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# RESEARCH ARTICLE

# BEHAVIOR OF RC SLABS UNDER STATIC LOADUSING HIGH PERFORMANCE FIBER REINFORCED CONCRETE

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## ABSTRACT

High performance concrete being one of the most widely used concretewhich gives better performance and uniformity requirements that cannot always be achieved by using conventional concrete, since the conventional concrete has limited resistance to ductility and tensile cracking to overcome these difficulties discrete fibers are used in high performance concrete.Slab is a flexural member which transverse the superimposed loads from super structure to beams and columns. In static tests the ultimate load carrying capacity in structural design is one of the important factor.The present research is aimed at experimental investigation focused on the behavior of high performance fibre reinforced concrete slabs under static loading. A series of twelvetest slab specimens of size 600 mm x 600 mm with varying thickness of 60 mm, 50 mm and40 mm were casted and tested under fixed edge condition. M60 grade of concrete mix integrated with Polypropylene fiber of 900 gms/m$^3$of concrete and 0.65% steel fiber by volume fraction.  Load cells and LVDT's are used to measure the load-deflection response. To study ductility index, toughness index and energy absorption capacity and cracking moment and consequently the load carrying capacity of test slab specimens from the load-deflection curve to access the enhancement in flexural strength using different fibre reinforced concrete matrices and same is to be optimize.



## INTRODUCTION

It is well known that conventional concrete designed on the basis of compressive strength does not meet many functional requirements such as impermeability, resistance to frost, resistance thermal cracking adequately and energy absorption capacity. These disadvantages can be minimized by using a material which meets all these requirements. One among the material which overcome all these difficulties is a high performance concrete (HPC). Use of continuous reinforcement in reinforced concrete members, increases strength and ductility, but requires careful placement and labor skill. Alternatively, introduction of fibers in discrete form in plain or reinforced concrete may provide a better solution. The modern development of fiber reinforced concrete (FRC) started in the early sixties. Addition of fibers to concrete makes it a homogeneous and isotropic material. When concrete cracks, the randomly oriented fibers start functioning, arrest crack formation and propagation, and thus improve strength and ductility. Static testing is cumulative application of load.

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Punching shear could occur in reinforced concrete slabs and footings. A structure that is strong for a large flexural load may fail due to heavy application of axial loads. There have been a number of studies on static resistance of reinforced concrete members over the past decades. Most of the studies have been carried out for slabs with different end conditions. To explore the feasibility of the utility of a four edge continuous slabs and also footings with axial loading, hence there is a need to study the behavior of slabs under static load. This paper presents an investigation carried out on the static behavior of Reinforced slabs with and without fibers.

### Literature review

HPC is an engineered concrete possessing the most desirable properties during fresh as well as hardened concrete stages. HPC is far superior to conventional concrete, as the ingredients of HPC contribute most optimally and efficiently to the various properties. Literature review carried out on high performance concrete. In most of the literatures it was observed that the high performance concrete is a brittle material and this brittleness can be reduced by incorporating the ductile materials like fibers (Sabale Vishal Dhondiram. B. B. Patil 2012). Strength and Durability Properties of High Performance Concrete incorporating High Reactivity

Metakaolin (HRM), with various percentage of HRM and replacement of cement by silica fume, GGBS and Fly Ash to 10% causes a significant increase in the mechanical properties of the HPC. (Parveen, 2013) found that the use of fibers increases the compressive and split tensile strength of concrete. (T.Ch.Madhavi, 2014) studied to optimize the percentage of polypropylene fiberreinforced concrete in reduction in the water permeability, plastic shrinkage and settlement and carbonation depthdue to the inclusion of polypropylene fibers as 0.9 kg/m$^3$ approximately0.1% by volume. (Ahsana Fathima 2014) effects of steel fibers and polypropylene fibers on the mechanical properties of concrete and found that there is significant increase in the mechanical properties of concrete due to the addition of these fibers. (Pu-Woei Chen 1996) have given idea of using polyethylene fibers for concrete mixes and compared the results of tensile compression and flexural properties and experimental evident that high ductility causes high flexural toughness. (Saadun 2016) made a study on fibers in concrete to comprised concrete mixed with1.0 kg/m$^3$ Polypropylene fiber and 2.0 kg/m$^3$Polypropylenefiber, as well as plain concrete and result shows that dynamic increase factor yielded highest value with addition of 2.0 kg/mm$^3$of polypropylene fibers. (Zhang Huili2011) investigated properties and mechanism on flexural fatigue of concrete containing polypropylene Fibres and ground granulated blast furnace slag (GGBS). Fatigue properties decreases as the stress level increases (Samen Ezeldin 1989) investigated on the bond behavior for normal and high strength concrete with parameters of silica fume content, fiber length and fiber content and bar size as variables.

Addition of fibers improves the ductility of concrete to a considerable extent. Fibers are compatible with admixture silica fume and cement chemistry. (Doo-YeolYoo 2012) performed experiment to enhance the resistance of concrete slabs by strengthening it with fiber reinforced plastics (FRPs) and hooked steel fibers having 30mm length, two types of FRPs which were externally bonded with the help of epoxy resins were used, the result concluded that addition of steel fiber in strengthening prevents the crack propagation and enhance the ductility of material (Ramakrishnan V 1987)carried out an extensive experimental investigation on the performance characteristics of fibre reinforced concrete which included compressive strength, static flexural strength, deflection, modulus of rupture, load deflection curve, determining of first crack load, post cracking strength, flexural fatigue, ultimate failure and dynamic modulus of elasticity. They concluded that due to the addition of steel fibres, the ductility and energy absorption capacity were greatly increases. There was a tremendous increase in the static flexural and fatigue strength. Hence, an attempt has been made in the present experimental research investigation on behavior of RC slabs under static load using high performance fiber reinforced concrete which consisting of M60 grade concrete slabs of size 600x600mm with varying thickness of 60, 50 and 40 mm with steel fibers polypropylene fibers and combination of both and to study Load-Deflection variation, Ductility index, Toughness index, Energy absorption capacity under static loading and same is to be optimized with economical.

## Materials and mix procedure

In this present experimental investigation OPC 53 grade with specific gravity of 3.20 confirming to 269:2015,coarse aggregate of 12.5 mm down retaining on 10 mm, specific gravity 2.63, fineness modulus of 6.6, bulk density 1629 kg/m$^3$, fine aggregate having fineness modulus of 3.14, specific gravity 2.61, bulk density 1736 kg/m$^3$, conforming to zone-II (IS 383-1970), Glenium 8233 super plasticizer obtained from BASF Chemicals, 15% GGBS and 10% Silica fume as partial replacement of cement having a specific gravity of 2.32 and 2.26.

**Poly-Propylene Fibre (PF):** The poly-propylene fibre used was of Recron3s type. The fibers were of length 12 mm, specific gravity of 0.9 and tensile strength of 700 MPa. The dosage was as per instructed by the manufacturer i.e. 900gm/m$^3$.

**Steel Fiber (SF):** Crimped end steel fiber supplied by Steelwools India Pvt.Ltd Nagpur, Maharashtra having length of fiber 36 mm, diameter 0.45 mm, density 7850 kg/m$^3$, ultimate strength 1500 MPa, poisson's ratio 0.28,with 0.65% volume fraction is used for the present investigation

For 110 mm slump the concrete mix proportion is obtained after trail mixes viz. Cement: Silica Fume: GGBS: FA: CA: Water (1: 0.139: 0.268: 0.984: 2.501: 0.30) and the same is adopted for present experimental investigation

## Test specimen and experimental programme

In the present study, Behaviour of Fiber Reinforced Concrete Slabs under static loads was carried out by casting and testing of 600 x 600 mm test slab specimens with M60, M60+PF, M60+SF, M60+PF+SF having steel reinforcement as shown in Table1 conforming to IS: 1786 (Fe 500D) further the test slab specimens are divided into 40, 50 and 60 mm thickness as shown in Figure1.

**Table 1. Details of Reinforcement for slab specimens**

| Thickness (mm) | Main Steel (mm) | Distribution Steel (mm) | Spacing (mm) |
|---|---|---|---|
| 60 | 6 | 6 | 90 mm c/c |
| 50 | 6 | 6 | 80 mm c/c |
| 40 | 6 | 6 | 55 mm c/c |

## Casting of specimens

Steel prefabricated formworks were used for casting the test slab specimens of varying thickness. The slabs were casted with the help of hand trowel and Pick-Mattock. Needle vibrator of 25 mm diameter was used for proper consolidation of the concrete till the lattice layer appears and the same is cured for 28 days. The details of slab test specimens are tabulated in Table 2.

**Table 2. Details of Slab test specimens**

| Slab Designation | Thickness (mm) | Slab Type |
|---|---|---|
| CS (M60) | 60<br>50<br>40 | Control Specimen |
| M60+PF | 60<br>50<br>40 | M60+ Polypropylene fibre (PF)<br>(900 gm / m$^3$) |
| M60+SF | 60<br>50<br>40 | M60+ Steel fibre SF)<br>(0.65 by volume fraction) |
| M60+PF+SF | 60<br>50<br>40 | M60+<br>Polypropylene fibre (PF)+<br>Steel fibre (PF) |

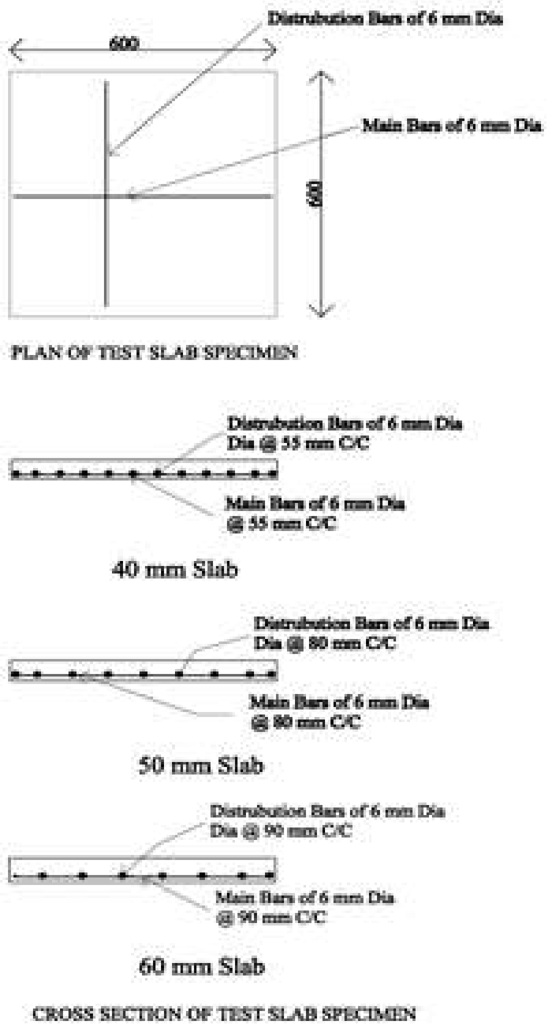


**Figure 1. Plan and Cross Section of Test Slab Specimen**

### Test Programme

The experimental programme consisting of four series of test slab specimens under static loading, the loading arrangement and instrumentation are shown in figure 2. The static testing machine is fabricated and installed at Civil Engineering Department, Bangalore University, Bengaluru - 56.

Static testing machine is a manual operated hydraulic jack system and was rigidly fixed to a RCC pedestal foundation to a height of 0.3 m above ground level and the pedestal was extended up to 0.7 m giving it total height of 1 m, to which a frame of height 2.5 m fabricated with I sections of ISMB 250. The loading assembly is supported vertically by a horizontal I section of ISMB 250 attached to the vertical sections. The test slab specimens were rested upon I sections of square frame of 600 mm x 600 mm which was made up of ISHB 160 that itself rests upon the pedestal. For testing of the test slab specimens fixed edge condition is considered. Two C-clamps on each side of the specimen was fixed to frame to obtain the required end condition. Two LVDT's, one at ¼th and one at center at the soffit is attached to the test slab specimens. The load was measured through load cell and load was applied by operating the10-ton capacity hydraulic jack in incremental load till the test slab specimen fails.

### Instrumentation

***Load Cell:*** Load cell was attached vertically to the hydraulic jack with the purpose of measuring reactions. The load cell used was SI-430C with 10 tons' capacity manufactured by SYSCON INSTRUMENT.

***LVDT:*** LVDT (Linear Variable Different Transformer) is a sensitive device, used for measuring minute mechanical displacements. Two LVDT's were fixed at the bottom surface to measure the deflections. The range of LVDT's was 0-25 mm.

***Data Acquisition System:*** 4 channel data acquisition system was used. For acquiring different responses, software visual basic 6.0 was used.

### Test Procedure

The test slab specimen was kept on the supporting frame with C-Clamps attached to all side of the specimen to attain fixed edge condition, then two LVDT's are placed. After completion of preliminary setup, the load cell assembly is mounted vertically at the center of the test slab specimen. The load is applied in gradual manner and crack development was observed simultaneously. The first crack load, ultimate load and deflection were recorded for each increment of load till specimens fails by punching.

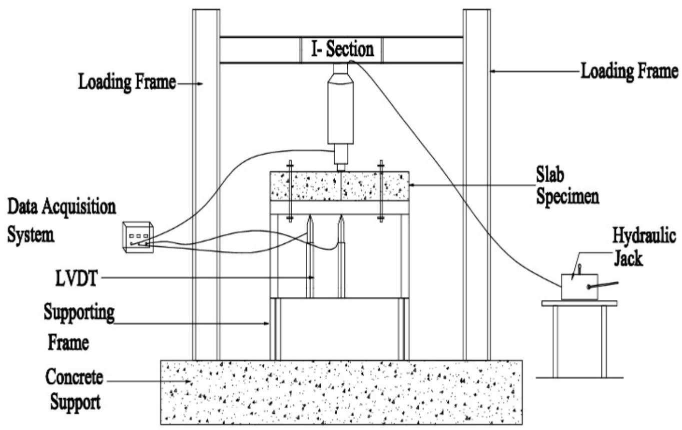


**Fig2. Static Test Setup**

## RESULTS AND DISCUSSIONS

The behavior of high performance fiber reinforced concrete test slab specimens under static loading for fixed end condition are observed from the load-deflection curve on the following parameters: deflection, cracking loads, ductility factor, toughness index and energy absorption. The experimental cracking moments and cracking loads are compared with corresponding moments and loads calculated as per IS: 456-2000.

### Load -deflection curves

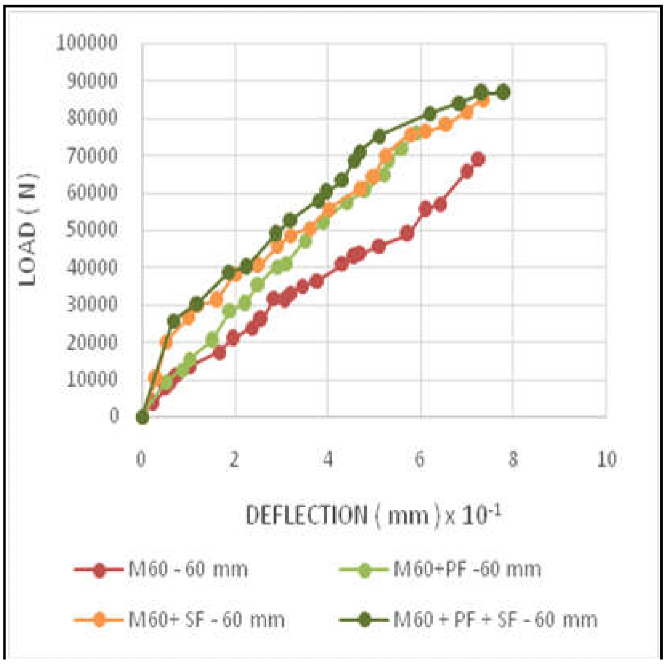


**Figure 3. Load VS Deflection variation of slabs under static loading for different fiber combinations**

The main aim of the structural design by the limit state method philosophy is to ensure both 'safety and serviceability'. In design of the limit state method, ultimate limit state and serviceability limit state are considered. Ultimate limit state method deals with important safety factor in terms of strength, overturning, sliding buckling, fatigue fracture.

Whereas in serviceability defection, cracking, vibration, durability is considered so that the structure performs it intended function satisfactorily. It is observed from Figure 3, the load carrying capacity of slab with 60 mm thickness and with polypropylene and steel fibre (M60+PF+SF) is 86.7 kN. Whereas test slab specimen with 40 mm thickness without fibrein CS (control specimen) is35.6 kN load followed by M60+PF and M60+SFrespectively.

### First crack load

The first crack load is also referred as yield load and can be used as a primary factor for design of Structures. The stage at which an appearance of first crack within elastic limit occurs is called first crack load. The theoretical and experimental first crack loads are tabulated in Table 3.

### Ultimate load

The term ultimate load is the maximum load which produces actual failure for the member consideration. The theoretical and experimental ultimate crack loads are tabulated as shown in Table 4.

**Table 3. Experimental and theoretical values of first crack loads**

| Slab Designation | Thick-ness mm | Experimental first crack load (E)N | Theoretical first crack load(T)N | Ratio T/E |
|---|---|---|---|---|
| | 40 | 12700 | 12940 | 1.01 |
| CS (M60) | 50 | 17300 | 20360 | 1.17 |
| | 60 | 22300 | 29230 | 1.31 |
| | 40 | 15200 | 13380 | 0.88 |
| M60+PF | 50 | 18200 | 20940 | 1.15 |
| | 60 | 26400 | 30100 | 1.14 |
| | 40 | 16765 | 14872 | 0.88 |
| M60+SF | 50 | 20887 | 18765 | 0.89 |
| | 60 | 25700 | 31099 | 1.08 |
| | 40 | 21200 | 13810 | 0.59 |
| M60+PF+SF | 50 | 23200 | 21520 | 1.48 |
| | 60 | 28765 | 31120 | 1.21 |

**Table 4. Experimental and theoretical values of ultimate loads**

| Slab Designation | Thickness mm | Experimental ultimate crack load(E)N | Theoretical ultimate crack load(T) N | Ratio T/E |
|---|---|---|---|---|
| CS (M60) | 40 | 35600 | 31010 | 0.87 |
| Control specimen | 50 | 54400 | 50794 | 0.93 |
| | 60 | 69000 | 87540 | 1.26 |
| | 40 | 48600 | 33820 | 0.69 |
| M60+PF | 50 | 55000 | 55130 | 1.09 |
| | 60 | 85200 | 94520 | 1.10 |
| | 40 | 49076 | 34087 | 0.69 |
| M60+SF | 50 | 57987 | 56430 | 0.97 |
| | 60 | 85654 | 97390 | 1.13 |
| | 40 | 49900 | 34950 | 0.70 |
| M60+PF+SF | 50 | 58000 | 57300 | 0.99 |
| | 60 | 86700 | 98798 | 1.15 |

It is evident from experimental results the first crack load and ultimate load is found highest for the test slab specimen (M60+PF+SF) and followed by M60+SF, M60+PF and M60 (CS) respectively.

### Ductility factor

Displacement ductility in addition to serviceability design of reinforced concrete structure is very important because in the extreme cases of structures being loaded to failure it should be capable of undergoing large deflections at near maximum load carrying capacity. The ductility of a member can be measured using load deflection response. The deformation may be strain/rotation/curvature/deflection etc. the ratio of ultimate deformation to the first yield is defined as ductility factor. Displacement ductility factor is given by

$$\text{Ductility factor } (\mu_d) = \frac{Ultimate\ Deformation}{Defeormation\ at\ first\ crack}$$

$$(\mu_d) = \delta_u / \delta_y$$

The ductility factor for different test slab specimens is shown in Table 5.Table 5, shows the variations of the ductility factor for all test slab specimens. For 60 mm thickness test slab specimen with polypropylene and steel fiber (M60+PF+SF) highest ductility factor is obtained as compared to the other test slab specimens tested. As it can be observed that ductility factor increases as the thickness of test slab specimen increases.

### Energy absorption capacity

The absorbed energy capacity gives its ability to sustain the structural integrity or internal resistance capacity. The energy absorption capacity of given material can be obtained from the load vs deflection response. The energy absorption capacity was computed by the measuring area under the load-deflection curve.

**Table 5. Ductility index**

| Concrete Matrices | Thick-ness mm | $\delta_y$ mm | $\delta_u$mm | $\mu_d = \delta_u / \delta_y$ |
|---|---|---|---|---|
| | 40 | 0.31 | 0.95 | 3.06 |
| CS(M60) | 50 | 0.17 | 0.73 | 4.29 |
| | 60 | 0.09 | 0.59 | 6.94 |
| | 40 | 0.23 | 0.72 | 3.13 |
| M60+PF | 50 | 0.13 | 0.82 | 6.30 |
| | 60 | 0.10 | 0.73 | 7.30 |
| | 40 | 0.21 | 0.68 | 3.23 |
| M60+SF | 50 | 0.14 | 0.63 | 4.50 |
| | 60 | 0.09 | 0.73 | 8.11 |
| M60+PF+SF | 40 | 0.16 | 0.67 | 4.18 |
| | 50 | 0.11 | 0.61 | 5.54 |
| | 60 | 0.08 | 0.78 | 9.75 |

**Table 6. Energy absorption Capacity**

| Concrete Matrices | Thickness mm | Energy absorption capacity kN-mm |
|---|---|---|
| | 40 | 168.70 |
| CS ( M60) | 50 | 197.52 |
| | 60 | 198.80 |
| | 40 | 211.71 |
| M60+PF | 50 | 207.50 |
| | 60 | 288.50 |
| | 40 | 166.09 |
| M60+SF | 50 | 187.98 |
| | 60 | 290.87 |
| | 40 | 167.33 |
| M60+PF+SF | 50 | 178.02 |
| | 60 | 343.00 |

The total energy absorbed as obtained from load-deflection curve for 60 mm thickness test slab specimen (M60+PF+SF) is 343 kN-mm, is the highest followed by M60+SF, M60+PF and CS(M60) respectively.

## Toughness Index

It is well known that concrete will be effective in resisting the load until the formation of first crack. At this stage concrete is relieved of its tensile stress and steel takes the entire load at cracked section. Hence an attempt is made to obtain the area under load deflection curve up to first crack load. Then the area obtained from the load deflection curve with 80% of post peak load as cut off point was divided by the area computed up to the first crack load, and this is termed as Toughness Index. The value of toughness index for different test slab specimen under investigation is given in Table 7

$$\text{Toughness index} = \frac{\text{Area under the post peak load deflection curve up to } 0.8\text{Pu}}{\text{Area up to first crack load}}$$

**Table 7. Toughness index**

| SlabDesignation | Thickness mm | Toughness Index |
|---|---|---|
| | 40 | 08.69 |
| CS ( M60) | 50 | 13.81 |
| | 60 | 34.73 |
| | 40 | 10.29 |
| M60+PF | 50 | 21.61 |
| | 60 | 37.43 |
| | 40 | 10.99 |
| M60+SF | 50 | 22.54 |
| | 60 | 38.98 |
| | 40 | 11.69 |
| M60+PF+SF | 50 | 23.46 |
| | 60 | 40.20 |

Table 7 shows the variation of toughness index for different test slab specimens, for 60 mm thickness (M60+PF+SF) it is found to be highest and followed by M60+SF, M60+PF and M60 (CS) respectively. It is also observed that, as thickness of test slab specimen decreases the toughness index also decreases.

## Crack pattern

The first stage of damage in the concrete matrix cracking concentrated at the center consequently cracks on the tension surface were concentrated along the diagonals, extending radially from the loading point (center) towards the edges of the specimen. With the increased loading, newer cracks were developed along the middle axes and cracks were widely spread on tension surface. As expected, test slab specimen failed by punching, circular load cell punching suddenly through the specimen and slight scabbing and circular wide cracks were observed around the center on tension surface as a result of the punching. The loading was done continuously and crack were observed and marked for all test slab specimens till it fails. It can be observed from the figure 4 that the crack propagations are more in case CS (M60), and very less cracks have observed for the test slab specimens with fibre reinforced concrete and the specimens with both fibres (M60+PF+SF)are showing very less crack compared to all other test slab specimens. The crack patterns of all four types of test slab specimens are shown Figure (4.1, 4.2, 4.3 and 4.4).

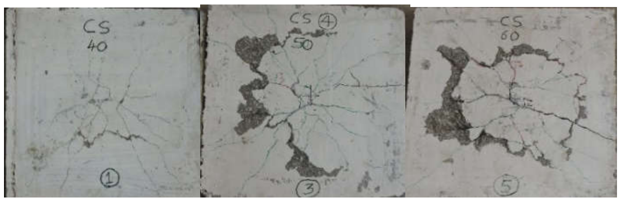

**Fig. 4.1. Crack pattern of CS (M60)(40 mm, 50 mm, 60 mm)**

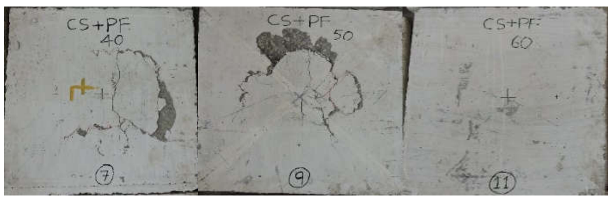

**Fig. 4.2. Crack pattern of M60 +PF(40 mm, 50 mm, 60 mm)**

**Fig. 4.3. Crack pattern of M60 +SF(40 mm, 50 mm, 60 mm)**

**Fig. 4.4. Crack pattern of M60+PF+SF(40 mm, 50 mm, 60 mm)**

**Conclusions**

Based on the detailed experimental investigations, following conclusions are drawn.

- It is evident from experimental results the first crack load and ultimate load is found highest for the test slab specimen (M60+PF+SF) and followed by M60+SF, M60+PF and M60 (CS) respectively. The ultimate load for 60 mm thickness of test slab specimen for M60 (CS), M60+PF, M60+SF, (M60+PF+SF) is 69 kN, 85.20 kN, 85.65kNand 86.7kN.
- All test slabs show increase in the ductility factor as thickness increases. For 60 mm thickness test slab specimen with polypropylene and steel fibre(M60+PF+SF) is 40.5% more compared to the CS (M60) test slab specimens, followed by M60+SF and M60+PF.
- The toughness index is found to be highest for test slab specimen of 60 mm thickness (M60+PF+SF) is 15.75% more compared to the CS (M60).
- Energy absorption capacity for 60 mm thickness test slab specimen (M60+PF+SF) is 343 kN-mm. and 72.5% higher compared to CS (M60) test slab specimens and also resistance to energy absorption capacity varies with thickness of test slab specimens.
- Frustum-shaped fracture zone and radial cracks was noticed on soffit of the all test slab specimens after ultimate loads. The number of cracks was less in fibre reinforced test slab specimen as compared to CS (M60)

It can be concluded that test slab specimen (M60+PF+SF-60 mm) shows highest ultimate load and have more ductility, toughness index and energy absorption capacity and lesser cracks compared to other test slab specimens.

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