The Effect of Long-Term Performance on the Behavior of Strengthened Slabs

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Abstract—**Reinforced concrete structures often require strengthening or repair at some point during their life time. The effect of long-term performance on repaired sections is rarely taken in consideration. The repaired sections might be affected by long-term performance so they should be considered in design. Long-term effects in the form of shrinkage and creep stresses reduce the structural capacity of the repaired sections. The main goal of this research is to investigate the long-term performance of the strengthened reinforced concrete slabs [deflection, stress-strain, shrinkage strain and creep strain] by using finite element analysis. An in-house program was modified to perform finite element tie history analysis taking into consideration the special factors of strengthened reinforced concrete slabs. A parametric study was done on repaired reinforced concrete slabs using different types of repair at different time intervals to evaluate the efficiency of repaired slab sections for long-term performance, and find which method of repaired was better at different time. The parametric study contains four simply supported slabs by using different type of strengthening, were created four models, the first was a control slab the second is strengthened using new concrete layer without reinforced, the third was strengthened new concrete layer with reinforced and the fourth was strengthened by using carbon epoxy laminated layer attached to the tension side of slab. A comparison between the result was done using the different type of repaired at different time for different load capacity.**

Keywords—Types of repair; Long-term effects; shrinkage and creep stresses; finite elements analysis.

1. Introduction

The aim of this study is to study the effect of long term strains (creep and shrinkage) on strengthened slabs, under the effect of different strengthening materials, Deflection, stress, and strain will be considered through this analysis. A modified finite element program was verified with experimental works to be used in studding the effect of long term performance on strengthened reinforced concrete slabs [1,2]. The studied slabs were observed under different times, such that: At time (0) days for short term, (200), (600) and (1200) days. The four slabs were

Classified as control slab with no repair layer (Un-strengthened slab) and the otherthree slabs were strengthened by three types of repaired materials as strengthened slabs with new concrete layer without reinforcement, strengthened slabs with new concrete layer with reinforcement and strengthened slabs with carbon epoxy laminate.

2. Description of Studied Slabs

All slabs are simply supported with four beams with equal span (5*5) meter and (15) cm in thickness with mesh (6 Ø8/m) reinforcement as shown in Fig. 1. It is subjected to uniform distributed load (10ton/m^2) which is divided into 10 load step. The parametric study contains 4 types of slabs, table1 summarized the description studied slabs.

TABLE1. SUMMARIZED THE DESCRIPTION OF THE STUDIED SLABS

Specimen	***Slab Dimension (cm)***	***Thickness (cm)***	***Slab RFT***	***Type of repaired***
Control Slab (S1)	500x500	15	6 Ø8/m	Without repair
Concrete Strengthened(S2)	500x500	12+ repaired thickness	6 Ø8/m	3cm of a new concrete layer without reinforcement
Reinforced Strengthened(S3)	500x500	12+ repaired thickness	6 Ø8/m	3cm of a new concrete layer with(6 Ø12/m) additional reinforcement
CFRP Strengthened(S4)	500x500	15	6 Ø8/m	2 layers of carbon epoxy laminates (0.12 cm)

3. Description of Finite Element Model for Studied Slabs

A nonlinear finite element program based on updated lagrangian formulation has been prepared [3,4,5] and employed in the present study. The program was utilized by consider the effect of creep and shrinkage strains by using ACI formula [6]. Concrete behavior under the biaxial state of stress is represented by a nonlinear constitutive relationship which incorporates tensile cracking at a limiting stress, tensile stiffening between cracks and the strain-softening phenomenon beyond the maximum compressive strength. The steel reinforcement is represented by a bilinear, strain hardening model where Bauschinger effects are considered.

The program employs a layered approach where perfect bond is assumed to exist between the various successive layers. The constitutive relationship for concrete is a nonlinear elastic model based on isotropic formulation (hypo-elastic formulation). The incremental stress-strain relationship takes the form:

$$\begin{bmatrix} d\sigma_1 \\ d\sigma_2 \\ d\tau_{12} \end{bmatrix} = \frac{1}{(1-\nu^2)} \begin{bmatrix} E_1 & \nu\sqrt{E_1 E_2} & 0 \\ \nu\sqrt{E_1 E_2} & E_2 & 0 \\ 0 & 0 & (1-\nu^2)G' \end{bmatrix} \begin{bmatrix} d\varepsilon_1 \\ d\varepsilon_2 \\ d\gamma_{12} \end{bmatrix} \quad (1)$$

Where,

Indices 1,2 refer to the principal stress directions.

σ and τ are the normal and shear stresses.

G' is the shear modulus.

ε and γ are the normal and shear strains.

ν is the Poisson's ratio.

E1 and E2 are the modulus of elasticity in direction 1 and 2 respectively.

$$G' = \frac{1}{4(1-\nu^2)}\left[E_1 + E_2 - 2\nu\sqrt{E_1 E_2}\right] \quad (2)$$

In order to account for the effect of confinement of micro cracking for the case of biaxial compression, use is made of the equivalent uniaxial stress strain curve where Poisson's effect is totally eliminated. The following relationship then holds,

$$\sigma_i = \frac{E_O \varepsilon_{iu}}{1 + \left[\frac{E_O}{E_S} - 2\right]\left[\frac{\varepsilon_{iu}}{\varepsilon_{ic}}\right]^2} \quad (3)$$

Where Eo, Es are initial and secant modulus of elasticity respectively.

For the purpose of the parametric study, a simply supported two way slab with equal span (5.0*5.0) meter and with thickness equal (15) cm. The slab divided into 81 nodes and 128 triangle elements which the area of each element is 1953.125cm2as shown in Fig. 2. It was subjected to uniform distributed load normal to surface per unit area. The slab section for controlled slab (S1) divided into 10 layers of concrete with (1.5) cm for each layer. It has (6 Ø8/m) reinforcement which is convert to layer with smart thickness as shown in Fig. 2.

However, The slab section for repaired three slabs divided into 10 layers which have 8 layers of concrete with 1.5cm for each layer but layer 9 is resins material (epoxy) with (0.04) cm. The last layer is a repaired material which is deferent for three repaired slabs. Last layer in concrete strengthened slab (S2) is (3) cm of high strength concrete, reinforcement strengthened slab (S3); (3) cm of high strength concrete with (6 Ø12/m) reinforcement. While CFRP strengthened slab (S4) have 8 layers of concrete with 1.875cm for each layer but layer 9 is resins material (epoxy) with (0.04) cm and the last layer is 2 layers of Carbon epoxy laminates with (0.12)cm . For reinforcement strengthened slab (S3) the reinforced steel is converting to layer with smart thickness as shown in Fig. 2.Table2 shows all properties of the studied slabs.

TABLE (2) PROPERTIES OF THE USED MATERIAL FOR STUDIED SLABS

Property	Model 1
a- Concrete properties	
Concrete compressive strength (Fcu)	20 Mpa
Modulus of elasticity of concrete (Ec)	19799 Mpa
Allowable tension stress in concrete(Ft)	2 Mpa
Concrete Strain	0.003
B- new concrete layer properties	
Concrete compressive strength (Fcu)	30 Mpa
Modulus of elasticity of concrete (Ec)	24248.7 Mpa
Allowable tension stress in concrete(Ft)	3 Mpa
Concrete Strain	.003
Thickness of 2 layers	2x.023 inches
C-Epoxy Resins Properties	
Compressive strength	80 Mpa
Modulus of elasticity of concrete (E)	10.5 Mpa
D- Carbon Epoxy Laminated (CFRP) Properties	
Thickness of 2 layer	2*0.06 cm
Allowable tension stress in CFRP (Ft)	14 MPa
Modulus of elasticity of CFRP (E)	10 Mpa
E- Steel properties	
Allowable steel stresses	360 Mpa
Modulus of elasticity of concrete	201 Mpa
Maximum Strain	0.13

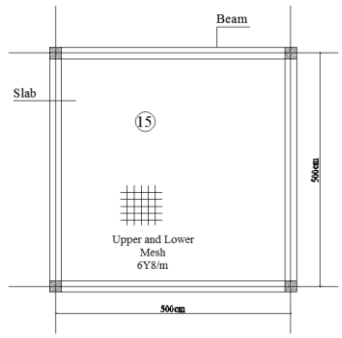

Fig. 1. Plan of Studied Slab Before Repaired

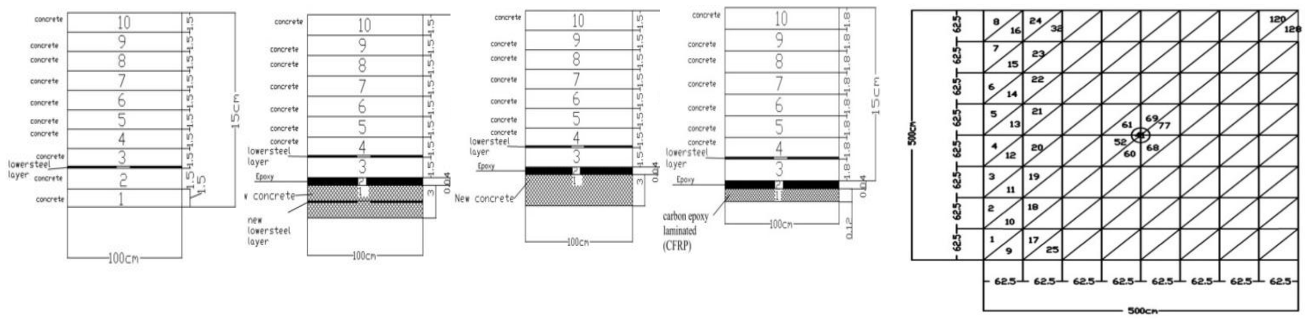

Fig. 2. Fnite element mesh and cross sections for studied slabs

4. RESULTS AND DISCUSSION

Considering the studied parameters of the present study, the following notes were observed:

4.1 Effect of Time Dependent Analysis on Deflection for Different Type of Slabs

It is clearly seen from Fig. 3, at time (0) the controlled slab gives the highest deflection range between (2.4 – 4.5) mm while the repaired slabs using carbon epoxy laminate gives lower deflection range between (0.56 – 1.7) mm. Otherwise using new concrete layer without reinforcement and new concrete layer with reinforcement gives deflection range between (1.7 -4.2) mm and (1.46 -3.9) mm respectively. Also, we can observe from Figs. 4 to 6, that as time increase the deflection of controlled slab and all repaired slabs are increased. By comparing the repaired slab using carbon epoxy laminate at time (200), (600) and (1200) we get the smallest deflection than the others, while the controlled slab gives the largest deflection in all figures. With increasing time and load the repaired slab using new concrete layer with reinforcement reflects lower deflection than repaired slab using new concrete layer without reinforcement.

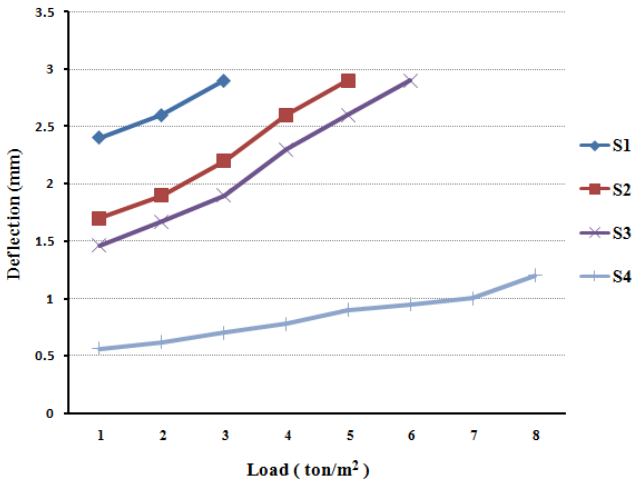

Fig. 3. Load -Deflection Curve for Different Slabs Type at Time (0) Days

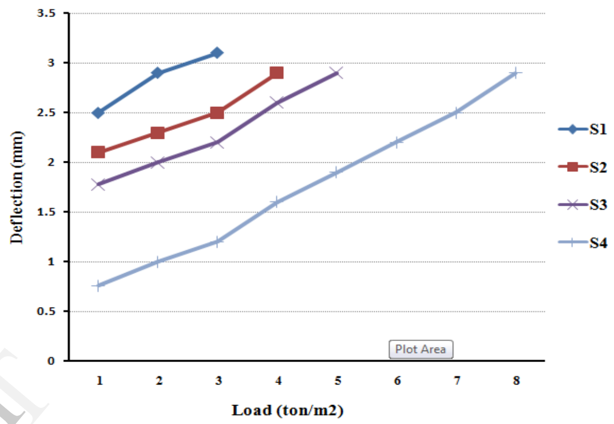

Fig. 4. Load -Deflection Curve for Different Slabs Type at Time (200) Days

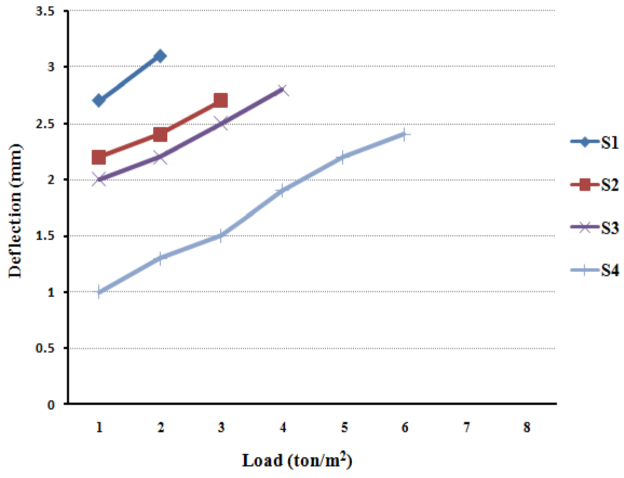

Fig. 5. Load -Deflection Curve for Different Slabs Type at Time (600) Days

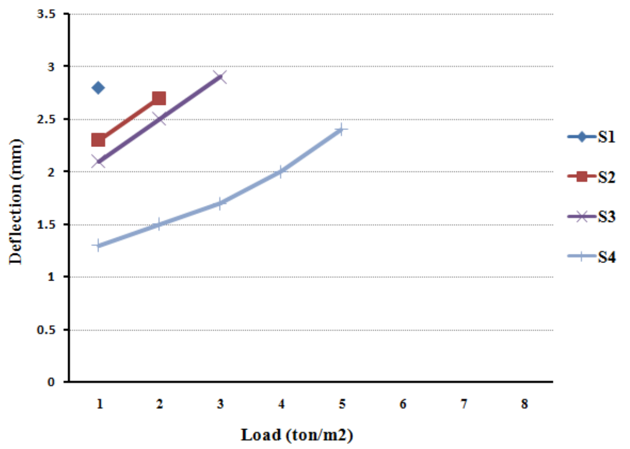

Fig . 6. Load -Deflection Curve for Different Slabs Type at Time (1200) Days

4.2 Effect of Time Dependent Analysis on Stress and Strain for Different Type of Slabs

It is clearly seen from Figs. 7 to 10, by increasing strain the stress increases till it reaches the maximum stress then the stresses decreases gradually ,so the ultimate strain obtained at the maximum stress. Controlled slab(S1) reflect always the lowest stress-strain curve for different time but, stress-strain curve was increased when used new concrete layer without reinforcement(S2) and used new concrete layer with reinforcement for repaired(S3). When using carbon epoxy laminated for repaired (S4) gives the highest stress-strain curve.

At time (0): The maximum stress is (32Mpa) at ultimate strain (0.0031) for S1, while the stress of repaired slabs S2 is (35Mpa) at ultimate strain (0.0032) and S3is (37Mpa) at ultimate strain (0.0032). But, for S4, it gives (50Mpa) at ultimate strain (0.0032). At time (200): The maximum stress is (33Mpa) at ultimate strain (0.0033) for S1, while the stress of repaired slabs S2 is (34Mpa) at ultimate strain (0.0032) and S3is (36Mpa) at ultimate strain (0.0032). But, for S4, it gives (49Mpa) at ultimate strain (0.0033).At time (600): The maximum stress is (34Mpa) at ultimate strain (0.0031) for S1, while the stress of repaired slabs S2 is (36Mpa) at ultimate strain (0.0032) and S3is (37Mpa) at ultimate strain (0.0032). But, for S4, it gives (47Mpa) at ultimate strain (0.0033).At time (1200): The maximum stress is (37Mpa) at ultimate strain (0.0031) for S1, while the stress of repaired slabs S2 is (39Mpa) at ultimate strain (0.0032) and S3is (40Mpa) at ultimate strain (0.0032). But, for S4, it gives (46Mpa) at ultimate strain (0.0032).

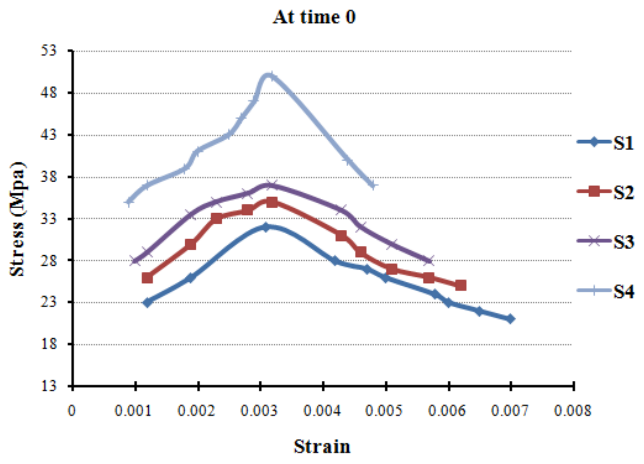

Fig. 7. Stress -Strain Curve for Different Slabs Type at Time (0) Days

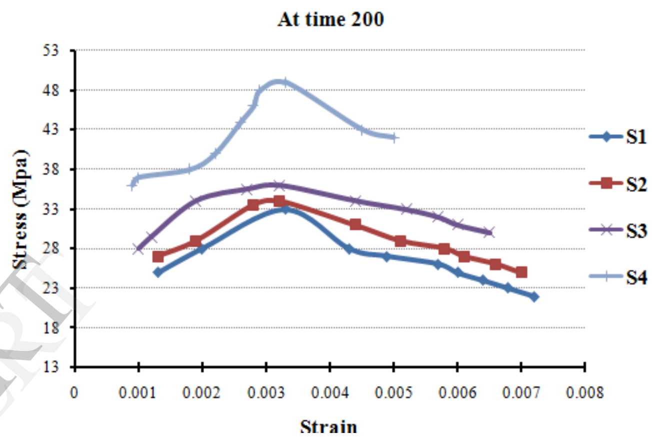

Fig . 8. Stress -Strain Curve for Different Slabs Type at Time (200) Days

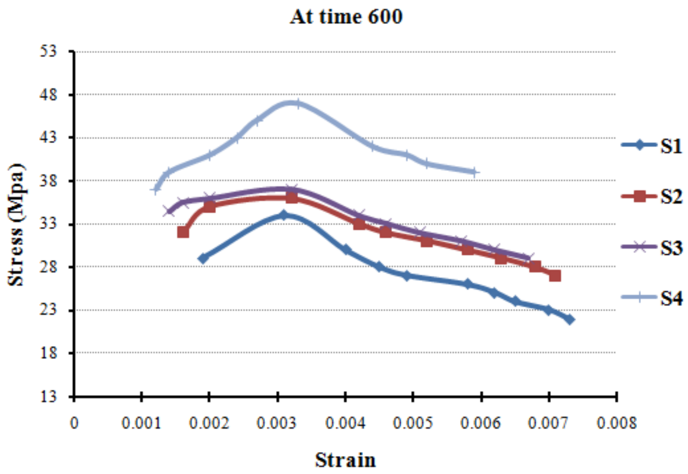

Fig . 9. Stress -Strain Curve for Different Slabs Type at Time (600) Days

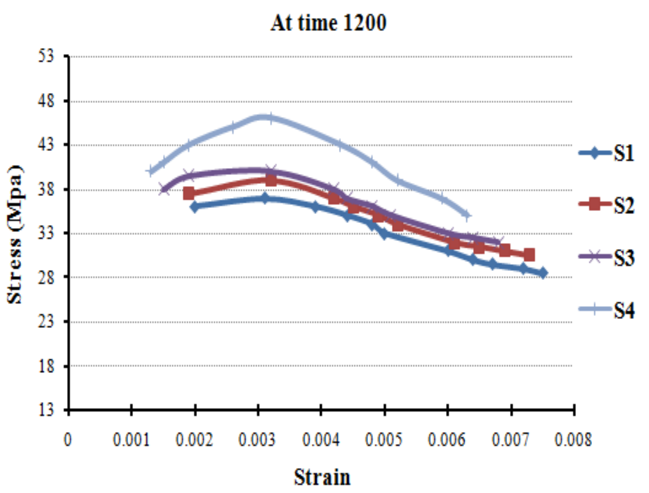

Fig . 10. Stress -Strain Curve for Different Slabs Type at Time (1200) Days

4.3 The Effect of Increasing Load on Shrinkage-Strain for Different Type of Repaired Slab at Different Time

As can be observed from Figs. 11 to 13, the effect of increasing load on shrinkage-strain for different type of repaired slab at different time. As time increase the shrinkage-strain of controlled slab and all repaired slabs are increased. The controlled slab gives the largest shrinkage-strain in all figures. With increasing time and load the repaired slab using new concrete layer with reinforcement reflects higher shrinkage-strain than repaired slab using new concrete layer without reinforcement. At time (0) No shrinkage-strain. At time (200) the controlled slab gives the largest shrinkage-strain while the repaired slabs with new concrete layer with reinforcement gives lower shrinkage-strain than using new concrete layer without reinforcement. The increasing in load in case of controlled slab which varies through (1 to 10) ton/m2 reflects the increasing in shrinkage-strain which was varies between (-0.0016 – -0.0074) while the shrinkage-strain in repaired slabs using new concrete layer without reinforcement varies between (-0.00125 – -0.007) and new concrete layer with reinforcement varies between (-0.001 – -0.0066) for the same load range. At time (600) the controlled slab gives the largest shrinkage-strain while the repaired slabs using new concrete layer with reinforcement gives lower shrinkage-strain than using new concrete layer without reinforcement. The increasing in load in case of controlled slab which varies through (1 to 10) ton/m2 reflects the increasing in shrinkage-strain. Which was varies between (-0.0026 – -0.008) while the shrinkage-strain in repaired slabs using new concrete layer without reinforcement varies between (-0.0014 – -0.0073) and new concrete layer with reinforcement varies between (-0.0012 – -0.0069) for the same load range.

At time (1200) the controlled slab gives the largest shrinkage-strain while the repaired slabs using new concrete layer with reinforcement gives lower shrinkage-strain than using new concrete layer without reinforcement. The increasing in load in case of controlled slab which varies through (1 to 10) ton/m2 reflects the increasing in shrinkage-strain. Which was varies between (-0.0034 – -0.0082) while the shrinkage-strain in repaired slabs using new concrete layer without reinforcement varies between (-0.0025 – -0.0074) and new concrete layer with reinforcement varies between (-0.0023 – -0.007) for the same load range.

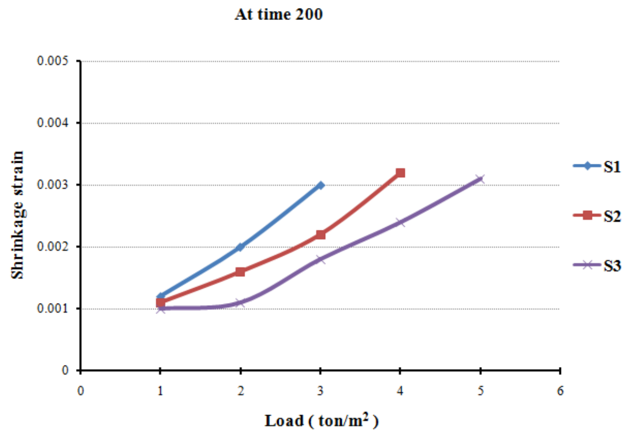

Fig. 11. Load –shrinkage-strain curve for different slabs type at time (200) Days

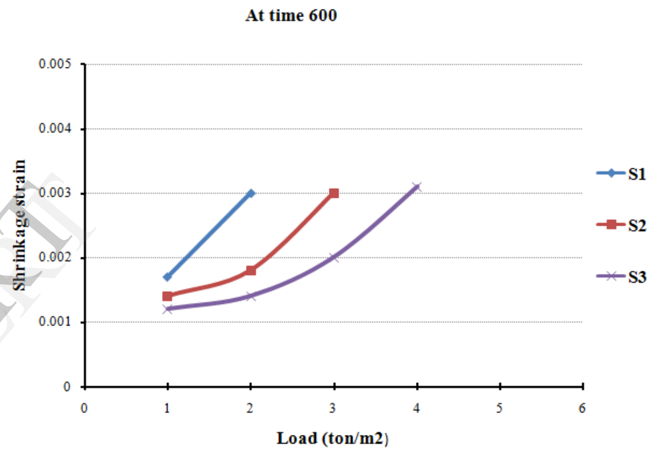

Fig. 12. Load –shrinkage-strain curve for different slabs type at time (600) Days

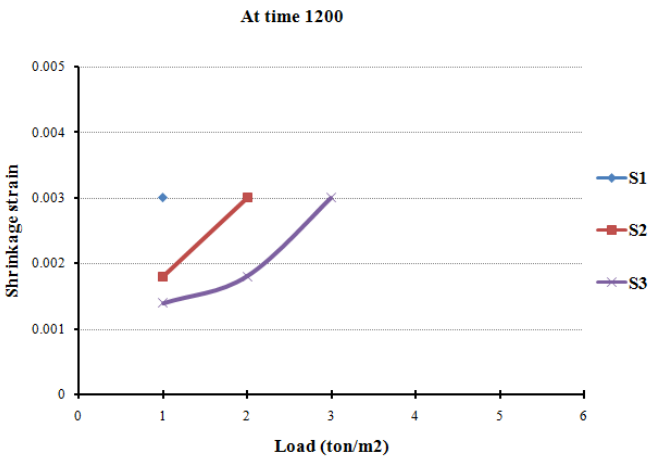

Fig. 13. Load –shrinkage-strain curve for different slabs type at time (1200) Days

4.4 The Effect of Increasing Load on Creep-Strain for Different Type of Repaired Slab at Different Time

We can observe from Figs. 14 to 16, the effect of increasing load on creep-strain for different type of repaired slab at different time. At time (0) No creep-strain. At time (200): the controlled slab gives the largest creep -strain while the repaired slabs using new concrete layer with reinforcement gives lower creep -strain than using new concrete layer without reinforcement . The increasing in load in case of controlled slab which varies from (1 to 10) ton/m2 reflects the increasing in creep-strain which was varies between (0.0019–0.0082) while the creep -strain in repaired slabs using new concrete layer without reinforcement varies between (0.0017–0.0075) and new concrete layer with reinforcement varies between (0.0014– 0.0069) for the same load range. At time (600) the controlled slab gives the largest creep-strain while the repaired slabs using new concrete layer with reinforcement gives lower creep-strain than using new concrete layer without reinforcement. The increasing in load in case of controlled slab which varies through (1 to 10) ton/m2 reflects the increasing in creep-strain which was varies between (0.0026–0.0079) while the shrinkage-strain in repaired slabs using new concrete layer without reinforcement varies between (0.0018–0.0073) and new concrete layer with reinforcement varies between (0.0017– 0.0069) for the same load range. At time (1200) the controlled slab gives the largest creep -strain while the repaired slabs using new concrete layer with reinforcement gives lower creep-strain than using new concrete layer without reinforcement. The increasing in load in case of controlled slab which varies through (1 to 10) ton/m2 reflects the increasing in creep-strain which was varies between (0.0035–0.0082) while the shrinkage-strain in repaired slabs using new concrete layer without reinforcement varies between (0.0022–0.0076) and new concrete layer with reinforcement varies between (0.002– 0.0072) for the same load range.

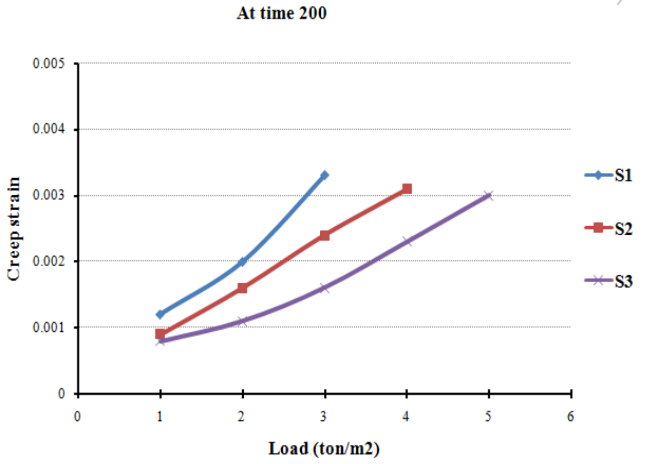

Fig. 14. Load –Creep-Strain Curve for Different Slabs Type at Time (200)

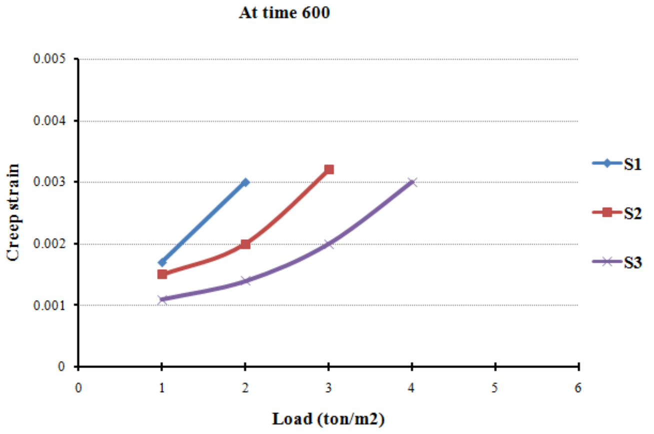

Fig. 15. Load –Creep-Strain Curve for Different Slabs Type at Time (600)

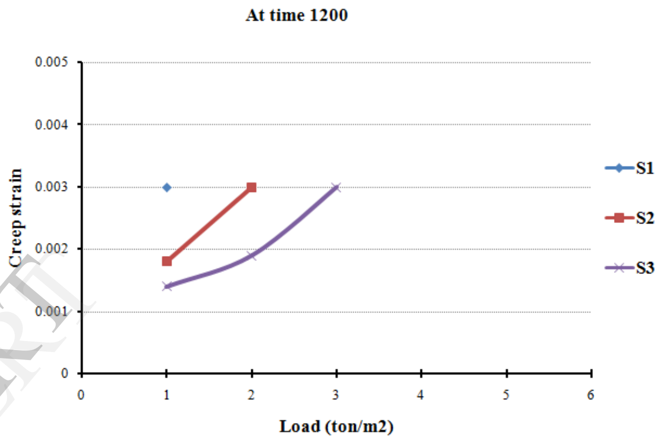

Fig. 16. Load –Creep-Strain Curve for Different Slabs Type at Time (1200) Days

5. CONCLUSIONS

- When CFRP laminates were used for repairing, the deflection was decreased in rang (62-79%) at time (0) While at time (200) days it was decreased in range (32-69%). However, at time (600) it was decreased in range (40-62%). Also it was decreased in range (45-63.5%) at time (1200) compared to control slab.
- When CFRP laminates were used for repairing, the ultimate load was increased by (166%) at time (0) and time (200), while at time (600) it increased by(200%).However, at time (1200) it increased by(400%) compared to control slab.
- When CFRP laminates were used for repairing, the maximum stress was increased by (56%) at time (0) While at time (200) it was increased by (48%). However, at time (600) it was increased by (38%). Also it was increased by (24%) at time (1200) compared to control slab.
- The strengthening of R.C slabs using externally bonded CFRP laminated gives lowest deflection, highest stress strain curve, lowest and highest ultimate load for long-term.
- Long-term had slight effect (lowest effect) on slab strengthened with CFRP laminates (less than 10% loss initial strength).

- The repaired slab using new layer of concrete without reinforcement gives the lowest shrinkage and creep strain.
- The ultimate load of repaired slab using new layer of concrete with reinforcement was higher than using new layer of concrete without reinforcement.
- The strengthening of R.C slab using new layer of concrete with reinforcement gives slight different behavior from using new layer of concrete without reinforcement in (deflection, stress strain, shrinkage and creep strain for long-term.
- The strengthening o f R.C slabs using externally bonded CFRP laminated is gives the best performance compared to the other strengthening technique for long-term.

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