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Behavior of Reinforced Concrete Flat Slab Exposed To Fire Experimentally And Numerically By (ANSYS).

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***Abstract**: The behavior of reinforced concrete slab exposed to fire was presented. Two stages of analysis were carried out, in the first step(group A), the fire duration was variable and ranged between one to three hours while, the concrete cover were fixed and equal to 25mm. In the next step(group B), the concrete cover was variable from 30 mm to 35mm and 40mm while the fire duration was constant at 4 hours. The responses of structure depend on the thickness of concrete cover and fire duration. The RC slabs were modeled to show the effect of slab thickness, and different fire duration. Deflection, lower strain and upper strain of RC slab at temperature of 600C^{o}were also evaluated for the two stages. To cover variables' eight slabs were tested (sample control without fire + (4 for group A)+ (3 for group B)) concrete cover samples(group A ranging from 2.5 to 4 cm and different fire durations)and (group B with constant fire duration and cover thickness ranging between 30mm to 40mm) the load was increased gradually up to collapse of all tested slabs. In the first stage (group A) the failure load decreases from 15.3% to 36.6% compared to control slab. In the second stage (group B) the failure load decreases from 10.22% to 21.9% compared to control slab. And the failure load increases due to increases the concrete cover from 2.5 cm to35 cm by 22.22% which burned for constant duration (4 hours) at the same temperature .*

I. Introduction

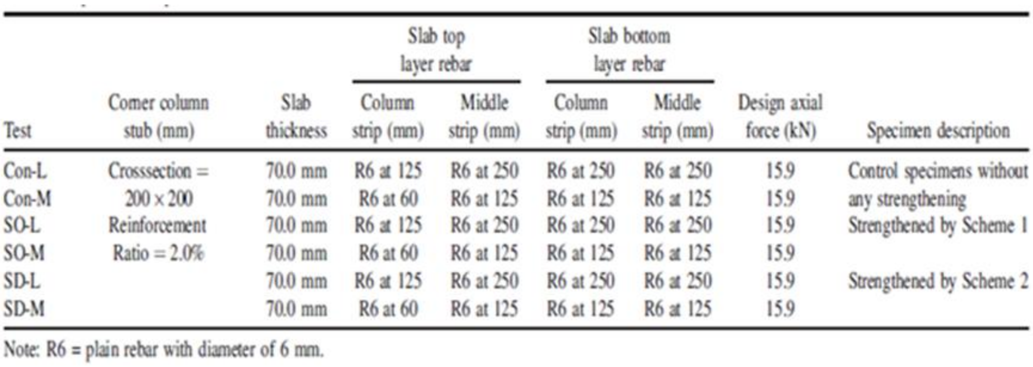
JEREMY CHANG et al. [1] carried out a study to provide recommendations to designers, and to propose a simple method for designers to model the structural behaviour of hollowcore concrete floor slabs in fire. The proposed finite-element model incorporates a grillage system using beam elements to capture the thermal expansion of the precast units in both directions, with the topping concrete over several precast units modelled by shell elements. The research reported herein compares the proposed model with various fire test results of hollow core concrete slabs. The simulation outcomes show good agreement with the experimental results.

Several hollow core concrete slab flooring systems tested previously at the University of Canterbury for seismic purposes were simulated using this modeling scheme. Various supporting schemes have been considered, and the results show that different arrangements of axial and rotational restraint at the supports can significantly influence the fire performance of the concrete slab floors.

Mr. C Sangluaia et al..,[2] The behavior of reinforced concrete slab exposed to fire is presented. Two stages of analysis is carried out using Finite Element package ABAQUS to find thermal response of structural members namely thermal analysis and structural analysis. In the first step, the distribution of the temperature over the depth during fire is determined. In the next step, the mechanical analysis is made in which these distributions are used as the temperature loads. The responses of structure depend on the type of concrete and the interactions of structural members. The RCC slab were modeled to show the role of slab thickness, percentage of reinforcement, width of slab and different boundary condition when expose to fire loading. Effects for both materials in RCC slab at elevated temperatures are also evaluated.

Kai Qian., A. M. ASCE and Bing. [3] have indicated that RC flat slabs, especially without drop panels, are high vulnerability to progressive collapse because no beams could assist in redistribution the axial force previously carried by lost columns. In order to reduce the likelihood of progressive collapse, necessary strengthening schemes should be applied. six specimens of similar dimensions and reinforcement details were prepared, two of which were unstrengthened and served as control specimens, while the remaining four were strengthened with two different schemes: orthogonally (Scheme 1) or diagonally (Scheme 2) bonded carbon-fiber- reinforced polymer (CFRP) laminates on the top surface of the slab. The progressive collapse performance of the strengthened specimens was studied in terms of their load - displacement relationships, first peak strength, initial stiffness, and energy dissipation capacities. The dynamic ultimate strength and corresponding dynamic effects of flat slabs after the sudden removal of a corner column was also discussed due to the dynamic nature of progressive collapse. Test results indicated that both schemes were effective in improving the performance of RC flat slabs in resisting progressive collapse.

Table (1): Specimens properties.[3]



Test	Corner column stub (mm)	Slab thickness	Slab top layer rebar Column strip (mm)	Slab top layer rebar Middle strip (mm)	Slab bottom layer rebar Column strip (mm)	Slab bottom layer rebar Middle strip (mm)	Design axial force (kN)	Specimen description
Con-L	Crosssection =	70.0 mm	R6 at 125	R6 at 250	R6 at 250	R6 at 250	15.9	Control specimens without
Con-M	200 × 200	70.0 mm	R6 at 60	R6 at 125	R6 at 125	R6 at 125	15.9	any strengthening
SO-L	Reinforcement	70.0 mm	R6 at 125	R6 at 250	R6 at 250	R6 at 250	15.9	Strengthened by Scheme 1
SO-M	Ratio = 2.0%	70.0 mm	R6 at 60	R6 at 125	R6 at 125	R6 at 125	15.9	
SD-L		70.0 mm	R6 at 125	R6 at 250	R6 at 250	R6 at 250	15.9	Strengthened by Scheme 2
SD-M		70.0 mm	R6 at 60	R6 at 125	R6 at 125	R6 at 125	15.9	

Note: R6 = plain rebar with diameter of 6 mm.

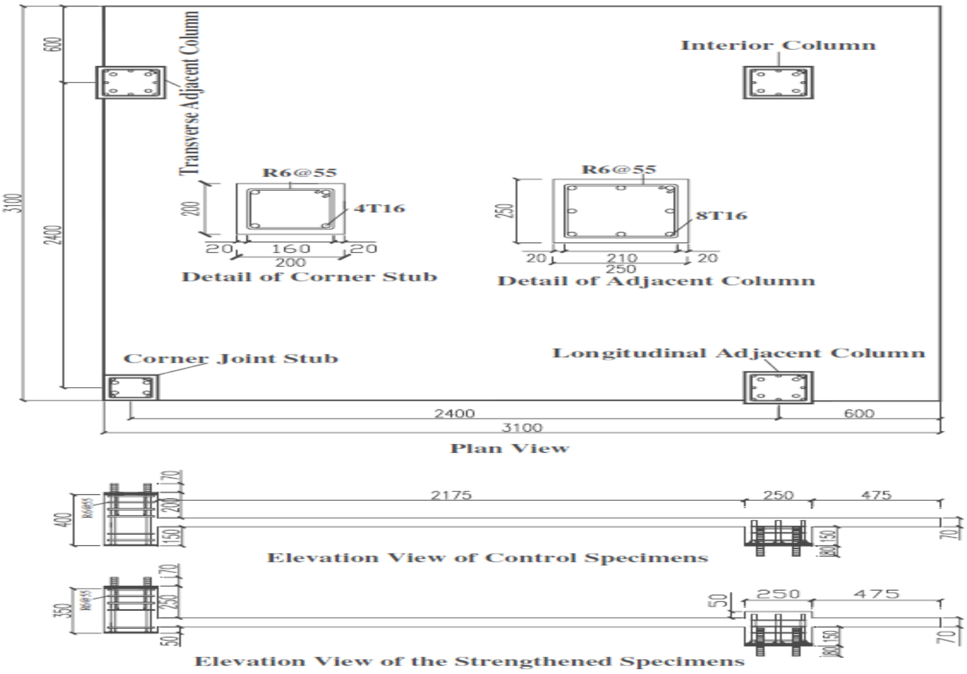
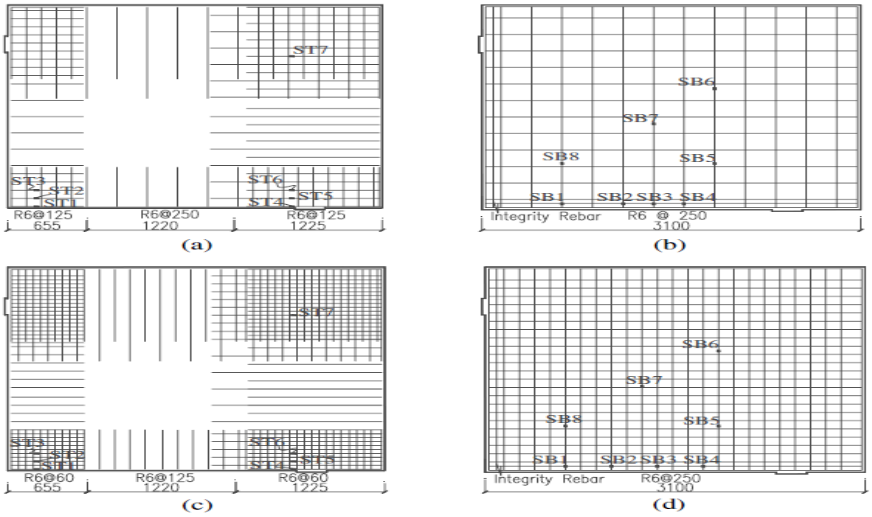


Figure (1): Dimensions of the test specimens. [3]



(a) (b)

(c) (d)

Figure (2): Slab reinforcement details. [3]

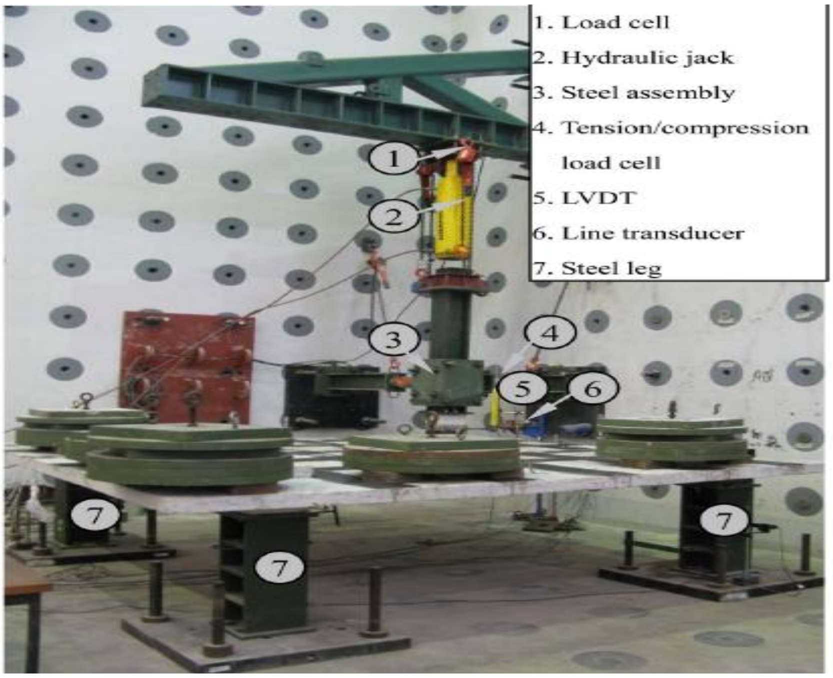


Figure (3): CFRP strengthened specimen ready for test. [3]

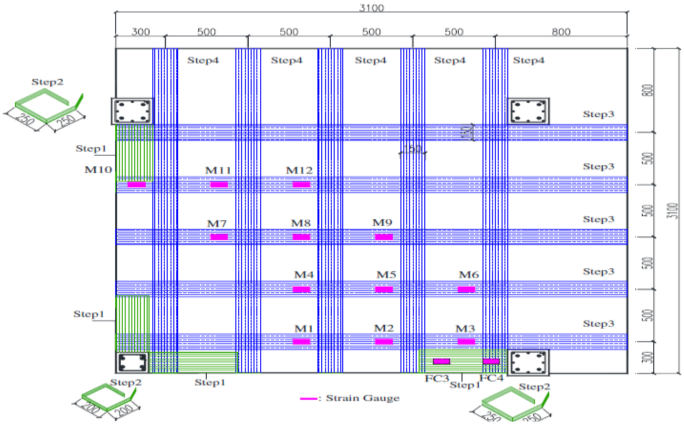


Figure (4): Plan view of the strengthening Scheme 1. [3]

This research is devoted to investigate the behavior of reinforced concrete slabs loaded and exposed to fire flame for different durations., some strain and deflection behavior of reinforced concrete slab specimens under the effect of burning is presented. The concrete specimens and slabs were subjected to fire flame temperature at 600 °C for different durations of 1,2,3,4 hours and different concrete cover . It is found that the deflection for specimens exposed to the same fire duration but with concrete cover thickness indicate that, deflection of specimen with 35 mm concrete cover has higher deflection than that of specimens with cover thickness of 30 and 40mm.With regard to the maximum upper strain, it is equal to 248 $x10^{-6}$ mm and corresponding to load of 21.52 ton, while the maximum lower strain of steel corresponding to load of 21.52 ton and equal to $2013x10^{-6}$

II. Research Scope and Objectives

The experimental program includes 8 slabs, which were tested. All slabs with lower longitudinal steel bars 8 Ø12/m, and upper longitudinal steel bars of 8 Ø10/ m.

The objective of this work is to study the effect of fire duration on RC flat slab with different concrete cover.

III. Experimental Study

3.1 Materials

Detailed information about the available materials and their properties are given in this section.

1. Aggregate

Coarse aggregate of crushed dolomite with nominal maximum size of 20 mm and fine aggregate of natural sand with fineness modulus of 2.84 were mixed with ratio of 0.68: 0.32 respectively to obtain the combined aggregate.

Grading of this mix is shown in Table (3) and Figure (4). Physical properties for coarse and fine aggregates are shown in Table (2) and Table (3) respectively.

Table (2) Sieve Analysis for combined Aggregates

Sieve Size (mm)	Percentage Passing
40	100
20	96
10	78.72
5	45.96
2.5	38.52
1.25	32.92
0.65	13.08
0.3	1.88
0.16	0.36

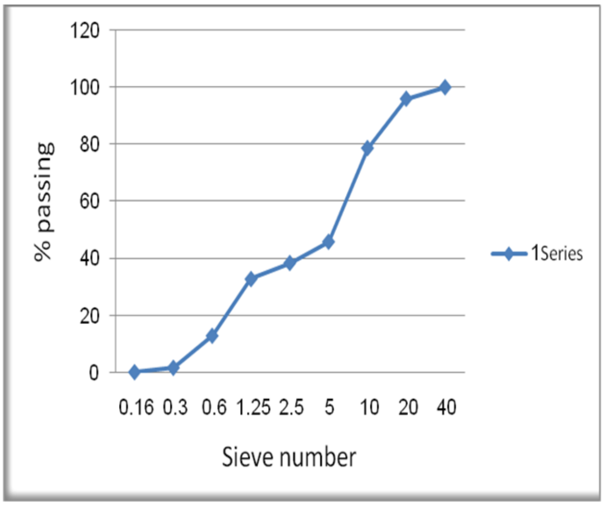


Figure (5) Grading of Combined aggregates

Table (3) Properties of Coarse Aggregate(Dolomite and Physical Properties of Fine Aggregate (Natural Sand)

Properties of Coarse Aggregate(Dolomite)		**Physical Properties of Fine Aggregate (Natural Sand)**	
Property	Value	Property	Value
Specific Gravity of oven dry	2.72	Specific Gravity of oven dry	2.61
Unit weight (kg/m^3)	1590	Unit weight (kg/m^3)	1650
Fineness Modulus	6.3	Fineness Modulus	2.84
Abrasion %	19.26	Material finer than sieve#200 %	2.6
Crushing %	23	Absorption by weight %	1.5
Absorption by weight %	2.03		

2. Cement

Ordinary Portland cement (OPC) CEMI-42.5N that meets The Egyptian Standard Specification (ESS) No. 2421/2005 requirements was selected considering compressive strength, fineness, and heat of hydration. The chemical composition and physical properties of ordinary Portland cement are listed in Table (4).

3. Water

Potable water has been used in mixing concrete constituents and in curing of hardened concrete.

Table (4) Chemical Composition and Physical Properties of Ordinary Portland Cement

Property		Test Results	Limits of the E.S.S
Specific Gravity		3.15	--------
Expansion (mm)		1.2	< 10
Initial Setting Time (hr's min's)		01:40	< 60 min
Final Setting Time (hr's min's)		03:20	< 10 hrs
Compressive Strength (Kg/cm^2)	2 days	240	> 200 kg/cm^2
	7 days	375	> 270 kg/cm^2
	28days	375	> 425 kg/cm2

Reinforcing Steel

In this study mesh of high tensile steel (36/52) deformed bars of 12 and10 mm diameter were used as upper and lower reinforcement respectively. Tests were carried out according to the Egyptian standard specifications (ESS) No. 262/2000 [3]. Table (5) presents the results of performed tests.

Table (5) Properties of Reinforcing Steel

Property	Value	Specification
Yield Strength (kg/cm^2)	3800	3600
Ultimate Strength (kg/cm^2)	6150	5200
Weight per meter Length (kg/m)	0.601	0.587-0.649
Ultimate Strength/ Yield Strength	1.5	1.05
Elongation	14	12

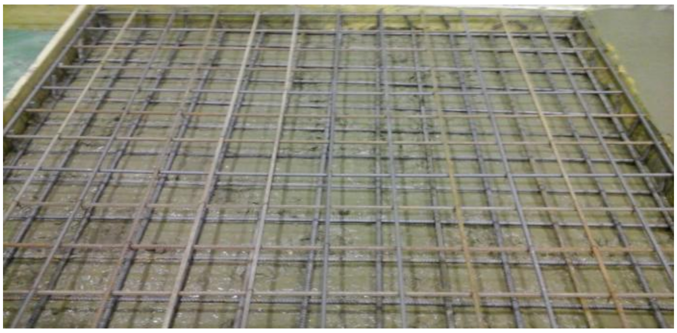


Figure (6) Reinforcement of Concrete Flat Slab

3.2 Concrete Mix Design

Concrete mix design were made according to British method, such as the desired compressive strength and adequate workability. Concrete mix with characteristic compressive strength of 250 kg/cm^2 was used. The mix proportions were based on the B.S Charts, employing the sequence outlined in that standard practice, the quantities of ingredients per cubic meter of concrete were calculated and given in Table (6).

Table (6) concrete Mix Proportions (kg / 1 m^3 Concrete)

Material	Water	Cement	Sand	Dolomite
Weight (Kg)	175	350	640	1280

Figure (7) Pouring Concrete of Flat Slab Specimen.

3.3 Mixing, casting and curing

Mixing, compacting, finishing, and curing are complimentary operations to obtain desired high quality concrete. Mixing was carried out in a 60 kg revolving electric mixer of pan drum type for three minutes. In mixing process, all dry ingredients were mixed first. In the second step, the amount of water was added gradually and mixing continued till producing uniform concrete.

Group (A); Five specimens have concrete cover of 25 mm and exposed to fire for different durations
Group (B); Three specimens have different concrete cover of 30, 35,and 40 mm.
The details of group (A) and group (B) are listed briefly in Table (7).

Table (7) Details of Specimens (group A and group B)

Group	Slab Code	Concrete Cover (mm)	Fire Duration (hr)	Strengthening Material	Description
A	1	25	0	….	Control Specimen
	2	25	1	…..	….
	3	25	2	…..	……
	4	25	3	…..	……
	5	25	4	……	…..
B	6	30	4	……	….
	7	35	4	……	……
	8	40	4	……	…..

Fig. (8) Curing of Flat Slab Concrete Specimens

Fig. (9) Multi-burners Furnace with Thermal Insulation.

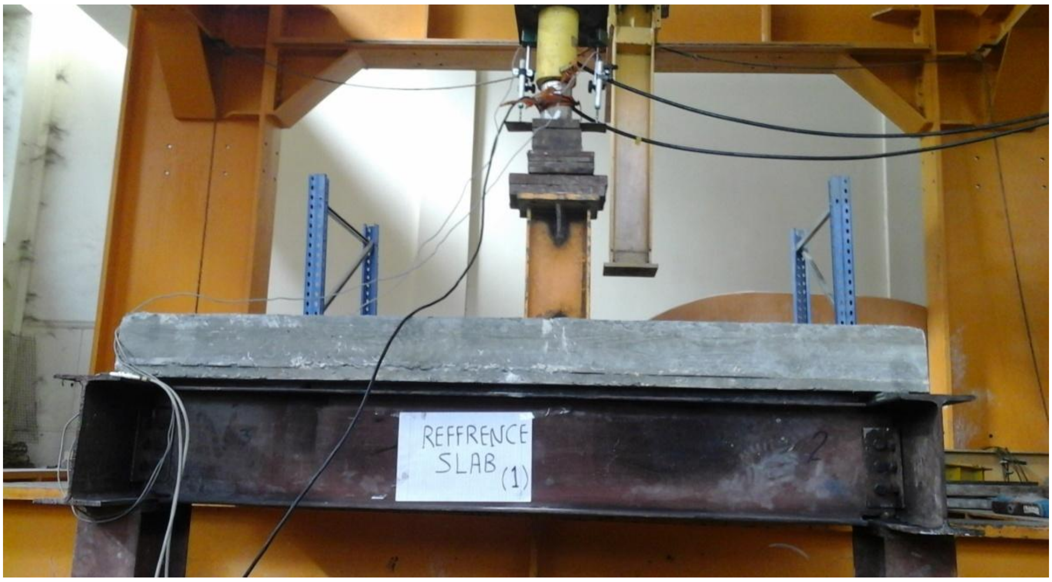


Figure (10) Load Cell 100 ton Capacity.

3.4 Results and Discussion:-

- Compressive Strength

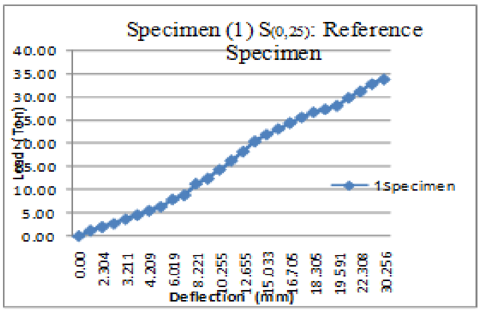
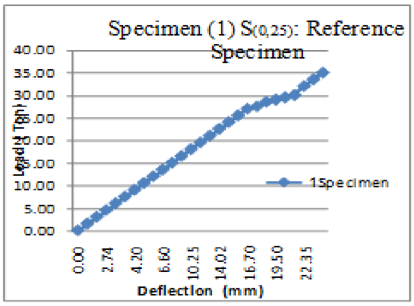
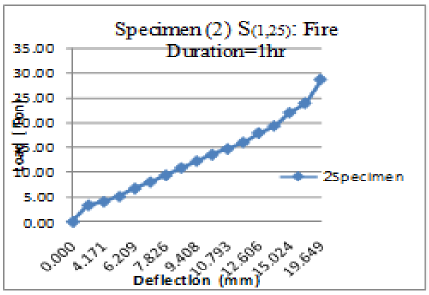
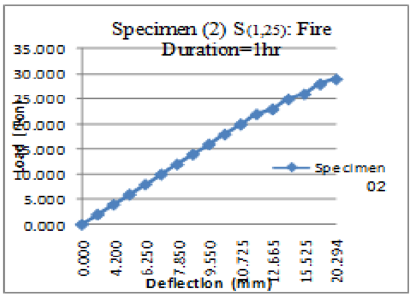
Table (8) illustrates the development of compressive strength for concrete mix containing sand as fine aggregate and crushed dolomite after curing for 7 and 28 days at room temperature. It is evident that, the average compressive strengths of concrete mix at 7 days are 283 kg/cm^2 in case of cubic mould and 269 kg/cm^2 in case of cylinder mould. The chart also shows that, the compressive strengths of concrete mix at 28 days are 369 kg/cm^2 and 358 kg/cm^2 for cubic and cylinder moulds respectively.

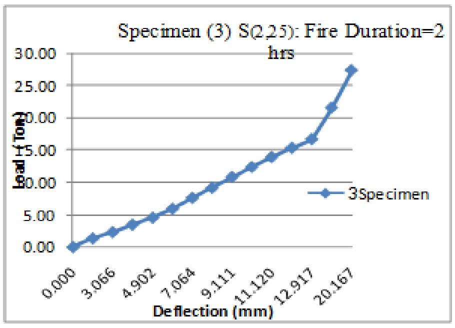
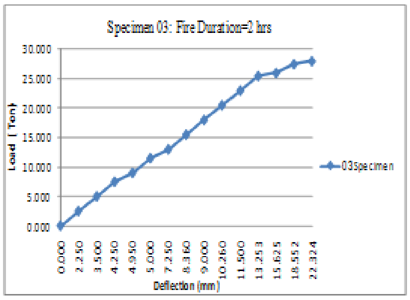
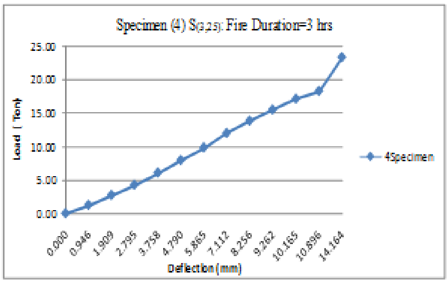
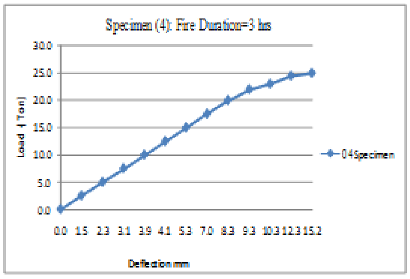
Table (8) Compressive Strength Test Results at 7 and 28 days

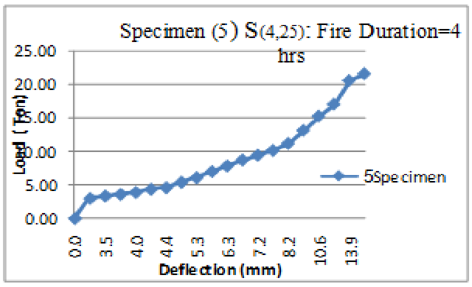
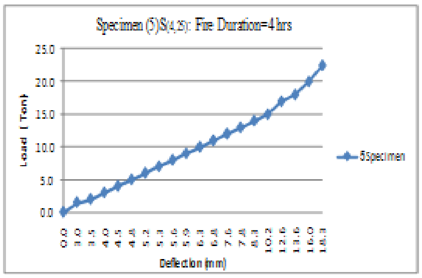
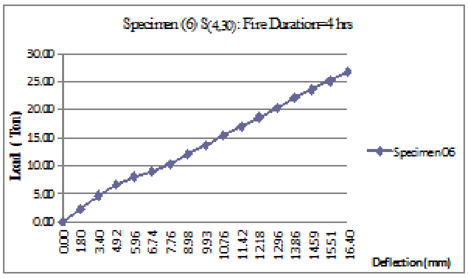
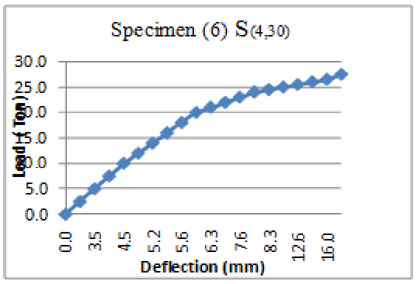
Specimen Mould	Day of Test	Compressive strength Kg/cm^2	Average Compressive Strength Kg/cm^2
cube	7	260	283
		275	
		315	
		280	
	28	350	369
		390	
		421	
		315	
Cylinder	7	269	269
		281	
		256	
	28	344	358
		362	
		369	

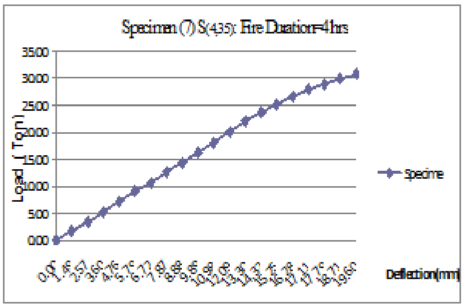
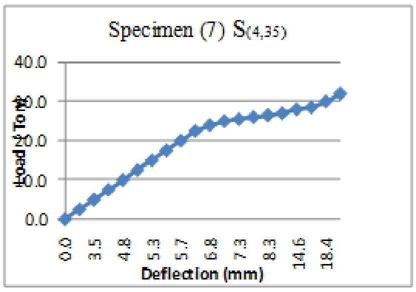
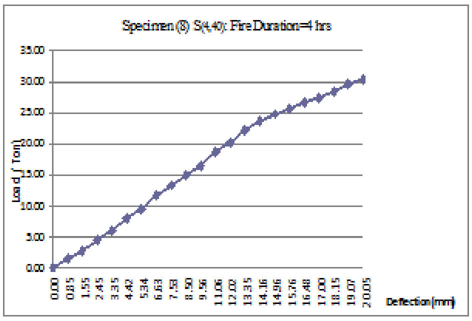
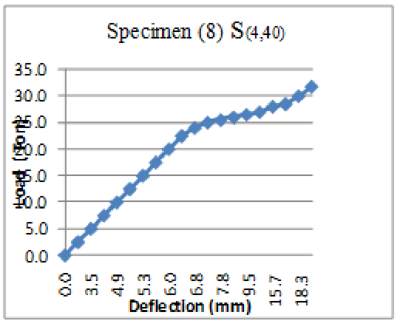
3.4.2 Test Results of experimental failure load and deflections of flat slabs:-

Figure (11):-Results for specimens.

Slab number	EXPERIMENTAL FAILURE LOAD WITH DEFLECTIONS.	NUMERICAL FAILURE LOAD WITH DEFLECTIONS.
1		
2		

Slab number	EXPERIMENTAL FAILURE LOAD WITH DEFLECTIONS.	NUMERICAL FAILURE LOAD WITH DEFLECTIONS.
3		
4		

Slab number	EXPERIMENTAL FAILURE LOAD WITH DEFLECTIONS.	NUMERICAL FAILURE LOAD WITH DEFLECTIONS.
5		
6		

Slab number	EXPERIMENTAL FAILURE LOAD WITH DEFLECTIONS.	NUMERICAL FAILURE LOAD WITH DEFLECTIONS.
7		
8		

3.4.2.1 Comparison between Experimental and Numerical Ultimate Load of the Analyzed Slabs:-

Table(9) :-Comparison between Experimental and Numerical Ultimate Load of Slabs.

Group	Specimen Designation	Concrete Cover (mm)	Fire Duration (hr)	Numerical Failure Loads(Ton)	Experimental Failure Loads(Ton)	% Increase for Failure load	Numerical Experimental
	1 S(0,25)	25	0	35	33.96	2.970	1.03
	2 S(1,25)	25	1	29	28.76	0.827	1.01
	3 S(2,25)	25	2	28	27.50	1.790	1.02
	4 S(3,25)	25	3	25	23.41	6.360	1.07
	5 S(4,25)	25	4	22.5	21.52	4.360	1.05
	6 S(4,30)	30	4	27.5	26.72	2.840	1.03
	7 S(4,35)	35	4	32	30.81	3.820	1.04
	8 S(4,40)	40	4	31.8	30.35	4.560	1.05

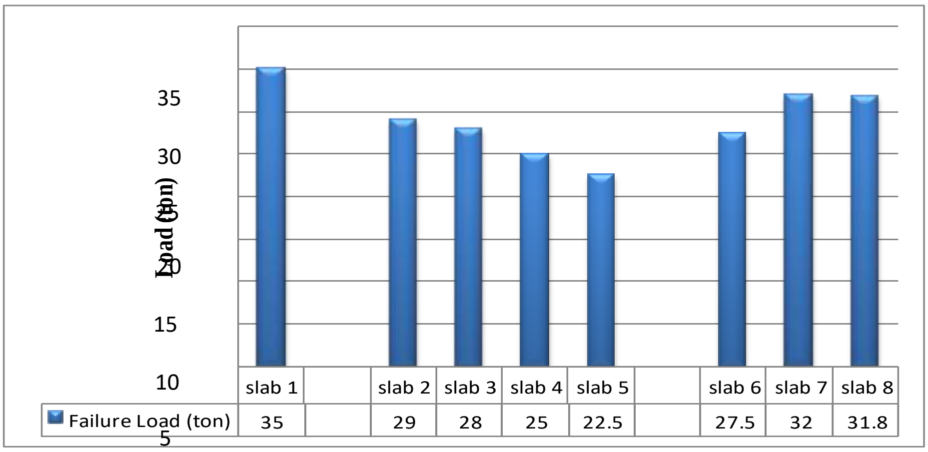


Figure (12) Numerical failure load by ANSYS modeling for all slabs.

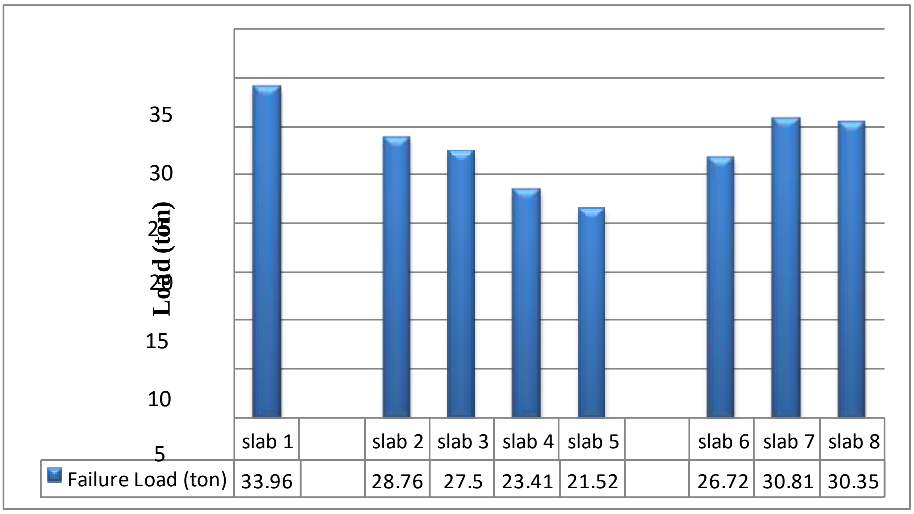
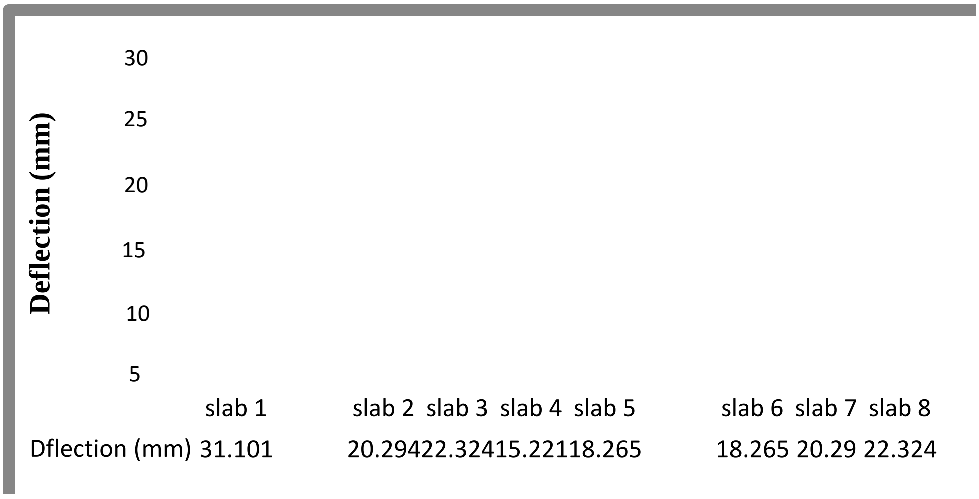


Figure (13) Experimental failure load modeling for all slabs.

3.4.2.2 Comparison between Experimental and Numerical Ultimate Deflections of the Analyzed Slabs:-

Table (10) Comparison between Experimental and Numerical Ultimate Deflections of the Analyzed Slabs.

Group	Specimen Designation	Concrete Cover (mm)	Fire Duration (hr)	Numerical Deflections (mm)	Experimental Deflections (mm)	% Increase for Deflections
	1 S(0,25)	25	0	31.101	30.256	2.72
	2 S(1,25)	25	1	20.294	19.649	3.18
	3 S(2,25)	25	2	22.324	20.167	9.66
	4 S(3,25)	25	3	15.221	14.164	6.94
	5 S(4,25)	25	4	18.265	16.10	11.85
	6 S(4,30)	30	4	18.265	16.40	10.21
	7 S(4,35)	35	4	20.290	19.60	3.40
	8 S(4,40)	40	4	22.324	20.05	10.19



Figure(14) Numerical deflection at failure load by ANSYS modeling for all slabs.

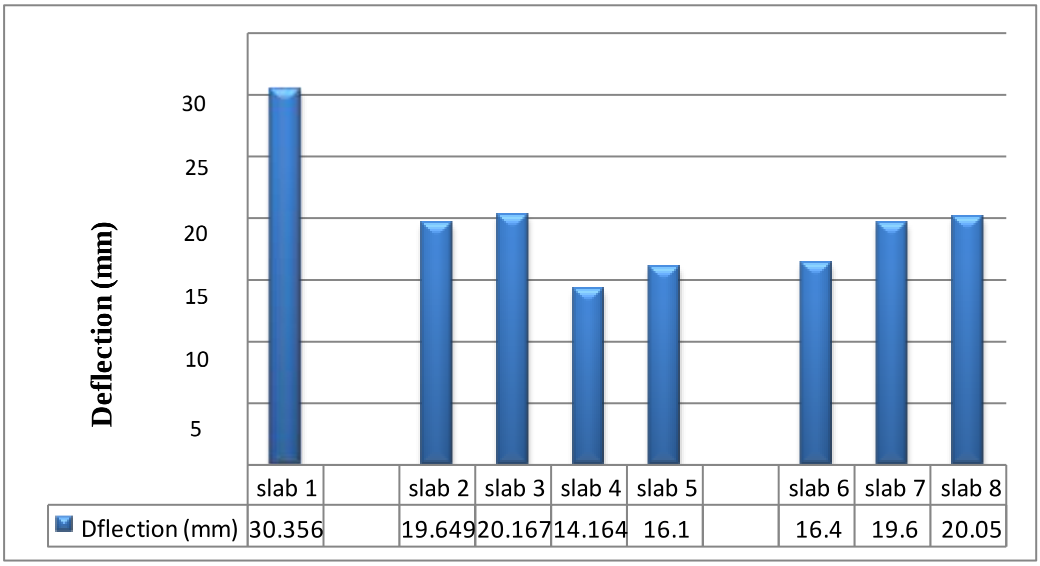
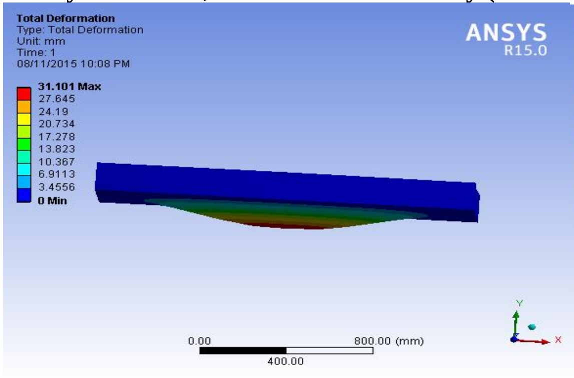


Figure (15) Experimental deflection at failure load for all slabs.

3.4.2.3 Analyses of load ,strain and deflection by (ANSYS)



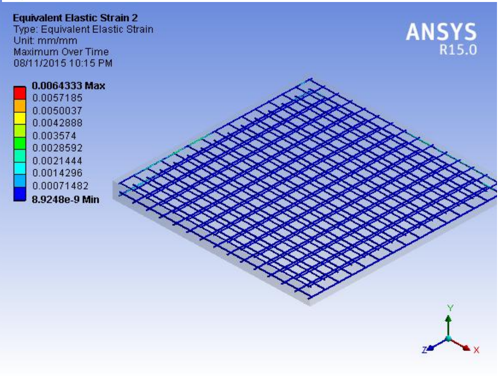


Figure (16):-Total deformation for reference slab S(0,25) **Figure (17)**:-Strain in lower reinforced steel for reference slab S(0,25).

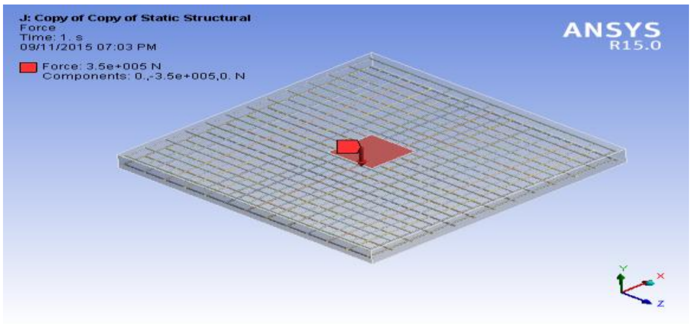
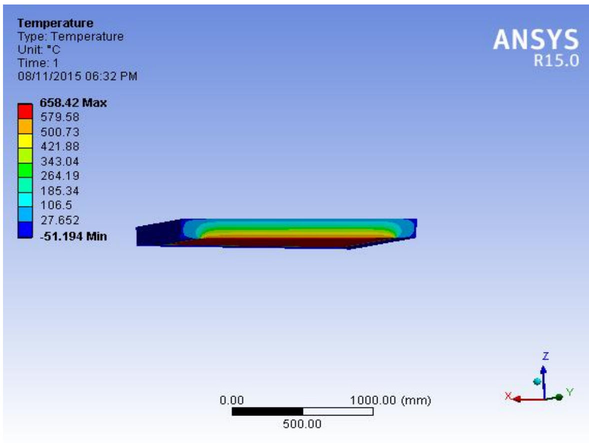


Figure (18:-Maximum failure load for reference slab S(0,25).



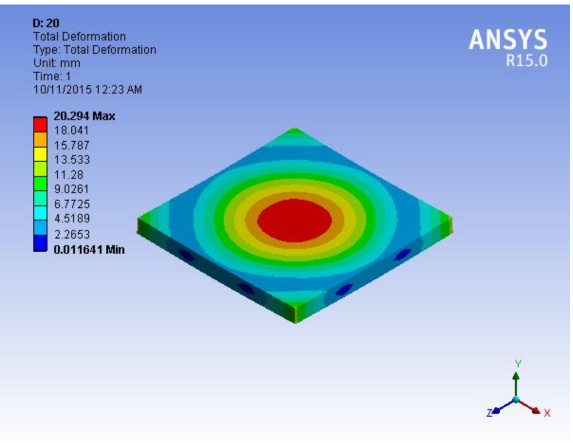
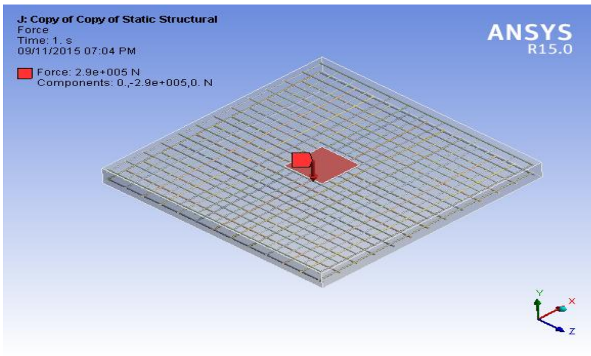


Figure (19:- Effect of Temperature one hour for slab 2 S(1,25).
Figure (20) Total deflection at failure load for slab 2 S(1,25) .



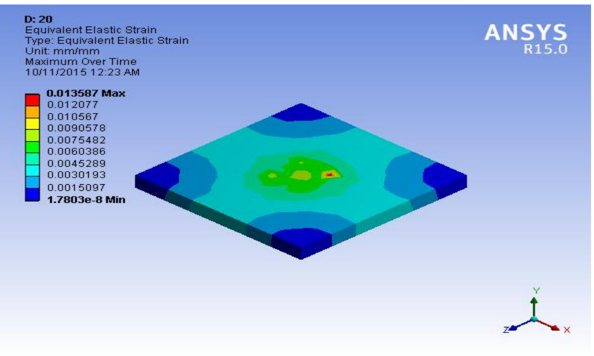
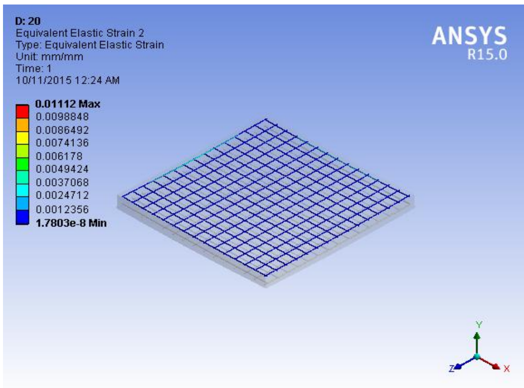


Figure (21:-Failure load for slab 2 S(1,25).

Figure (22:-Equivalent elastic strain in concrete for slab 2 S(1,25)



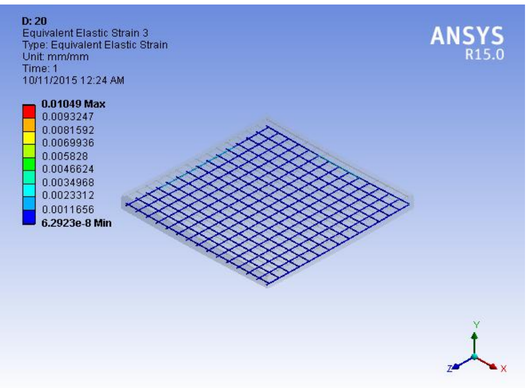
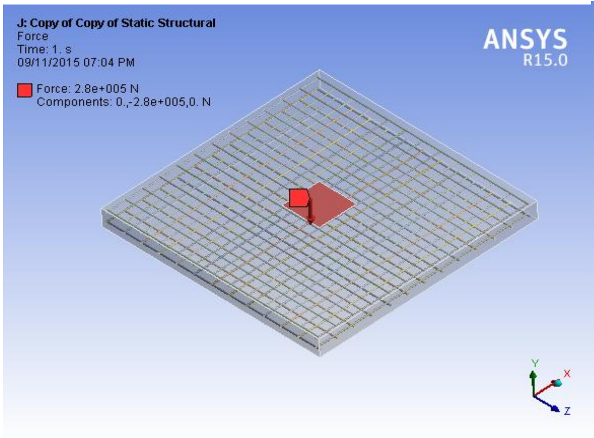


Figure (23:- Equivalent elastic strain in lower mesh layer Steel for Slab 2 S(1,25)

Figure (24:- Equivalent Elastic Strain in Upper mesh layer steel for slab 2 S(1,25) .



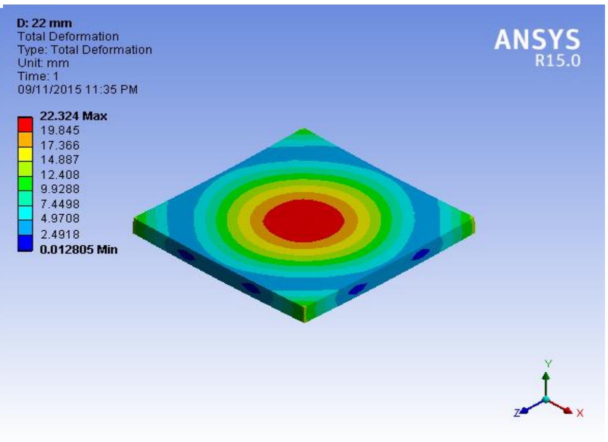
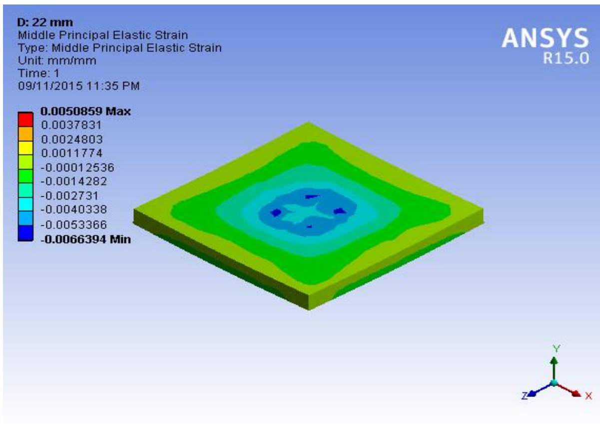


Figure (25:- Failure load for slab 3 S(2,25). **Figure (26:-**Total deflection at failure load for slab 3 S(2,25) .



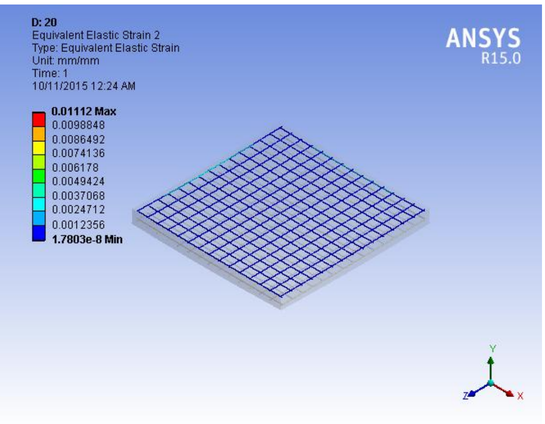


Figure (27:-Equivalent elastic strain in concrete for slab 3 S(2,25)

Figure (28:- Equivalent elastic strain in lower mesh layer steel for slab 3 S(2,25)

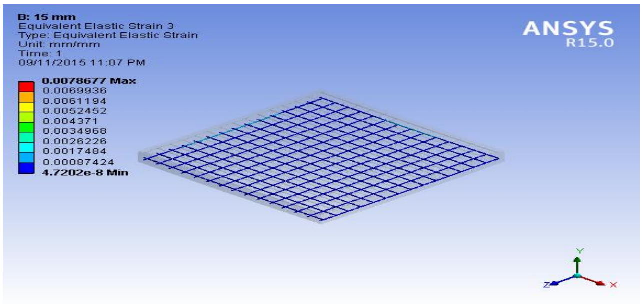
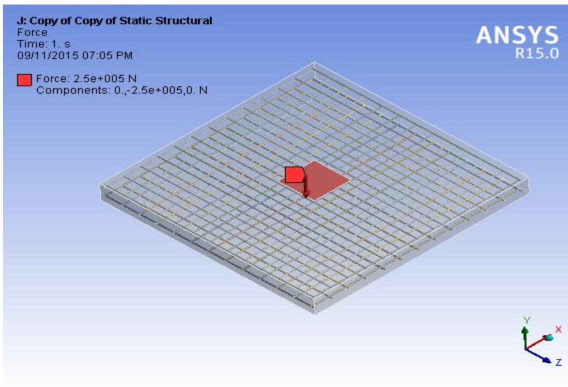


Figure (29:- Equivalent elastic strain in upper mesh layer steel for slab 3 S(2,25) .



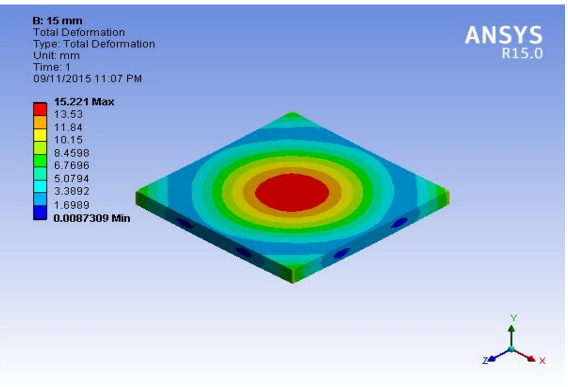
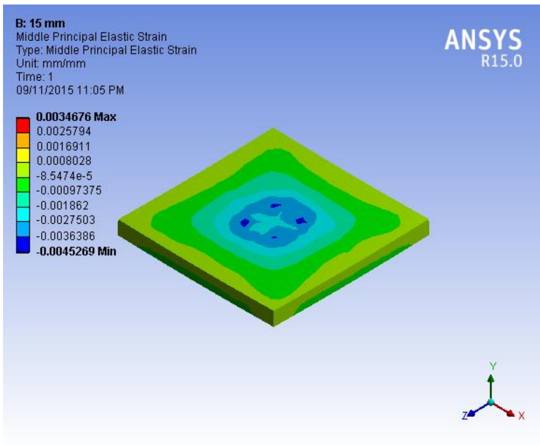


Figure (30:- Failure load for slab 4 S(3,25). **Figure (31:-** Total deflection at failure load for slab 4 S(3,25).



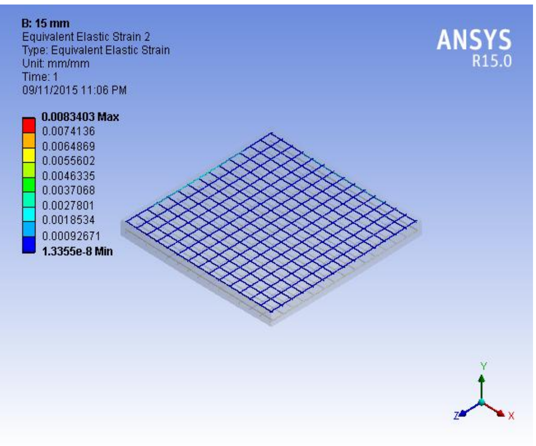


Figure (32:- Equivalent elastic strain in concrete **Figure (33:-** Equivalent elastic strain in lower mesh layer steel for slab 4 S(3,25).

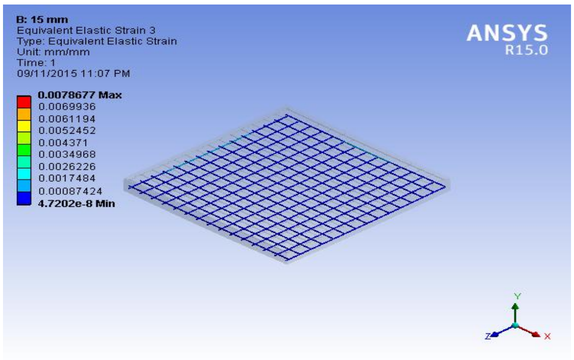
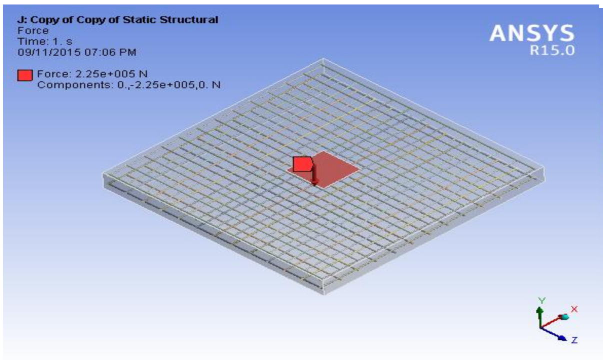


Figure (34:- Equivalent elastic strain in upper mesh layer steel for slab 4 S(3,25).



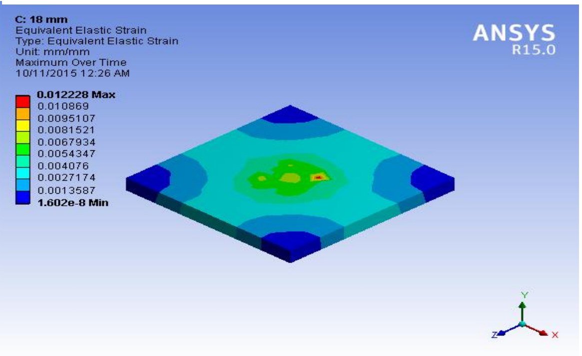
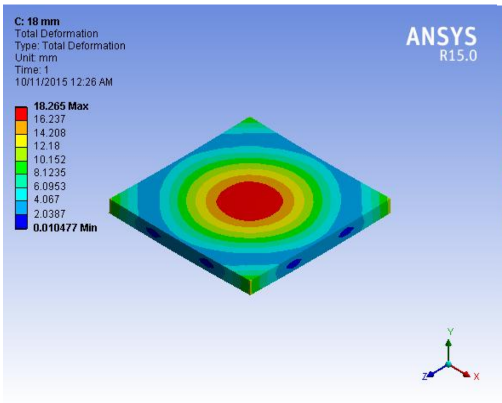


Figure (35:- Failure load for slab 5 S(4,25) . **Figure (36:-** Equivalent elastic strain in concrete for slab 5 S(4,25).



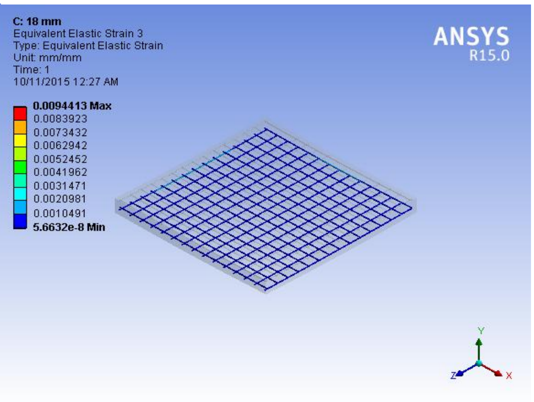


Figure (37:-Total deflection at failure load for slab 5 S(4,25). **Figure (38:-** Equivalent elastic strain in lower mesh layer steel for slab 5 S(4,25).

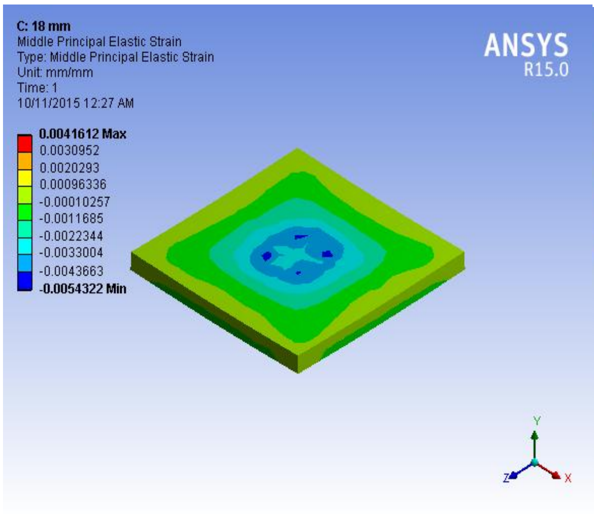


Figure (39- Equivalent elastic strain in upper mesh layer steel for slab 5 S(4,25).

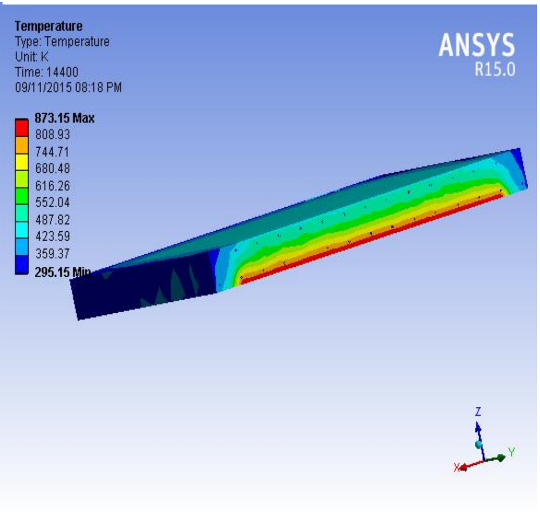


Figure (40:- Effect of Temperature on four fours slab 5 .

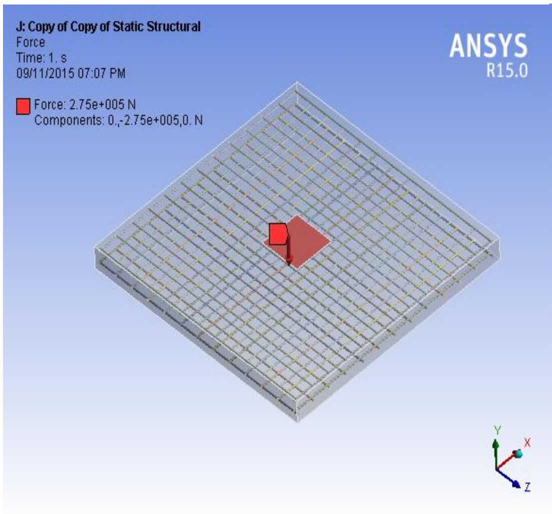


Figure (41:-Failure load for slab 6 S(4,30).

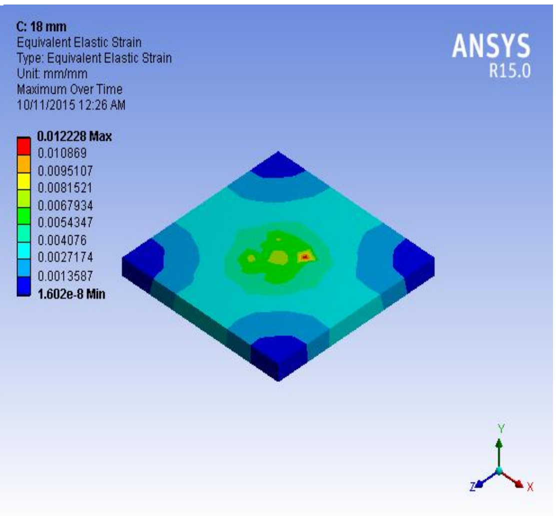


Figure (42:-Equivalent elastic strain in concrete for slab 6 S(4,30)

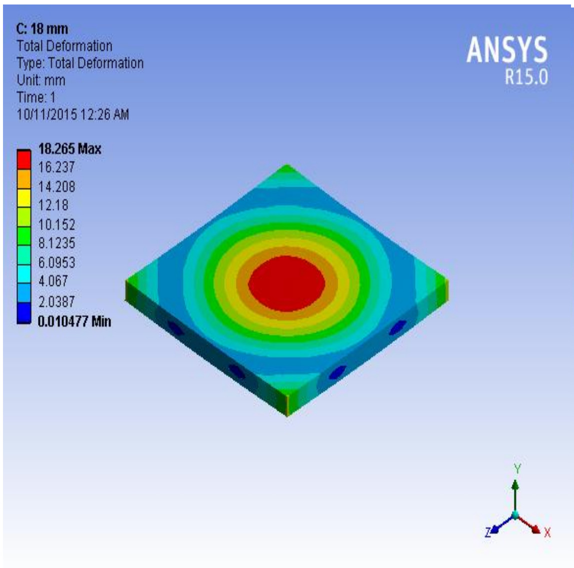


Figure (43:- Total deflection at failure load for slab 6 S(4,30).

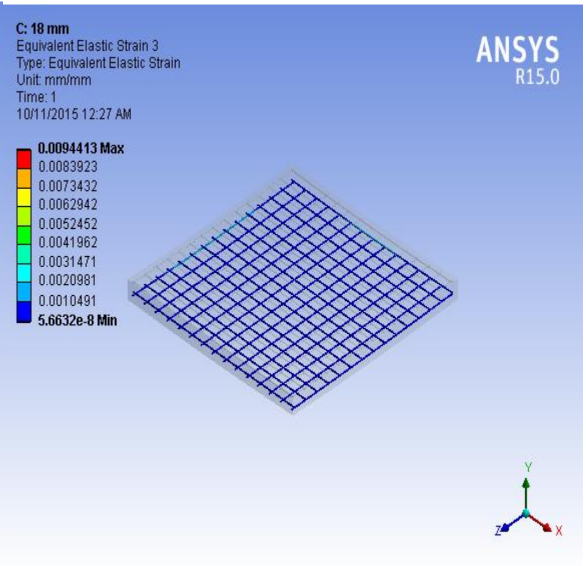


Figure (44:-Equivalent elastic strain in lower mesh layer steel for slab 6 S(4,30)

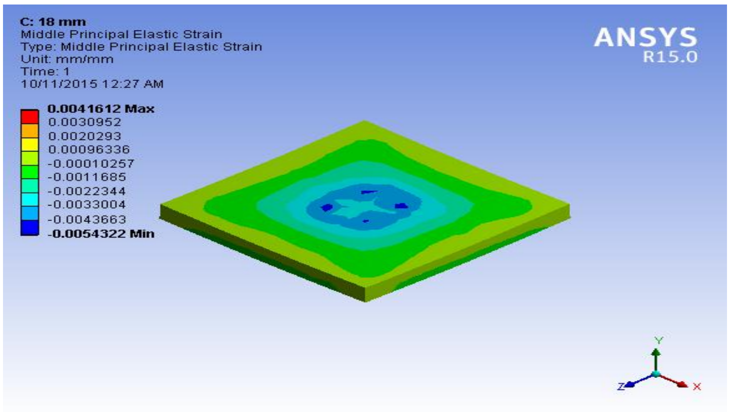
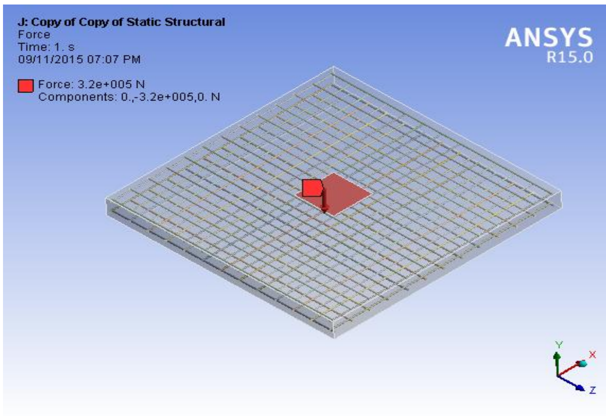


Figure (45:- Equivalent elastic strain in upper mesh layer steel for slab 6 S(4,30).



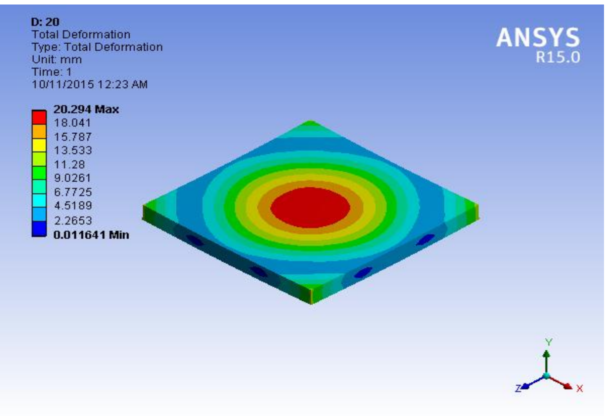
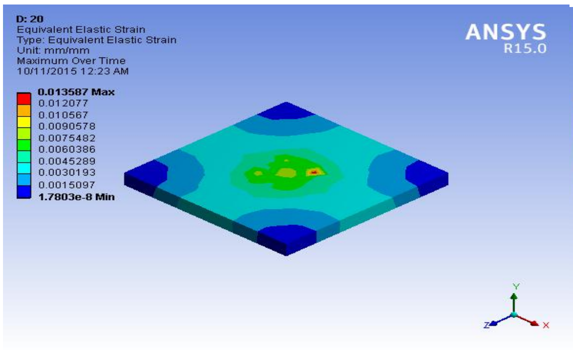


Figure (46:- Failure load for slab 7 S(4,35). **Figure (47:-** Total deflection at failure load for slab 7 S(4,35) .



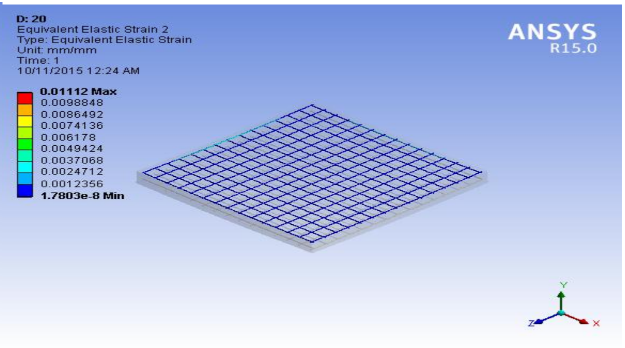


Figure (48:-Equivalent elastic strain in concrete for slab 7 S(4,35). **Figure (49-** Equivalent elastic strain in lower mesh layer steel for slab 7 S(4,35).

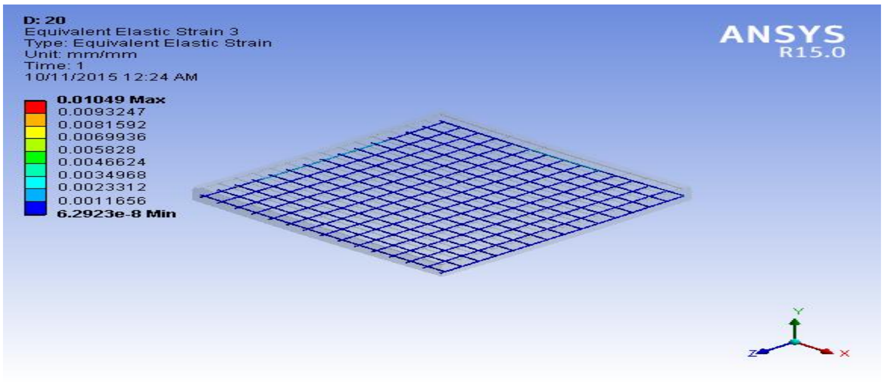
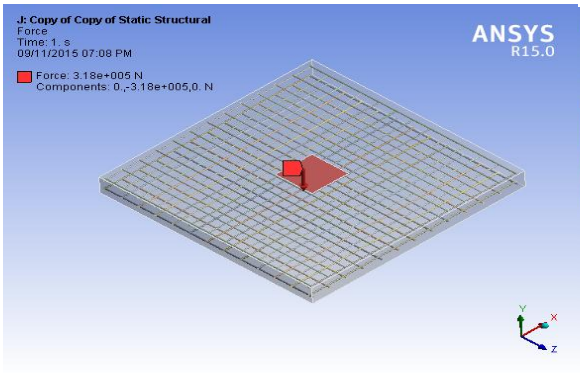


Figure (50:-Equivalent elastic strain in upper mesh layer steel for slab 7 S(4,35) .



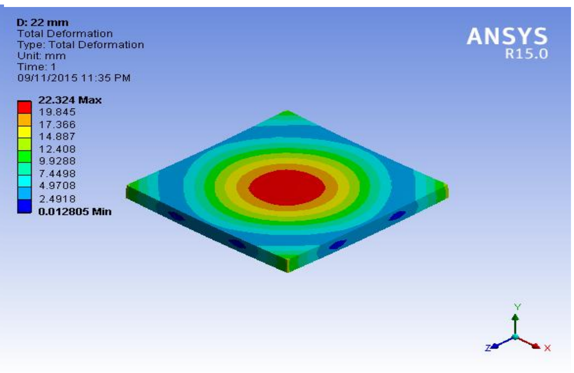
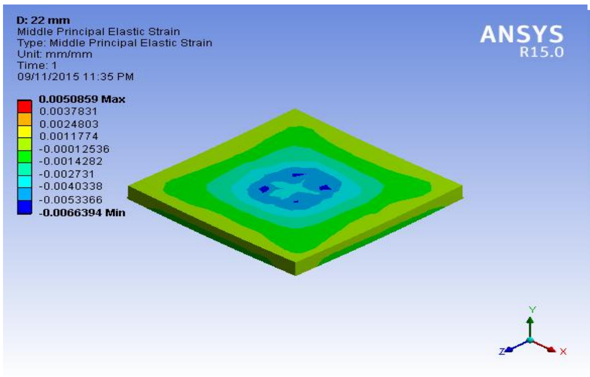


Figure (51:-Failure load for slab 8 S(4,40). **Figure (52:-** Total deflection at failure load for slab 8 S(4,40)



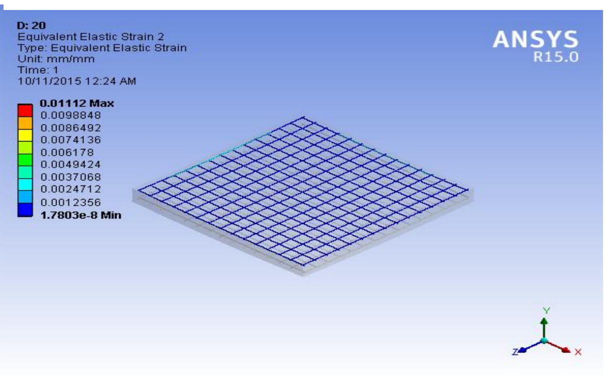


Figure (53:- Equivalent elastic strain in concrete for slab 8 S(4,40) . **Figure (54-**Equivalent elastic strain in lower mesh layer steel for slab 8 S(4,40).

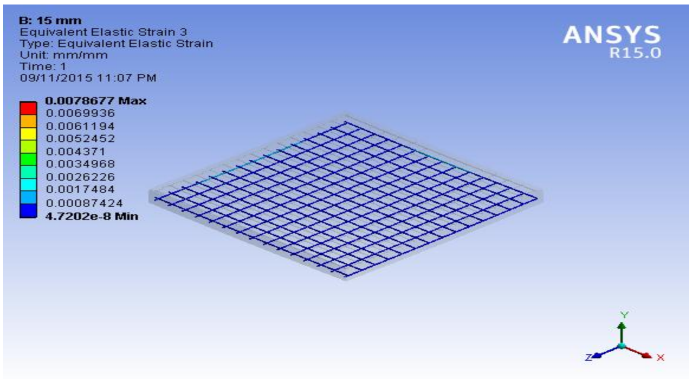


Figure (55:-Equivalent elastic strain in upper mesh layer steel for slab 8 S(4,40).

IV. Conclusions

Based on the results obtained from the tests considered in this study some general conclusions may be drawn as follows:

1. Exposure of flat slab specimen to fire of 600 °C for four hours cause deflection higher than that of other specimens at all times.
2. With increase fire duration under constant concrete cover thickness the capacity of slab decrease, failure load for slab (2)S(1,25) with one hour fire decrease with 15.31% compared to reference slab(1) S(0,25), failure load for slab (3) S(2,25) with two hours fire decrease with 19.02% compared to reference slab (1) S(0,25), failure load for slab (4) S(3,25) with three hours fire decrease with 31.07% compared to reference slab (1) S(0,25) and failure load for slab (5) S(4,25) with four hours fire decrease with 36.63% compared to reference slab(1) S(0,25).
3. With increase concrete cover thickness the capacity of the slab for ultimate failure load increased, failure load for slab (6) S(4,30) with concrete cover 30mm increase with 19.6% compared to slab (5) S(4,25) with concrete cover 25mm at constant fire duration for four hours fire,.

4. Comparison between Experimental and Numerical (ANSYS) deflection at failure ultimate load of slabs , for slab (1) S(0,25),(2) S(1,25),(3) S(2,25),(4) S(3,25), (5) S(4,25),(6) S(4,30),(7) S(4,35) and (8) S(4,40) the deflection of numerical modeling(ANSYS) increase for experimental results as :- 2.40%,3.18%,9.7%,6.94%,11.85%,10.21%,3.40 %and 10.18 %respectively.
5. BY analytical model method (ANSYS) numerical failure load increasing from 2.3% up to 6.3% compared to experimental failure load.

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