Analysis on Multiple Slab Types Flat Slab And Waffle Slab By Applying Finite Element Techniques

Nilaya Meshram[1], Prof. Sanjay Denge[2], Prof. Girish Sawai[3]
[1]Dept of Civil Engineering
[2, 3]Asst. Professor, Dept of Civil Engineering
[1, 2, 3] V.M. Institute of Technology Nagpur, Nagpur-Maharshtra, India

Abstract- *Food, cloth and shelter are the basic need of the human being. For the shelter the roof concept originated. But due to the rain or highly speedy wind, the roof is flied or collapsed so that the new concept originated i.e. slab structure. But in that time slab is made up of mud but it also not giving strength to the structure and it is not to be sustain the loading of the structure so that the concrete slab concept is generated. In this project the three type of slab is required i.e. conventional slab structure, flat slab structure and the waffle slab structure. The structure is modeled in ETABs-18 software whose story is G+11. The longitudinal and the lateral loading are applied to the structure for the stability check. The slab should be designed by the response spectrum analysis and also the pushover analysis. The rebar intensity for the designing of the slab is also calculated by the CSi-Detail software in which the position of the reinforcement is calculated and the estimated requirement of the material is also calculated. The pushover curve is plotted for the conventional slab, flat slab and the waffle slab. The hinge result is also calculated by the software.*

Keywords- Conventional Slab, ETABS-18, Flat Slab, Story Displacement, Rebar Intensity, Waffle Slab

I. INTRODUCTION

A slab is bolstered on two backings or more. On the off chance that the heap is conveyed one way it is delegated a one way Slab and henceforth, just need fortification toward this path. On the off chance that the heap is conveyed in two ways it is delegated a two-way slab and will along these lines need support in two ways. The measure of fortification can contrast in the various headings of the slab bringing about an alternate solidness and bearing limit in these headings.

A concrete slab is regular basic component of present day structures. Flat slabs of steel fortified cement, regularly somewhere in the range of (100 and 500 millimeters) thick are frequently used to develop floors and roofs. On the specialized drawings, fortified solid slabs are regularly condensed to "R.C.C. slab" or essentially "R.C.". A fortified solid slab is abroad flat plate typically with almost equal top and base surfaces and may upheld by strengthened solid shafts or straightforwardly by slabs or stone work block divider or fortified solid dividers (Shear dividers).

Types of RCC Slabs:

RCC slabs can be different sorts relying upon different measures. For example, ribbed slab, flat Slab, strong slab,nonstop slab, just upheld slab and so on. Today we will talk about the sorts of strong RCC slabs. For a suspended slab, there are various structures to improve the solidarity to-weight proportion. In all cases the top surface stays flat, and the underside is adjusted:

Corrugated, for the most part where the solid is filled a folded steel plate. This improves quality and forestalls the Slab bowing under its own weight. The creases stumble into the short measurement, from side to side.

- A ribbed slab, invigorating extensive extra on one bearing.
- A waffle slab, invigorating included the two bearings.
- A one way slab has basic quality most limited way.
- A two way Slab has auxiliary quality in two ways.

II. LITERATURE REVIEW

Pier Luigi Nervi

Conceived in 1891, Mr. Nervi moved on from the workforce of Civil Engineering, University of Bologna in 1913. In 1923 he began his own organization, himself filling the job of a planner and temporary worker. Mr. Nervi accepted that strengthened cement is the most delightful valuable framework that humanity ever found[8]. He likewise made a shell explicit adaptation of cement called 'Ferrocement' in the last long periods of his life.

Mr. Nervi has an amazing rundown of notorious structures in Italy. Around then in Italy significant common undertakings were given to contractual workers dependent on the recommendations they set forward. They were welcome to present their thoughts for the venture which was granted to the best generally speaking structure. This is the place Mr. Nervi was especially renowned for submitting recommendations which were delightful, efficient and modest to develop. His structures were grand combinations of science and craftsmanship. The opposition he won in 1930, for the planning the arena in Florence, is a genuine case of his inheritance.

Mr. Nervi is additionally known for his broad model testing procedures. He generally accepted that the estimation of instinct is crucial for a designing as it prompts development. His design for the 1935 Italian Air Force rivalry is a demonstration of this reality. Because of absence of hypothetical information and count instruments, he made a test celluloid model to comprehend worries in the structure all the more cautiously. He improved the model for the subsequent plan to consolidate ribs and stiffeners. He utilized preassembled components in this structure, something which had not been done previously.

Nicolas Esquillan

Mr. Esquillan, conceived in 1902 in France, was another pioneer in the field of shell structures. He was a functioning individual from IASS (International Association of Shell and Spatial Structures) and contributed essentially to the improvement of lightweight spatial structures. Most prominent undertakings incorporate a few record breaking long range spans, trailed by the superb CNIT finished in 1958, which remains the longest range shell structure till date. The subtleties of this task will be considered and talked about in following areas.

Heinz Isler

MrIsler was a swiss structural designer notable for dainty solid shell plan. He didn't manage long crossing shell structures. The vast majority of his activities had a range of 40-60 m, similar to the Burgi Garden Center and the SICLI Company building. Regardless, his work in the field of shape and structure finding was phenomenal during that time. One of his eminent commitments was in the main congress of IASS in 1959, where he presented the thoughts of "the unreservedly formed slope, the film under tension and hanging material turned around" in his introduction "New Shapes for Shells". It is additionally imperative to present Isler's perspectives on shell structures around then. He was uncommonly inquisitive about shells and shapes which happened in characteristic structure in the earth.

These included straightforward items like egg shells, onion strips and nuts to progressively complex shells obtanied from mollusks, shellfish, and so forth. He accepted that these characteristic structures, are the most efficient types of shells and saw them as "stiffened shells, twofold bended shells, pivot shells and a few different varieties".

Alaa C. Galeb, Zainab F. Atiyah, 2011

Two contextual analyses are discussed; the first is a waffle slab with strong heads, and the second is a waffle slab with a band that radiates along slab centrelines. The immediate plan technique is utilized for the primary examination and plan of slabs. The expense work addresses the expense of cement, steel, and formwork for the slab. The plan factors are taken as the successful profundity of the slab, ribs width, the dividing between ribs, the top slab thickness, the space of flexural support right now basic segments, the band radiates width, and the space of steel support of the pillars. The limitations remember the imperatives for measurements of the rib, the imperatives on the top slab thickness, the requirements on the spaces of steel support to fulfill the flexural and the base region prerequisites, the limitations on the slab thickness to fulfill flexural conduct, oblige support and give sufficient substantial cover, and the imperatives on the longitudinal support of band radiates. A PC program is composed utilizing MATLAB to play out the underlying investigation and plan of waffle slabs by the immediate plan strategy. The improvement cycle is done utilizing the underlying hereditary calculation tool stash of MATLAB.

Bhautik D. Jasoliya, maulik Kakadiya 2020

In R.C.C working without a shear divider, the bar and slab size is very weighty and there is a parcel of the clog of support at the joint it is hard to put and vibrate concrete at these spots and uproot is very substantial which prompts weighty powers in part. The examination is via completion of R.C.C working with the various posting of the shear divider on the floor plan by utilizing E-TABS programming. It gives the possibility of examination of R.C.C working with the various arrangements. The primary goal of quake engineers is to plan and fabricate a construction so that harm to the design during the tremor is limited. In multi-storeyed structures flat slab and waffle, slabs are by and large connected when segment dispersing is more. Flat slabs and waffle slabs are utilized in structures as prerequisites for seriously working spaces like business structures, studios, get-together structures, and so on. The fundamental inconvenience of designs with flat slabs and waffle slabs is their absence of withstanding seismic burdens. In this study are introduced the parts of a square formed waffle slab computation, upheld dependably and having a two-way post-tensioning support arranged allegorically. It is depicted the waffle slab framework, its attributes, starter plan of forming components, mechanical viewpoints with respect to the assembling of precast boards, insights about utilized materials, the support format, and the computation of prestressing power.

Shubham Sharma, Amritansh Sharma and Dr. Pankaj Singh June 2020

Waffle slab development comprises substantial joists at right points to one another with strong heads at the segment which is required for shear necessities or with strong wide pillar areas on the slab centrelines for uniform profundity development. Waffle slab development permits an extensive decrease in the dead heap of the general design when contrasted with flat slabs and ordinary RCC slabs. The thickness of waffle slabs can be limited to an extraordinary degree when contrasted with flat slabs and RCC slabs. The base part of the waffle slab has many square projections with ribs traversing in two ways. The ribs are built up with steel to oppose flexural ductile anxieties. The plan of the waffle slab is done in such a way as to accomplish better burden circulation. This paper manages a similar investigation of Waffle slabs with flat slabs and regular RCC slabs and features the benefits waffle slabs have over flat slabs and RCC slabs. This examination is displayed with the assistance of a contextual investigation by planning waffle slabs alongside flat slabs and RCC slabs with the assistance of IS 456-2000 and displayed with a correlation of different focuses.

Aashapak Rashid Shaikh, N.C. Dubey March 2020

Timoshenko's hypothesis of plates is utilized to assess plan minutes and shears happening in the ribs of a Grid floor precisely. Notwithstanding, it includes accepting extents of boundaries like separating of ribs, the thickness of the slab, and width of the rib which have a significant impact on the general economy of the Grid floor slab. The point of this review is to systematically discover the impact of these expected boundaries on the general economy of the design. Framework floors of sizes 12 m X 16 m, 14 m X 16 m, and 16 m X 16 m were intended for different elements of the slab, rib, and distinctive separating. The expense of every slab is assessed and collaboration bends are created. From this review, it tends to be presumed that the expense of the lattice floor would be least if the least thickness of slab, least width of ribs, and greatest dividing of ribs is embraced. Further, for the run-of-the-mill case considered, the estimated technique for Ranking - the Grashoff hypothesis thinks little of the minutes by around 20 %.

Mohammed J. Hussein, Hussain A. Jabir, Thaar S. Al-Gasham 2021

For this situation, the mechanical properties of slabs amazingly diminish, and reinforcement should be applied. Along these lines, this examination proposed four strategies to recover the lost mechanical attributes of slabs inferable from openings. Six built-up substantial slabs were ready with comparable measurements, 1300*1300*120 mm. One of them was a reference without opening, while the others contained a square edge opening of 350 mm side. For slabs with openings, one example was the control left without fortifying, and the excess four were fortified using different strategies, which were Carbon Fiber Reinforced Polymer (CFRP), steel plates, steel bars, and close surface mounted Engineered Cementations Composite (ECC) with steel network. The slabs were presented to consistently dispersed burden up to disappointment.

Jasim M. Mhalhal 2021

This work principally planned to contrast the air bubble slab tentatively and strong slabs affected by restricted rehashed four-point loads. In this manner, six slab strips were fabricated in similar structures, aside from the cross- segment type. Three were strong, and the others were voided due to putting 70 mm-distance across balls inside them. Likewise, the shear range to powerful profundity proportion (a/d) was additionally contemplated. In like manner, one slab from each kind was tried, with the a/d being either 2, 3.5, or 5. The applied burdens were rehashed ten cycles at a heap level of 25 kN, addressing 70 % of a definitive burden assessed by the ACI-19 code, and afterward endured bit by bit until the slabs fell. The outcomes recorded that the balls' quality caused slabs to flop unexpectedly because of shear mode paying little mind to the a/d. For a similar slab type, the slabs' solidarity, firmness, and sturdiness decreased as the a/d was expanded; all things considered, the flexibility showed a contrary pattern. Contrasted with strong similar, the air pocket slabs' mechanical estimations, barring the assistance solidness, dropped prominently.

III. METHODOLOGY

Method to evaluate Structure

Create a New Model

We will start a new model using the following steps:

1. Set the units to kN and meter, "kN-m", using the dropdown box in the lower right corner of the ETABS screen.
2. Select the File menu > New Model command.
3. Click the No button in the New Model Initialization form. This indicates that we do not wish to use a previous model as the starting point for this model.
4. This now opens the Building Plan Grid System and Story Data Definition form, where much of the definition of the structure takes place.
5. Following are the specification of building.
    - Grade of concrete- M 20
    - Zone factor (Z) -0.36
    - Grade of steel -Fe 500
    - Response reduction factor (R)- 5.0
    - Floor to floor height -3 m
    - Importance factor (I) -1.0
    - Ground floor height -3m
    - Soil type Medium soil- II
    - Dead load- 4.5 kN/m^2
    - Slab thickness -200 mm
    - Slab Type: 1. Conventional Slab 2. Flat Slab

    3. Waffle Slab
    - Columns -450 × 450 mm
    - Beams -300 × 450 mm
    - Live load on all floors -3 kN/m^2
    - Damping ratio- 5%

Fractional Safety Factors

The plan quality for cement and fortification is acquired by partitioning the trademark quality of the material by an incomplete wellbeing factor, γm. The estimations of γm utilized in the program are as per the following:

Fractional security factor for support, γs = 1.15 (IS 36.4.2.1)
Fractional security factor for concrete, γc = 1.5 (IS 36.4.2.1)

These variables are as of now consolidated into the plan conditions and tables in the code. These qualities can be overwritten; in any case, alert is prompted.

1. Set out the grid line with the 3 x 3 bays.
2. Draw base plan of building in the ETAB's 2018 and multiply of the story up to G+11th story. Each story height is defined as 3m and the height from base to plinth level is also 3m.

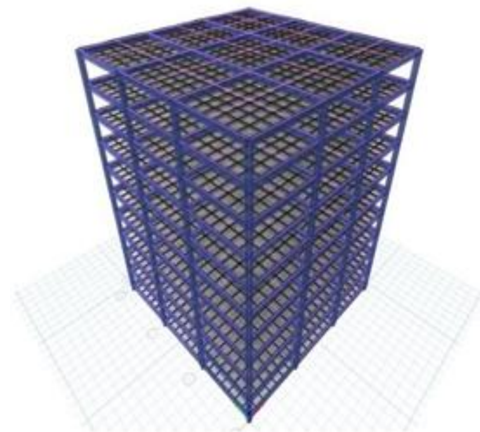


Figure 1. 3-D model of multi-storey building

3. Specify the material properties like M20 for slab, column and beam and HYSD 500 bar for reinforcement.

Table 1: Specification of Material Properties

Name	Type	EMPa	Unit WeightkN/m³	Design Strengths
HYSD500	Rebar	200000	76.9729	Fy=500 MPa, Fu=545 MPa
M20	Concrete	22360.68	24.9926	Fc=20 MPa

Table 1 Shows the specifion of material properties.

4. Specify the width and depth for column and beam for the building. As we were take 450mm x 450 mm size of column and 350mm x 450mm depth for beam. We apply the material properties for the column and beam and apply to the building.
5. We take torsional constant as 0.7 for column and 0.35 for the beam as we take always 50% by the column. And the moment of inertia for beam and column is 0.01 kN/m^2 about 2-2 and 3-3 axis respectively.
6. We introduced the slab portion as 150mm Shell thin thickness with HYSD500 bar.

IV. RESULTS

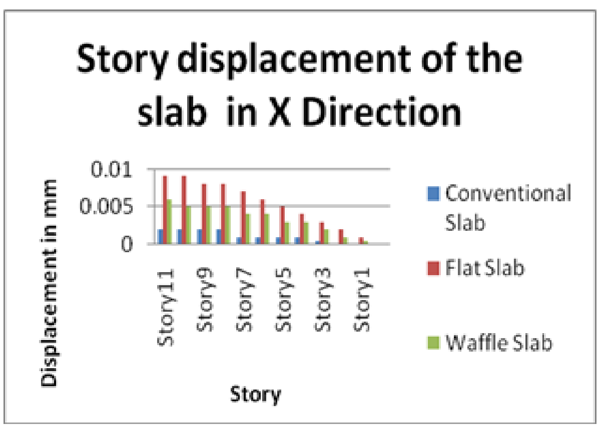
Story displacement

The longitudinal movement produce in the structure due to the application of the load is known as story displacement. In this the story displacement is occur due to the live load and earthquake load in X and Y direction respectively. As the maximum displacement occurs then the story is supposed to be collapsed and need to change the dimension of the structure. The following results are found after the analysis of the structure.

Table 2: Story displacement of the slab in X Direction

Story	Conventional Slab	Flat Slab	Waffle Slab
Story11	0.002	0.009	0.006
Story10	0.002	0.009	0.005
Story9	0.002	0.008	0.005
Story8	0.002	0.008	0.005
Story7	0.001	0.007	0.004
Story6	0.001	0.006	0.004
Story5	0.001	0.005	0.003
Story4	0.001	0.004	0.003
Story3	4.77E-04	0.003	0.002
Story2	2.17E-04	0.002	0.001
Story1	1.19E-05	0.001	4.92E-04
Base	0	0	0

Table No. 2 Shows story displacement of the slab in X-direction



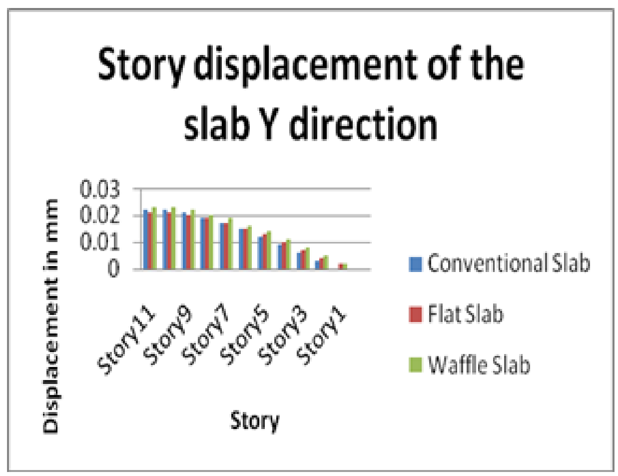
Graph 1: Comparative result of story displacement of the slab in X direction

The above graph 1 shows that the story displacement of slab in X-direction. In this graph the maximum displacement occur in flat slab as compare to the waffle slab and conventional slab. When the values are considered then the displacement occur is very less but when the comparison consider the values is maximum.

Table 3: Story displacement of the slab in Y Direction

Story	Conventional Slab	Flat Slab	Waffle Slab
Story11	0.022	0.021	0.023
Story10	0.022	0.021	0.023
Story9	0.021	0.02	0.022
Story8	0.019	0.019	0.02
Story7	0.017	0.017	0.019
Story6	0.015	0.015	0.016
Story5	0.012	0.013	0.014
Story4	0.009	0.01	0.011
Story3	0.006	0.007	0.008
Story2	0.003	0.004	0.005
Story1	1.46E-04	0.002	0.002
Base	0	0	0

Table No. 3 Shows story displacement of the slab in Y-direction



Graph 2: Comparative result of story displacement of the slab in Y direction

In the above graph 2, the displacement occurs due to earthquakes in Y-direction. The displacement of the waffle slab is more as compared to the conventional and flat slab. The maximum displacement in the waffle slab in the 11th story is 0.023mm and that of base displacement is negligible.

Rebar Intensity

The steel required for the construction of the slab. The thickness of the slab is depending upon the reinforcement. For different slab, different quantity of the reinforcement is required that is discussed in this section.

Conventional Slab

In the conventional slab the rebar intensity is minimum as per the dead and live load applied on the structure. The rebar intensity is depend upon the quality of slab, thickness of slab, load on slab. And type of slab. In the conventional slab following type of rebar is required.

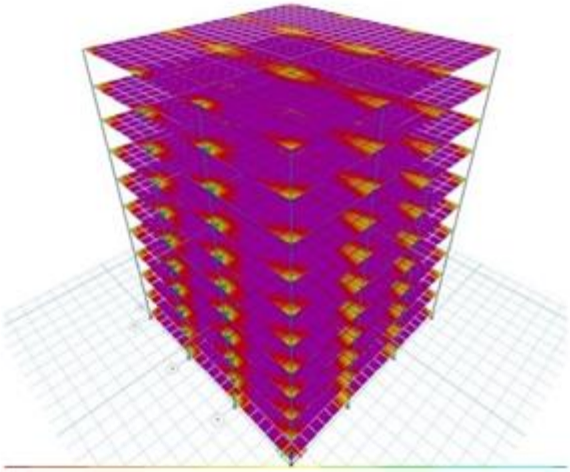


Figure 2: Top rebar intensity of conventional slab

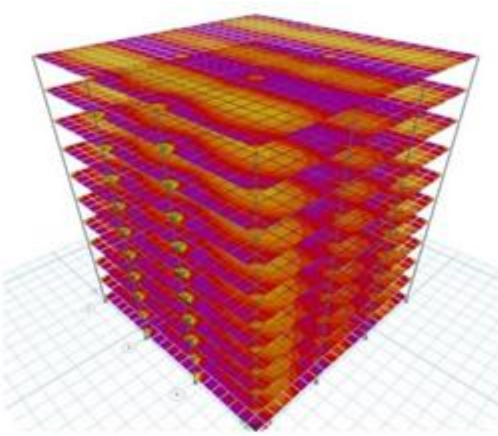


Figure 3: Bottom rebar intensity of conventional slab

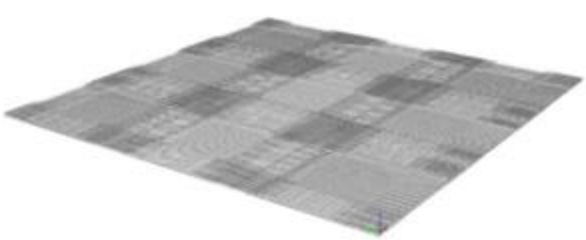


Figure 4: Rebar Cage of the conventional Slab

In the figure 2 & 3, the rebar intensity of the slab is shown in the structure. In this, the violet color shows that the minimum intensity of the rebar and the yellowish part shows that the maximum intensity of the rebar. In figure 4, the rebar cage diagram is shown in which it is formed in the CSi- Detail software. The file of the conventional slab is imported into the CSi- Detail software and the rebar cage diagram is formed. This figure shows the placement of the rebar in the story of the structure for the slab formation.

Flat Slab

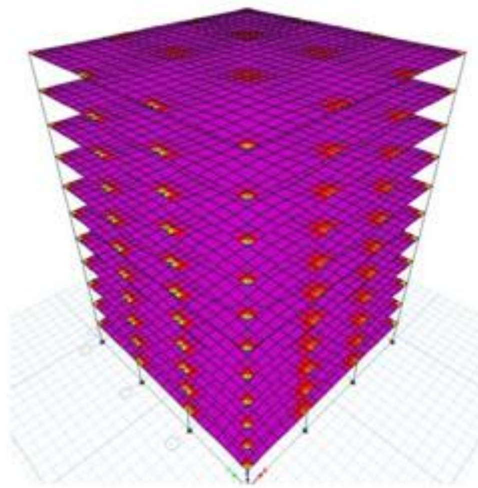


Figure 5: Top rebar intensity of Flat slab

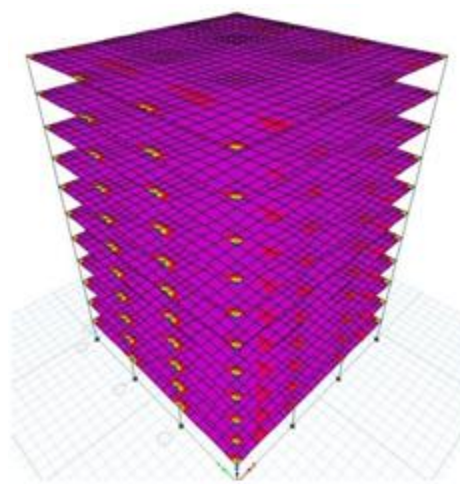


Figure 6: Bottom rebar intensity of Flat slab

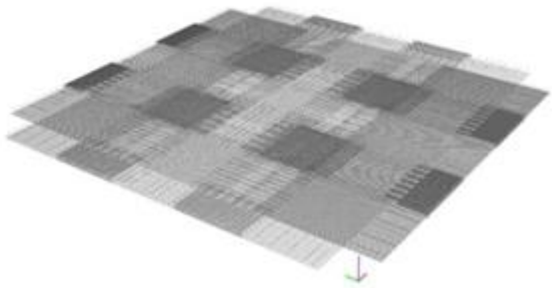


Figure 7: Rebar cage of Flat Slab

The reinforcement intensity in the top and bottom of the structure is shown in the figure 5 & 6. In this the rebar intensity is maximum in drop panel of the slab and in outside of the drop panel the rebar intensity is minimum. In figure no. 7, the position of the reinforcement is shown. The intensity is maximum in the middle of the structure. This slab passes over the loading condition that is applied on the structure.

Waffle slab

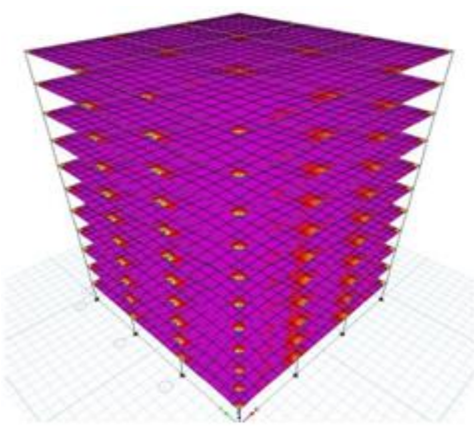


Figure 8: Top rebar intensity of Waffle slab

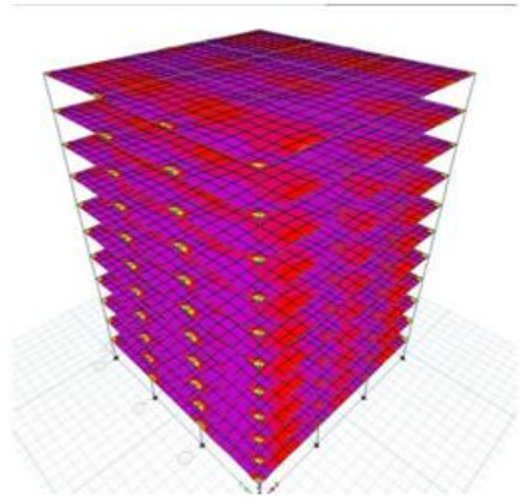


Figure 9: Bottom rebar intensity of Waffle slab

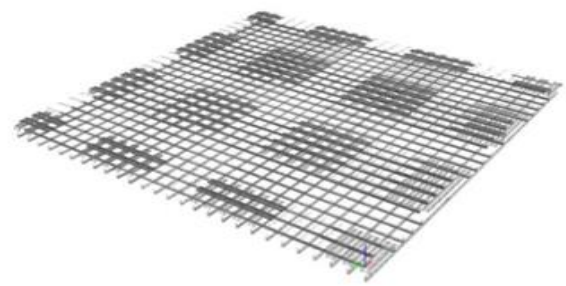


Figure 10: Rebar Cage of the waffle slab

In Fig. 10, the placement of the reinforcement for the construction of the slab is different as compare to the flat slab and the conventional slab. The top rebar is bent at the starting and the ending side of the slab and also the bend is provided at the drop of the slab in which the intensity of the reinforcement is quite increased.

Estimate of the material

The computer generated estimate is calculated by the CSi- details software in which the quantity of the reinforcement required for the conventional slab, flat slab and the waffle slab is calculated and their weight is also calculated by this software. The estimated weight of the material required for the slab is discussed below.

Table 4: Software generated bill of material of the conventional slab structure

BILL OF MATERIALS: FLOOR SLAB

SR. NO.	ITEM	QUANTITY	UNIT
1	TOTAL AREA, A	6,336.00	SQ M
2	TOTAL VOLUME, V	1,267.200	CU M
3	AVERAGE THICKNESS, T=V/A	200	MM
4	TOTAL REBARS WEIGHT, W	1,84,287	KG
5	REBARS PER AREA, W/A	29.086	KG/SQ M
6	REBARS RATIO, W/V	145.4288	KG/CU M

Table 5: Software generated estimated rebar quantity of the conventional slab structure

REBAR QUANTITIES: FLOOR SLAB

SR. NO.	BAR SIZE	LENGTH (M)	WEIGHT (KG)
1	12	57,000.0	50,600
2	14	982.1	1,186
3	16	43,816.5	69,162
4	18	31,707.8	63,339

Table 6: Software generated bill of material of the Flat slab structure

BILL OF MATERIALS: FLOOR SLAB

SR. NO.	ITEM	QUANTITY	UNIT
1	TOTAL AREA, A	7,227.00	SQ M
2	TOTAL VOLUME, V	1,579.050	CU M
3	AVERAGE THICKNESS, T=V/A	218	MM
4	TOTAL REBARS WEIGHT, W	1,89,455	KG
5	REBARS PER AREA, W/A	26.215	KG/SQ M
6	REBARS RATIO, W/V	119.9806	KG/CU M

Table 7: Software generated estimated reinforcement quantity of the Flat slab structure

REBAR QUANTITIES: FLOOR SLAB

SR. NO.	BAR SIZE	LENGTH (M)	WEIGHT (KG)
1	10	3,360.1	2,070
2	12	61,500.1	54,595
3	14	3,019.0	3,647
4	16	41,748.3	65,897
5	18	23,839.3	47,621
6	25	4,055.1	15,625

Table 8: Software generated bill of material of the Waffle slab structure

BILL OF MATERIALS: FLOOR SLAB

SR. NO.	ITEM	QUANTITY	UNIT
1	TOTAL AREA, A	7,884.00	SQ M
2	TOTAL VOLUME, V	2,539.200	CU M
3	AVERAGE THICKNESS, T=V/A	322	MM
4	TOTAL REBARS WEIGHT, W	36,834	KG
5	REBARS PER AREA, W/A	4.672	KG/SQ M
6	REBARS RATIO, W/V	14.5063	KG/CU M

Table 9: Software generated estimated reinforcement quantity of the Waffle slab structure

REBAR QUANTITIES: FLOOR SLAB

SR. NO.	BAR SIZE	LENGTH (M)	WEIGHT (KG)
1	#3	3,809.3	2,347
2	#5	233.7	369
3	12	396.9	352
4	14	213.5	258
5	16	20,735.6	32,730
6	18	66.8	133
7	22	216.2	645

In this section the bill of the material that is generated by the software is shown in the tabular form (table no. 4,6,8) and the quantities of the rebar (table no. 5,7,9) is also shown for the various slab regions. The maximum quantity of rebar is required for the conventional slab and the minimum quantity of rebar is required for waffle slab.

V. CONCLUSION

1. The story displacement in X direction is maximum in flat slab while the story displacement in Y direction is maximum in waffle slab.
2. The story drift in X direction is maximum in flat slab while it is similar for the all story of the three type of slab in Y direction.
3. The rebar intensity is maximum in conventional slab as compare to the flat slab and waffle slab.
4. The punching shear is produced in the waffle slab in high intensity as compare to the conventional slab and the flat slab.
5. The pseudo spectral acceleration of the conventional slab has a maximum value as compare to the other slab.
6. As the base force increases the monitored displacement increases. The maximum base force is applied on the conventional slab structure and the minimum base force is generated in flat slab structure.
7. All the slabs are satisfies the hinge result which is calculated by the pushover analysis.

8. The rebar intensity of the conventional slab is more as compare to the other slabs.

REFERENCES

[1] Agrawal, C.P. and Khedikar, A.R., 2018. Linear and Nonlinear Dynamic Analysis of RC Structure for Various Plan Configurations Using ETABS. i- Manager's Journal on Structural Engineering, 7(2), p.70.

[2] Jayswal, P.K. and Khedikar, A.R., 2018. Seismic Analysis of Multistorey Building In Different Zones. International Journal of Research, 5(13), pp.131-134.

[3] Ghormade, N.P. and Khedikar, A., 2018. Analysis of Multi-Storieyed Irregular RC Building Under Influence of Wind Load. International Journal of Research, 5(13), pp.113-119.

[4] P. Hoogenboom, “Lectures on CIE4143 Shell Analysis, Theory and Application.”

[5] J. Blaauwendraad and J. H. Hoefakker, Structural Shell Analysis, vol. 200 of Solid Me-chanics and Its Applications. Dordrecht: Springer Netherlands, 2014.

[6] E. Ramm and G. Mehlhorn, “On shape finding methods and ultimate load analyses of reinforced concrete shells,” Engineering Structures, vol. 13, no. 2, pp. 178–198, 1991.

[7] E. Ramm, Ultimate Load and Stability Analy sis of Reinforced Concrete Shells.

[8] V. Weingarten, E. Morgan, and P. Seide, “Elastic stability of thin-walled cylindrical and conical shells under combined internal pressure and axial compression,” 1965.

[9] L. Samuelson and S. Eggwertz, Shell Stability Handbook. 1992.

[10] R. Motro and B. Maurin, “Bernard Laffaille, Nicolas Esquillan, Two French Pioneers,” 1968.

[11] L. Huxtable, Pier Luigi Nervi. G. Braziller, 1960.

[12] N. Walliman and B. Baiche, Ernst and Peter Neufert Architects’ Data. Blackwell Science.

[13] R. N. Maten, “Ultra High Performance Concrete in Large Span Shell Structures,” tech. rep., 2011.

[14] T. Diana, Diana 9.5 User’s Manual, 2014.

[15] Peerdeman, “Analysis of thin concrete shells revisited,” tech. rep., TU Delft, 2008.

[16] E. Chao, “Pier Luigi Nervi 1891-1979,” pp. 32–38, 2005.

[17] J. F. Abel and J. C. Chilton, “Heinz Isler - 50 years of "new shapes for shells",” Journal of the International Association for Shell and Spatial Structures, vol. 52, no. 169, pp. 131– 134, 2011.

[18] M. Millais, Building Structures: From Concepts to Design. Taylor and Francis, 2005.

[19] T. Iori and S. Poretti, “Pier Luigi NerviâĂŹs Works for the 1960 Rome Olympics,” Small, pp. 27–29, 2005.

[20] Amway Center, “Production Guide Version 2,”

[21] L. T. Ltd., “LED Display Solutions at Bradley Center,” 2011.

[22] H. Cowan, A history of masonry and concrete domes in building construction, vol. 12 of Building and Environment. Jan. 1977.

[23] F. v. H. F. Huijben and R. Nijsse, “Concrete Shell Structures Revisited: Introducing a new ’Low-Tech’ construction method using Vacuumatics Formwork,” 2011.

[24] Roylance, “Finite Element Analysis,” tech. rep., Department of Materials Science and Engineering, Massachusetts Institue of Technology, 2001.

[25] L. Sluys and R. de Borst, “Lecture Notes for CIE5142 Computational Methods in Non-Linear Solid Mechanics,” May 2013.

[26] Amey R. Khedikar, Mohd. Zameeruddin, P. S. Charpe (2022) “Investigation on Progression in the Damage-Based Seismic Performance Evaluation of Reinforced Concrete Structures”, Design Engineering, pp. 15094 - 15115. Available at: http://thedesignengineering.com/index.php/DE/article/view/8741

[27] Walde, N.N., Manchalwar, S. and Khedikar, A., 2015. Seismic Analysis of Water Tank Considering Effect on Time Period. International Journal of Research in Engineering and Technology.

[28] Chandewar, L.P. and Khedikar, A.R., 2018. Seismic Control of RCC Frame Using Linear Bracing System. International Journal of Research, 5(13), pp.92-96.

[29] Ramteke, V. and Khedikar, A.R., 2018. Dynamic Respone of RCC High Rise Building for Different Types of Sub-structure System. International Journal of Research, 5(13), pp.218-223.

[30] Jayswal, M.P.K. and Khedikar, A.R., Seismic Analysis of Multistorey Building with Floating Column and Regular Column. International Journal on Recent and Innovation Trends in Computing and Communication, 6(4), pp.136-143.

[31] Agrawal, C.P. and Khedikar, A.R., 2018. Seismic Analysis of High Rise RC Structure with Different Plan Configuration. International Journal of Research, 5(13), pp.78-84.

[32] Agrawal, C.P. and Khedikar, A.R., 2018. Dynamic Analysis of High Rise RC Structure Using Etabs For Different Plan Configurations. International Journal of Research, 5(12), pp.5729-5733.

[33] Sayyed, N.M. and Khedikar, A., 2018. Performance of Various Parameters of Buildings Under The Composite Action of Blast Load And Earthquake. International Journal of Research, 5(13), pp.103-109.

[34] Ghonmode, A., Khedikar, A. and Bhadke, S., 2018. Critical Analysis of Vertical Tall Buildings. International Journal of Research, 5(13), pp.59-63.
[35] Navghare, S.A. and Khedikar, A., Research on Dynamic Analysis of RCC Columns with Different Cross Sections.
[36] Panker, B. and Khedikar, A., 2018. Smart Sensor Techniques for Structural Health Monitoring of Civil Engineering Structures. International Journal of Research, 5(13), pp.71-77.
[37] KHADSE, P. and KHEDIKAR, A., 2018. Comparative Study of G+ 5r. C Building With And Without Staircase Model At Different Location. International Journal of Research, 5(13), pp.808-834.
[38] Sayyed, N.M. and Khedikar, A.R., 2018. Performance of Various Structural Parameters of Buildings under the Composite Action of Blast Load and Earthquake.
[39] Jayswal, P.K. and Khedikar, A.R., 2018. Seismic Analysis of Multistorey Building In Different Zones. International Journal of Research, 5(13), pp.131-134.
[40] Patel, H. and Khedikar, A.R., 2018. Review of Fluid Viscous Dampers In Multi-Story Buildings. International Journal of Research, 5(13), pp.85-88.