RESEARCH ARTICLE OPEN ACCESS

Finite Element Analysis for the Behavioral Study of Composite Waffle Slab Using ANSYS

Rinsha C [1], Asha Mary Jose [2]
Department of Civil Engineering
Vimal Jyothi Engineering College, Chemperi
Kerala -India

ABSTRACT

Waffle slab is a monolithic construction of slab and narrow beams spanning in both directions. Waffle slab is an excellent option for architects when larger span in a building has to be covered with minimum no. of columns. This project proposes a new kind of composite waffle slab that consist of orthogonal steel girder and flat RC slab. Shear studs are used to connect the steel girders and RC slab. Behaviour of composite waffle slabs with different size of steel section, different angular arrangement of ribs, varying percentage of steel fibres and changing the grade of steel sections with varying percentage of steel fibers are analysed using finite element analysis in ANSYS workbench 16.1. Also analyse the performance of composite waffle slab by changing I beam into castellated beam with and without stiffener. From ANSYS result, it is found that ISMB250 is the most economical steel section. It's been observed that skewed grid reduces the ultimate strength of composite waffle slab. Reduction in the strength of slab obtained in 60° rib orientation is 16.56%. Load carrying capacity of composite slab with 60º rib orientation was increased about 5.33% when 1.5% steel fiber is added. Composite waffle slab of Fe345 grade steel section and 0% steel fiber is well accepted for building where loads are more and architectural beauty is compulsory. Also concluded that composite waffle slab by changing I beam into castellated beams with and without stiffener increases the ultimate strength of the slab.

Keywords **:-** Finite Element Analysis, Ansys

I. INTRODUCTION

Waffle slab system consists of beams or ribs spaced at regular intervals in perpendicular direction and monolithic with slab. Providing columns inside the buildings such as auditorium, stadia, hospital, and schools will restrict the utilities. So, waffle slabs stand as an excellent option for architects and engineers when larger spans in a building have to be covered with minimum number of columns. They are generally used to cover large floor spaces of parking garages, commercial and industrial buildings, airport and residential structures. The grid floor (waffle slab) is often preferred for marriage halls where column free space is required over a large area. It is preferred by architects since the rectangular square void between the ribs can be advantageously utilised for concealed architectural lighting.

Applications of waffle slabs are not limited to buildings, but it is also used in bridges. Lot of investigations are done on traditional RC waffle slab. But few studies have been found to investigate the behaviour of the composite waffle slab. So it is thus necessary to perform a research on the composite waffle slab. In this project behaviour of composite waffle slabs subjected to concentrated load on middle of the slab is studied.

II. OBJECTIVES

The main objectives of this study are

- To investigate the flexural behaviour of composite waffle slab with different size of steel girders (ISMB200, ISMB250, ISMB300).
- To analyse the behaviour of composite waffle slab with different angular arrangement (30°,45°,60°) of ribs by using the better size of steel section.
- To find out at which percentage of steel fibers (0.5, 1, 1.5) in composite waffle slab gives better load carrying capacity.
- To find out the effect of adding steel fibers by changing the grade of steel section (Fe 345).
- To analyse the behaviour of composite waffle slab by changing I beam into castellated beam with and without stiffener.
- To compare ultimate load carrying capacity and corresponding deflection of composite waffle slab.

III. SCOPE

The scope of this study is to find out the suitability of adopting angular pattern of ribs. The response of composite waffle slab by varying the % of steel fibers and changing the grade of steel sections with varying percentage of steel fibers are studied. Also find out suitability of adopting castellated beam instead of solid I beam in composite waffle slab.

IV. DETAILS OF THE SPECIMEN

Out to out plan diamension of composite waffle slab is taken as 4700x4700mm with a clear span of 4500x4500mm.Thickness of RC slab is 50mm. Flexural reinforcing bar of 10mm diameter and is spaced at 100mm c/c. Concrete grade of M25 and structural steel grade of Fe250 has been used.

A. Models Considered for the Analysis

- CWS1- Composite waffle slab with ISMB200 size of steel section
- CWS2- Composite waffle slab with ISMB250 size of steel section
- CWS3- Composite waffle slab with ISMB300 size of steel section
- CWR1- Composite waffle slab having 30º rib orientation
- CWR2- Composite waffle slab having 45º rib orientation
- CWR3- Composite waffle slab having 60º rib orientation
- CWF1- Composite waffle slab of Fe250 grade steel section and 0.5% steel fiber
- CWF2- Composite waffle slab of Fe250 grade steel section and 1% steel fiber
- CWF3- Composite waffle slab of Fe250 grade steel section and 1.5% steel fiber
- CWF4- Composite waffle slab of Fe345 grade steel section and 0% steel fiber
- CWF5- Composite waffle slab of Fe345 grade steel section and 0.5% steel fiber
- CWF6- Composite waffle slab of Fe345 grade steel section and 1% steel fiber
- CWF7- Composite waffle slab of Fe345 grade steel section and 1.5% steel fiber
- CWCB- Composite waffle slab by changing I beam into castellated beam without Stiffener
- CWCS- Composite waffle slab by changing I beam into castellated beam with Stiffener

V. NUMERICAL STUDY

The numerical study was carried out for the following cases

B. Composite Waffle Slab with Different Size of Steel Section

Composite waffle slab with different size of steel girders such as ISMB200, ISMB250, and ISMB300 are modelled and analysed using ANSYS workbench 16.1. From this better size is selected, remaining models are done by using this size.

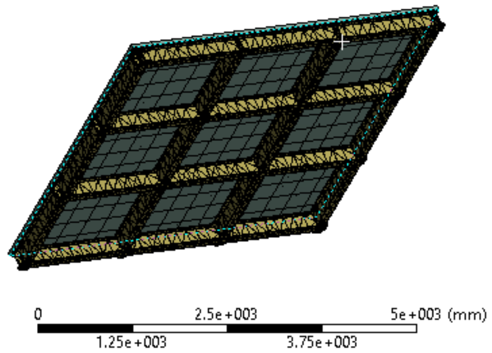

Fig. 1 Meshed view of composite waffle slab (ISMB250)

C. Composite Waffle Slab with Different Angular Arrangements of Ribs

Composite waffle slab with three different angular arrangements of ribs are studied. The ribs are arranged at 30º, 60º and 45°angle. These angular arrangements of ribs are evolving as a new trend for architect because it enhances the architectural beauty. These are done by using the better size of steel section

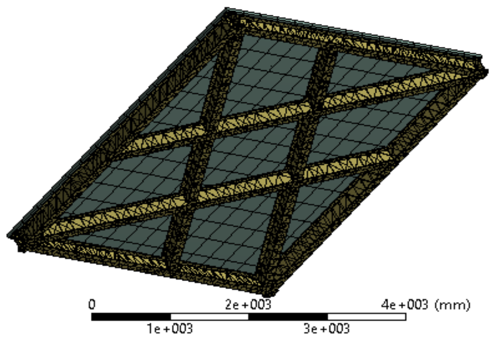

Fig. 2 FEM of skewed grid (60º rib orientation)

D. Composite Waffle Slab with Varying Percentage of Steel Fibers

During recent years, steel fiber reinforced concrete has gradually advanced from a new, rather unproven material to one which has now attained acknowledgment in numerous engineering applications. In the present study steel fibre with an aspect ratio of 50 were used. From better angular arrangement of rib is selected, steel fibers of varying percentage is added to this model .The different models considered for analysis are

1) Composite waffle slab of Fe250 grade steel section and 0.5% steel fiber
2) Composite waffle slab of Fe250 grade steel section and 1% steel fiber
3) Composite waffle slab of Fe250 grade steel section and 1.5% steel fiber

E. Composite Waffle Slab by Changing the Grade of Steel Section and Varying Percentage of Steel Fibers

Effect of adding fibers by changing the grade of steel section is studied. Structural steel grade of Fe 345 has been used and steel fibres of 0%, 0.5%, 1% and 1.5% of volume of concrete are added. These are done by using 60° rib orientation. The different models considered for analysis are

1) Composite waffle slab of Fe345 grade steel section and 0% steel fibre (CWF4)
2) Composite waffle slab of Fe345 grade steel section and 0.5% steel fibre (CWF5)
3) Composite waffle slab of Fe345 grade steel section and 1% steel fibre (CWF6)
4) Composite waffle slab of Fe345 grade steel section and 1.5% steel fibre (CWF7)

F. Composite Waffle Slab by Changing I Beam

The performance of composite waffle slab by changing I beam into castellated beam with and without stiffener is studied. Nowadays the applications of castellated steel beams become very popular due to its advantageous implementations in buildings constructions. Here depth of castellated beam is 1.5 times greater than the parent I section.ie depth of castellated beam is 375mm. Castellated steel beams having an yield strength of 250Mpa.The models considered for analysis are

1) Composite Waffle Slab by changing I beam into castellated beam without stiffener
2) Composite waffle slab by changing I beam into castellated beam with stiffener

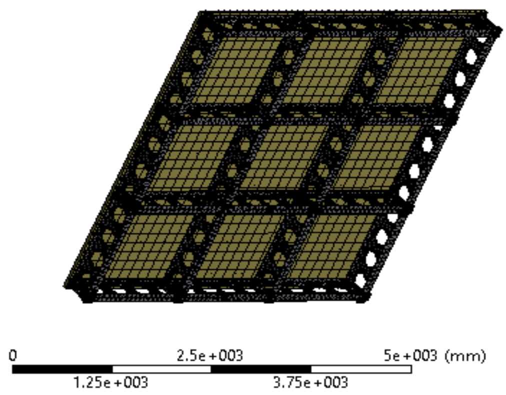

Fig. 3 FEM of composite waffle slab by changing I beam into castellated beam without stiffener

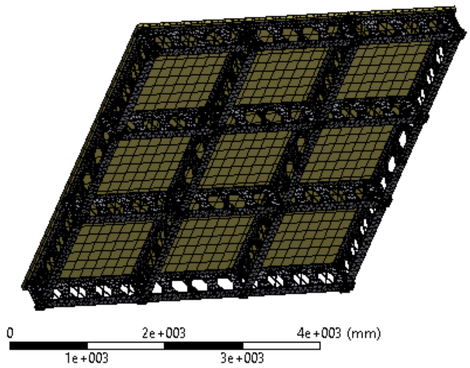

Fig. 4 FEM of composite waffle slab by changing I beam into castellated beam with stiffener along shear zone.

VI. RESULTS AND DISCUSSION

The results of non linear static analysis of different composite models are compared. Ultimate load carrying capacities of the structure are used to compare the performance of composite waffle slab models under gradually increasing load. Following comparisons are done.

G. Comparison of Composite Waffle Slab with Different Size of Steel Section

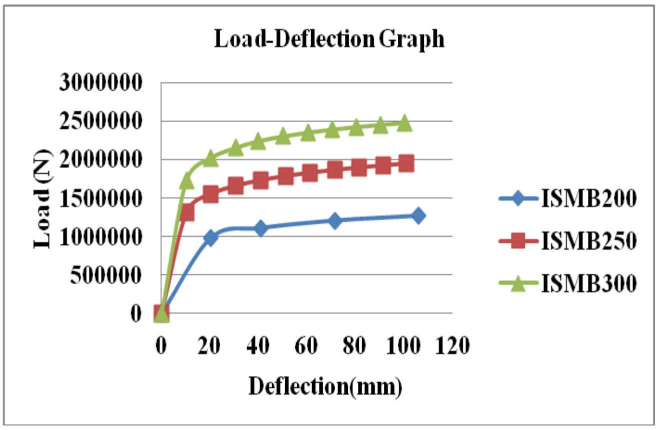

Fig. 5 Load deflection behaviour of composite waffle slab with different size of steel section

From the above fig.5, it can be seen that ISMB300 has maximum load carrying capacity and minimum deflection value. This is due to its higher depth of the section. The load-deformation graph of different size of steel section shows that the load carrying capacity of the composite waffle slab is increased as the size of steel section is increased. Maximum load obtained for ISMB200 is 1267.2 kN with a corresponding deflection of 104.99mm and that for ISMB250 and ISMB300 are 1948.8 kN and 2480.4 kN respectively.

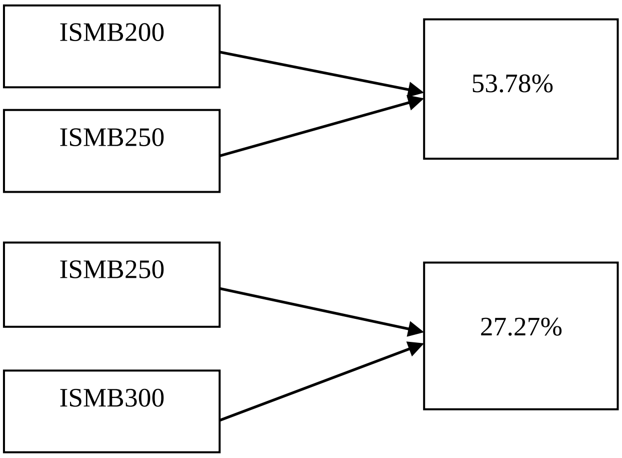

Fig. 6 Percentage increase in strength of composite waffle slab

From the above fig.6, it can be seen that by comparing ISMB200 and ISMB250 steel section, ultimate strength of composite waffle slab with ISMB250 was increased about 53.78%. While comparing ISMB250 and ISMB300 steel section, ultimate strength of composite waffle slab with ISMB300 was increased about 27.27%. It can be concluded that ISMB250 steel section is the optimum section. So it is most economical section than other sections.

H. Comparison of Composite Waffle Slab with Different Angular Arrangement of Ribs

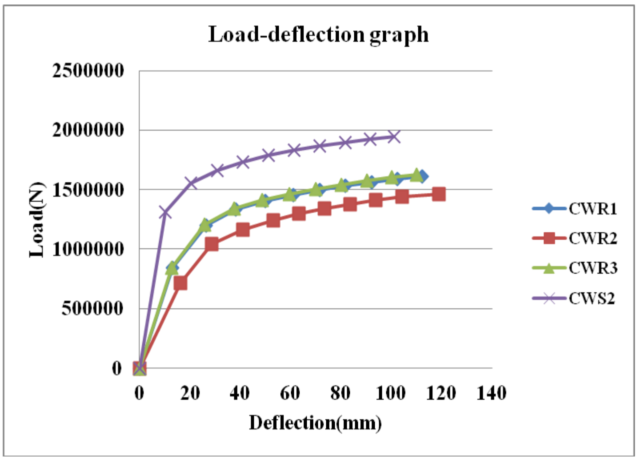

Fig. 7 Load deflection behaviour of composite waffle slab with different angular arrangement of ribs

From the above fig 7, it can be concluded that composite waffle slab without angular arrangement of ribs is better than composite waffle slab with angular arrangement of ribs. 30° and 60° rib orientations have almost similar performance. While comparing the above three angle (30º, 45º, 60º), it is found that 60° rib orientation is better than others. Maximum load obtained for composite waffle slab having 60° rib orientations is 1626 kN with a corresponding deflection of 109.83mm. Reduction in the strength of composite waffle slab is more in 45°rib orientation. i.e., strength was reduced about 24.87%. Reduction in the strength of slab obtained in 30°rib orientation is 17.19% and that for 60°rib orientation is 16.56%.

I. Comparison of Composite Waffle Slab with Varying Percentage of Steel Fiber

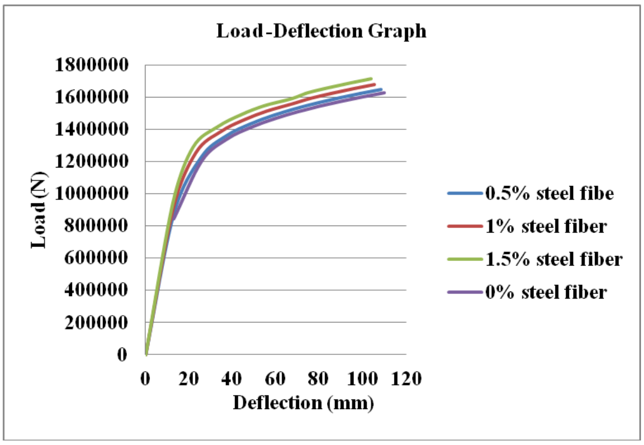

Fig. 8 Load deflection behaviour of composite waffle slab with varying percentage of steel fiber

From the above fig 8, it can be seen that addition of steel fiber increases the load carrying capacity. Better load carrying capacity is obtained by increasing the percentage of steel fibers.ie composite waffle slab having 1.5% steel fibers has maximum load carrying capacity and minimum deflection value. Maximum load obtained for composite waffle slab having 1.5% steel fiber is 1712.7 kN with a deflection of 103.85mm. Load carrying capacity of composite waffle slab was increased about 1.34% when 0.5% of steel fibers are added and an increment of 3.29% and 5.33% in strength is observed when 1% and 1.5% steel fiber is added. From this study it's been observed that load carrying capacity of composite waffle slab with 60º rib orientation was increased when steel fibers are added. But this value did not reach as much value as composite waffle slab without angular arrangement of ribs

J. Comparison of Composite Waffle Slab by Changing the Grade of Steel Section and Varying Percentage of Steel Fiber

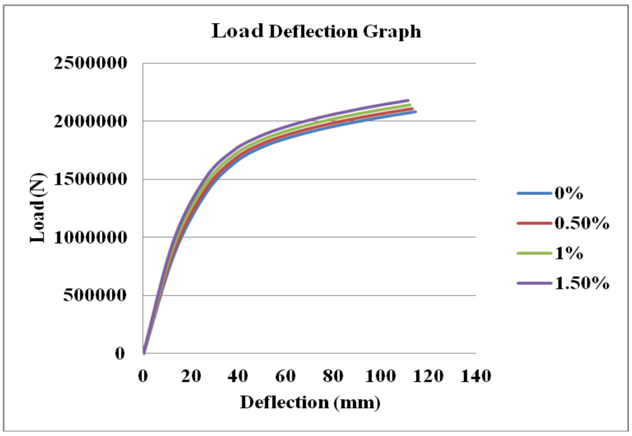

Fig. 9 Load deflection behaviour of composite waffle slab by changing the grade of steel section and varying percentage of steel fiber

From above study, it is clear that load carrying capacity of composite slab with 60º rib orientations was increased when fibers are added. But this did not reach as much value as composite waffle slab without angular arrangement of ribs. So the grade of steel section is increased to Fe345 and maximum load carrying capacity is studied without adding steel fibers. From these results, it is observed that changing the grade of steel section increases the load carrying capacity of composite waffle slab than 0º rib orientation. Further addition of fibers to this increases the load carrying capacity of composite waffle slab. Load carrying capacity of composite waffle slab was increased about 1.20% when 0.5% of steel fibers are added and an increase of 2.91% and 4.6% in strength is observed when 1% and 1.5% steel fiber is added.

K. Comparison of CWS2, CWF3 and CWF4

On comparing values of composite waffle slab without angular arrangement of ribs (CWS2), by adding 1.5% of steel fibers (CWF3) and by changing grade of steel section and 0% steel fiber (CWF4), and in order to check whether the load carrying capacity of CWF3 and CWF4, could reach as much load carrying capacity as composite waffle slab without angular arrangement of ribs

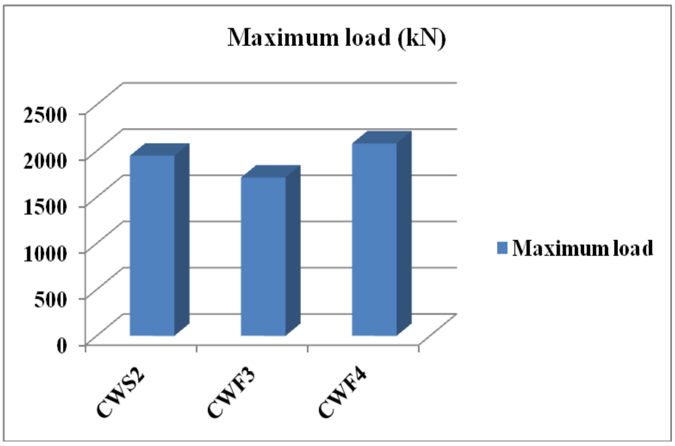

Fig. 10 Ultimate load of composite waffle slab

From the above fig 10, it can be seen that CWF4 has maximum load carrying capacity followed by CWS2 and CWF3. Maximum load obtained for composite waffle slab of Fe345 grade steel section and 0% steel fiber is 2081.6 kN. While comparing CWS2 and CWF4, ultimate strength of CWF4 was increased about 6.81%. By Comparing CWF3 and CWF4, ultimate strength of CWF4 was increased about 21.53%.

From the results of CWS2, CWF3 and CWF4, it can be concluded that maximum load carrying capacity is for composite waffle slab of Fe345 grade steel section and 0%

steel fiber. But this is not economical to use this high grade steel section. From the economical point of view, composite waffle slab without angular arrangements of rib (CWS2) is the best model. But composite waffle slab by adding steel fibers (CWF3) is well accepted for building where loads are generally less and architectural beauty is compulsory. In such a case loads are more and architectural beauty is compulsory, CWF4 is well accepted.

L. Comparison Of Composite Waffle Slab By Changing I Beam

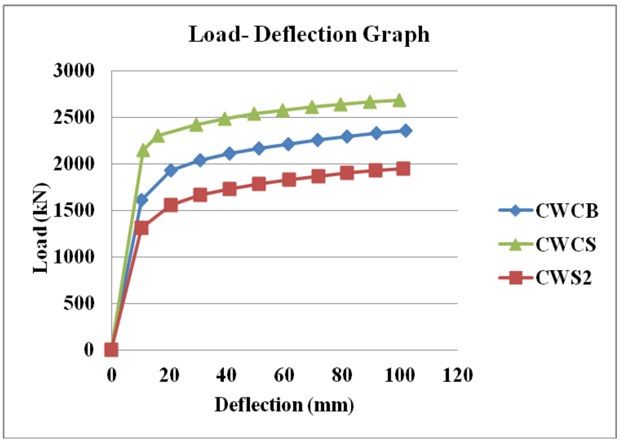

Fig. 11 Load deflection behaviour of composite waffle slab by changing I beam into castellated beam with and without stiffener

From the above fig.11, it can be concluded that composite waffle slab by changing I beam into castellated beams can increases the ultimate strength of the slab by increasing its height without adding any material. But web opening causes shear failures. So this can be eliminated by providing diagonal stiffener along shear zone. Composite waffle slab by changing I beam into castellated beam with stiffener increases the ultimate strength of slab without any shear failure. Minimum deflection also occurs in this case. The value of maximum load obtained for composite waffle slab by changing I beam into castellated beam with stiffener is 2684.28 kN with a corresponding deflection of 99.85mm.

Composite waffle slab by changing I beam into castellated steel beams with stiffener increases the ultimate strength of slab about 37.74% than the parent I-section. Composite waffle slab by changing I beam into castellated steel beams without stiffener increases the ultimate strength of slab about 20.91% than the parent I-section.

VII. CONCLUSIONS

The conclusions drawn from the present research are given below

- ISMB250 steel section is the optimum section. So it is most economical section than other sections.
- Strength of composite waffle slab was reduced when skewed grid is adopted
- Reduction in the strength of slab obtained in 60°rib orientation is 16.56%. Least deflection occurs in 60°rib orientation. Least deflection indicates that stiffness is more.So these angular arrangements of ribs are well accepted for buildings where loads are generally less.
- Load carrying capacity of composite slab with 60° rib orientation was increased about 5.33% when 1.5% steel fibers are added. It may be due to the fact that concrete is relatively weak in tension and may require some form of reinforcement to cope with tensile forces. So addition of steel fibers to concrete increases its energy absorption. It would appear that the dispersion of steel fibers throughout a concrete mix affords a degree of toughness between the reinforcement bar spacing.
- Composite waffle slab of Fe345 grade steel section and 0% steel fibers are well accepted for building where loads are more and architectural beauty is compulsory.
- Composite waffle slab by changing I beam into castellated beam with stiffener is an excellent option for increasing the load carrying capacity and stiffness. This may be due to the fact that stiffeners provided in the open web causes the smooth flow of the shear forces. The obtained deflection value is less by providing diagonal stiffener along shear zone.
- When diagonal stiffeners are provided on the web openings along shear zone, which infers that web portion of I beam is stiffened, shear strength across the holes increases. This leads to higher strength of slab and lesser deflection. i.e., Web holes are stiffened due to the presence diagonal stiffener. So it can be concluded that these are well accepted for using in long span roofing because of its advantage of increased depth of section without adding any material.

REFERENCES

[1] JianguoNie, Xiaowei Ma, and LingyanWen (2015) ‘‘Experimental and Numerical Investigation of Steel-Concrete Composite Waffle Slab Behavior’’ *American society of civil engineers*

[2] Anurag Sharma, Claudia Jeya Pushpa.D (2015), ‘‘ Analysis of Flat Slab and Waffle Slab in Multi-storey Buildings using ETABS’’, *International Journal*

for Scientific Research & Development, Vol.3, Issue 02, ISSN (online): 2321-0613

[3] Alaa C. Galeb, Zainab F. Atiyah (2011), "Optimum design of reinforced concrete waffle slabs'' *International journal of civil and structural engineering* Volume 1, No 4

[4] Muhammed Yoosaf.K.T , Ramadass S, Jayasree Ramanujan (2013), '' Finite element analysis and parametric study of grid floor slab'', *American Journal of Engineering Research,* (AJER) e-ISSN : 2320-0847 p-ISSN : 2320-0936 Volume-3 pp-20-27 www.ajer.org

[5] Avinash Joshi , Pradeep reddy ,Punith kumar and Pramod hatker, ''Experimental work on steel fibre reinforced concrete'', *International Journal of Scientific & Engineering Research*, Volume 7, Issue 10, October-2016

[6] S.G. Jeurkar1, K.S. Upase, "Behavior of Steel Fiber Reinforced Concrete for M-25 Grade", *International Journal of Emerging Trends in Science and Technology*, Vol 2, 2015

[7] Dr. Hayder Wafi Al-Thabhawee, "Experimental study of effect of hexagonal holes dimensions on ultimate strength of castellated steel beam", *Kufa Journal of Engineering*, Vol. 8,2016