Behaviour of Waffle Slab, Flat Slab, Ribbed & Secondary Beam in a multi-storey Building under Seismic Response: A Review

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Abstract— The demand of multi-story Building is increases day by day. The purpose of building is mandatory things to design a building. The building may be residential or residential plus commercial. The new trend introduced the use of different types of slabs and structural engineers have the big challenge to work on it. The use of advanced slabs in building predominantly for the need of large span. The large span is needed for Flat slab, Waffle slabs & ribbed slab stands as a better & effective option for architects under the building required larger spans. The benefit is it covered least possible number of columns. Therefore, it is necessary to study about its structural behaviour. The paper consists of summaries report on different research papers based on use of different types of slabs such as flat slab, waffle slab, ribbed slab concept by different researchers. Some researchers also used the secondary beam with the normal slab to transfer the load of the structure effectively to the column. The review paper concluded that flat slab can be effectively used for the multistorey building. The use of waffle and ribbed can also be used with high rise & tall structure construction due to more resisting moment capacity of the slabs. The use of secondary beam is adopted for large span requirement.

Keywords: Flat Slab, Waffle Slabs & Ribbed Slab, Multistorey Building, Secondary Beam

I. INTRODUCTION

Recent earthquakes in which many concrete structures have been severely damaged or collapsed, have indicated the need for evaluating the seismic adequacy of existing buildings. About 60% of the land area of our country is susceptible to damaging levels of seismic hazard. We can't avoid future earthquakes, but preparedness and safe building construction practices can certainly reduce the extent of damage and loss. Different types of slabs stand as an excellent option for architects when larger spans in a building have to be covered with the least possible number of columns. As such, waffle, ribbed, flat slab is evolving as a new trend and are becoming a big challenge for structural engineers. Slabs are the structural elements that carry the additional dead and live loads in different structures. They are used in buildings, paths and bridges. Usually, they can be classified to one way and two ways systems. One-way slabs with beams in one direction are commonly used for small spans up to six meters. Two-way slabs with beams and without beams are used for larger spans. Two- way slab systems are mainly used to resist high loads or they are used when there are large spans to minimize the slab thickness and to decrease the internal forces in the slab and to limit the slab deflection. It is common to have two-way slabs in parking floors as the spans are long. Two-way ribbed slabs are commonly used in residential and office buildings. Waffle slabs can be used in halls, industrial buildings and parking floors. There is major three slab are used other than normal slab. These slabs are as follows:

A. *Waffle Slab*

A waffle slab is made of reinforced concrete with concrete joists spanning in mutually perpendicular directions on its bottom. Due to the grid arrangement generated by the R.C. ribs is termed as waffle. It is also known as two-way joist slab. It is mainly used when span is greater than 12 m. It is stronger than other type slab. The slab has two parts. The part one is in top side which is flat surface and second part at bottom consist of joists create a grid like structure. The grid is appeared when moulds are removed in it. It is also used when heavy loads are acting n the structure. Under the effect of rigidity this type of Slab is used when buildings require minimal vibration, such as used for laboratory, manufacturing facilities.

Fig. 1: Typical examples of waffle slab

B. *Ribbed Slab*

These types of slabs are slabs cast completely with a series of closely spaced joist which in turn are supported by a set of beams. The main benefit of ribbed floors is the lowering in weight achieved by removing part of concrete below the neutral axis. This creates this type of floor economical for buildings with a long span with light or moderate loads. Ribbed slabs are slabs cast integrally with a series of closely spaced joist which in turn are supported by a set of beams. The main advantage of ribbed floors is the reduction in weight achieved by removing part of concrete below the neutral axis. This makes this type of floor economical for buildings with a long span with light or moderate loads.

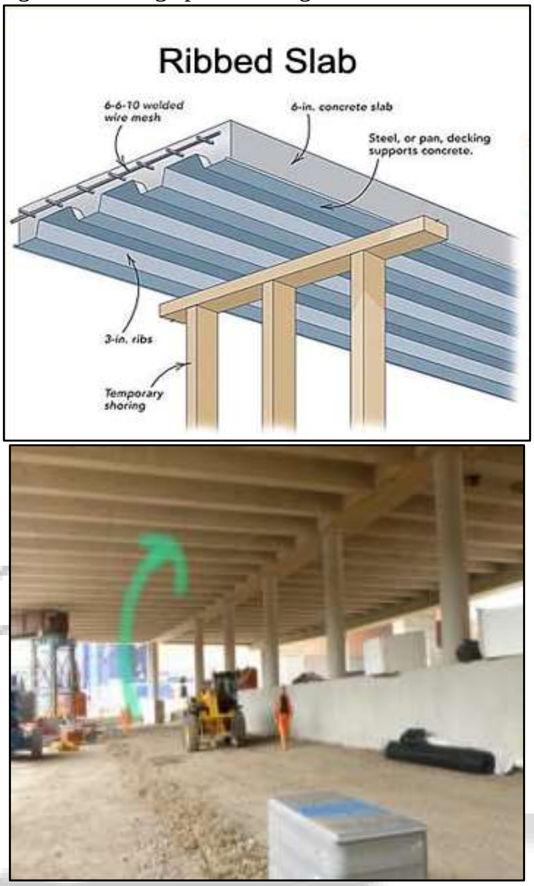

Fig. 2: Typical examples of ribbed slab

C. *Flat Slab*

A reinforced concrete slab supported directly by concrete columns without the use of beams. These types consist different system of elements such drops, column head, perimeter beam etc along with flat slab. These types of structures use column heads and column strips as a replacement of beams to provide large spans of columns. Whole slab rests on these column heads and column strips and acts as a diaphragm. These structures are vulnerable to dynamic earthquake forces so analysis regarding dynamic earthquake behaviour of the structure must be done before designing these structures in earthquake prone areas

Fig. 3: Typical examples of flat slab

D. *Secondary Beams*

The beams which are constructed to transfer the load of slab on main beams are called secondary beams. Basically, secondary beams are not directly rests on column, but are supported on main beams which are supported by columns directly. Beam which rests on column directly are termed as primary beams. Secondary beams are generally used to provide architectural benefits and for space restrictions. Reinforcement details are calculated on the basis of the quantity and type of load exerting on every beam

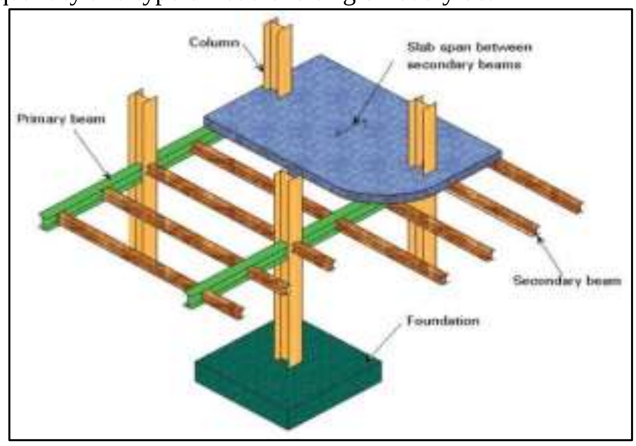

Fig. 4: Structure having secondary beam

II. REVIEW OF LITERATURE

The following research papers are studied under the study of analysis of a Structure containing the different slabs such as Flat Slab, Waffle Slab, and Ribbed & Secondary Beam. The summarized reports of different researchers are as follows:

A. Imran S. M., Raghunandan Kumar R., Arun Kumar (2020)

Carried out optimised design of reinforced cement concrete (RCC) ribbed slab & waffle slab. The objective of these articles is the combined cost of the reinforcement, concrete and formwork which sums up the cost of the ribbed slab. The structure is analysed using the direct design method. The objective function is developed after studying the ribbed slab in detail. The optimization process is carried out for different grades of concrete. The comparative results for different grades of concrete are enumerated and laid out in the tabulated form. Optimization for reinforced cement concrete (RCC) ribbed slab is illustrated and the results of the optimum design and conventional design are compared. Optimization problem is a constrained nonlinear programming problem (NLPP). The mathematical model is analyzed by using mathematical software. From the analysis, it was found that savings up to 25 percent can be obtained by optimizing the reinforced concrete ribbed slab.

B. Raj Joshi, Gagan Patidar, Mayank Yadav, Piyush Natani, Praduman Dhakad (2020)

Analysed the feasibility of G+3 building with a single column, alternatively applying the flat and waffle slab in place of the conventional one at a time to check the difference in the characteristics of a building like bending moment, end moments, deflection, shear force, etc. The interpretative study between both the slabs along with the G+3 single column building with varying floor span, slab span, slab thickness, column thickness, adding dome like structure on bottom has been carried out under the influence of loading via a software specially used for the analysis of the multi-storied building named as ETABS. The course of Single Column Multi-Storied Building is nothing different from the journey of any structural design when it comes to the point it was first developed and till now when it is near the edge of being completely adopted in the daily chores. Single Column Multi-Storied Building demonstrates how contrasting structural members could also be assimilated into the traditional multi-storied building design to get the design of showing different properties having great impact in terms of environmental, structural, construction management aspect. Flat Slab and Waffle Slab in one form (with or without outer column) have had noticeable effect in the properties of the multi-storied building design, enabling its utilization for different purposes of the building.

C. Zekirija Idrizi and Isak Idrizi (2017)

Compared a solid and a waffle slab system. A typical 14-story RC building structure is selected as an example for this study. The first part of this study is focused in deriving an optimal solution for a solid and waffle slab system which are later on considered as constituents of all stories of the 14-story building. In the second part, it is elaborated the effect of both slab systems over the 14-story building model. This study aims to emphasize the advantages of mid-rise buildings constituted of waffle slab system over the buildings characterized with solid types of slabs, in terms of economy, structural safety and performance.

D. Midhun M. S. (2017)

Carried out to get the response of waffle slabs with openings and the behaviour of slabs when span between I beams are altered. The effect of varying size of openings are studied. the location of the opening is fixed at the centre of the slab. The spans between beams are also varied and the responses of waffle slab to such a change are studied. it is concluded that the provision of openings has a significant impact on the strength of the waffle slabs and it may reduce the strength by 38%. Varying the size of span between the I beam has lesser impact as compared to the effect of openings. It reduces the strength only by around 20%. Special considerations have to be done while providing holes in the waffle slab. Proper retrofitting techniques have to applied so that places near the hole may not fail immediately due to stress concentration. From the comparison table it can be interpreted that a hole size of 1400mm reduces the strength of the waffle slab by 38.62% only. If higher loads are acting, the hole size may be limited to 1000mm. this high load carrying capacity is achieved mainly due to the presence of I beams which add considerable strength to the waffle slab structure. Varying the span of I beams does not have significant impact on the strength of the waffle slab as compared to the effect of holes. By increasing the span, higher economy can be achieved without compromising much on the load carrying capacity of the waffle slab.

E. Archana Shaga, Satyanarayana Polisetty (2016)

Presented work RCC flat slab structure and conventional slab structures are considered for comparative study of 6 storey building which is situated in earthquake zone-II and for earthquake loading, the provisions of IS: 1893 (Part1)-2002 is considered. A three-dimensional modelling and analysis of the structure are carried out with the help of E-tabs 2015 software. Linear Static Method of Analysis and Response spectrum analysis method are used for the analysis of both Flat slab structure and Conventional slab structure. The forces and all the relative displacements, storey shears and overturning moments that are developed in each of the structure are analyzed. The results that are obtained from the analysis are discussed. Further these results have been used for understanding the performance of flat slab structure and conventional slab structure under the effects of lateral loads and earthquake. The results are compared and found that flat slab structure perform well in earth quake condition than the conventional slab structure.

F. Anuj Bansal, Aditi Patidar (2016)

Presented work is to compare the behaviour analysis, we can know the weak zones in the of multi-storey buildings having flat slab with that of having grid structure and then slab and to study the effect of base shear, storey drift and whether the particular part is retrofitted or maximum displacement purpose three cases of multi-story buildings are considered with under seismic forces. For this rehabilitated as per requirement. area 20 m x 20 m having 4 storey, 8 storey and

12 storeys with 3.6 m storey height considered. All the three cases are considered having flat slab and grid slab, and also analyzed by using software SAP2000. Observation shows that pushover analysis is a simple way to explore the nonlinear behaviour of building. Analysis is an approximation method based on static loading. It "Seismic Performance of Different RC Slab may not accurately represent dynamic phenomena. Performance points for flat slab are larger than in grid slab models. Resultant Systems for Tall Building", investigated displacements for flat slab are quite larger than in grid slab analytically different types of RC slab taken as an models and also base shear in both types of slabs is almost example and performed the various analytical similar. Present work provides a good source of information on the parameters of pushover analysis of multi-story buildings.

G. S. N. Utane, H. B. Dahake (2016)

Examine the compare the various parameters like base shear, story displacement and story drift acting on flat slab and waffle slab system. With that behaviour of expansion joint which is provided between existing building and industrial structure in earthquake prone region is also checked. Analysis of the large industrial structures constructed using flat slab and waffle slab in square shape and rectangular shape layout will be done with the help of ETABS software by using IS 456-2000 code Displacement of industrial structure constructed using flat slab system is more than the waffle slab system for both square and rectangular layout. Displacement of rectangular shape layout of industrial structure constructed using flat slab and waffle slab is more than the square shape layout structure. With the increase in height of structure displacement is also goes on increasing. Story shear of industrial structure constructed using flat slab system is more than the waffle slab system for both square and rectangular layout.

H. Ubani Obinna Uzodimma (2016)

In this paper, a hall of 12m x 20m dimensions was designed with no interior columns using Eurocode2. The floor system of the hall was supported by an interaction of primary and secondary beams. The full steps for load analysis, load transfer from secondary beam to primary beam, structural analysis, and full design of the structure was carried out manually. After the analysis and design, a section of 900mm x 400mm, and reinforcement ratio of 1.786% was found to satisfy both ultimate and serviceability limit state requirements of the primary beams. Finally concluded that Interaction of primary and secondary beams can be employed as alternatives in large span construction, provided that adequate analysis, design, and detailing of the members are carried out.

I. Gagankrishna R.R & Nethravathi S.M (2015)

The analysis methodology adopted for the present study is non-linear static or pushover analysis. Pushover analysis is typically of displacement control type and is carried out as per the guidelines of ATC-40 and FEMA documents. The analytical parameters that influence the performance of structures and comparative studies on flat plate and flat slab of RC frames are considered. It is found that pushover analysis is a relatively simple way to explore the non-linear behavior of the structures. From the result it is found that base shear is so high in case of all structural systems with edge beam and shear wall compared to flat slab without shear wall. It is due to increase in lateral stiffness of the structures. And also observe that the displacement decreases with the increase in lateral stiffness by adopting the shear wall and edge beam for both flat plate and flat slab.

J. Anurag Sharma, Claudia Jeya Pushpa.D (2015)

Investigated the seismic effect on multi storey building of G+9, G+14 and G+19 floors with waffle slab and flat slab using the software ETABS 2013. The seismic evolution is performed by response spectrum analysis as per IS 1893 (2002). It is observed that waffle slabs are advisable for structure with a height less than 40m, whereas for structures of height above 40m it is advisable to go with flat slab. From the above obtained result it can be observed that for structure with a height less than 40m it is advisable to use waffle slab other than flat slab, whereas for structures of height above 40m it is advisable to use flat slab.

K. Mohana H.S, Kavan M.R (2015)

Carried out by taking a G+5 commercial multi-storeyed building having flat slab and conventional slab has been analysed for the parameters like base shear, storey drift, axial force, and displacement. The performance and behaviour of both the structures in all seismic zones of India has been studied. In the present work the storey shear of flat slab is 5% more than conventional slab structure, the axial forces on flats lab building is nearly 6% more than conventional building, the difference in storey displacement of flat and conventional building are approximately 4mm in each floor. The present work provides reasonable information about the suitability of flat slab for various seismic zones without compromising the performance over the conventional slab structures. Storey shear of flat slab is 6% more compared to conventional slab structure, and storey shear is Maximum at base and least at top storey. The design axial forces on flat slab are more compared to conventional structure the difference of forces is nearly 5.5%. Storey displacement is Maximum at roof level than at base, and storey displacement of flat slab structure is greater than conventional structure, there will be an average 4mm displacement variation in each seismic zone for both structures.

L. Ilinca Moldovan, Aliz Mathe (2015)

Presented the aspects of a square shaped waffle slab calculation, supported punctually and having a two-way post tensioning reinforcement disposed parabolically. It is described the waffle slab system, its characteristics, preliminary design of composing elements, technological aspects regarding the manufacturing of precast panels, details regarding used materials, the reinforcement layout and the calculation of prestressing force. The work presented the design, calculation and layout, of prestressing reinforcement (TBP9 tendons) that are to be placed in the ribs of a waffle type slab. It is mentioned the sequence the tendons are stressed, the geometrical characteristics of their layout and is presented the computation of prestressing force in terms of maximum force applied to the TBP9 tendons and initial prestressing force at time t=to. It is to be mentioned that the angular change in tendon profile causes a transverse force on the member which 'balances' structural dead loads.

M. Arman I. M. (2014)

Adopted the ACI direct design method is used as a manual or hand method of calculation and the solution will be compared with the analysis results of the three dimensional structural model done by the computer program Sap2000. The moments in beams, slab column strip and slab middle strip will be determined. It will be illustrated that the distribution of moments in two-way slabs with hidden beams likes the distribution of moments in slabs without beams as the stiffness of the hidden beams is small. It is recommended that the use of three-dimensional modelling by computer software is the best solution for moment's determination and distribution.

N. R.S. More, V. S. Sawant, Y. R. Suryawanshi (2013)

Carried out by means of comparing the behaviour with that of conventional beam column framing. Grid slab system is selected for this purpose. To study the effect of drop panels on the behaviour of flat slab during lateral loads, flat plate system is also analyzed. Zone factor and soil conditions the other two important parameters which influence the behaviour of the structure, are also covered. Software ETABS is used for this purpose. In this study relation between the number of stories, zone and soil condition is developed.

O. K. Soni Priya, T. Durga Bhavani, D. Sriman Chowdary, Ch. Veerendra, P. Poluraju (2012)

Performed the push over analysis on flat slabs by using most common software SAP2000.Many existing flat slab buildings may not have been designed for seismic forces. Hence it is important to study their response under seismic conditions and to evaluate seismic retrofit schemes. But when compared to beam-column connections, flat slabs are becoming popular and gaining importance as they are economical. Under the pressure of recent developments, seismic codes have begun to explicitly require the identification of sources of inelasticity in structural response, together with the quantification of their energy absorption capacity. Many existing buildings do not have been designed for seismic forces. The push over analysis is gained importance for the strengthening and evaluation of the existing structures. By conducting the pushover analysis on flat slabs, pushover curve and demand curve can be obtained. Then, based on the results decision is made that rehabilitation or retrofitting depending upon the seismic zone of the existing structures.

P. Ahmed B. Shuraim (2002)

Examines the behaviour and the appropriate Method of analysis for two-way slab systems supported by a grid of main and secondary beams are not fully understood. The overall objective of this two-part study is to investigate the applicability of the ACI code methods for evaluation of design of moments for such slab systems. This part analyses five beam-slab-systems of different configurations through the code and finite element procedures. One slab system was without secondary beams while the remaining four have secondary beams with bearing beam- to-slab depth ratios from 2.6 to 5. The secondary beams, were found to reduce the floor weight by up to 30 % when the five slab systems were of equal stiffness. However, achieving slab-systems of equal stiffness is not straightforward and cannot be evaluated from section properties only. It was found that derivation of equal stiffness of the slab system based on section properties alone resulted in an error of 38 % in computed deflection. In beam slab system the rib projection of the beam poses a modelling challenge. Two options were considered: physical offset with rigid link option or equivalent beam option in which the size of the beam was increased to compensate for the rib offset. In this part the study the advantages and drawbacks of both modelling approaches are discussed.

III. CONCLUSIONS

The following conclusion is made based on the study and surmised report on review of literatures. The conclusions are as follows:

– The different researchers used different slabs in the structure as per the needs, therefore multistory buildings flat slab is predominant and with high rise the waffle and ribbed can be adopted for large span structure.
– The analysis is carried out with rigid frame structure and seismic response mainly with single slab or compare with conventional slab.
– Commercial utilization flat is more used and architect purpose the waffle and ribbed can be adopted.
– The scaffolding is easy in flat with somehow more required and tuff task in waffle and ribbed slab and more aesthetic view to the building.
– Flat slab suggests more reinforcement and stiffness as compare to normal slab and used with by post tensioning and as well as by conventional reinforced concrete.
– In earthquake zone we shall provide only flat slab drop with head & ductile detailing for all structure.
– Ribbed slab is more effective in moment resisting by optimizing the effective depth and the percentage of reinforcement. It is used for larger span of slab and floor with less number of columns.
– The waffle slab Structure exhibits load carrying capacity is greater than the other types of slabs along with Savings on weight and materials. & Good vibration control capacity. It also impact on Fast and speedy construction.
– The secondary beam is adopted when large span is required with the main beam.

IV. FUTURE SCOPE

The following work should be taken in future for research purpose.

– Comparative study of different types of slab in for a single building to find optimized structure.
– Use of different types of structural form such outrigger, core, tube in tube etc with slabs.
– Use of different seismic methods such RSA & THA and compare between them.
– Assessment of dynamic wind analysis as per CFD & Wind Tunnel data.
– Study based on Slabs with dampers.
– Study with Slabs with composite structures.

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