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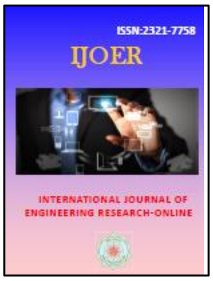
NUMERICAL ANALYSIS ON IMPACT RESISTANCE OF TURN STEEL FIBRE REINFORCED CONCRETE SLAB

AJITH K P[1], MANJU P M[2]

[1]M.Tech Student, Dept. of Civil Engineering, Sree Narayana Gurukulam College of Engineering, Ernakulam, Kerala, India
ajithkp005@gmail.com
[2]Associate Professor, Dept. of Civil Engineering, Sree Narayana Gurukulam College of Engineering, Ernakulam, Kerala, India



ABSTRACT

Concrete made with fibres have several advantages compared to conventional ordinary portland cement concrete. Using these steel fibre reinforced concrete (SFRC), higher values of tensile and compressive strength can be obtained with greater fracture toughness and energy absorption capacity. Hence the impact resistance capacity of SFRC will vary with addition of steel fibres in concrete. In this numerical analysis study of impact resistance of turn steel scrap fiber reinforced concrete slabs, repeated impact loading is done using ANSYS software. Here the fibres used are the scraps from lathe shops, impact resistance of reinforced fixed supported concrete slabs (600 mm x 600 mm x 60 mm) of 0.25%, 0.5%, 0.75% & 1% as percentage of turn steel fibres by weight of cement is compared with ordinary reinforced cement concrete slab. Impact was given by dropping steel hammer of 10 kg weight from a height of 1 m. Number of blows of hammer required for first crack and ultimate failure of the slab was noted. Results obtained from this study showed that reinforced concrete slab with 0.75 % turn steel fibre need maximum number of blows of hammer required for ultimate failure as compared with conventional concrete slab.

Keywords— Fibre reinforced concrete, Turn steel fibres, Impact resistance, First crack, Ultimate crack

INTRODUCTION

Concrete is a composite material composed of coarse aggregates and fine aggregates mixed in a hard matrix of cement paste thereby gluing them together. It is a vital construction material used all over the world. Concrete have very large compressive strength and comparatively low tensile strength. When an unreinforced concrete structure is subjected to tension or flexural loads, it initially deforms elastically. So crack develops, thereby fracture occurs. Hence, fibre materials are added to concrete to enhance its mechanical properties like compressive strength, tensile strength, toughness etc. Conventional HYST steel bars of various cross sections are used in concrete structures like foundations, columns, beams, slabs etc. But these steel bars are prone to corrosion. Water enters the concrete through cracks and corrodes the rebar's.

Concrete structures are mainly subjected to dead loads and imposed loads. Dead loads are constant in nature, it includes the self-weight of the structural members and partition walls. But imposed loads vary greatly as the magnitude of these cannot be predicted with great accuracy and the design values depend upon the intended use of the structure. The weight of occupants, snow, vehicles, forces induced by wind and earthquakes are examples of imposed loads. Hence, it has both static and dynamic loads. Static loads include normal tension, compression and static flexural loads. Dynamic loads such as large cyclic loads, earthquake loads, impact loads etc, are more dangerous than static loads.

Impact is an instantaneous application of load. High loading rate at very short period of contact is the characteristics of impact loading. It leads to high strain rate in structures. Impact loading in concrete structures occurs due to accidental struck by low speed objects. A structure that is strong enough for a large static load may fail due to suddenly applied loads of relatively small magnitudes due to impact effect. Improved impact resistance is one of the advantage of fiber reinforced concrete (FRC).[14]

In structures there may be many situations in which structures undergo impact loads, which are explosion loads, impact of ice load on foundations, tornado generated impact, ship impact on marine structures, missile impacts on nuclear plants, aircraft landing and accidental drop weights.

Experimental works done by Vasudev *et.al* found that addition of turn steel fibres in concrete can improve its tensile property, compressive strength, first crack and ultimate failure load. Also he found that addition of turn steel fibres improves the crack arresting ability of concrete and thereby achieve improved chemical attack resistance in concrete.[3,4]

K.C.G. Ong *et.al* (1999) low velocity projectile impact test was carried out in FRC. Polyolefin, polyvinyl alcohol and steel fibres were used as different types of fibres in concrete slabs. Volume fraction of fibres used were – 0.5 %, 1 % and 2 %. Slab specimen of size- 1 m x 1 m x 5 cm was adopted for the study. He used impactor of weight 43 kg from a fall height of 4 m. Then graph of fracture energy vs Volume fraction of fibres was plotted. Also plotted Fracture energy vs displacement graph of fibre reinforced concrete specimens with 2 % of fibre content. It was concluded that Steel FRC slabs have superior performance in terms of cracking characteristics, energy absorption, integrity upon impact when compared to slabs reinforced with polyolefin and PVA fibres. Also found that when considering up to 20 mm displacement at 0.5 %, 1 % and 2 % of steel fibre. SFRC has 40 %, 100 %, and 136 % higher fracture energy than control specimens without fibres [8].

In the experimental study done by T. Kiran *et.al* (2015) ten specimens of size 600 mm (length) x 600 mm (width) x 60 mm (thick) were casted with nine different combination of geopolymer concrete mix using different molar sodium hydroxide solutions and varying percentages of mineral admixtures and a normal concrete slab as control specimen. The molarity of NaOH solution used was 8 M, 12 M, and 16 M. Fly-ash and GGBS admixtures were used in three different ratios of 100:0, 75:25, and 50:50. The slabs were oven cured at 600 ^{o}c for 24 hours. These slabs were subjected to impact loading by drop weight impact test method. All the slabs were tested under a drop weight of 75.50 N through a guide pipe from a height of 700 mm. the results obtained from this study showed that with the increase in the molarity of NaOH solution the strength characteristics and the impact resistance capacity of the specimen increases. Also increase in percentage of GGBS content as replacement for fly-ash content increase the impact resistance and overall strength characteristics of geopolymer concrete. From the test results it was clear that geopolymer concrete slab with 16 M NaOH solution and 50:50 ratio of fly ash - GGBS content showed higher impact energy absorption capacity as compared other geopolymer mixes [14].

S. Elavenil et.al (2012) done an experimental study on dynamic behavior of steel fibre reinforced concrete plates under impact loading using drop weight impact test. Then energy absorbed at first crack and failure was measured. Slab specimens of 600 mm x 600 mm in dimensions with different thickness of 20 mm, 25 mm, and 30 mm were adopted. Various fibre volume percentages were used are 0.5 %, 0.75 % and 1 %. The tests were repeated with different aspect ratio plates as 50, 75 and 100. For the drop weight tests, impactor used was made with stainless steel ball of

0.5 kg connected to a cylindrical drop weight of 4.5 kg. All the panels shows that energy absorbed at first crack and failure increases with both aspect ratio and percentage volume content of fibres in concrete. Also the test results demonstrated that concrete plate with aspect ratio 100 and 1 % steel fibre gave maximum value of energy absorption [11].

In this study numerical analysis of repeated impact of steel hammer on reinforced concrete slab is done. The numerical modelling of repeated impact analysis is done in two steps. In the first step, a single drop of the hammer was analysed and the acceleration-time history of the hammer was plotted. The maximum acceleration obtained from this can be used to calculate the maximum impact force coming on the slab and then can be repeatedly applied on the slab as time history loading in the second step. In the second step, the number of blows required for first crack and ultimate failure is obtained.

Slab specimens of size 600 mm × 600 mm × 60 mm is selected for the analysis. Mild steel bars of 6 mm diameter at 110 mm spacing is provided as reinforcement in both directions. The reinforcement is kept in minimum to reduce its contribution to the impact resistance of the slab. The bottom cover of the slab is 15 mm and 25 mm cover in all directions. The slabs are fixed on all sides. Five mixes of concrete with turn steel scrap fibre contents 0 %, 0.25 %, 0.5 %, 0.75 % and 1 % by weight of cement are selected for analysis. The aspect ratio of the fibres was chosen to be 35. The impact was simulated by a drop weight of mass 10 kg from a height of 1 m at the centre of the slab at a frequency of 60 blows per minute.

EXPERIMENTAL STUDY

Materials

Ordinary Portland cement of grade 53 was used. The coarse aggregates used were crushed angular aggregates passing through 20 mm sieve and retaining on 4.75 mm sieve. The fine aggregate used was M sand conforming to zone I of IS 383:1970. The grade of concrete chosen for the study was M30. The mix design for M30 was done according to the recommendations and calculations mentioned in IS 456:2000 and IS 10262:2009. Admixture of type GLENIUM SKY 8433 produced by BASF Incorporation was added to increase the workability of concrete and to minimize the amount of water-to-cement ratio, for obtaining a desired slump range of 75 mm–125 mm for normal RCC work as per IS 456:2000, Cl.7.1. The proportioning for the mix is given in the Table I.

TABLE I: CONCRETE MIX DETAILS

Mix proportion	1:1.758:3.06
Mass of cement per m^3 of concrete (kg)	403.32
Mass of coarse aggregate per m^3 of concrete (kg)	1234.83
Mass of fine aggregate per m^3 of concrete (kg)	708.89
Water-Cement ratio	0.38
Percentage of admixtures by weight of cement (%)	0.3
Slump (mm)	120

Properties of turn steel fibre used are given in Table II.

TABLE II: PROPERTIES OF TURN STEEL FIBRE

Sl: No:	Properties	Values
1	Cross Section	Rectangular & twisted
2	Thickness/Diameter (mm)	0.9 - 1.1
3	Length (mm)	30 – 40
4	Aspect Ratio	33 – 37
5	Density (kg/m^3)	7830
6	Young Modulus (MPa)	2×10^5
7	Tensile Strength (MPa)	500 – 1000
8	Specific Gravity	7.83
9	Elongation (%)	5- 20

Compressive strength

The compressive strength was determined at the age of 28 days using 150 mm x 150 mm x 150 mm concrete cubes in accordance with IS 516-1959. Compressive strength of normal M30 grade concrete, M30 grade concrete with 0.25 %, 0.5 %, 0.75 % and 1 % by weight of cement is tested and results are given in Table III.

TABLE III: COMPRESSIVE STRENGTH TEST RESULTS

Mix ID	Load value (kN)			Compressive strength N/mm^2
	Cube 1	Cube 2	Cube 3	
Conventional concrete	800	750	-	34.44
TSSFRC0.25%	790	820	800	35.7
TSSFRC0.5%	820	840	820	36.74
TSSFRC0.75%	780	840	810	36.00
TSSFRC1%	790	780	800	35.11

Split tensile strength: The split-tensile strength was determined at the age of 28 days using concrete cylinder of 150 mm diameter and 300 mm height in accordance with IS 5816-1999. Split tensile strength of normal M30 grade concrete, M30 grade concrete with 0.25 %, 0.5%, 0.75 % and 1 % by weight of cement is tested and results are given in Table IV.

TABLE IV: SPLIT TENSILE STRENGTH TEST RESULTS

Mix ID	Load value (kN)			Split tensile strength N/mm^2
	Cube 1	Cube 2	Cube 3	
Conventional concrete	245	260	235	3.469
TSSFRC0.25%	240	270	255	3.60
TSSFRC0.5%	305	260	285	4.008
TSSFRC0.75%	295	280	320	4.22
TSSFRC1%	280	260	275	3.843

Modulus of elasticity: The modulus of elasticity was determined at the age of 28 days using concrete cylinder of 150 mm diameter and 300 mm height in accordance with IS 516-1959. E value of normal M30 grade concrete, M30 grade concrete with 0.25 %, 0.5 %, 0.75 % and 1 % turn steel fibre by weight of cement is tested and results are given in Table V. Fig. 1 shows the stress strain curves.

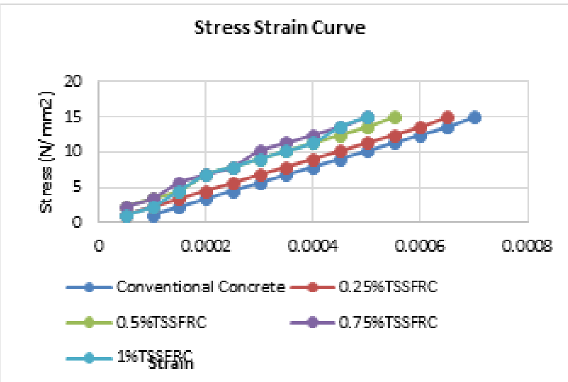


Fig. 1. Stress – strain curve

TABLE V: MODULUS OF ELATICITY RESULTS

Mix ID	Modulus of elasticity (MPa)
Conventional concrete	22633
TSSFRC0.25%	22635
TSSFRC0.5%	27160
TSSFRC0.75%	28295
TSSFRC1%	29102

NUMERICAL STUDY

A. *Modeling and analysis of a single drop of hammer*

The modelling and analysis of a single drop of the hammer was done using the Explicit Dynamic suite. An explicit dynamic analysis is used to determine the dynamic response of a structure due to stress wave propagation, impact or rapidly changing time-dependent loads. This type of analysis can also be used to model mechanical phenomena that are highly nonlinear. Events with time scales of less than 1 second (usually of order 1 millisecond) are efficiently simulated with this type of analysis. Algorithms based on first principles accurately predict complex responses such as large deformations and failure, interactions between bodies and fluids with rapidly changing surfaces. It is suitable to study highly complex situations, especially ones with high strain rates and other complications, which are too difficult to solve with general purpose implicit solution methods.

The CONC-35MPA material model available in the Explicit Dynamics material library was used to model the properties of concrete. It is a RHT (Reidel-Hiermaier-Thoma) Concrete Model which is an advanced plasticity model for brittle materials developed by Reidal *et.al* (2014). The ANSYS material library contains a predefined model for mild steel. This was used for both the hammer and the reinforcement bars. The ANSYS Design Modeler was used to model the slab and the hammer with the specified dimensions. The hammer was placed at a height of 10 mm above the face of the slab. The velocity of the hammer at that point can be given as an initial condition.

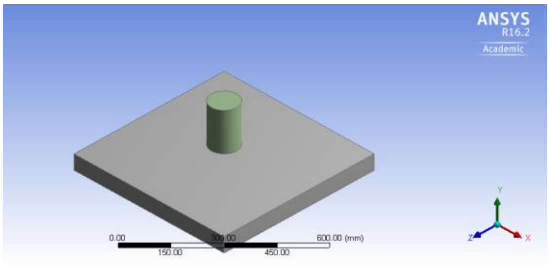


Fig. 2. Modelling of slab and hammer

The concrete and reinforcement bars were meshed with an element size of 20 mm and the hammer was meshed with an element size of 10 mm. SOLID164 element is chosen for concrete, SOLID168 element is chosen for hammer and BEAM188 element for reinforcement.

Analysis was done with an end time of 0.01 sec. Nodal results were stored at thousand equally spaced points during the analysis. The directional acceleration-time history of the hammer was requested to be calculated during the post-processing. The maximum impact force can be calculated by multiplying the maximum acceleration of the hammer with it's mass.

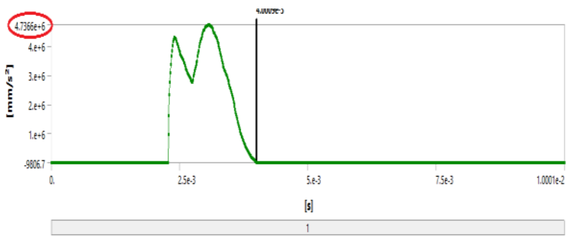


Fig. 3. Acceleration- Time history graph of hammer at conventional slab

Maximum acceleration of hammer on different slabs are different, hence force exerted by single drop of the hammer varies with slab specimens. Maximum impact force by single drop of the hammer is given in Table VI.

TABLE VI: MAXIMUM IMPACT FORCE

Designation of the slab	Maximum acceleration (m/s^2)	Maximum impact force (N)
Conventional slab	4736.7	47367
TSSFRC0.25%	4816.4	48164
TSSFRC0.5%	4877.5	48775
TSSFRC0.75%	4834.5	48345
TSSFRC1%	4780	47800

B. *Modelling and analysis of repeated impact*

The modelling and analysis of the repeated impact was done using the Transient Structural suite. Transient structural is analysis is a time-history analysis that uses ANSYS Mechanical Solver. The Concrete material model available in the ANSYS material library was used to model the properties of concrete. It is suitable to predict the failure of brittle materials. The concrete was meshed with SOLID65 elements and the reinforcement bars with BEAM188 elements. The body interaction between the steel bars and the concrete in the slab was defined as a bonded contact. The slab was fixed on all side faces. The impact load was applied as a time-history loading on the central nine nodes of the slab. The force-time history is assumed to be an isosceles triangle with duration of 0.02 second. The height of the triangle is assumed to be the maximum impact force obtained from the explicit dynamic analysis.

In the transient analysis, the time-history load was repeatedly applied till the slab failed. The impact was specified at a frequency of 1 blow per second. The analysis was done with 100 substeps per each second. The failure of the slab is indicated by a convergence error. MAPDL database file was saved during the analysis and was later imported to Mechanical APDL to obtain the first crack and ultimate crack pattern.

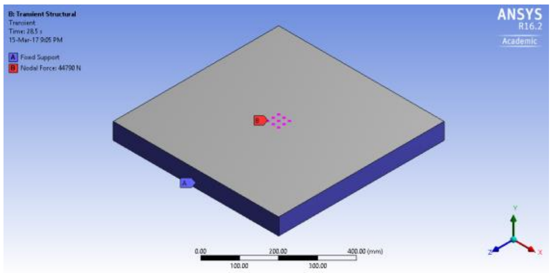


Fig. 4. Application of time history loading as nodal force

ANALYSIS RESULTS AND DISCUSSION

C. *First crack*: ACI 549R (1997) describes that micro cracks are inherent in cement mortar matrix even before application of impact load; by the application of impact loads, micro cracks widens, propagate and joined together to become first visible crack in structures. The first crack patterns of different slabs are shown in Fig. 5 to 9.

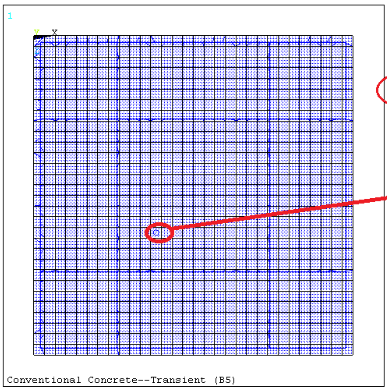


Fig. 5. First crack pattern of conventional slab

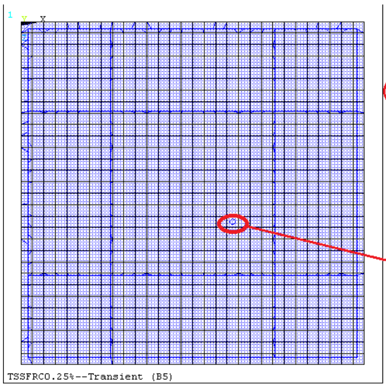


Fig. 6. First crack pattern of TSSFRC0.25%

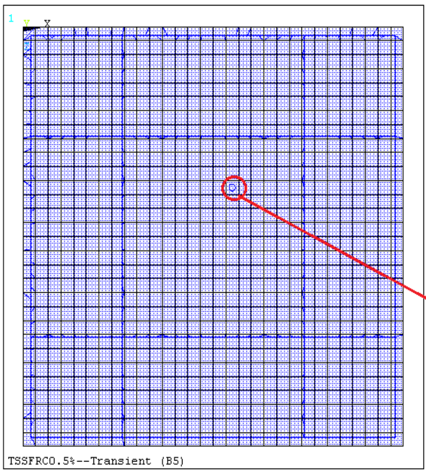


Fig. 7. First crack pattern of TSSFRC0.5%

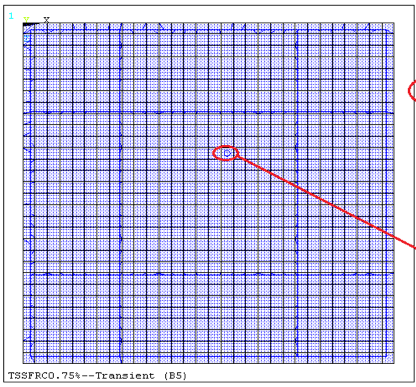


Fig. 8. First crack pattern of TSSFRC0.75%

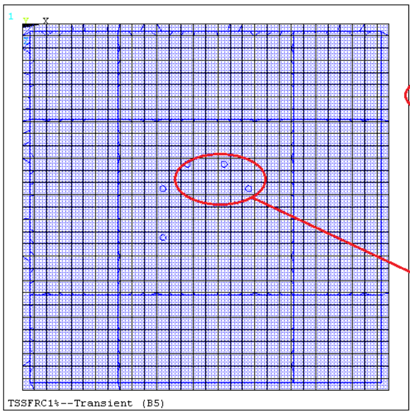


Fig. 9. First crack pattern of TSSFRC1%

There is a phenomenal increase in the number of blows required for the first crack with the addition of turn steel fibres. With 0.25 % fibre content, the number of blows has increased by 25 % as compared to the control slab. For 0.5 % fibre content, there is a 75 % increase. By adding 0.75 % fibres, there is an increase of 100 % in the number of blows required for the first crack.

D. *Ultimate failure*

The plot of turn steel fibre content against the number of blows required for the ultimate failure is shown in Fig. 9.The final crack patterns of different slabs are shown in Fig. 11 to 15. The blue circles represent cracks while the red circles indicate crushes.

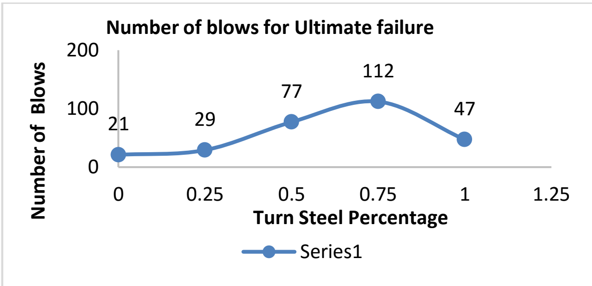


Fig. 10. Variation of number of blows for ultimate failure with percentage turn steel

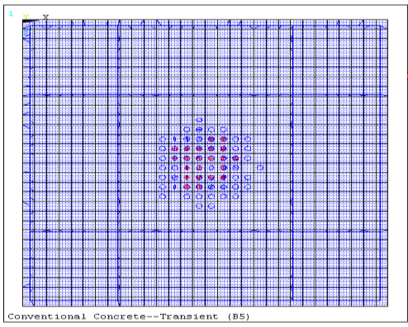


Fig. 11. Final crack pattern of conventional concrete

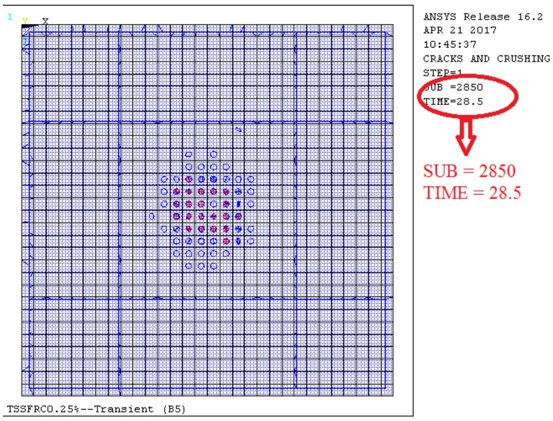


Fig. 12. Final crack pattern of TSSFRC0.25%

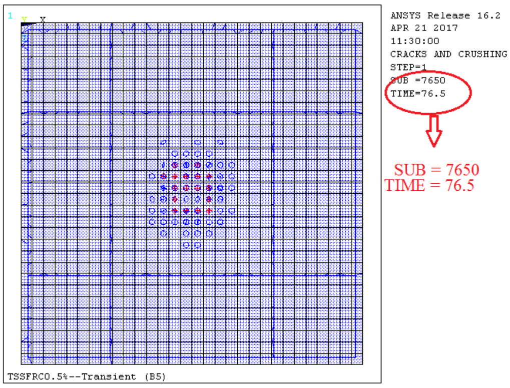


Fig. 13. Final crack pattern of TSSFRC0.5%

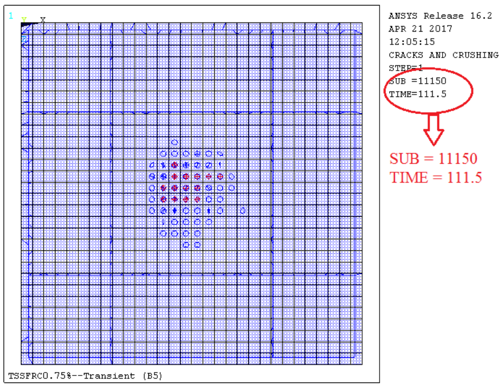


Fig. 14. Final crack pattern of TSSFRC0.5%

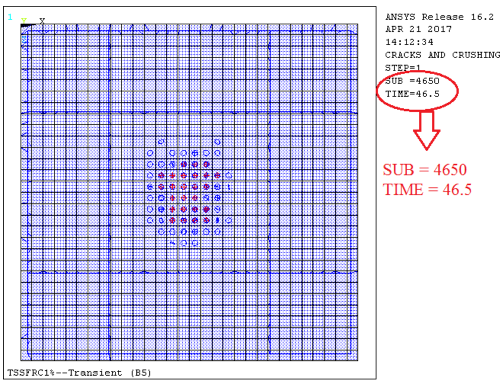


Fig. 15. Final crack pattern of TSSFRC1%

The impact resistance of the slab have increased greatly with the addition of turn steel scrap fibres. By adding 0.25 % turn steel fibres by weight of the cement, there is an increase of 38.09 % in the number of blows required for ultimate failure as compared to unreinforced control slab. The addition of 0.5 % turn steel fibres has resulted in an increase of 266.66 % while 0.75 % increases the impact resistance by 433.33 %. Then by adding fibres, number of blows required for ultimate failure reduces. Hence 0.75 % is the optimum percentage steel for getting maximum impact strength in concrete slabs.

CONCLUSION

The experimental investigations and numerical modelling of repeated drop weight impact test on turn steel scrap fibre reinforced concrete slabs were done and the following conclusions could be derived from the results.

- The addition of turn steel fibres into the concrete increased the compressive strength slightly. There was a maximum increase of 6.67 % in compressive strength when 0.5 % turn steel fibres by weight of cement was added.
- The addition of turn steel fibres into the concrete resulted in an appreciable increase in the tensile strength of concrete. There was a maximum increase of 21.64 % in tensile strength when 0.75 % turn steel fibres by weight of cement was added. This can be attributed to the crack control properties of the steel fibres.
- Young's modulus of elasticity increases with increase in turn steel fibre content.
- The number of blows required for the first crack was increased by 100 % with the addition of 0.75 % turn steel fibres by weight of cement. This can be explained by the increase in tensile strength of the concrete.
- The number of blows required for the ultimate failure of the slab was increased by 433.33 % by the addition of 0.75 % turn steel fibres by weight of cement. This can be attributed to the improvements in tensile strength and ductile behaviour of concrete.

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