Study on Strengthening of RC Slabs using CFRP Wrapping Techniques for Impact Loading

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Abstract— Study deals with experimental and numerical investigation on CFRP strengthened slabs under drop weight impact load test. 10 slabs of size 600mmx600mmx60mm were tested. Impact load of mass 10 pounds was dropped from 18 inches height through guide channel. Fixed support condition is adopted. The CFRP fabrics are strengthened by covering 25%, 50%, 75% and 100% slab area from centre with one and two layers of wrapping. Wet lay-up strengthening technique is adopted. Energy absorption, strengthening effect and punching cone angle parameters are compared with control specimen. Numerical model generated in ANSYS workbench 15. 9 specimens are modelled, crack patterns developed in software and experiment are compared. Two layer 100% CFRP wrap has shown good behavior under impact by absorbing 366.67% more energy than control specimen. Punching cone angle has reduced from 27.3◦ to 17.92◦. Crack pattern observed in ANSYS showed good agreement experimental results.

Key words: Strengthening, ANSYS, CFRP, Punching, Impact Load

I. INTRODUCTION

Reinforced concrete structural elements have been used in construction field for several years. Number of infrastructure projects have been executed. Enormous amount of resources and money have been invested in these projects. Due to improper design, poor construction practices, accidental damages, natural events, aggressive environmental conditions, etc. strength of the concrete decreases and deterioration of concrete is a natural phenomenon with ageing. For making the old structures usable and safe, structural components must be upgraded to meet the design recommendations. Therefore, these structural components must be strengthened. Retrofitting and Rehabitation are the techniques to upgrade the structure. Externally bonded FRP composite system is the new method of strengthening. This method is used widely because of its ease of application, light weight, high strength, corrosion resistant, low thermal expansion, resistance to fatigue, etc. Materials like CFRP and GFRP composites are commonly adopted for strengthening process. In this technique 2 or more materials are combined to obtain a new material and these materials are mainly fibre and matrix, they are bonded together. Matrix gives protection from environment and rigidity, fabric gives stiffness and strength.

Dynamic load is classified into 3 categories as (i) Steady state harmonic loads like foundations for machines and rotating machines, (ii) Random loads like wind loading and seismic loading, (iii) Sudden shock or impact loads like missile impact on structural elements, structure subjected to blast loads, rock fall, vehicle collision, industrial accident events, military structures, nuclear energy industry, ice fall, aircraft crashes, terrorist attacks, off shore applications, bridges under wheel impact, flying objects because of natural disasters like volcano, hurricanes, etc. The impact load have high rate of loading and acting for a short period of time, which causes high stain in structural element. The impact behaviour is complex and various factors are involved, like mass, velocity, material properties like rigidity, sizes, shapes, height, contact zone, contact time period, cycles of impact, hardness etc., due to this the failure and damage pattern varies.

Impact load are of 2 types namely hard impact and soft impact. When a structure undergoes certain amount of deformation under impact i.e., kinetic energy of the impact load is absorbed by the deformation of the structure then it is called as soft impact. When no much deformation has occurred but material has failed and the imparter has completely penetrated into the material then it is called hard impact, mainly due to high velocity, mass and greater altitude. Impact resistance structures have gained more importance especially after the growth of the nuclear power stations and safe guarding it from terrorist attacks.

Different methods are available to measure the impact behaviour of the structure, they are (i) drop weight experiment with single or repeated impact, (ii) weighted pendulum test, (iii) projectile missile or bullet test, (iv) blast or explosion test, (v) constant rate of strain test, (vi) split Hopkinson bar test. The structural impact resistance of elements can be measured by (i) number of blows required to fail the element, (ii) energy required to fail or fracture or crack the specimen, and (iii) depending on damage size like length of crack, width of cracks, spalling or scabbing of materials, penetration size or depth the damage is measured.

ANSYS is finite element analysis software which has ability to analyse different type of problems. Engineering problems like fluid mechanics, rigid dynamics, static structural, transient structure, explicit dynamics, response spectrum, etc. Linear and non-linear analysis can be done through ANSYS software. Complex loading, geometry, boundary condition, heterogeneous material, non-homogeneous continuum can be analyse in ANSYS.

II. LITERATURE REVIEW

Abdulkader Ismail studied the behaviour of Ferro cement slab under impact. Slabs were tested with low velocity high velocity impact. In this paper the influence of no of layers and different height of fall is investigated. Slab dimension 500mmx500mmx50mm weight of impact is 1.3 kg dropped at 2.4m, 0.83m and 1.2m. For high velocity impact bullet of 72mm fired from 15m distance. Failure observed is spalling, scabbing and inclusion or perforation. Area of damage, scabbing decreased with increase in the no of mesh layers and polymer content. With increase in height of fall the resistance of the slab decreased when compared to the 0.83m height of fall. Mode of failure observed was cracks and cracks increased with repetitive blow.

Vaishali et al. studied the resistance of HPC 2 way slab under fixed condition subjected to impact loading. This paper investigates on the performance of HPC under impact load. Mass of 50N with 100mm dia and fall from 450mm height. Guide barrel is attached to direct the mass to fall at centre. No of blows required for first crack and ultimate crack is investigated and corresponding energy absorption is found. Results showed that the HPC and NC has similar failure patters. Increase of silica fumes increased the energy absorption. HPC had higher energy absorption that is twice the energy absorption of NC. With 15% replacement of cement by silica fumes showed good behaviour than others.

Doo-Yeol Yoo et al. studied on strengthening concrete slab with FRPS and steel fibres under impact load. In this paper normal concrete and steel fibre concrete slabs strengthened with FRP and without FRP and varying steel fibres content by 0.5%, 0.75%, 1.0%, 1.25% and 1.5%, were evaluated. One way slab of size 50mmx100mmx350mm are casted with CFRP and AFRP fabrics. Impact absorption capacity of strengthened slabs increased by 2.3 to 2.7 times the normal control specimen. The strengthened slabs absorb 19% higher peak load and also the deflection gets reduced to 34% compared to normal control specimen. In central span deflection of the CFRP wrapped specimen showed 1.3 times higher deformation than AFRP wrapped specimen this concluded that the AFRP sheets showed good behaviour than CFRP wrapped specimens.

K. –H. Min et al. studied on influence of fibre reinforced and FRP sheets in punching and flexural behaviour under impact loading. In this journal study on static and impact load with one way flexure and two way punching was done with 50mmx100mmx350mm and 50mmx350mmx350mm size specimen. FRP wrapping with 45˚ and 90˚ orientation showed almost same max load and max deflection but in energy absorption 90˚ wrapping showed greater absorbing capacity than 45˚ for normal concrete. Where as in UHPC 45˚ showed greater absorbing capacity than 90˚ orientation. FRP fabrics showed good performance in punching behaviour.

Ambily et al. studied on behaviour of Geo-polymer reinforced concrete under impact loading. In this paper, study on experimental and numerical behaviour of Geo-polymer slab with and without steel fibres. ANSYS software is used for numerical analysis. Dimension of the slab 1000mmx1000mmx60mm. ANSYS is used to compare the crack pattern observed in test results. Hinged conditions were adopted. Impact function was triangular, and impulse time 5 milliseconds. The GPC showed higher resistance than OPC. Higher resistance was shown by the fibre induced Geopolymer by 4.9 times more energy absorption than Geopolymer concrete. Hence, presence of fibres increases the energy absorption, resistance, ductility, bond characteristics and toughness.

T Kiran et al. studied on impact behaviour of Geopolymer concrete slab. Geopolymer concrete is produced by using GGBS, fly ash and aggregates with different molar NaOH and with different percentage of mineral admixtures. In this study, 600mmx600mmx60mm size slab was casted. 8M, 12M, and 16M molar NaOH solution and 100:0, 75:25, 50:50 ratios of fly ash to GGBS was used. Failure pattern observed was spalling at top face and scabbing at bottom face. Result showed that Geopolymer concrete had greater energy resistance capacity than normal slab. The energy absorption increased with increases in molar solutions. As the content of GGBS increased the impact resistance increased. 16M NaOH and 50:50 fly ash and GGBS ratio showed high energy a carrying capacity than all others.

Tan et al. (2011) studied on strengthened RCC slab under impact. Twelve RCC slab with 1650mmx1650mmx150mm size slab is subjected to single and iterative load by dropping weight of 300 kg mass. Velocity of 1m/s to 4m/s was applied as impact load in increment of 1m/s till 4m/s, after 4m/s velocity the increment decreased to 0.5 m/s increment until failure. Failure pattern observed is spalling, radial cracks, punching and scabbing of concrete. The elastic limit of all slabs were within 3m/s. FRP strengthened slabs slowed debonding failure. The energy absorption depends on volume of FRP material and loading type. DMF value remains 2 for all slabs Under impact the bi directional FRP that is AFRP showed greater resistance behaviour than uni- directional because it could dissipate the tensile stress developed at bottom slab effectively.

T. Sundararajan studied on influence of impact strength with different natural fibre. In this paper, four natural fibres coir, jute, sisal and hibiscus is used to find the impact resistance of concrete slab. Size of slab is 300mmx300mmx20mm and different percentage of fibres are used starting from 0.5%,1.%, 1.5% and 2.0% to weight of cement and also three different length of fibres i.e., 40, 30, and 20mm. Mass of 450 grams and falling height of 200mm is adopted. According to the results the addition of fibres has increased the impact resistance by 3 to 18 times the normal slab without fibres. Out of four fibres, coir fibre has more energy absorption than other fibres.

Ramana et al. have performed impact test on SIFCON slab. In this study a comparison of normal concrete, fibre concrete and SIFCON with and without the reinforcement of slab size 600mmx600mmx50mm is investigated. SIFON with varying percentage of steel fibres i.e., 8, 10 and 12 were used. For FRC concrete 2% fibres were added. Results showed that SIFCON showed good behaviour followed by FRC and lastly by normal concrete. With increase in percentage of fibre concrete the energy absorption also increased in SIFON that is 12% fibre SICON showed higher resistance then 8 and 10% SICFON. SIFCON with reinforcement showed more resistant than without reinforcement. The crack and damage was less in slab containing more fibre volume.

III. Objectives

From the gap analysis, following objectives were drawn:

1) To study the response of the RCC slab under drop weight impact test.
2) To study the failure pattern of RCC slab under drop weight impact test.
3) To determine ultimate energy absorption of RCC slab.
4) To adopt suitable wrapping techniques to strengthen RCC slab using CFRP fabrics depending on the failure patterns observed in control specimens.

5) To determine ultimate energy absorption of strengthened RCC slab.
6) To compare energy absorption capacity with and without strengthened RCC slab.
7) Modelling in ANSYS software and comparing the failure pattern with experimental results.

IV. EXPERIMENTAL WORK

Experimental work includes:

1) Casting of 10 slabs of dimension 600mmx600mmx60mm out of it 2 are control slabs and 8 are strengthened.
2) The strengthening is done by covering 25%, 50%, 75% and 100% of the slab area by wet layup CFRP wrapping technique.
3) Strengthening is done for same bond area by one layer and two layer of wrapping.
4) Results are compared with influence of bond area and no of layers with control specimen.
5) Modelling and comparing the failure pattern with software and experimental results.

A. Materials

In the experimental program following materials are used:

1) Cement.
2) Coarse aggregate.
3) Fine aggregate.
4) Water.
5) Reinforcement.
6) CFRP fabrics.
7) Epoxy.
8) Cement

Sl. no	Properties	Obtained values
1	Specific gravity	3.15
2	Standard consistency	28%
3	Setting time Initial Final	90 minutes 300 minutes

Table 1: Properties of cement.

1) Coarse aggregate

Sl. no	Properties	Obtained values
1	Specific gravity	2.67
2	Water absorption	0.5%
3	Aggregate impact value	22.03%
4	Aggregate crushing value	22.38%

Table 2: Properties of coarse aggregate.

2) Fine aggregate

Sl. no	Properties	Obtained values
1	Specific gravity	2.48
2	Water absorption	1.1%
3	Zone	II

Table 3: Properties of fine aggregate.

3) Water

Bore well water is used in mixing and curing.

4) Reinforcement

6mm HYSD of Fe 415 dia bars used for reinforcement for the slab

5) CFRP properties

Property	Magnitude
Fibre Orientation	Uni-Directional
Fibre Density (g/cm^3)	1.8
Width (mm)	500
Tensile Strength (N/mm^2)	3000
Ultimate Elongation (%)	1.4

Table 4: CFRP fabric properties from manufacturer.

6) Epoxy Resin

Description	Nitrowrap 30	Nitrowrap 410
Colour	Clear	Amber
Density	1.14 g/cc	1.25-1.26 g/cc
Quantity	3.5 Lt	4 Lt
Pot life(min)	25 at 27°C	120 at 30°C
Curing time	4 – 5 hours	5 days @ 30°C
Coverage area per Lt	8-10 m^2	m^2

Table 5: Properties of primer and resin.

B. Experimental program

Sl no	Specimen name	Dimension in mm	M20 concrete
1	Slabs	600x600x60	10
2	Cubes	150x150x150	9
3	Cylinders	150 Dia. x300 Depth	3
4	Prims	500x100x100	3

Table 6: Number of specimen

Total no of specimens 25
Mix design for M20
Water/Cement ratio : 0.55
Water : 220.5 liters
Cement : 401 kg/m^3
Fine aggregates : 889.055 kg/m^3
Coarse aggregates : 783.14 kg/m^3
Ratio C: FA: CA = 1: 2.21: 1.95

1) Casting

Firstly, coarse and fine aggregates are mixed for 2 min. secondly, cement is added and mixed till uniform color. Thirdly, water is added and mixed uniformly. Fourthly, slump is checked. Fifthly, concrete is placed in the slab mould and slab is casted. Sixthly, slab is demoulded and cured for 28 days. Finally, slabs are white washed to observe the cracks.

2) Retrofitting of slabs

Retrofitting of slabs was carried out by wet lay-up technique. Firstly, they have to be covered with epoxy primer then continued with application of resin. Followed with application of fabric on the applied resin. Steps are followed as per the fabricator. Steps followed assure that there is good bond and act as one composite material. Therefore, stresses and loads are transferred to FRP through the concrete.

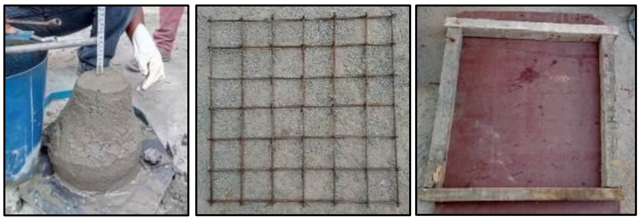

Fig 1: Slump check(a), Preparation of rebar(b) and mould(c).

Fig. 2: Caasting (a) and finished surface(b).

Fig. 3: Demoulding (a) and curing with gunny bags(b).

Steps followed as per fabricator:

1) Preparation of surface.
2) Primer application.
3) Cutting fabrics for strengthening.
4) Resin and hardener.
5) Placing of fabric sheets.

Fig. 4: Application of the resin(a) and fabric is placed and rolled with roller(b).

Fig. 5: Prepared specimen with increasing bond area by 25, 50, 75 and 100% the slab area.

C. Impact testing 0123

1) Components

2 short columns of dimension 250mm wide, 1100mm long and 600mm height supports 1800mm steel frame, 150mm dia with 60mm thick pulley is attached to frame at top, guide barrel of dimension 160mm dia, 420 mm long and 4mm thick cylinder is attached to the frame through plate by welding. 4.5 kg hammer with dimension of 170mm long, 60mm square cross section and it contains a hole of 30mm width and 40mm length is attached to 15mm wire.

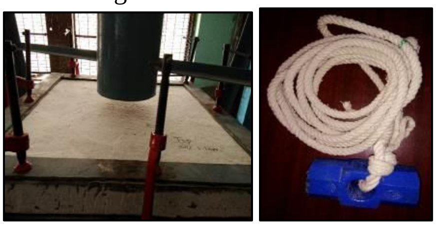

Fig 6: Testing specimen with c-clamps (a) and hammer of 10 pounds connected with rope (b).

2) Test Setup:

Slabs are placed on the support frame, steel plate is placed on it and fixity is ensured by clamping C-clamps all along the edges of the slab at 8 point. Guide barrel is used, to direct the mass to fall to center. 10 pounds or 4.5 kg steel hammer is connected to the wire and 460mm or 18 inch free fall height is marked on wire. Number of blows required to cause first and ultimate crack in control samples is noted down. In strengthened samples the number blows to cause ultimate failure i.e., debonding of fabric is tabulated,

Energy absorption = Weight of ball x Fall of height x Number of blows

V. RESULTS & DISCUSSION

Mode of failure of control specimens: With repetitive blows the radial crack appeared from center to outward direction. As number of blows increased, crack length and width increased, also scabbing of concrete took place at bottom and spalling at top increased. At the point of ultimate failure, punching failure was observed connecting the radial cracks. Reinforcement was seen at bottom with scabbing of the concrete. Punching cone angle was found to be 27.32°.

Mode of failure of strengthned samples: Bulging of CFRP was observed at initial phase. Hair line cracks appeared as number of blows increased. CFRP fibres stiches started to widen up, and bulging was observed. Spalling was observed at top. Debonding of fibres is the ultimate failure. In 25% one, two and 50% one layer debonding occur along the sides of the wrapping. Whereas in all other specimens debonding occur within the wrapped area. Punching cone angels gets reduces as the bond area and layer of wrapping increases.

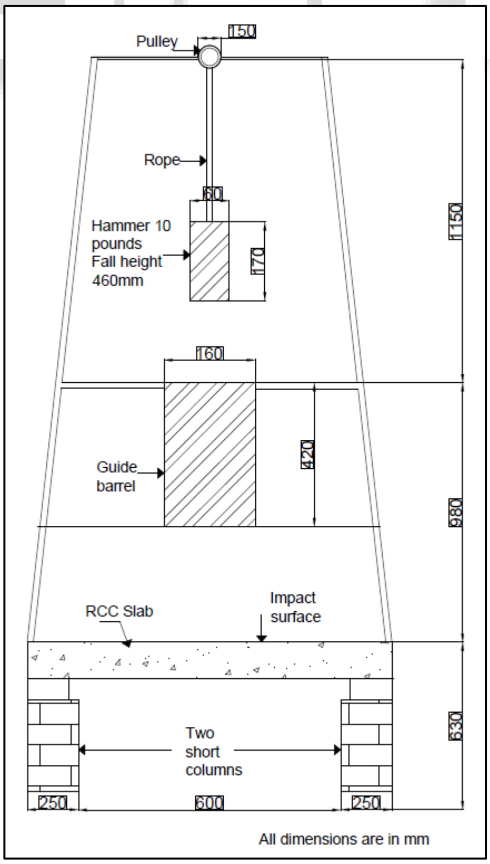

Fig. 7: Diagrammatic setup arrangements.

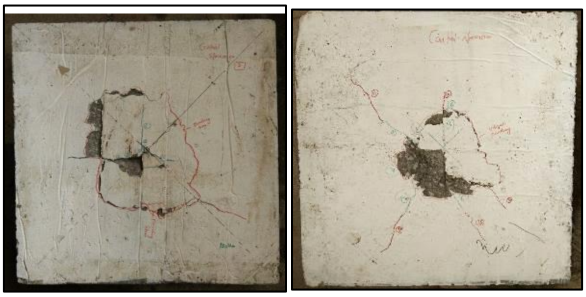

Fig. 8: Failure of control sample 1 and 2 bottom view.

Fig. 9: Failure of 25% wrap one and two layer bottom view.

Table 7: Comparison of strengthened and non-strengthened samples.

Sl no	Slab	No of blows to ultimate failure	Energy absorption in kJ	Strengthened effect	Strengthened percentage	Punching cone angle in degree
1	Control specimen	121	2.730	1	0	27.315
2	25% wrap - 1 layer	134	3.023	1.1074	10.74	26.33
3	25% wrap - 2 layer	182	4.106	1.5041	50.41	25.69
4	50% wrap - 1 layer	167	3.768	1.3802	38.02	23.89
5	50% wrap - 2 layer	278	6.273	2.2975	129.75	23.49
6	75% wrap - 1 layer	217	4.896	1.7934	79.34	20.98
7	75% wrap - 2 layer	423	9.544	3.4959	249.59	19.76
8	100% wrap - 1 layer	354	7.987	2.9256	192.56	18.25
9	100% wrap - 2 layer	566	12.771	4.6777	367.77	17.92

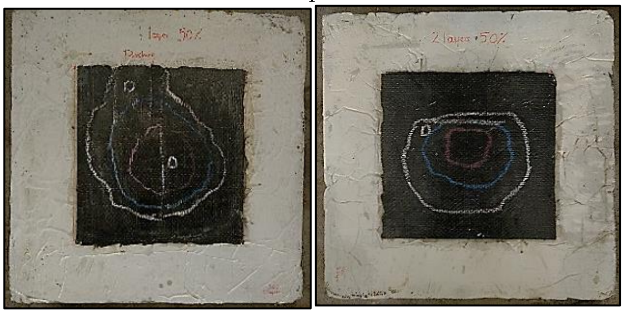

Fig. 10: Failure of 50% wrap one and two layer bottom view.

Fig. 11: Failure of 75% wrap one and two layer bottom view.

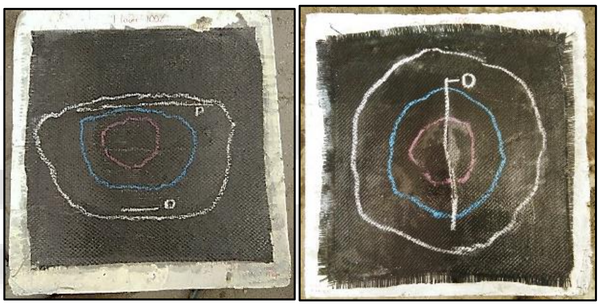

Fig. 12: Failure of 100% wrap one and two layer bottom view.

VI. NUMERICAL ANALYSIS

Steps followed in ansys workbench 15 is

1) Defining the material properties like concrete steel and CFRP.
2) Geometric modeling of slab, impact and cfrp is done
3) Assigning material properties to the geometric models.
4) Meshing is done for the required size.
5) Boundary condition, and symmetry is adopted.
6) Impact load is appplied by defining the velocity of 3m/s and end time of 1e-3 s is adopted for all models.
7) Required paramets are defined and solved.

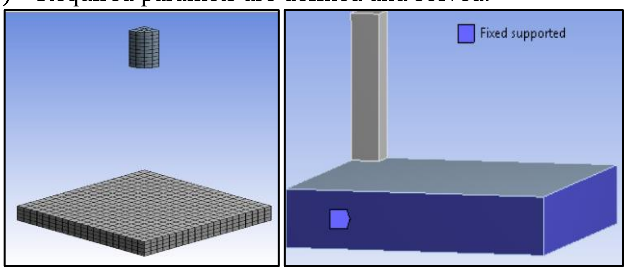

Fig. 13: Meshing the elements and assigning the boundary condition.

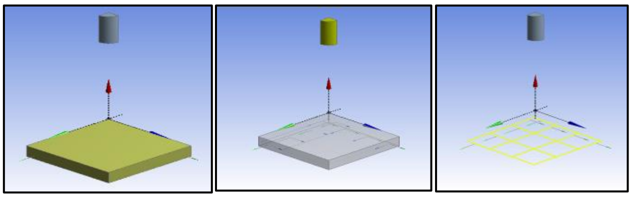

Fig. 14: Modelling of slab impact and rebar elements.

Behaviour of strengthened slab under impact load

- Stress concentration is more at the center and gradually reduces towards the supports.
- Velocity is maximum at the start and decreases as time elapses.
- Acceleration increases to peak value and reduces with respect to increase in time, similar pattern is seen in deflection graph.
- Strengthened specimens bulges under the impact and the size spreads in contours.
- As the bonding area and number of layers increases the deflection reduces.
- And also punching shear failure decreases with increase in bonding area and no of layers.
- Slab strenghtened with two-layers of CFRP fabric with 100% wrapping, observed more energy and performed well compared to all other strengthen slabs.

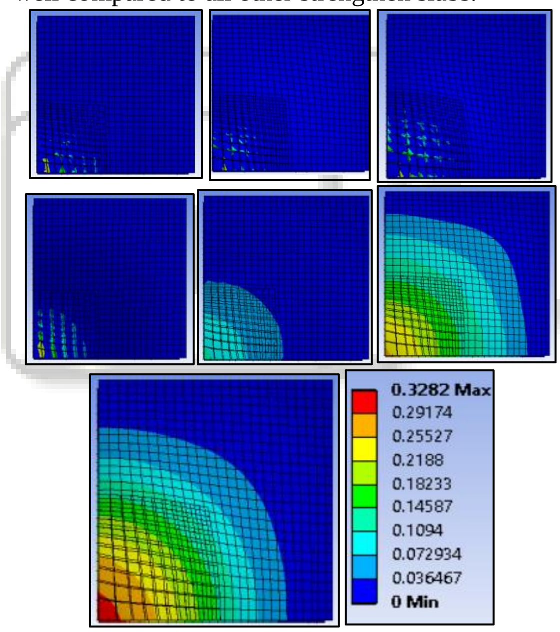

Fig. 15: Progressie failure of 25% one layer CFRP sheets and concrete.

VII. CONCLUSION

1) The strengthened slabs using CFRP fabric under impact load enhanced the energy absorption capacity and by increasing the bond area and layer of wrapping the energy absorption was further increased.
2) One layer 100% CFRP wrapping slab has higher energy absorption of 192.56% with respect to control slab.
3) Two layer 100% CFRP wrapping slab has higher energy absorption of 366.67% with respect to control slab.
4) Experimental results suggested that, by increasing the number of layer of CFRP and bonding area the punching cone angle decreases.
5) Results from analytical work showed decent agreement with experimental results. Therefore, for analyzing impact load on retrofitted slabs ANSYS software can be used.

ACKNOWLEDGMENTS

I would like to thank BIT, Department of civil engineering, Guide, HOD, PG coordinator and all faculties. Also thank UVCE for allowing me to do testing. Material sponsorship for this dissertation work was from CONCRETE PROTECTIVE SYSTEM.

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