EasyChair Preprint

№ 7573

A Review on Seismic Performance Analysis of High Rise Building with Waffle Slabs Located in Irregular Pattern of Architectural Plan

Mohammad Imran Rahmani and Jagdish Chand

EasyChair preprints are intended for rapid dissemination of research results and are integrated with the rest of EasyChair.

March 17, 2022

A Review on Seismic Performance Analysis of High Rise Building with Waffle Slabs Located In Irregular Pattern of Architectural Plan

Mohammad Imran “Rahmani” [1] Jagdish “Chand” [2]

[1] P.G. student in Civil Engineering Department, Chandigarh University, Punjab-India

[2] Associate Professor in Civil Engineering Department, Chandigarh University, Punjab-India

ABSTRACT

Improvements of technology has resulted in drastic changes in the requirements in terms of the architectural appearance of residential and commercial buildings. In most of the cases, these types of customer requirements necessitate reviewing and restructuring the existing practices and methods in structural engineering. In addition, the existing methods of design and practices should be understood in depth to meet these requirements in a safe and serviceable manner.

In this research paper a G+15 story building considered, with waffle slab located in irregular pattern in its architectural plan in different stories. The structure will be modelled and analyzed in seismic zone IV using ETABS 2018 software, and dynamic analysis of the structure will be carried out using response spectrum analysis method. This will be done to find out of this structure’s response to combination of gravity and dynamic loads, and solutions will be provided to overcome the weak points in the structure’s body. The feasible solution will be implemented in the structure by re-modelling it in the software and showcase that the solution has helped the building to

Better resist the loads in spite of having waffle slabs irregularities in architectural plan composed of conventional slabs.

Keyword: Waffle slab, Irregular position of waffle slab, Dynamic analysis

1. INTRODUCTION

Improvements in technology have resulted in drastic changes in the requirements in terms of the architectural appearance of residential and commercial buildings. Finally, the growth of the human population and the decline in the availability of space to construct facilities such as residential buildings and commercial complexes throughout the last decades has led many to construct high-rise buildings with different types of slabs.

Conventional slab: also called solid system which supporting on beams, the loads are carrying directly through beams in to columns. These slabs according load carrying capacity divided in to two types one way slabs and two way slabs. Slabs which the ratio of longer span to shorter span is equal or greater than two. Or supported in two opposite beam or two parallel walls, the load is carrying in one direction.

Slabs which the ratio of longer direction to shorter direction is always less than 2. Or supported by four side beams, the load is carrying in two.

Flat slab: slabs which is directly supported on columns without existence of beams. According geometric shape four types of flat slabs are in here such flat slab having drop, flat slab including capital head, flat slab having drop panel and capital,and flat slab without drop and capital head.

Ribbed slab: a panel composed of thin slab reinforced by thin rib in one direction is called ribbed slab.

1.2. WAFFLE SLAB

Waffle slab is also named two-way joist slab, consist of narrow top slab acting compositely with close space of thin beams or ribbed in both directions. The waffle slab can be placed on strip beam or directly on columns. These slabs might be used as ceiling and floor it is basically recommended in the area where less possible number of columns whit large span are required in case where conventional slabs are impressionable to large deflection.

Analysis, design, and construction of multi-purpose high-rise buildings require considering large spans and the least possible number of columns, as these areas might be designated to terminals, conference rooms, gymnasiums, industrial and commercial buildings, car parking, garages, and open areas in architectural plans of tall buildings due to having great performance of load carrying capacity and less deflection especially for large spans. Under such circumstances, the traditional solid slab system or conventional slab may not be recommended. Waffle slabs are frequently used for this purpose. Using a waffle slab can respond very well in this

situation, as its span can be longer, the number of columns obstructing the internal architecture can be significantly reduced, withstand the exerted loads with the deflection within the allowed values, lighter in weight than solid slabs, and aesthetically better looking than solid and flat slabs.
Such flat slab, a waffle slabs are develop to shear failure which is called as punching shear or two way shear failure. Even though this is a critical issue in construction of waffle slabs in buildings, it can be control easily by the following methods:
Increase the thickness of solid portion in slab-column joist, increase rib width, reduce rib spacing, and providing extra shear reinforcement.


Figure 1, Bottom view of Waffle slab (19)

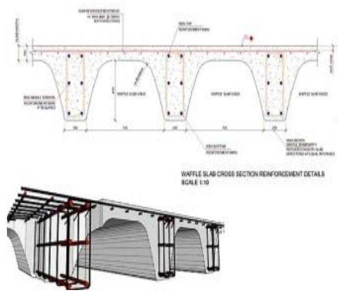
Figure 2, Waffle slab's cross Sectional (20)


Figure 3, Waffle slab's Formwork (21)

3. LITERATURE REVIEW

Rahmani A (2021), Experimental research refer the performance of waffle slab under effects of blast load, the two models are considered and analyzed in Ls-Dyna software. The performance of waffle slab subjected to blast load and compared its behavior with reinforced concrete slab is studied in addition other parameters are included in this paper such effects of compressive strength of concrete in the behavior of waffle slab subjected to blast load, the effects of explosive on the floor that may how much is the distance of blast, effects of the size of the bar also consider on the behavior of roof. in conclusion, it can be noted that the graphs and tables with the same reinforcement and concrete volumes present that the central deflection is reduced to the desired level in case of waffle slab it shows the better behavior of waffle slab compared to RC slab with same materials under effects of blast load.

Latha M.S (2020), Analyzing and comparing of a solid slabs, waffle slabs for symmetrical and unsymmetrical buildings. This paper presents 12 story building of symmetrical, unsymmetrical – horizontal and vertical regular and irregular structures for both conventional and waffle slabs considered. The models are modeled and analyzed by ETABS software for gravity and lateral loads as per IS 1893 codes. The static analysis is done for horizontal regular and irregular structures, for vertical irregular done the dynamic analysis, the results are compared for both conventional and waffle slab according to deflection, base shear, displacement, and story stiffness.

Mr.Vipin Kumar Tiwari (2020), behavior of waffle slab, flat slab, ribbed slab and considered a secondary beam in a multi-story building. Due to the demand for high-rise buildings engineers are faced with big challenges to find the solution of choosing slab system. The use of advanced and different slabs that might be feasible for high-rise buildings such as flat slabs, waffle slabs, ribbed slabs used for large spans, and the least possible number of columns. In addition for more safety and stability of structural behavior, a secondary beam is considered to carry the loads to the column. The research or study can be resulted, flat slabs can be suitable to be used for multi-story buildings and the use of waffle slabs, ribbed slabs might be a great choice for high-rise buildings due to having the high moment carrying capacity of slabs. And the using of secondary beam is considered for great span and the least possible number of columns requirement.

Stella Mary F (2020), a study on waffle slab with casting different spacing of grid beams or joists some tests are done for load-carrying capacity. From this studying, it can be concluded if inferred that waffle slab performance is better whereas solid slab, waffle slab spacing between grid beam and joist is the large load-carrying capacity decreases or the relation between grid beam spacing and carrying capacity is inverse.

Paritosh Singh (2019), Reviewed the past research and publication efficiency of different types of the slab in various buildings. This paper presents to understand the potential of various slab's types and their performance on structural analysis and designing. Using SAP2000 software. In conclusion, it can be summarized, formerly the researchers have been done on behavior of waffle slab and, flat slab wide-spreading, presently the studies expressed analysis and design of three systems in terms of slab system, conventional, flat, and waffle slab.

Rinsha C (2018), Studied the behavior of composite waffle slab with various sizes of steel cross sectional and dissimilar angular placement of grid beams or joists. Different percentage of reinforcement and changing the grade of steel is discussed and analyzed in ANSYS. In addition, analysis of waffle slab by exchange of I beam to embattled beam, with and without hardener. As ANSYS result, ISMB 250 is the best economical steel cross sectional, it has been detected that skew grids decrease ultimate strength of composite waffle slab, the loss of strength is due to 60-degree joist orientation about 15.6% therefore by adding of 1.6% steel fiber the strength of composite waffle slab increases by 5.3%. Fe345 grade steel used in composite waffle slabs is the most acceptable without adding fiber reinforcement where loads are more and architectural esthetics are mandatory. Eventually, it can be concluded waffle slab by placing I beam into a castellated beam with or without stiffener increase the final strength of waffle slab.

C.Arunkumar (2018), Behavior of punching shear in normal and waffle slab, this paper indicate the behavior of waffle slab subjected to punching shear at the slab-column-joist region, it shows that waffle slabs are similar to flat slabs in case of punching shear, however, shear capacity relatively reduces by extended waffle shape. An experimental case study of waffle slab for punching shear by column size of 100*100 mm and waffle slab size of 1200*1200 mm. The experimental result was compared with theatrical parts of IS code. Which indicated waffle slabs give more strength than conventional slab, the tested was done for waffle slab with the different size it can be inferred that waffle slabs with various size can be created by increasing the depth of slab 20% and wide of joists by 25% for better performance against punching shear.

Mr.Tejas B (2018), A G+9 story with gird or waffle slab structural subjected to seismic load. The model is analyzed under the response spectrum method in zone IV by ETABS 2016 software, he compared two models of structure and the comparison is carried out for base shear, story stiffness, story drift, and story displacement. After analyzing it was concluded that square box waffle slab increases the overall stiffness of the structure, in addition reducing the deflection of building and spacing of grid beams or joists will decrease load-carrying capacity of the building.

Risna Rasheed R A (2017), Effects of placing of grid beams and opening size in waffle slab, this paper express that sometimes it demands that opening should be considered in floors or slabs in various part of architecture plans such us stairs, ducts, elevators. This paper proposes to composite waffle slab which contains orthogonal steel girders, it can assist to decrease cracking in concrete. Composite waffle slab has good performance in case of load-bearing capacity. Because it makes complete to use compressive strength of concrete and tensile strength of steel. In addition, nonlinear static analysis is done to investigate the effect of joists and effect of opening size in the waffle slabs using FEM by ANSYS 2015 software.

Harish MK (2017), A G+4 story building with a waffle slab, analyzed and designed against gravity load and lateral load (wind load, earthquake load) as per IS code. The structure is analyzed by ETABS software and, the design part is done manually. Seismic analysis is done by the equivalent method and response spectrum method. As conclusion in this paper, the result shows the base shear and lateral displacement is more in the static analysis method than dynamic analysis method, in an economical structure due to the box's effect of waffle slab. It increases the overall stiffness and reduces sway of the building.

ZekirijaIndrizi (2017), Cost comparative study of normal slab and waffle slab in a typical 14 story RC building, the first section of this comparison discussed to obtain an optimum way for waffle slab and conventional slabs in 14 story building. The second part contained an analysis of the effects of both slabs over the whole building model. In conclusion it can be summed advantages of the multi-story building contained waffle slab is more and whereas conventional slab system in manner of economy, safety and behavior.

Salman I khan (2015), Comparative review of seismic performance of grid slab and, flat slab in RC high rise building. These two slab systems are the most esthetic and attractive commonly used as floor systems in tall buildings. There are some comparable aspects between these two slab systems regarding applying seismic forces. In conclusion, it can be summed flat slab due to a non-rigid frame is weaker in shear and seismic force whereas a grid slab in high-rise buildings.

Amit A. Sathwane (2015), the author studied analysis and design of waffle slab system, flat slab system with drop penal and without drop penal, and their costs compression is also considered. By assist of the above title he determined the most economical between waffle slab and, flat slab using drop and, without drop. The analysis of both slabs have done manually base on IS: 456 -2000 and by staad pro software. As conclusion it can observed maximum moments are obtained by using manually design. The result of software shows flat slab having drop is economical whereas compared to flat slab with having no drop.

Mohamed A.A. EL-SHAER (2014), Introduced different reinforced concrete slabs system solid slabs system, flat slabs, and waffle slabs system subjected to seismic loads in high-rise buildings in seismic regions. Subsequently after modeling and analyzing in ETABS software, can be concluded that flat slab due to non-rigid frame (slab-column) connections, unbalanced moments carrying, and high risk of punching shear not recommended in seismic regions. The solid system slab or conventional slabs (slabs, beams, columns) with direct connections can be selected to resist lateral forces, however, due to heavy loading relatively not recommended for constructing high-rise buildings. From this standpoint presently the choice of the system that provides rigid concrete slab and more resistance against lateral forces, less deflection than flat slabs, and is lightweight as compared to solid slab system to be chosen and named as a waffle slab.

This system of the joists-concrete slab is ductile and carries balanced moments between slabs and columns, eventually in seismic regions waffle slabs are recommended to be a gravity load and lateral load resistant system for high rise buildings of height/width ratio.

Tereza Denyse (2014), this paper discussed some activities such as walking, jumping, and skipping that can cause to create vibration in a waffle slab with a large span. The vibration can annoy people, some inquiries would be found about the structure's stability and safety may thought that the slab may or may not collapse. This paper present the main objective to evaluate the behavior of grid slab due to weighted people activities. Slabs are modeled and analyzed by finite element method in SAP2000 software, the result is verified based on Brazilian code that waffle slab is lie to high level of acceleration.

Shu-guang, **(2006),** an experimental study performance of a waffle slab system, an industrial floor system with high gravity load is tested. The test procedure has two reduced scale identical specimen models which are half the height of the inner column and a part of grid slab for earthquake assessment the lateral load is applied on the tested column by the bidirectional method. The result shows high deformation ductility with less failure to the waffle slab the mode of damage is governed by the constitution of stable plastic hinge between column and joist. It should be considered during modeling and analysis.

4. OBJECTIVES

1) To locate the position of waffle slab and evaluate the performance of waffle slab located in irregular pattern of architectural plan.
2) To check the stability of waffle slab for large opening areas with least possible number of columns.

3) To compare the sway displacement, storey drift and deflection of waffle slab with conventional slab system.
4) To evaluate the effects of earthquake load (base shear, storey displacement, storey drift) on waffle slab.
5) To check the seismic behavior of building with waffle slabs located in irregular and regular pattern of architectural plan.

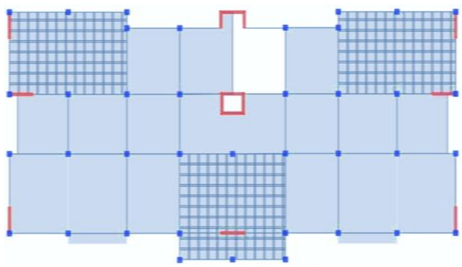

Figure (4), Position of waffle slabs as typical, from 1th up to 8th storey
(By author)

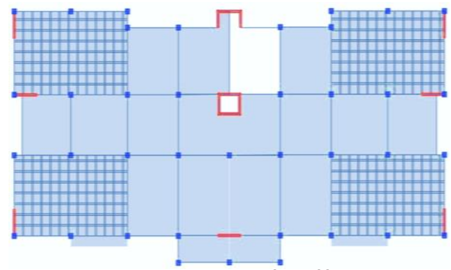

Figure (5), Position of waffle slabs as typical, from 9th up to 15th storey.
(By author)

5. CONCLUSSION

To conclude this research, the seismic performance of the G+15 storey building will be monitored with waffle slab irregularity in its architectural plan. If this irregularity results in large magnitude of deflection or failure of the structural elements, workarounds such as provision of shear walls, bracings, or dampers will be developed. Once it is assured that the building will be safe in the seismic region,
It can be used for implementing actual projects with such properties and for any future researches in this area of structural engineering.

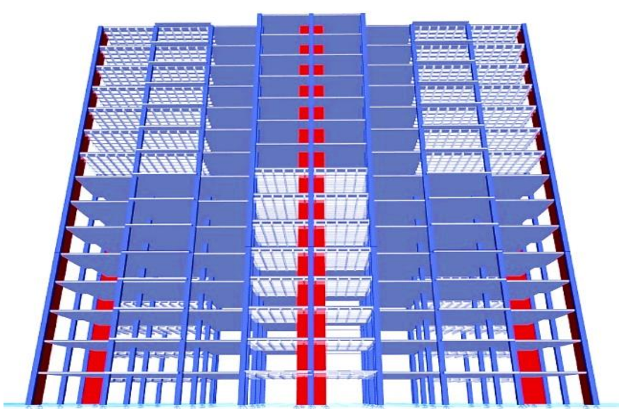

Figure (6), Project 3D Model (By author)

6. REFERENCES

[1] Costa, Y. C. V. D., & Araújo, T. D. D. (2014). Evaluation of dynamic behavior of waffle slab to gym center. *Latin American Journal of Solids and Structures*, *11*(7), 1114-1131.

[2] Shu-guang, W. A. N. G. (2006). Experimental study on the failure behavior of waffle-slab raft foundations under uniform column loads. *China Civil Engineering Journal*, *39*(10), 97-101.

[3] Risna, R., & Anima, P. (2017). Effect of spacing of grid beams and opening size in a waffle slab with central opening. *International Journal of Enigineering Research and General Science*, *5*(2).

[4] Akinyele, J. O., & Alade, G. A. (2014). Application of yield line theory in pre-cast waffle slab. *Nigerian Journal of Technology*, *33*(1), 27-32.

[5] Arunkumar, C., Saketh, K., & Jeyashree, T. M. (2018). Behaviour of punching shear in normal RC slab and waffle slab. *Asian Journal of Civil Engineering*, *19*(1), 27-33.

[6] Gorji Bandpey, G., Abdollahzadeh, G., & Rahmani, A. (2021). Waffle Slab Behavior Subjected to Blast Load. *Civil Engineering Infrastructures Journal*, *54*(2), 365-380.

[7] Rinsha, C., & Jose, A. M. Finite Element Analysis for the Behavioral Study of Composite Waffle Slab Using ANSYS.

[8] El-Shaer, M. A. (2014). Seismic load analysis of different RC slab systems for tall building. *Acta Technica Corviniensis-Bulletin of Engineering*, *7*(4), 65.

[9] BI, M. T., & ME, M. R. (2018). A Study on the Behavior of Grid Slab Subjected to Seismic Loading.

[10] Khan, S. I., & Mundhada, A. R. (2015). Comparative study of seismic performance of multistoried Rcc buildings with flat slab and grid slab: a review. *IJSCER*, *ISSN*, 2319-6009.

[11] Latha, M. S., & Pratibha, K. (2021). Analysis and comparison of conventional slab and grid slab for symmetric and asymmetric structures. *Materials Today: Proceedings*, *46*, 1860-1869.

[12] Malviya, S., & Tiwari, M. V. K. Behaviour of Flat Slab, Waffle Slab, Ribbed & Secondary Beam in a multistorey Building under Seismic Response: A Review.

[13] Nithyambigai, G., & Rameshwaran, P. M. (2021). Behaviour of waffle slab. *Materials Today: Proceedings*, *46*, 3765-3768.

[14] SAKETH, K., Arunkumar, C., & SRINIVASASENTHIL, S. (2017). Analytical study of punching shear on waffle slab with different rib size. *Journal of Industrial Pollution Control*, *33*, 1323-1327.

[15] Singh, P., & Joshi, R. (2019). Seismic Analysis of High Rise Building Structure Considering Flat and Grid Slab: A Review.

[16] Idrizi, Z., & Idrizi, I. (2017). Comparative Study between Waffle and Solid Slab Systems in Terms of Economy and Seismic Performance of a Typical 14Story RC Building. *Journal of Civil Engineering and Architecture*, *11*(12), 1068-1076.

[17] H.M.K, A. B.T, C. V R, S. M. Y, P. Student, and A. Professor, "Issue 6 | ISSN: 2456-3315 IJRTI1706083 International Journal (www," 2017. [Online]. Available: www.ijrti.org.

[18] Gorji Bandpey, G., Abdollahzadeh, G., & Rahmani, A. (2021). Waffle Slab Behavior Subjected to Blast Load. *Civil Engineering Infrastructures Journal*, *54*(2), 365-380.

[19] Rory Stott, December 23, 2015 [photograph], https://www.archdaily.com/779340/this-innovative-concrete-slab-system-uses-up-to-55-percent-less-concrete

[20] rnakos – November 1, 2015, Waffle Slab Cross Section Reinforcement Detail, structuraldetails.civilworx.com

[21] Al-Awadi Company, 2018 [Photograph], https://www.awadico.com/single.php?id=27