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RESEARCH ARTICLE

BEHAVIOUR OF FIBRE REINFORCED CONCRETE SLABS UNDER IMPACT LOADS

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ABSTRACT

Extensive use of reinforced concrete structures and composite materials in infrastructure, increases the demand of design of high strength and durable reinforced concrete structure subjected to static and impact loads. The structural design deals with various types of loads such as earthquake load, wind load, wave loads and impact occurs from various reasons such as vehicle collision, rock fall, military exercise, missile attacks etc. Construction industry is heading towards a new era with intensive use of High Performance Concrete (HPC). High performance concrete overcomes the limitations of conventional concrete. The use of HPC is not only limited to infrastructural projects but also in high rise structures, nuclear reactor, defense structure etc. Now-a-days fibers are the most used materials to improve the ductile property of concrete. The properties of carbon fibers, such as high stiffness, high tensile strength, low weight, high chemical resistance, high temperature tolerance and low thermal expansion makes them one of the most promising fiber materials to be used in the Fiber Reinforced concrete (FRC). Use of polypropylene fibers reduces cracks during plastic and hardened state particularly when it is use in structural elements such as beam, column, slabs etc. which improves the quality of concrete constructions. Hence, addition of carbon fibers and polypropylene fiber to HPC increases toughness, energy absorption capacity of High Performance Fiber Reinforced Concrete (HPFRC). The present experimental investigation has been focused to develop a comprehensive understanding of test slab specimen under impact loading. HPC of M60 grade of concrete integrated with carbon fibers and polypropylene fibers. Series of twelve slab test specimens having three each of M60 grade Slabs of (600x600mm) with varying thickness of 60, 50 and 40 mm with and without carbon fibres (0.5% by volume),polypropylene fibres (900 gm/m^3), and combination of both. Impact tests on the slab test specimens were carried out on a low velocity repeated impact test machine using instrumented drop weight hammer of 10.2 kg attached with Load Cell and was designed, fabricated and installed at Civil Engineering Department, UVCE, Bangalore University, Bengaluru - 56. Accelerometer, LVDT's was used to record the Time-histories and Load, Deflection, and Acceleration. The experimental result shows a significant increase in the energy absorption, peak loads same number of impact blows for the carbon and polypropylene fibre reinforced concrete test slab specimen.

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INTRODUCTION

In the construction industry, concrete technology is heading towards entirely new era by using fiber along with super plasticizer in concrete. High-performance concrete is defined as concrete that meets special combinations of performance and uniformity requirements that cannot always be achieved by using conventional concrete.

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High performance Concrete exhibits the property of high strength, high flow ability, and high durability. Increasing interest is shown in the area of new materials in the past decades. Many new raw materials have been discovered and many ground breaking composites have been developed, of which not all but some has proved to be a phenomenal success. Carbon fiber is one of these materials which are usually used in combination with other materials to form a composite. The properties of carbon fiber, such as high stiffness, high tensile strength, low weight, high chemical resistance, high temperature tolerance and low thermal expansion makes them one of the most popular materials in the Civil Engineering. Possessing strength up to five times that of steel and being one-third its weight, we might as well call it the "super hero" of the material world. With increase in the extensive use of reinforced structure and composite material, creates an increase in the demand of design of more efficient reinforced structure subjected to static and impact loads. In general, the design deals with various types of loads that a structure may be subjected to, such as earthquake load, wind load, ice loads etc. very few data are available regarding design of reinforced structure under impact loads. A reinforced structure may be subjected to impact loads from various reasons vehicle collision, rock fall, military exercise, terrorist attacks etc. With the aim to avoid structure from such disaster, experimental studies have been done on High Performance Carbon Fibre Reinforced Concrete Slabs to understand its behaviour under impact loading.

Literature review

Recently, various researchers show their interest in improvising properties HPC against impact loads with addition of different fibres. Earlier research shows that addition of fibres acts as crack arrester and also increases the energy absorption capacity of structural members (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. (Prashant Muley, 2015; Kinayekar 2014) The Compressive Strength, flexural strength increases significantly for 1 % carbon fibre content. (Rajagopalan *et al.,* 1995) investigated experimentally under repeated low energy impact loading on concrete beam 100x200x2300mm, M40. Impact head is instrumented with load cell, Accelerometer and LVDT are used to measure the dynamic response of the beam. The beam peak force reduces with increased number of impact blows for a giver energy of impact loading. (Anbuvelan, Yeol Yoo and Trevor D. Hrynyk 2012) the resistance of concrete slabs under impact loading by strengthening by Fiber Reinforced Polymer Sheets, steel fibre, Polypropylene fibre under impact loading shows a significant increase in the impact characteristic with respect to number of blows for first crack and also the ultimate load carrying capacity of the concrete member. The load carrying capacity of the specimen containing only steel fibre was increased by 19 % whereas the capacity increased by 30% in case of specimen containing steel fibre and fiber reinforced plastics. (Xue-Chao Zhu *et al.*, 1996) Drop-Weight Impact Test on U-Shape concrete specimens from a drop height of 400 mm with four different masses of weight (0.875, 0.8, 0.675 and 0.5 kgs), the results showed good reproducibility with coefficients of variation with Statistical and Regression Analysis. (Hadi, 2008) ductility of concrete slabs of dimension 820x820x80 mm supported by four rollers at their edges with steel and polypropylene fibres of 0.5% and 1.0%by volume. Point load was applied at the center of the slabs. The results showed that the addition of 1% steel fibres had significant increase on the ductility of the slabs. From the literature review a limited research work has been reported on behaviour of Fibre reinforced concrete slabs under low velocity repeated impact loading with addition of binary fibres such as carbon fiber and polypropylene fibers in high performance concrete matrix. Hence, an attempt has been made in the present experimental investigation on test slab specimens consisting ofM60 grade of concrete slab test specimen of size 600x600mm with varying thickness of 60, 50 and 40 mm with carbon fibres, polypropylene fibres and combination of both and to study the time histories, energy absorption capacity, toughness index so as to arrive on a conclusion regarding the state of health of structural component under impact loading.

MATERIALS AND METHODS

In this present experimental investigation OPC 53 grade with specific gravity of 3.20 confirming to 12269:1987,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, 0.5% by volume chopped carbon fibres of length 6mm with a density of 1600 kg/m^3 and tensile strength of 4.68 GPa, poly-propylene Recron3s typefibre of length 12 mm, specific gravity of 0.9, tensile strength of 700 MPa and dosage of 900gm/m^3 are used for the present experimental investigation. Potable water is used for the preparation, casting and curing of the test slab specimens. For 110 mm slump value, 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 Impact loads was carried out by casting and testing of 600 x 600 mm test slab specimens with M60, M60+CF, M60+PF, M60+CF+PFhaving steel reinforcement as shown in Table no 4.1 conforming to IS :1786(Fe 500D) further the test slab specimens are divided into 40, 50 and 60 mm thickness as shown in Figure 1 and Table 2.

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 lattice layer appears and is cured.

Table 2. Details of Slab test specimens

Slab Designation	Thickness(mm)	Slab Type
CS (M60)	60	Control Specimen
	50	
	40	
M60+CF	60	M60+ Carbon fibre (CF) (0.5%
	50	by volume)
	40	
M60+PF	60	M60+ Polypropylene fibre (CF)
	50	(900 gm/m^3)
	40	
	60	M60+
M60+CF+PF	50	Carbon fibre (CF)+
	40	Polypropylene fibre (PF)

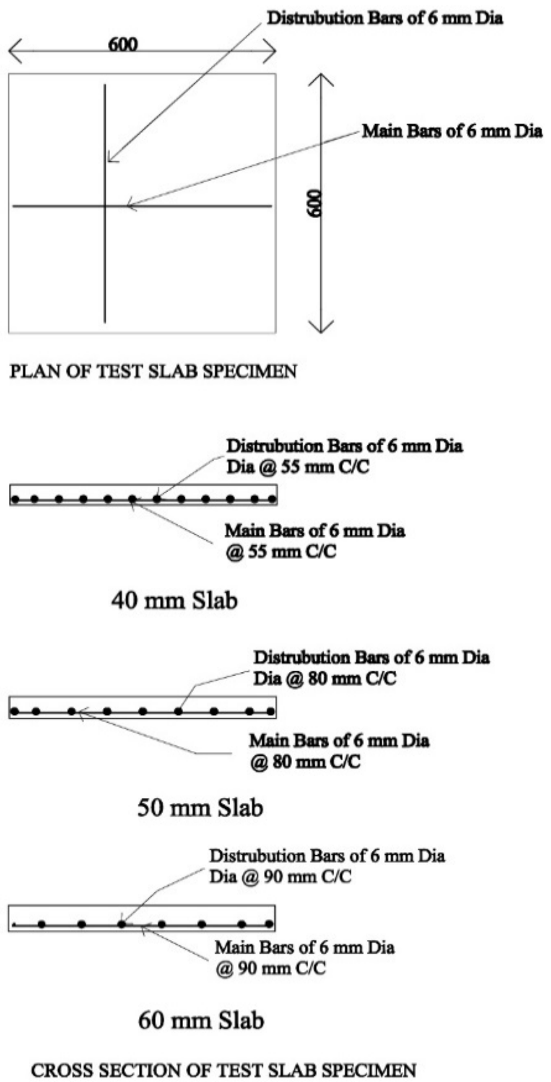

Fig. 1. Plan and Cross-section of test slab specimens

Test Programme and Impact Testing Machine

The experimental programme consist of testing 4 series of test slab specimen under low velocity vertical drop weight type instrumented repeated impact testing machine and instrumentation are shown in Fig 1. and 3. The impact testing machine was fabricated at Civil Engineering Department-Bangalore University, Bengaluru - 56. The impact testing machine was rigidly fixed to a RCC pedestal test foundation of having a height of 1 m above ground level and the pedestal was extended up to 0.6 m giving it total height of 1.6 m, to which a Frame of height 2 m fabricated with ISA 75x75x5 mm sections to support the guiding cylinder and pulley is attached. To the top of this frame a friction less pulley was attached centrally. The specimens were rested upon an I sections of square frame of 600x600 mm which was made up of ISHB 160 that rests upon the pedestal extension. The repeated impact test was carried out by a free drop of 1 m height of 10.2 kg hammer with a circular striking head, having length of 180 mm and diameter of 70 mm. The hammer was positioned vertically and steel cylinder was used for guiding during the course of impact. The striking head is fixed with 10-ton capacity load cell having a diameter of 55 mm and height of 70 mm.For testing of the slab specimens fixed edge condition is considered. Two clamps on each side of the specimen was fixed to frame to obtain the require end condition. One accelerometer is placed at 15 cm from the center at the top and two numbers of LVDT's, one at $\frac{1}{4}^{th}$ and one at center at the soffit is attached to the test slab specimens.

Instrumentation

Load Cell: Load cell was attached to the drop weight hammer with the purpose of measuring reactions. The load cell used was SI-430C with 10000 kg capacity manufactured by SYSCON INSTRUMENT, Bangalore.

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. One was fixed at the mid-point of the specimen and other at $\frac{1}{4}^{th}$ of the slab. The range of LVDT's was 0-25 mm.

Accelerometer: An accelerometer was attached to the slab specimens with the help of stud. The accelerometer was used to measure the vibration initiated in the slab specimens because of impact blows. The range of the accelerometer was ±500gpk (±4900m/s^{2}pk) and had a sensitivity of ±15% 10 mV/g (1.0mV/m/s^2).

Data Acquisition System: 4 channel data acquisition system was used. For acquiring different responses, software visual in basic 6.0 was used and for analysis of test data.

Test Procedure

The specimen was kept on the supporting frame; clamps were attached to all side of the specimen to attain fixed edge condition. The test slab specimen was fixed with accelerometer with the help of stud and two LVDT's were placed.

Fig. 2. Impact Testing Machine

Hammer attached with Load Cell was allowed to fall through the guiding cylinder. Load cell was used on every fifth blow to take responses and the remaining blows were performed with the help of dummy load cell. After each blow hammer is manually lifted and fixed to a height of 1 m for the next subsequent blow. Rebound of hammer is avoided after each impact blow. Load, deflection and acceleration were recorded and processed in Data Acquisition System. The test is carried out till the impact blow on which the test specimen fails to take any further load and shows a constant displacement.

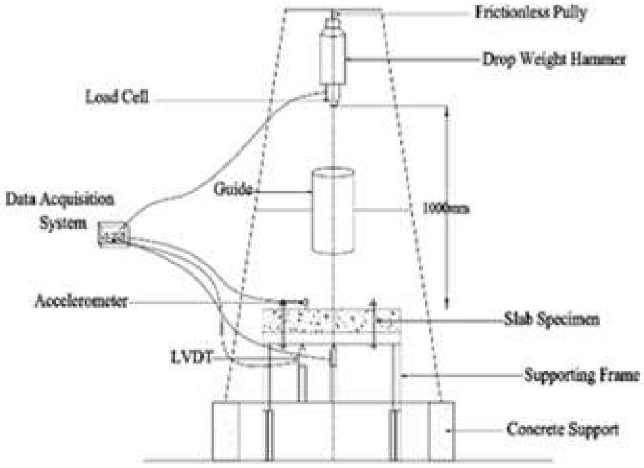

Fig. 3. Schematic diagram of Impact Testing Machine

ANALYSIS OF TEST RESULTS

Impact Test

Dynamic response of test slab test specimens consists of responses like Load-Time History, Displacement-Time History, Acceleration Time History, and Energy Absorption capacity.

Load – Time variations: For the problem of drop impact hammer with mass ma, hitting the concrete structure with an initial velocity of v_0 and the final velocity of v_f both in the same direction the momentum of the impact should be equal to the area of load time variation.

$$\int p(t)dt = ms(vo - vf)$$

From the Fig.4, it is observed that for the all test slab specimens the load time shows the time required for attaining ultimate load increases with addition of fibers and with thickness of the specimens. The pattern of the curve indicates that, the load increases with time and remains constant with slight variation during the contact period, followed by subsequent decrease in load with further increase in time. The peak load carried by M60+CF+PF- 60 mm of 50.550 kN was highest followed by M60+CF- 60 mm of 45.785 kN, M60+PF-60 mm of 40.987 kN.

Displacement - Time variations

The mid-point displacement time histories are provided in the Fig 5 (a,b). It should be recalled that initially before test, the slabs were identical except for the fact of addition of fibers. With every blow the FRC slab showed an increase in the displacement. The mid- point di

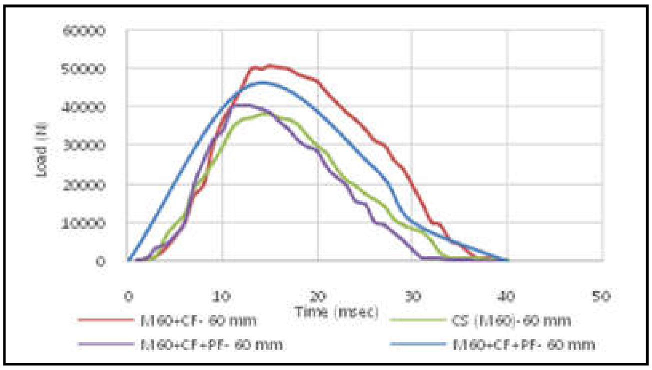

Fig. 4. Load vs. time graphs at 1st blow of specimens under impact loading using different concrete matrices

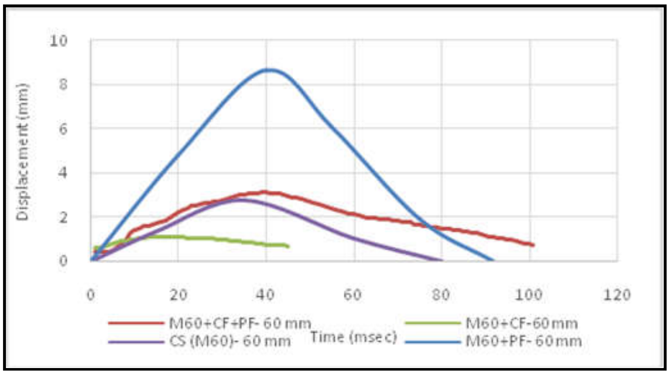

Fig. 5 (a). Displacement vs. time graphs of specimens under impact loading using different concrete matrices at 5th blow

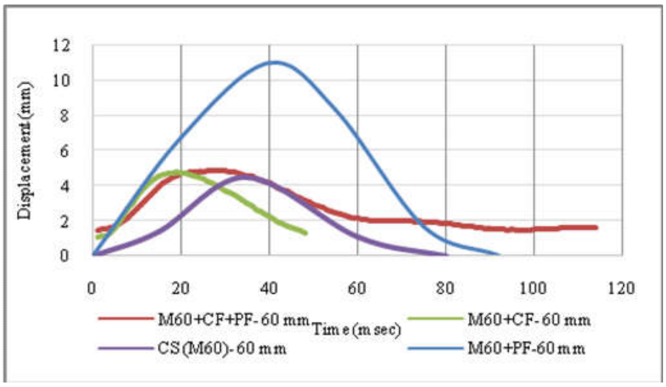

Fig. 5 (b). Displacement vs. time graphs of all specimens under impact loading using different concrete matrices at 8th blow

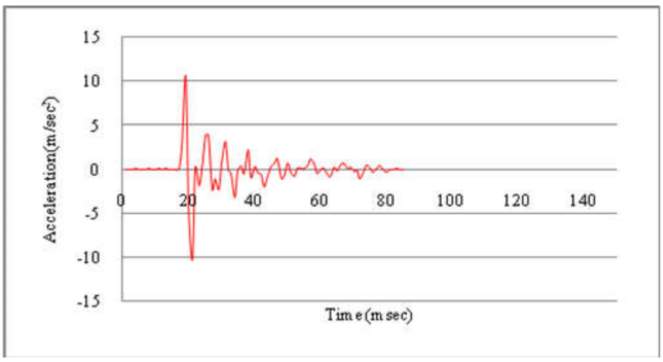

Fig. 6 (a). Acceleration vs. time graphs of M60+CF-60 mm specimens under impact loading

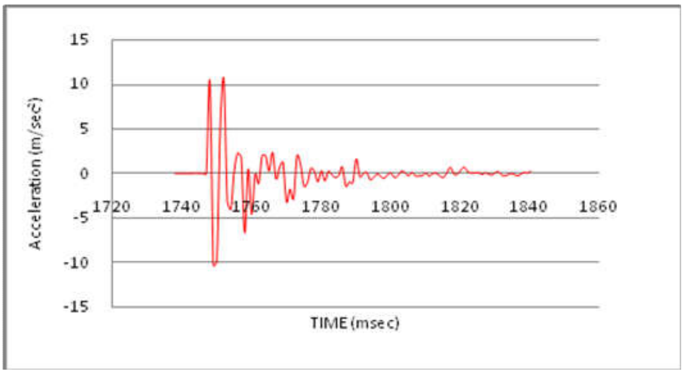

Fig. 6 (b). Acceleration vs. time graphs of M60+PF-60 mm specimens under impact loading

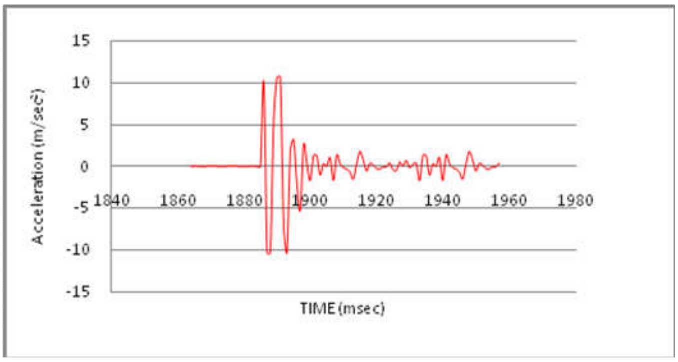

Fig. 6 (c). Acceleration vs. time graphs of M60+CF+PF-60 mm specimens under impact loading

Energy Absorption: In general, the reinforced concrete structure and materials are designed in the best possible way to absorb kinetic energy in a controllable and predictable manner Hence, understanding of energy absorption of structural members and its constituent materials is important in calculating the damage to the structure caused by accidental collision and assessing the residual strength of the structure after initial damage, its contents in the event of impact. The energy absorption of the test slab specimens can be calculated using the formula (Seeram aporva *et al.*, 2016);

E = N x (W x h) joules

Where,

E is the energy absorbed in joules
W is weight of drop weight hammer in Newton,
H is the height of drop in meter
N is the total number of impact blows
In this experimental investigation, H = 1 m and W = 10.2 kg

Table 3. Energy Absorption

Slab Type	Thickness (mm)	Number of Impact blows	Energy absorption (Joules)
	60	18	1800
CS (M60)	50	17	1699
	40	8	800
	60	23	2299
M60+CF	50	20	2000
	40	16	1599
	60	21	2099
M60+PF	50	19	1900
	40	14	1399
	60	24	2399
M60+CF+PF	50	21	2099
	40	16	1599

Table 4. Energy absorption capacity of the specimens compared to control specimens

Slab Type	Thickness (mm)	Energy absorption of CS (M6)	% increase in Absorption
M60+CF			22
M60+PF	60	1800	16
M60+CF+PF			25
M60+CF			15
M60+PF	50	1699	11
M60+CF+PF			19
M60+CF			100
M60+PF	40	800	74
M60+CF+PF			100

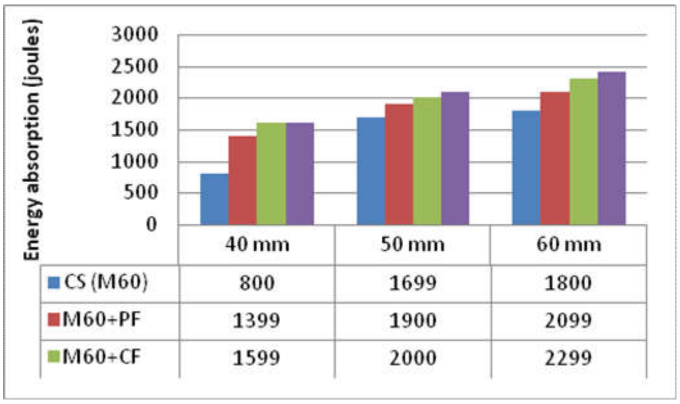

Fig. 7. Energy Absorption capacity of different test slab specimens

The results of energy absorption capacity of the test slab specimens are tabulated in the Table 3. The experimental investigation clearly shows that M60+CF+PF-60 mm have the highest energy absorption capacity 2399 Joules. It is clearly observed that the energy absorption capacity of the slab specimens increases with addition of fibres and with increase in thickness.

Crack pattern: Cracks on the tension surface were concentrated along the diagonals, extending radially from the impact point (center) towards the edges of the specimen. Initially hairline cracks were developed. With the increase in the number of blows, newer cracks were developed along the middle axes and cracks were widely spread on tension surface along with widening and extension of previous cracks as clearly seen in Figure 8, 9 and 10. With further blows, circular cracks at the bottom surface were observed along with new cracks along the diagonal. In addition, scabbing and spalling of concrete was observed along the circular crack region on the bottom surface of the slabs. As expected, significant scabbing was observed at the bottom surface during failure. Penetration of mass was also observed at the top surface. About 34 number of cracks were found on control test slab specimen of 50 mm thickness where as in other specimens irrespective of thickness lesser amount of cracks were noticed.

Fig. 8. Crack pattern of CS (40 mm, 50 mm, 60 mm)

Fig. 9. Crack pattern of M60+CF (40 mm, 50 mm, 60 mm)

Fig. 10. Crack pattern of M60+CF+PF (40 mm, 50 mm, 60 mm)

Conclusion

- The load carrying capacity of control specimen combined with carbon and Polypropylene fiber (0.5 % by volume) of thickness 60 mm was observed highest i.e. 50.550 kN as compared to other specimens.
- It is observed that with the addition of fiber, the peak of the displacement graph and residual displacement slowly decreases. Changes have been observed in the residual displacement with change in the thickness.
- The energy absorption capacity of test slab specimen combined with carbon and poly-propylene fiber was found to be highest i.e. 2399 joules with 24 number of impact blows and 25% higher when compared to Control Specimen of same thickness.
- Despite being change in the reinforcement ratio and constituents the maximum acceleration and its pattern with respect to time remains same.
- Frustum-shaped fracture zone and radial cracks were observed in the slab test specimens. The number of cracks and width of the cracks observed after the test were reduced with addition of fibres.

From the experimental results, it can be concluded that test slab specimen (M60+CF+PF-60 mm) shows better energy absorption capacity, peak load, lesser displacement and number of cracks as compared to other test slab specimens.

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