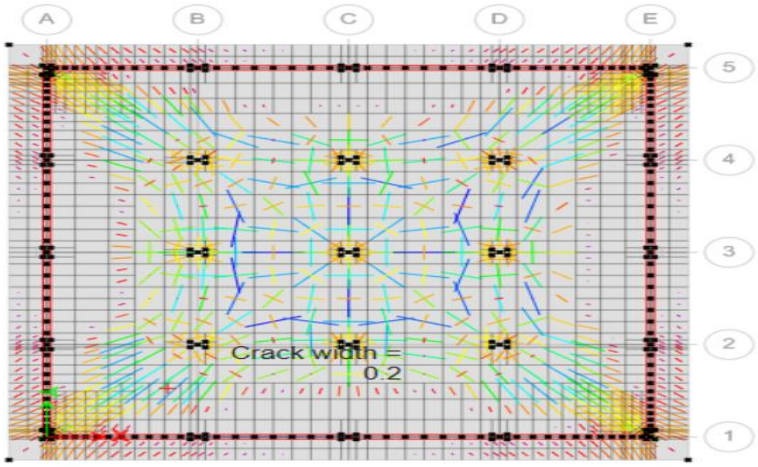


Fig No 20: Crack width with SW model

Maximum allowable crack width value according to exposure condition is 0.3 mm. The model with shear wall has crack width of 0.2mm which is less than maximum allowed. Hence, the structure is safe and within the limits.

3.5 Footing result without SW model

3.5.1 Soil Pressure

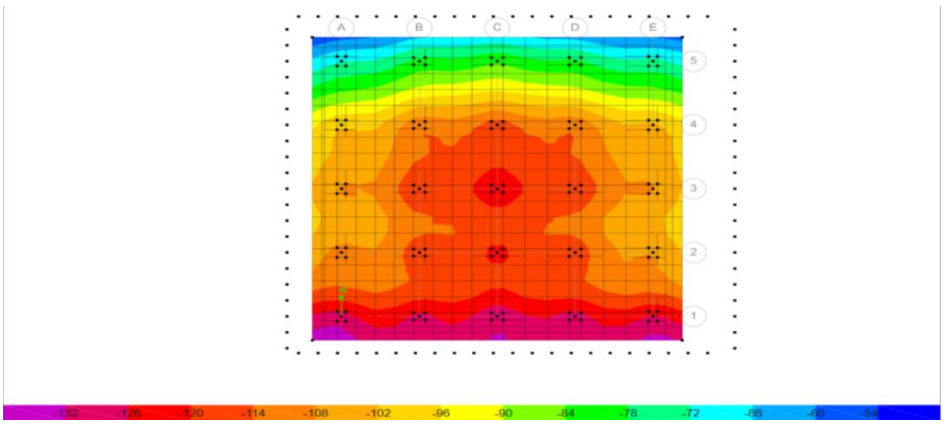


Fig No 21: Soil pressure without SW model

e-ISSN: 2582-5208
International Research Journal of Modernization in Engineering Technology and Science
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Volume:05/Issue:07/July-2023 Impact Factor- 7.868 www.irjmets.com

Maximum soil pressure exerted due to the building loads is 131.68 kN/m² which is less than the safe bearing capacity of 150kN/m². Hence, the structure is safe and within the limits.

3.5.2 Punching Shear

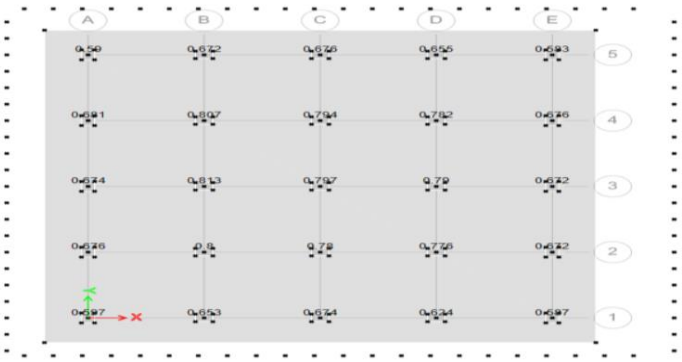


Fig No 22: Punching shear without SW model

Punching shear values for particular column must be less than 1. This criteria is satisfied for above model. Hence, the structure is safe and within the limits.

3.5.3 Crack width

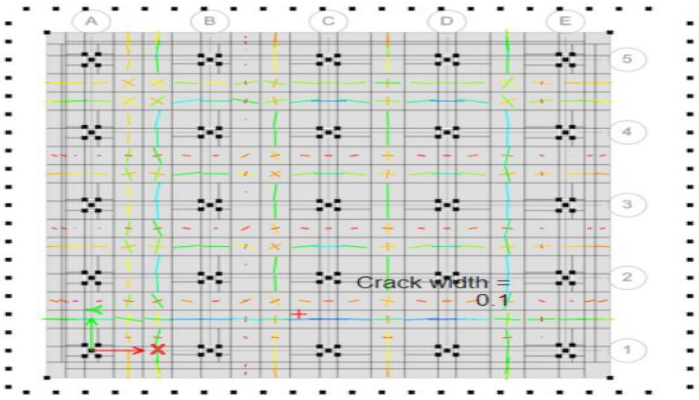


Fig No 23: Crack width without SW model

Maximum allowable crack width value according to exposure condition is 0.3 mm. the model with shear wall has crack width of 0.1mm which is less than maximum allowed. Hence, the structure is safe and within the limits.

- The project consists of a structure to be built in flood waters.
- American code ASCE 7-16, ASCE 24-14 is used and forces listed below are applied on the structure.
- The loads applied on the structure consist of

1) Flood load + wind load + Gravity
2) Earthquake load + Gravity
3) Gravity load + wind load

Table No 7:

Model condition		Gravity+Wind load	Gravity+Wind+Flood load	Gravity+Earthquake load
	Displacement	24.45 mm	27.544 mm	30.982 mm
Frame structure with RCC wall	Size of column	230 x300 mm	230 x 400 mm	400 x 600 mm
	Base shear	306.86 kN	869.29 kN	2154.96 kN
	Displacement	26.864 mm	36.435 mm	35.513 mm
Frame structure with RCC	Size of column	230 x 350 mm	450 x 600 mm	450 x 600 mm

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frame structure				
	Base shear	306.86 kN	395.26 kN	2065.9 kN

V. CONCLUSION

1. In frame structure, with RCC wall in basement model, displacement is more in Gravity + earthquake load when compared to the other structure, also sizes of column are higher.
2. In the structure, with RCC wall (shear wall) model, Base shear is higher in gravity+ earthquake load case, since the weight of the structure has increased due to the weight of RCC shear walls as base shear depends on the seismic weight of the structure.
3. In frame structure with RCC columns exposed to flooding zone, displacement is more when gravity+ wind+ flood loads are applied on the structure whereas sizes of the column are the same in the earthquake and flood model and lower in the gravity +wind load model.
4. Shear wall reinforcement for the earthquake model is found to be 2.5% where as the for flood model its value is higher i.e. 3.2% due to flood loads acting on the wall.
5. The load combination as suggested by ASCE 7-16 is converted to Indian conditions with suitable load factors. These load combinations could be used for any future design of flood resistant building.

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