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Time-dependent Analysis of FRP Reinforced Two–way Slabs subjected to high level stresses (Sustained Loads)

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ABSTRACT

In the present study, the effect of changes that developed in concrete structures with time is presented. A two-way slab investigated experimentally by (J. Radnić et al 2008) was analyzed using the finite element method by the ANSYS commercial program. Many parameters were studied, such as length to thickness ratio, reinforcement ratio, and ultimate load ratio. The slab has a dimension of 2360*2360*63 mm and is reinforced with different types of materials, such as steel bars, GFRP, and CFRP (fiber reinforced polymer) bars. The results show that the strain increases gradually with time after applying the load. It can be seen that the strain in the steel model increases with a ratio of 19.98% when the load increases from 75% to 90% and decreases with a ratio of 50% when the load decreases from 75% to 50%. That is, the change by increasing the strain is less and slower than the change by decreasing the strain, since the strain when dropping the load is less than the strain when lifting the load because the structure has not undergone any changes, its stiffness is still high, and it is trying to recover its original shape. It increases significantly at the beginning, and then the difference decreases or stabilizes approximately after 330 days.

1. Introduction

In structural design, strength and serviceability are the two main objectives that must be considered and detected. Strength and serviceability are the two primary goals. A concrete structure should be both safe and functional, with sufficiently low chances of failure during the design lifetime. A concrete structure must carry out its intended function for the duration of its working life in order to meet the requirements for serviceability. Excessive deflection shouldn't compromise the structure's functionality or be unattractive. Vibrations shouldn't upset the building's equilibrium or make its occupants feel uneasy (Gilbert, 2013). For this reason, and also to give up many problems such as the corrosion of steel bars in reinforced concrete structures, this research suggests the use of FRP (fiber reinforced polymer) as an alternative material. Glass fiber reinforced polymer (FRP) is a composite material made up of two materials: fiber and matrix. FRPs are categorized based on the composites used in the matrix, such as glass, carbon, aramid, and other materials. Glass fiber-reinforced polymer is GFRP, carbon fiber-reinforced polymer is CFRP, and aramid fiber-reinforced polymer is AFRP. FRPs are still new

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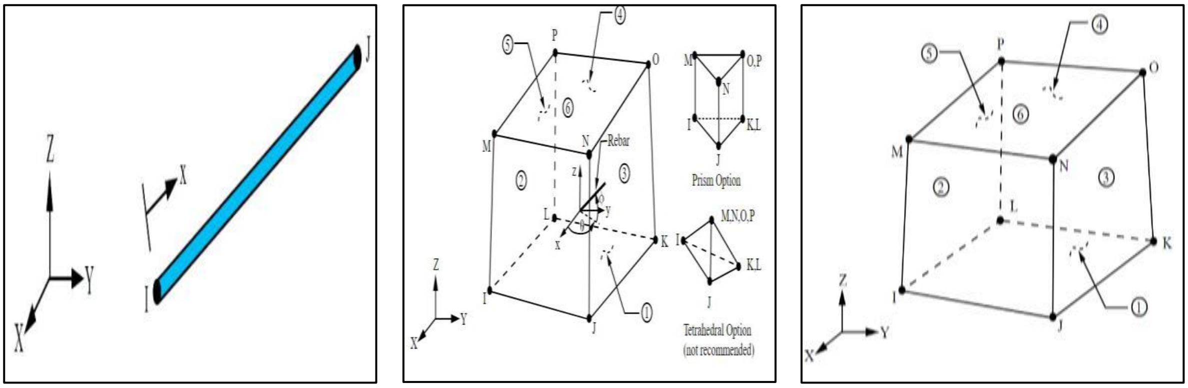
reinforcement materials; however, they have multiple applications, such as the retrofitting of RC slabs. The slab column connection is the most typical point of failure (ACI, 2006). There is a lack of previous studies to use FRP as reinforcing bars and discover how it behaves in the short term, and the deficiency is greater in the long term, and this is what the research intends to present. There are some studies that dealt with the subject of studying concrete structures analytically using finite elements, specifically the ANSYS program, and got good results from them. Al-Khatib (2014) studied the behavior of the finite element method with the ANSYS package for strengthening reinforced concrete columns. The study produced good agreement between numerical and available experimental results using eight specimens, of which three were studied for short periods of time and the remaining five were subjected to long-term loading. The five parameters investigated in this study are the magnitude of the sustained load (7% Pu, 28% Pu, and 72% Pu) kN, the e/h ratio (0.26-0.46), the length-to-diameter ratio (8-15-30), the compressive strength (30-40-50) MPa, and the type of FRP (glass or carbon). When the compressive strength was increased from 30 to 40 and 40 to 50 MPa, respectively, creep strain decreased by about 13.2% and 10.4%. However, creep strain increased by about 300% and 150% when the magnitude of the sustained load was increased from 7% Pu to 28% Pu and from 28% Pu to 72% Pu, respectively. The effect of eccentricity magnitude and length-to-diameter ratio on the creep strain was minimal (Al-Khatib, 2014). Radi (2022) conducted research on nonlinear time-dependent finite element modeling of two-way reinforced concrete slabs reinforced by fiber-reinforced polymer configurations. The parameters in the long-term analysis include length-thickness ratio, sustained load magnitude, compressive strength, and type of FRP over the strength of the slabs. The result of these simulations proves that the ANSYS models' capabilities are a good match with the results of the related experimental investigations. According to the parametric studies, increasing the length to thickness ratio (L/h) by 150% leads to an increase in mid-slab deflection of about 5.615 times (Radi & Mahmoud, 2023). Radnić and Matešan (2008) presented the results of experimental testing of a reinforced concrete rectangular slab under long-term load and unload. The slab was subjected to a high long-term load for a year, and the results showed a significant increase in the time deflections of the slab after applying the full load P. This was probably influenced by high stress levels in the slab, i.e., the effect of non-linear creeping and further spreading of cracks in the concrete tensile zone (Xiao, et al 2014). In analytical analysis branch Bakleh, et al 2023, predicted the time dependednt anlysis of reinfprced concrete cracked section analyticall. Good agrrements were issued from the predicted model. Time-dependent behavior of reinforced concrete beams under high sustained loads was ecvaluted by Shubaili, et al (2022). Finite lement method is a powerfull to evalutefd the concrte and composecte secy=tion in nomal and high strength convret (Armoosh et al 2015, Muhammed & Sakin 2018).

2. Significance of the research

Because of advances in computer technology and software, finite element analysis has become more widely used in recent years. It is currently the method of choice for examining concrete structural elements. These elements can be modeled much more quickly and affordably using computer software (Wolanski, 2004). A time-dependent strain reduces the useful life of concrete structures and may lead to failure as the concrete ages (Hadano et al., 1995). So, it will be studied numerically in this research. The numerical models adopted in the present study were developed 3D finite element model- by ANSYS 16.2 software, a commercial program. The behavior of RC two-way slabs reinforced by steel bars, glass fiber-reinforced polymer (GFRP) bars, and carbon fiber-reinforced polymer (CFRP) bars. From the results, we got the strain-time response by taking many parameters, such as three different length-to-thickness ratios, three reinforcement ratios, and three ratios of ultimate load, which are all included in these models.

3. Structural modeling and simulation models

Concrete was modeled using eight node solid elements (SOLID 65). Modeling steel and FRP bars was done using 3D spar components (LINK 180), while the Solid185 element was adopted to model the loading and support of the steel plate, as shown in Figure 1 (ANSYS, 2016). Appropriate boundary conditions were modeled, the symmetrical were restrained in their perpendicular directions, and the bottom portion was restrained in the vertical direction by using constraints in the FEM analysis. This was done by taking into account the symmetry of a quarter-slab of steel and CFRP and GFRP slabs. For concrete modeling, it is anticipated to be homogeneous and isotropic while taking into account time-dependent behavior descriptions such as interviscoelastic, Prony Curve Fitting, Maxwell number, bulk modulus, and shear modulus.



(a) LINK180 Geometry **(b) SOLID65 Geometry** **(c) SOLID185Geometry**

Fig.1 Elements used in the current model

4. Finite element verification

First, the non-linear FE software (ANSYS 16.2) was used to evaluate the three slab specimens listed in "Table 1," the original slab studied by Radnić et al. (2008). The thickness of the slab is 63 mm, its length is 2360 and its width is 2360 in total, and its span is 1960 x 1960 mm. The force put on the center of the slab was simply support along the four sides. The slab in origin was reinforced with steel bars and denoted by SM (Steel Model), then steel bars were replaced with GFRP bars and denoted by GM. When the slab is reinforced with carbon fiber-reinforced polymer CFRP bars, it is denoted by CM. All slabs were supported at edges as appear in origin slab "Fig. 2". The details of all specimens are displayed in Table 1, Table 2, and Table 3. Three slab specimens were examined in order to obtain the best simulation of laboratory models. (The steel elasticity modulus for specimen number one that was reinforced with steel is 200 GPa, and the concrete and steel Poisson's ratios were adjusted to 0.2 and 0.3, respectively.) FRP had a Poisson's ratio of 0.25. "Fig.4" depicts the samples' typical FE meshing.

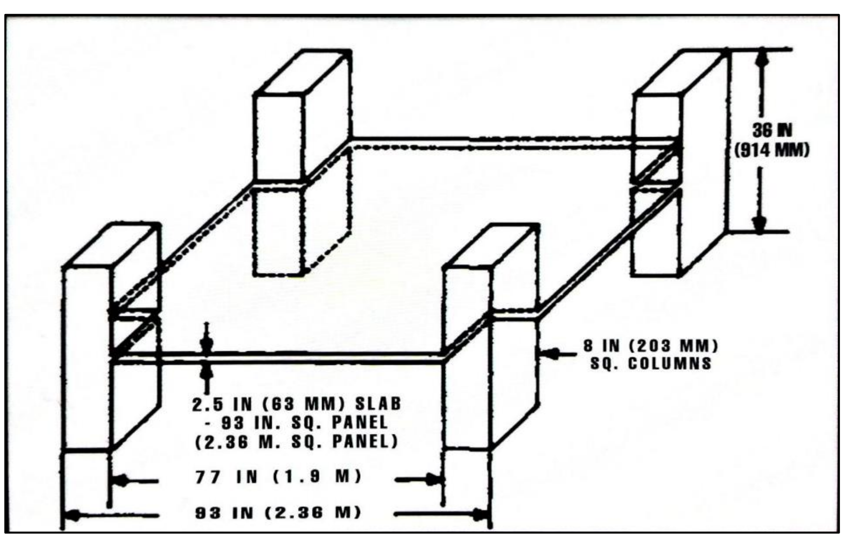


Fig. 2 Details of origin slab

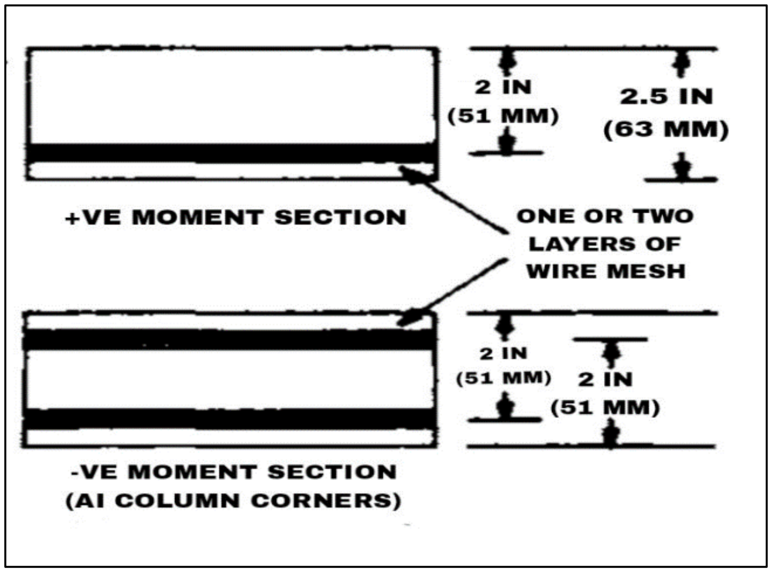


Fig. 3 Details of steel reinforcement

Table 1 – Slabs description.

Symbol of the Slab	Slabs Details
Steel bar reinforcement model SM	Control Slab (2360X2360X63mm)
CFRP bar reinforcement model CM	(2360X2360X63mm)
GFRP bar reinforcement model GM	(2360X2360X63mm)

Table 2 – Reinforcement details of the slabs.

SM SLAB	CM SLAB	GM SLAB
Ø5@150 in x and y direction (tension layer only)	Ø5@150 in x and y direction (tension layer only)	Ø5@150 in x and y direction (tension layer only)

Table 3 – Specimens and material properties.

Properties Set	SM	CM	GM
$\beta_\circ$	0.5*	0.5*	0.5*
β_c	0.5*	0.5*	0.5*
$f'c$ (Mpa)	45.5**	45.5**	45.5**
ft (Mpa)	4.177**	4.177**	4.177**
Ec (Gpa)	32.205**	32.205**	32.205**
Steel reinforcement			
Fy (MPa)	417**	Es (MPa)	200000**
CFRP reinforcement			
Fy (Mpa)	None	Ex (Mpa)	45000*
GFRP reinforcement			
Fy (Mpa)	None	Ex (Mpa)	12000*

***Assumed by researchers**

**** Calculated using ACI (2006) equation.**

Table 4 – Material characteristics vary over time.

Time (days)	Creep coefficient	Elasticity modulus Ec (Mpa)	Shear modulus G (Mpa)	Bulk modulus K (Mpa)
0	0	31668	13195.15	17593.54
28	0.9981	15849	6603.154	8805.134
60	1.2653	14052	5855.154	7806.872
90	1.405	13167	5486.55	7315.4
120	1.501	12662	5275.95	7034.6
150	1.572	12313	5130.3	6840.411
180	1.628	12050	5020.987	6694.649
210	1.673	11848	4936.458	6581.944
240	1.711	11681	4867.26	6489.683
270	1.743	11545	4810.479	6413.972
300	1.771	11428	4761.87	6349.161
330	1.796	11326	4719.29	6292.394
360	1.818	11238	4682.45	6243.267
400	1.843	11139	4641.275	6188.367
450	1.871	11030	4596.012	6128.017
500	1.894	10943	4559.48	6079.311
550	1.9154	10862	4526.016	6034.689
600	1.933	10797	4498.85	5998.478
650	1.949	10739	4474.45	5965.933
700	1.964	10684	4451.8	5935.739
750	1.977	10638	4432.36	5909.817
800	1.989	10595	4414.57	5886.094
900	2.01	10521	4383.77	5845.028
1000	2.028	10459	4357.71	5810.283
1100	2.044	10403	4334.8	5779.739

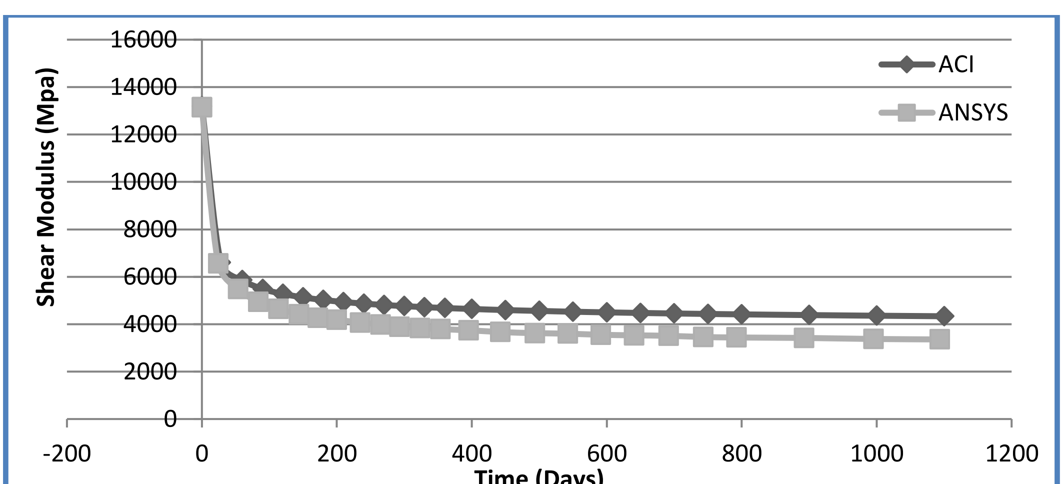


Fig. 4 ACI and ANSYS results of curve for the shear modulus vs time

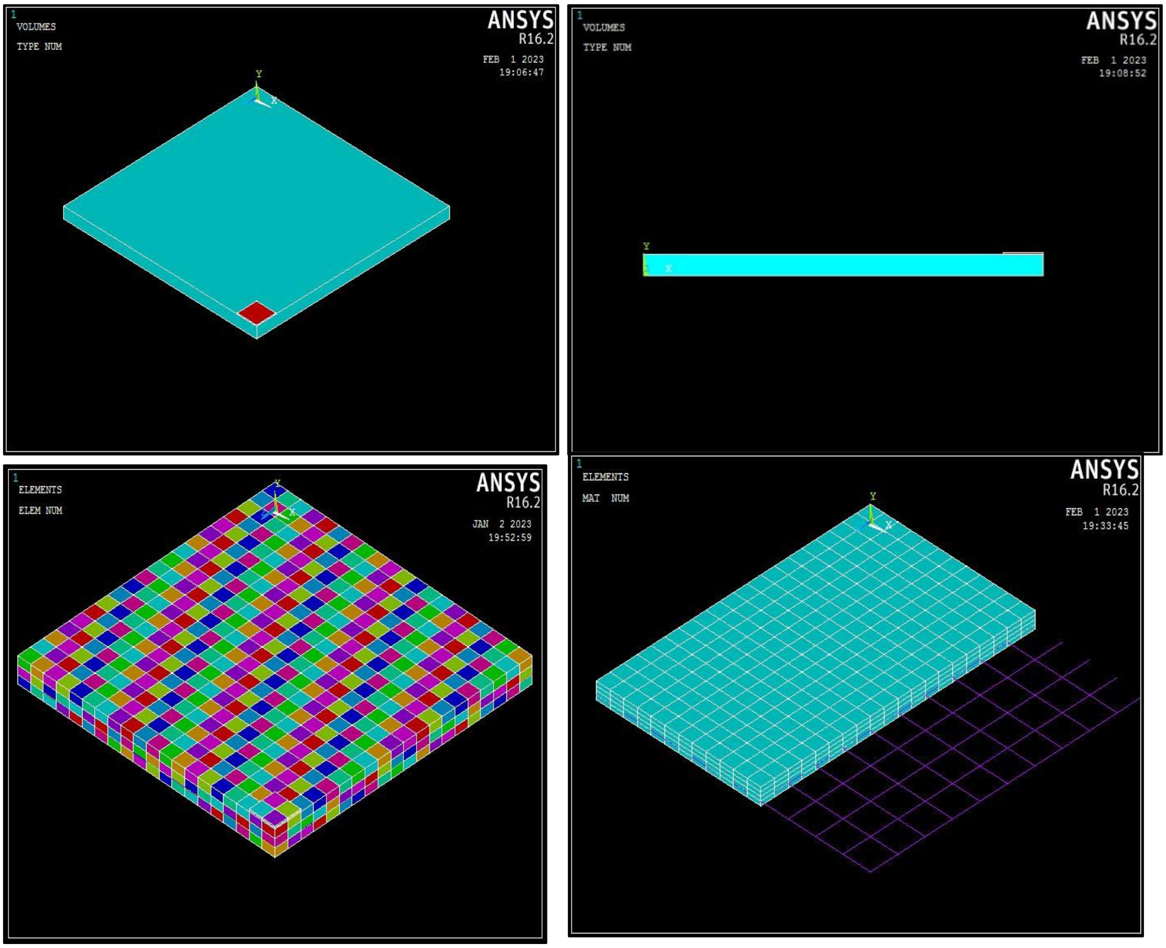


Fig. 5 Adopted the quarter slab's finite element mesh

5. Finite Element Modeling Results

Response to strain and time. In "figure.6", experimental and numerical results are compared with phrase of relationship between strain and time, that consider crucial to show the accuracy of the models in predicting the general behavior and stiffness properties of the slabs under analysis. "Fig.7" displays the slabs' deformation contours.

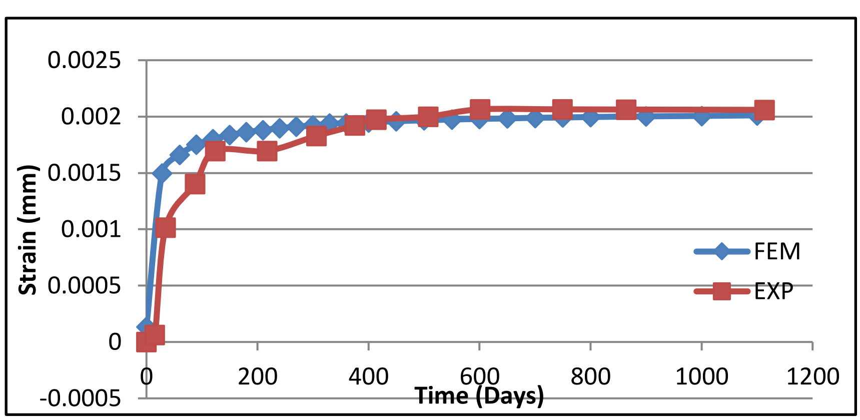


Fig. 6 Experimental and numerical results of curve for the time and Strain relationship

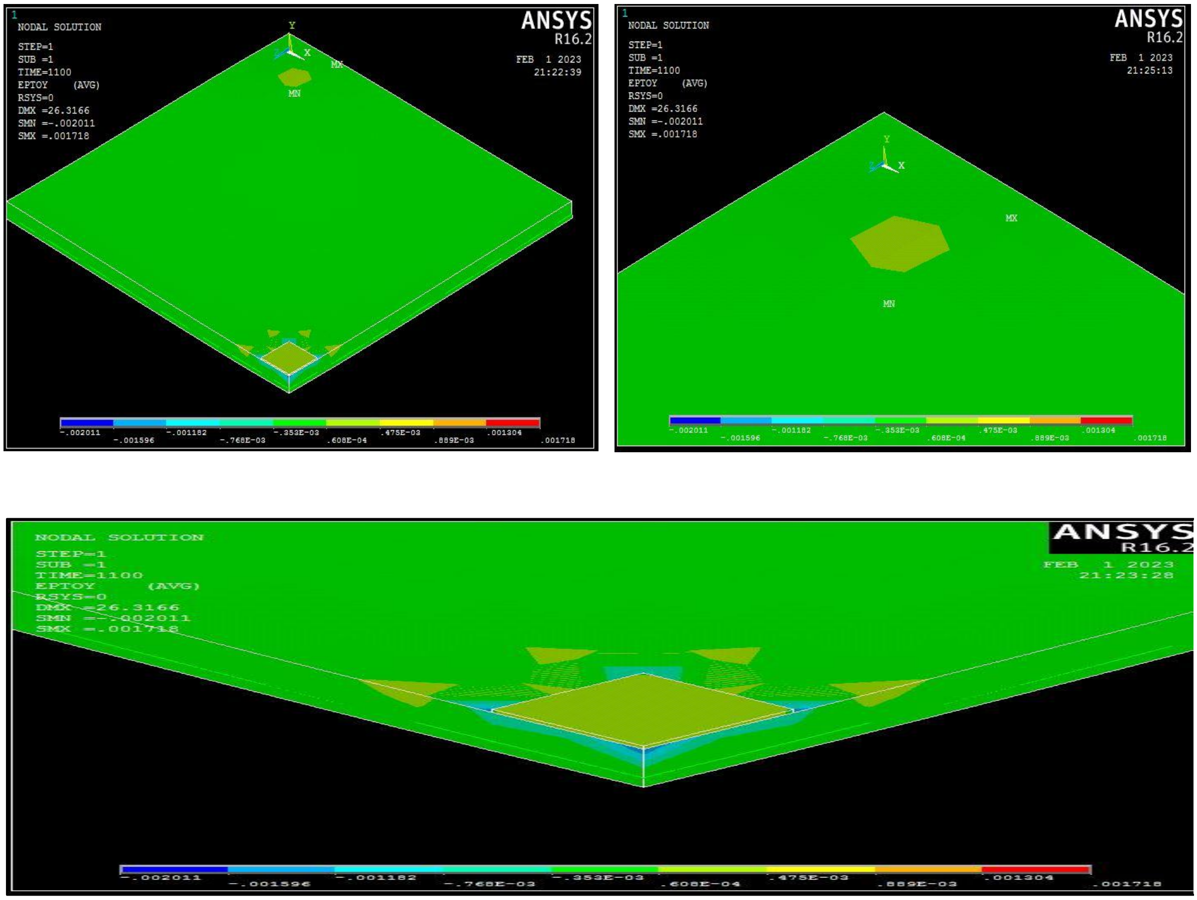


Fig. 7 Slabs' deformation (strain) contours under the ultimate load

6. Discussions and Analysis of Parameters

Three important factors are taken into account by the parametrical analysis:(length to thickness ratio, reinforcement ratio and sustained load magnitude)

In this research, there are 81 models, set in three groups: the first one contains 27 slabs reinforced with steel bars; the second group contains 27 slabs too but reinforced with CFRP; and the last group also contains 27 slabs but reinforced with GFRP. All of these groups come from three subgroups: reinforcement ratio (50%, 100%, 150%), the ratio of ultimate load for each of them (25%, 50%, 75%), and length to thickness ratio (25, 30, 40). Therefore, every model carries a sign denoting the origin and the changes or parameters that were studied, such as S-40-100-9. Pu denotes that the model represents a slab reinforced with steel bars with a length to thickness ratio equal to 40, a reinforcement ratio equal to 100%, and a ratio of applied load equal to 90% of the ultimate load.

1-Sustaind load effect when L/h=40(ρ=150%)

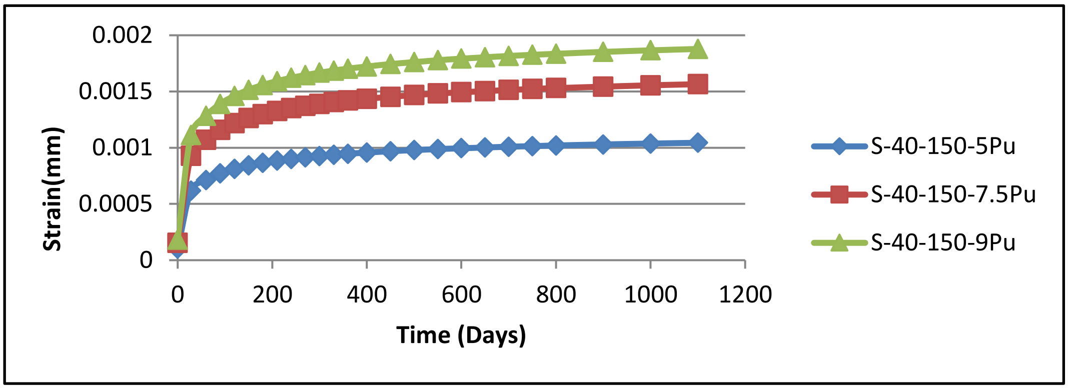


Fig. 8 Time and strain relationship for SM

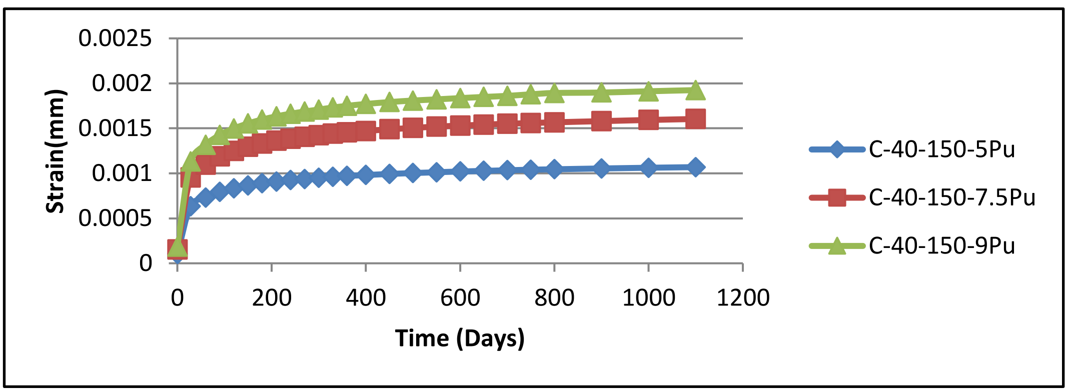


Fig. 9 Time and strain relationship for CM

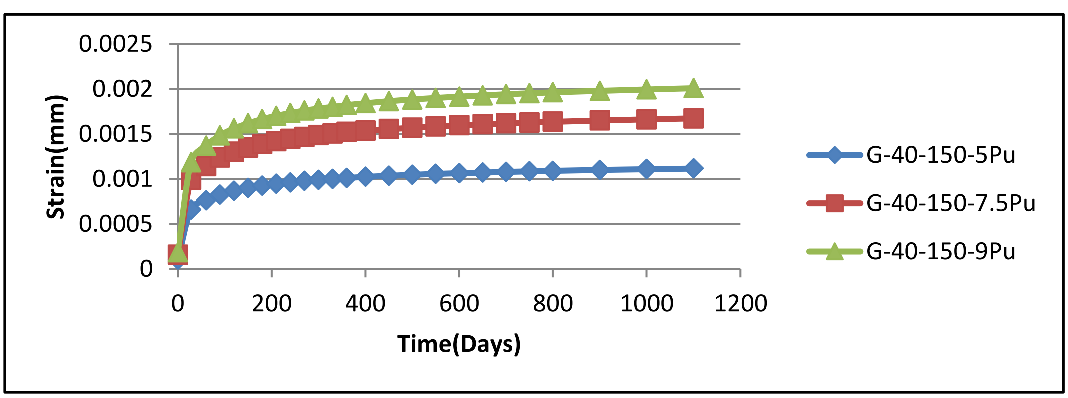


Fig. 10 Time and strain relationship for GM

2-Sustaind load effect when L/h=40(ρ=100%)

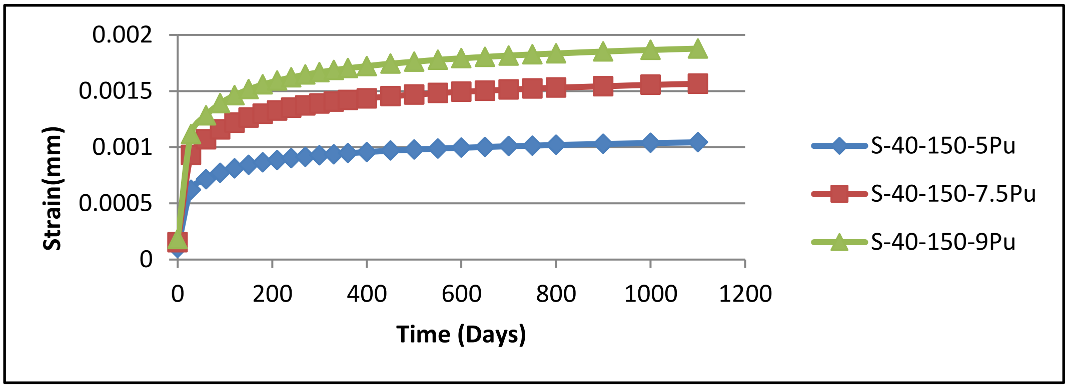


Fig. 11 Time and strain relationship for SM

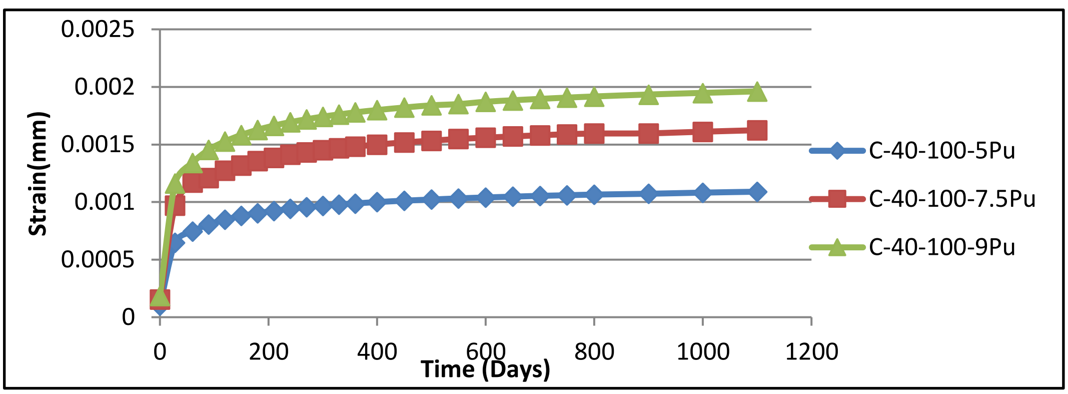


Fig. 12 Time and strain relationship for CM

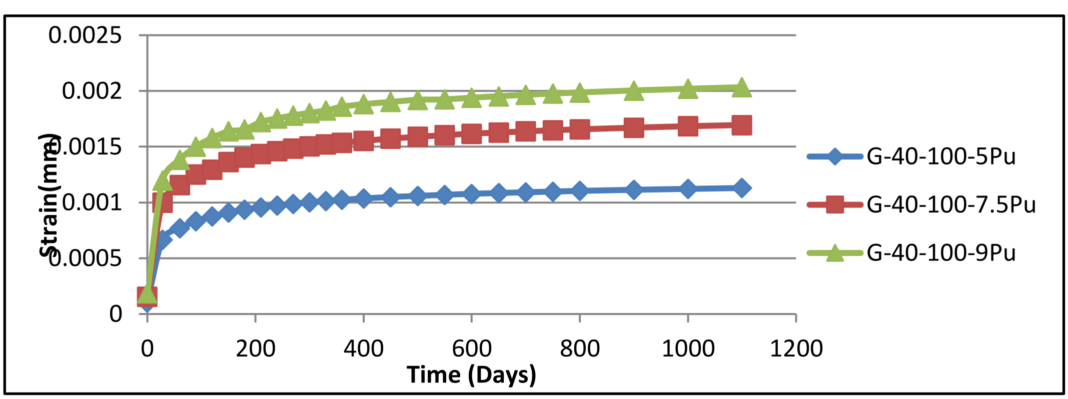


Fig. 13 Time and strain relationship for GM

3-Sustaind load effect when L/h=40(ρ=50%)

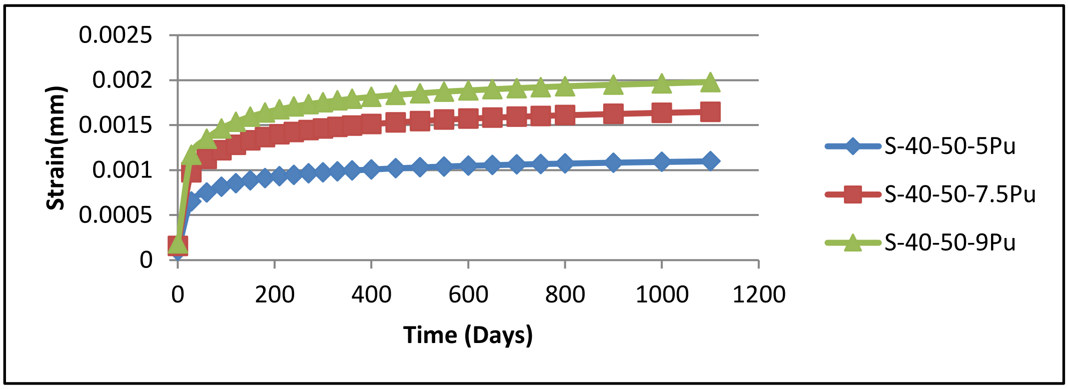


Fig. 14 Time and strain relationship for SM

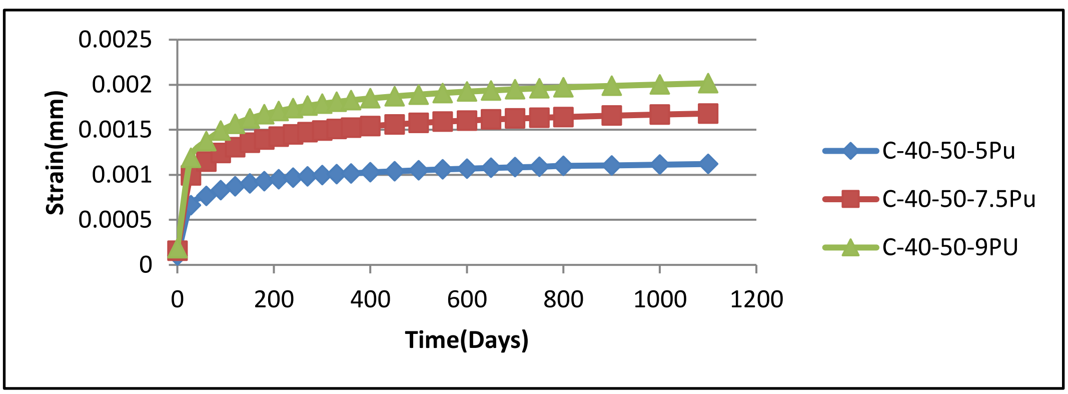


Fig. 15 Time and strain relationship for CM

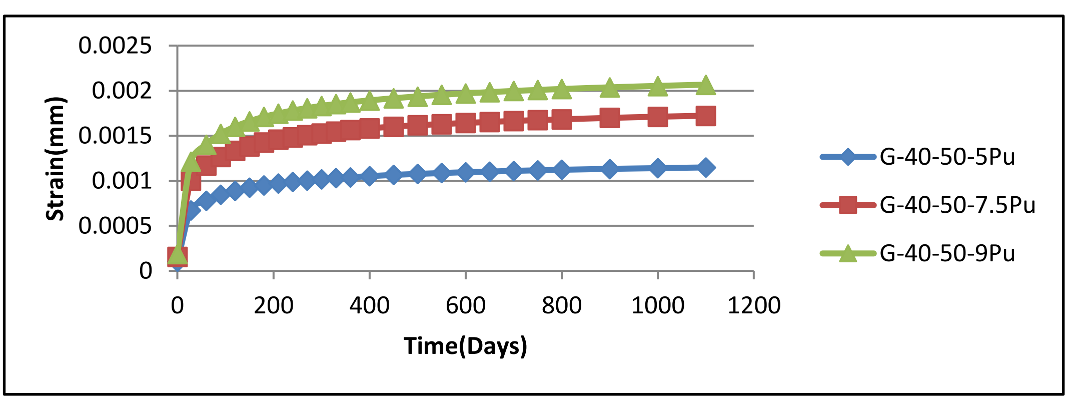


Fig. 16 Time and strain relationship for GM

1-Sustaind load effect when L/h=30(ρ=150%)

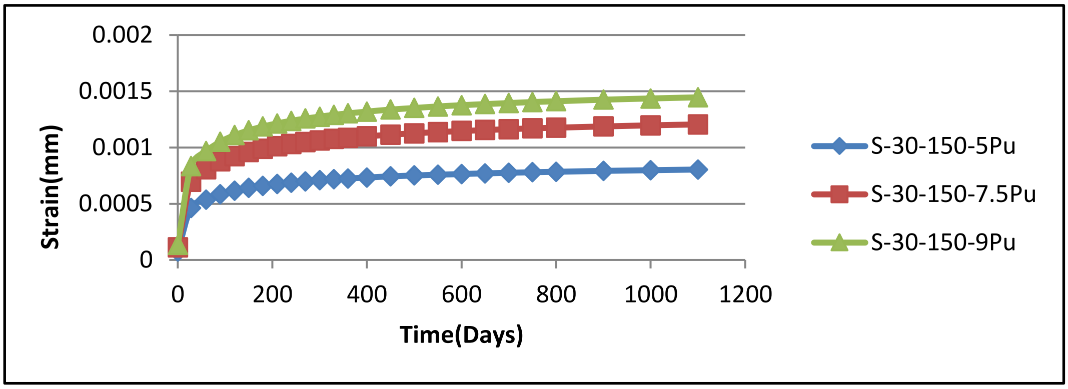


Fig. 17 Time and strain relationship for SM

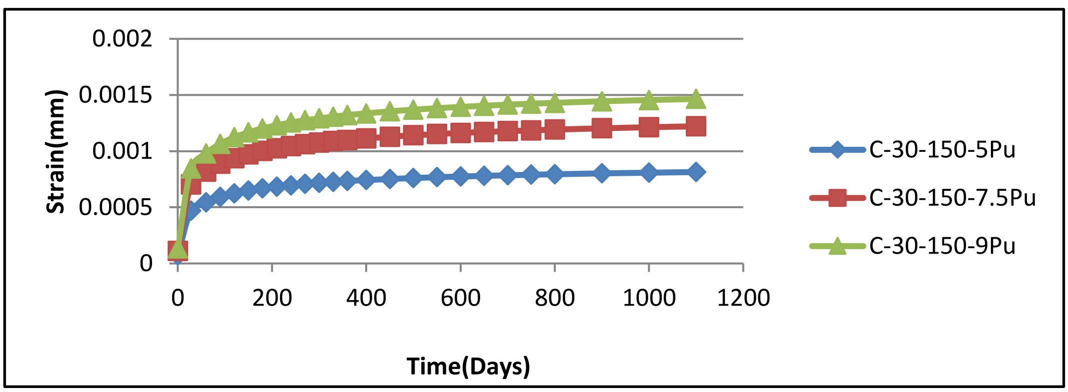


Fig. 18 Time and strain relationship for CM

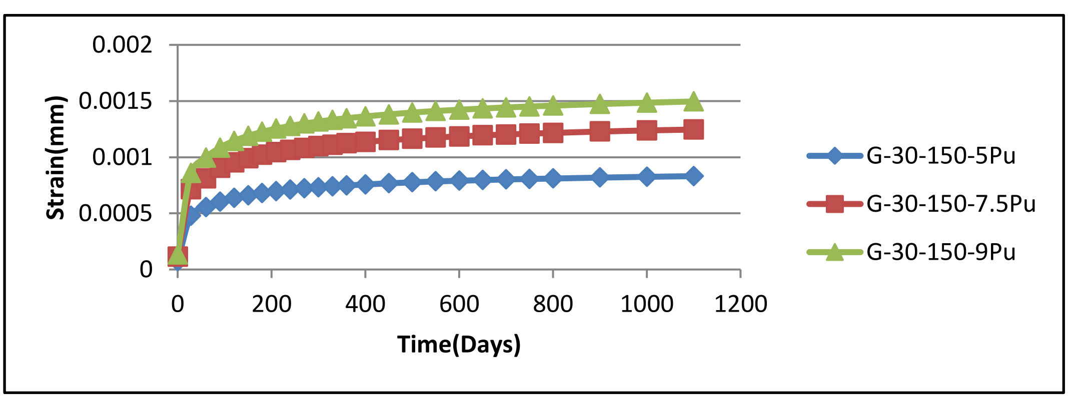


Fig. 19 Time and strain relationship for GM

2-Sustaind load effect when L/h=30(ρ=100%)

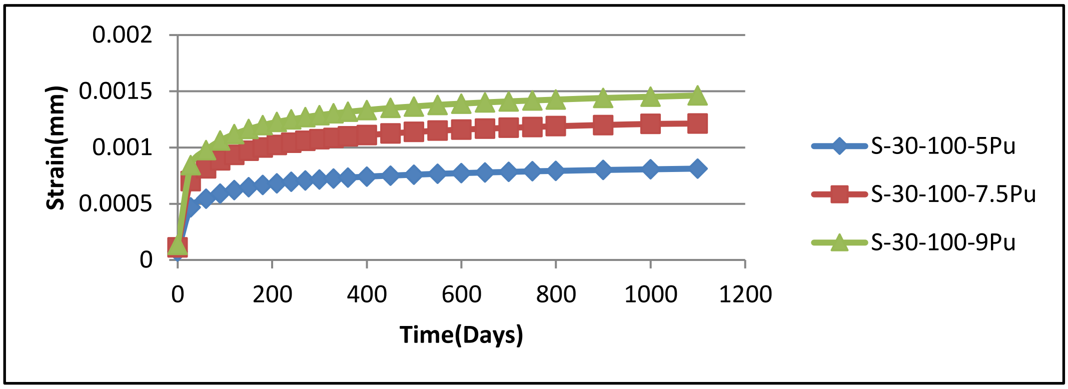


Fig. 20 Time and strain relationship for SM

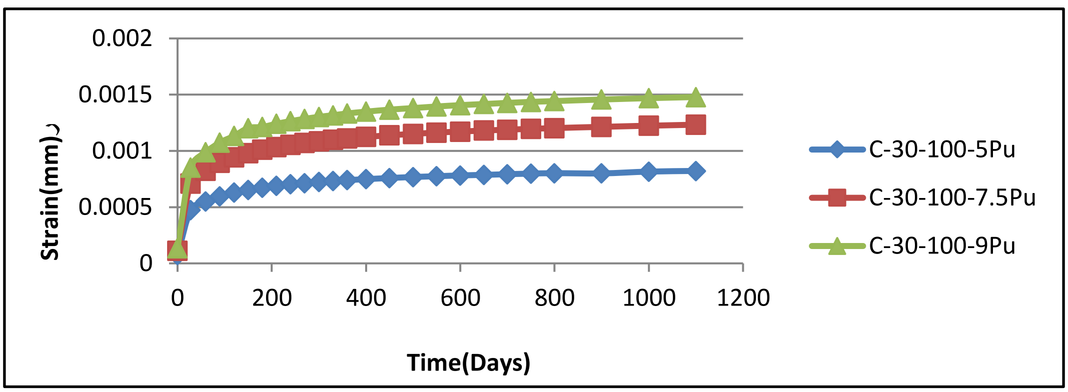


Fig. 21 Time and strain relationship for CM

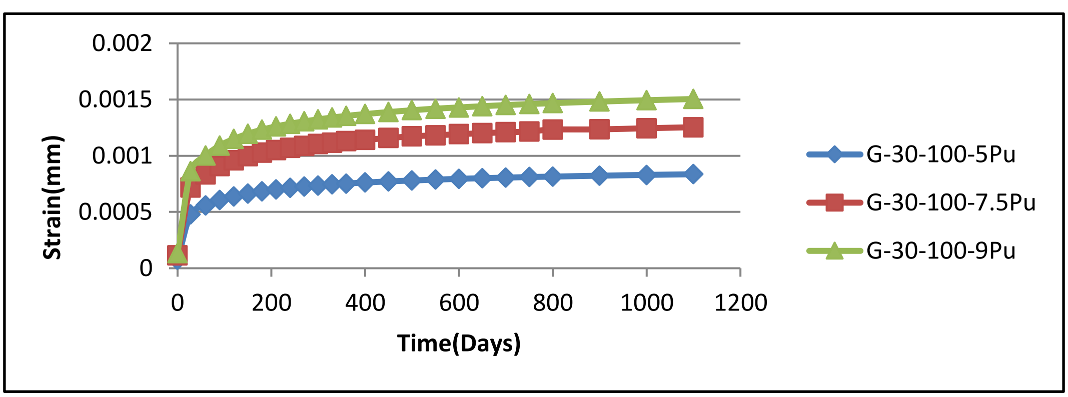


Fig. 22 Time and strain relationship for GM

3-Sustaind load effect when L/h=30(ρ=50%)

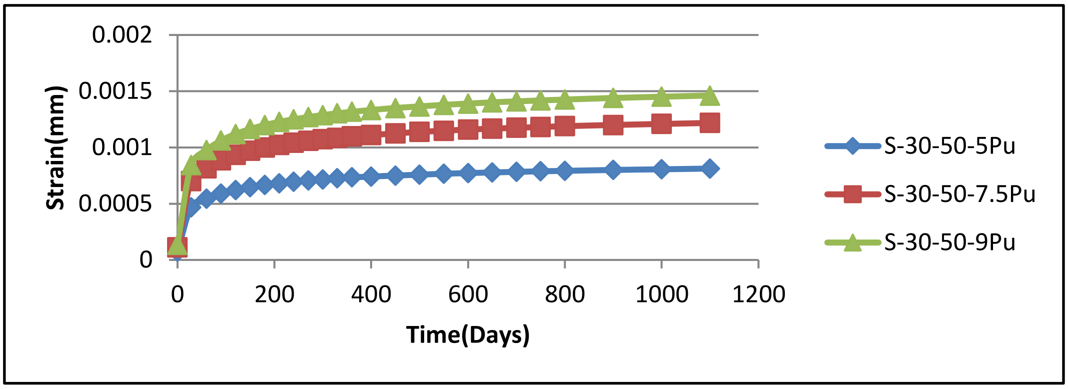


Fig. 23 Time and strain relationship for SM

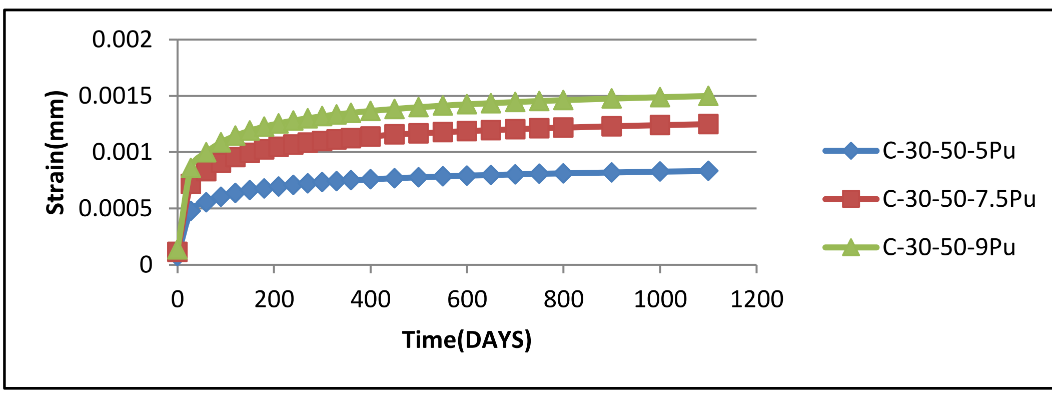


Fig. 24 Time and strain relationship for CM

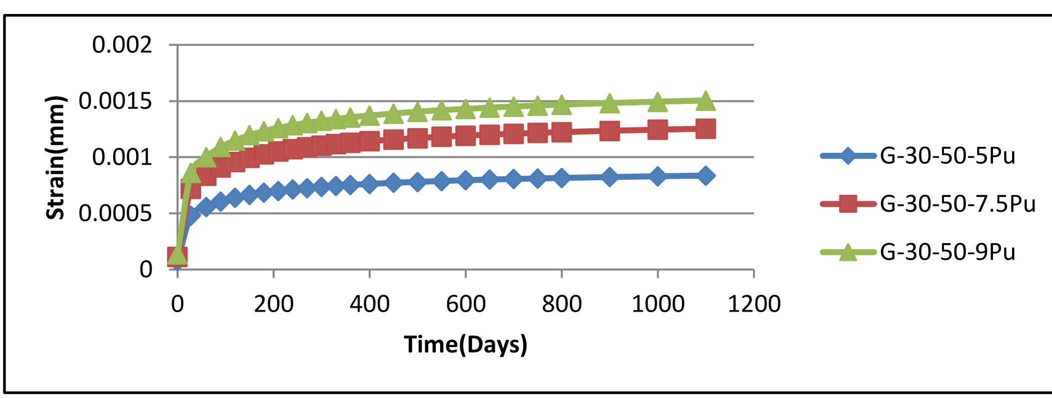


Fig. 25 Time and strain relationship for GM

1-Sustaind load effect when L/h=25(ρ=150%)

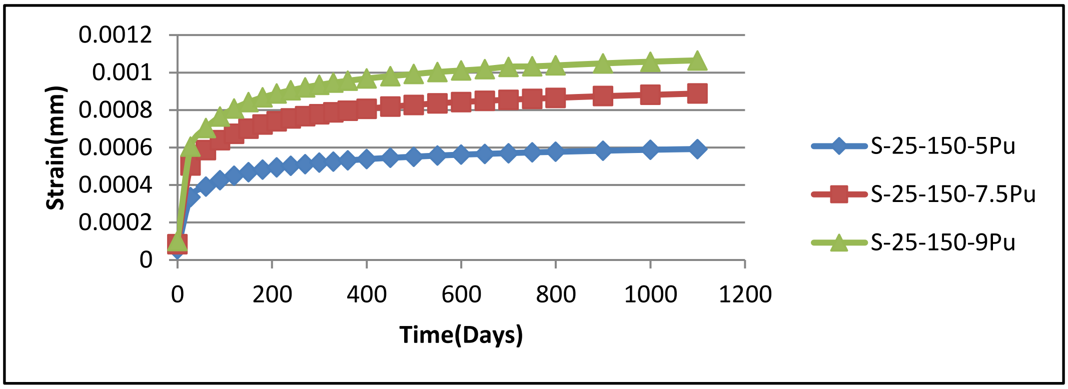


Fig. 26 Time and strain relationship for SM

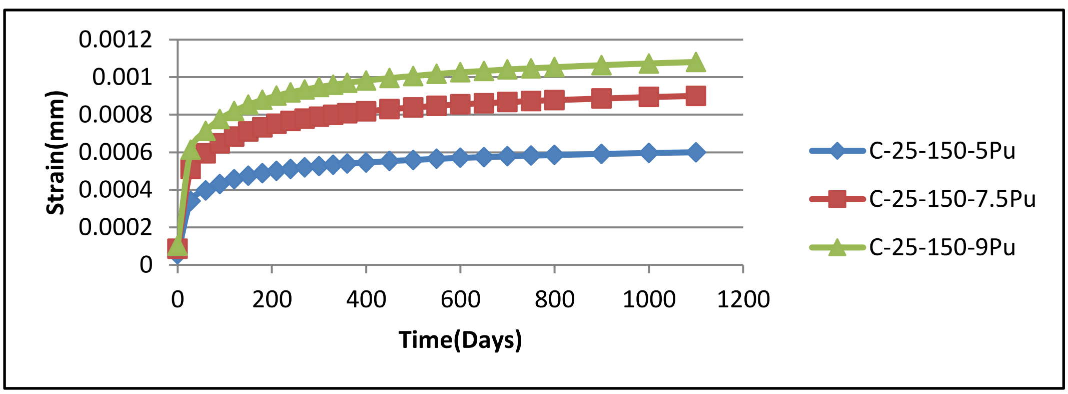


Fig. 27 Time and strain relationship for CM

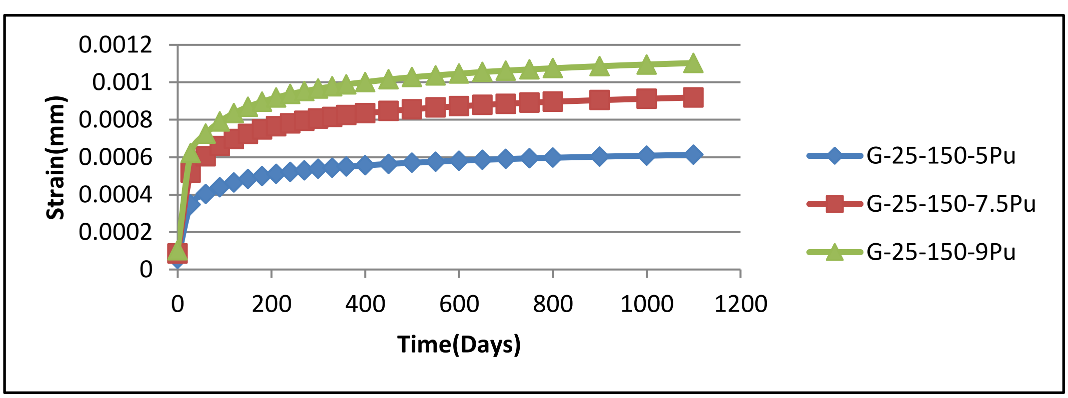


Fig. 28 Time and strain relationship for GM

2-Sustaind load effect when L/h=25(ρ=100%)

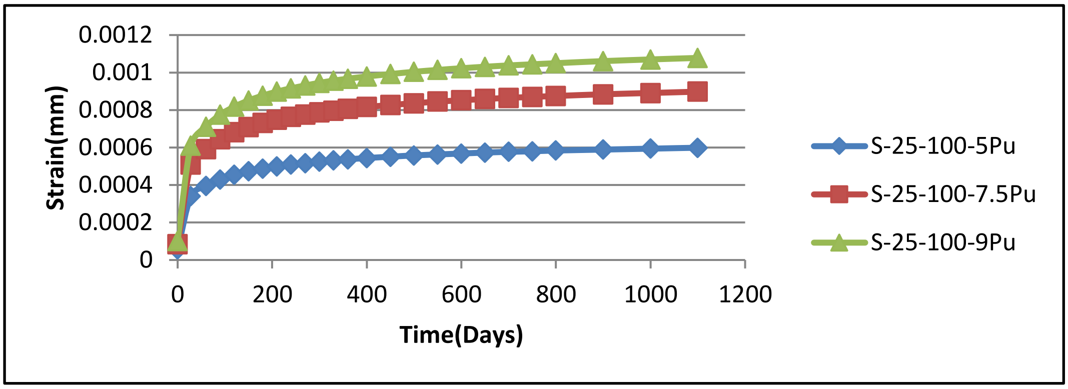


Fig. 29 Time and strain relationship for SM

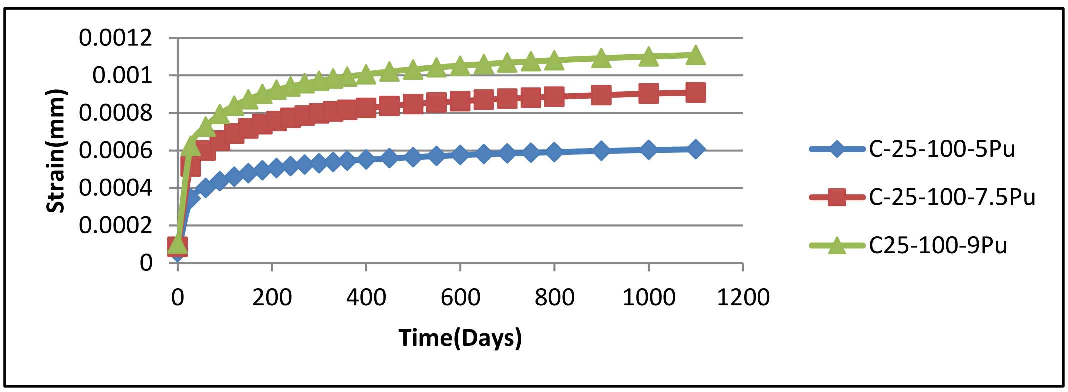


Fig. 30 Time and strain relationship for CM

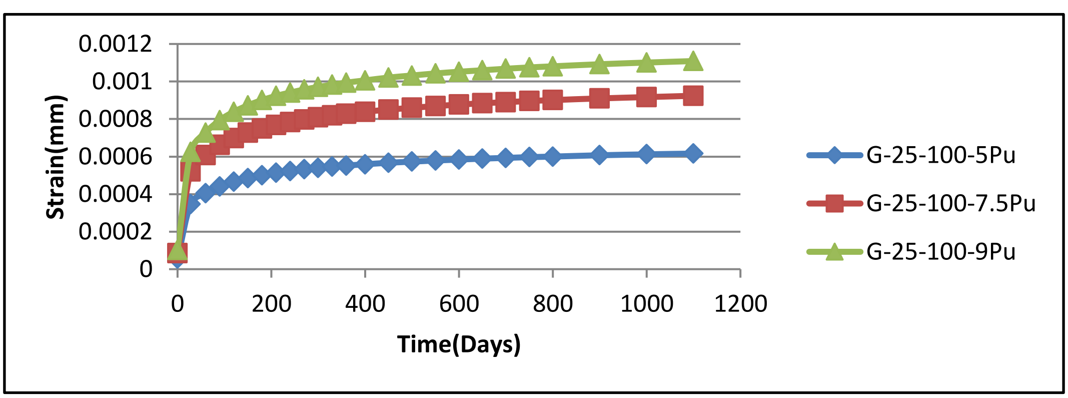


Fig. 31 Time and strain relationship for GM

3-Sustaind load effect when L/h=25(ρ=50%)

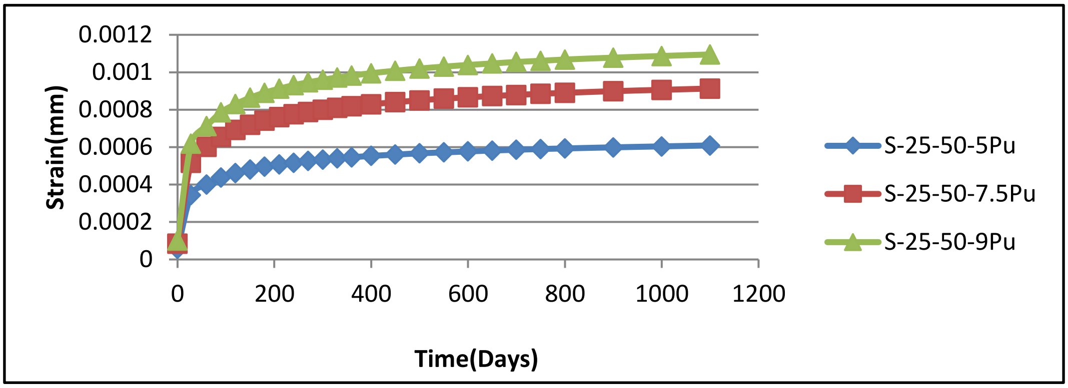


Fig. 32 Time and strain relationship for SM

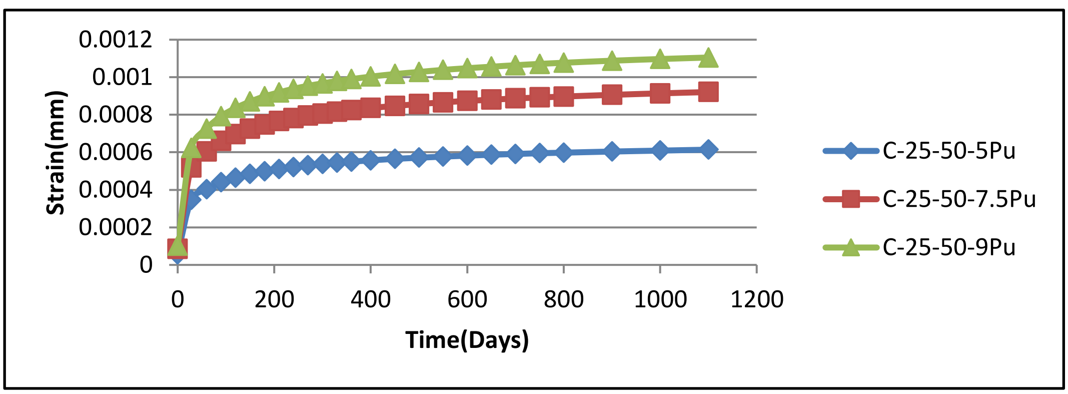


Fig. 33 Time and strain relationship for CM

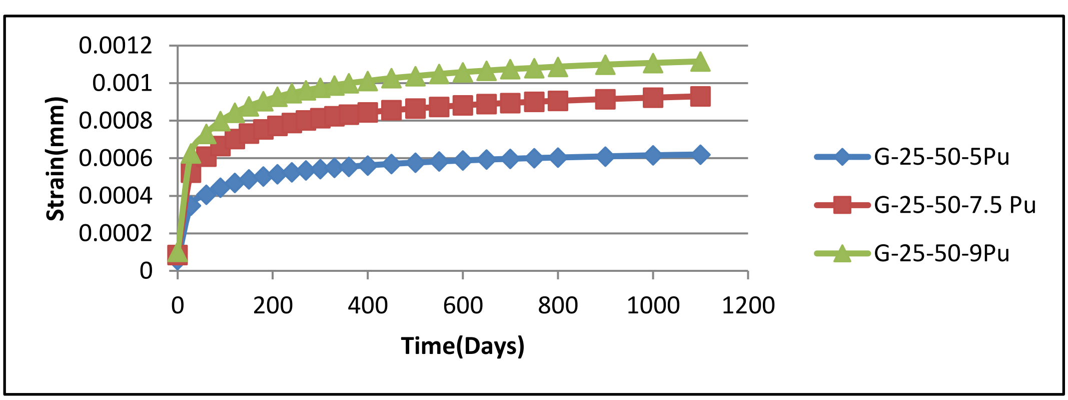


Fig. 34 Time and strain relationship for GM

When L/h equals 40 and ρ equals 100%, we can see that the strain in the steel model increases with a ratio of 19.98% when the load increases from 75% to 90% and decreases with a ratio of 50% when the load decreases from 75% to 50%. With respect to the slab that is reinforced with CFRP, the change seems to be approximately the same, where the strain increases with a ratio of 20.74% when the load increases from 7.5% to 90% and decreases with a ratio of 48.99% when the load decreases from 90% to 50%. Also, with respect to the slab that is reinforced with GFRP, the strain increases by 20% when the load increases from 75% to 90% and decreases by 50% when the load decreases from 75% to 50%. The results for the rest of the models represented in Figures 8–34 are listed in Table 5 below.

Table 5 – Result of changes in strain with respect to change of load for models reinforced with steel or FRP.

Slab symbol	ΔPu%	Δδ%	Slab symbol	ΔPu%	Δδ%
S-40-100-9Pu	+15	19.98	C-30-50-5Pu	-25	49.939
S-40-100-5Pu	-25	50	G-30-50-9Pu	+15	20.015
C-40-100-9Pu	+15	20.74	G-30-50-5Pu	-25	50
C-40-100-5Pu	-25	48.99	S-30-150-9Pu	+15	20
G-40-100-9Pu	+15	20	S-30-150-5Pu	-25	49.87
G-40-100-5Pu	-25	50	C-30-150-9Pu	+15	19.98
S-40-50-9Pu	+15	20.036	C-30-150-5Pu	-25	50
S-40-50-5Pu	-25	50	G-30-150-9Pu	+15	20.064
C-40-50-9Pu	+15	20	G-30-150-5Pu	-25	49.93
C-40-50-5Pu	-25	50	S-25-100-9Pu	+15	20.044
G-40-50-9Pu	+15	20.034	S-25-100-5Pu	-25	49.91
G-40-50-5Pu	-25	50	C-25-100-9Pu	+15	20.022
S-40-150-9Pu	+15	20	C-25-100-5Pu	-25	50
S-40-150-5Pu	-25	49.9	G-25-100-9Pu	+15	20.021
C-40-150-9Pu	+15	20.01	G-25-100-5Pu	-25	50
C-40-150-5Pu	-25	50.046	S-25-50-9Pu	+15	19.934
G-40-150-9Pu	+15	20.023	S-25-50-5Pu	-25	49.91
G-40-150-5Pu	-25	50.044	C-25-50-9Pu	+15	19.978
S-30-100-9Pu	+15	20.52	C-25-50-5Pu	-25	50
S-30-100-5Pu	-25	49.26	G-25-50-9Pu	+15	20
C-30-100-9Pu	+15	19.95	G-25-50-5Pu	-25	50
C-30-100-5Pu	-25	50	S-25-150-9Pu	+15	19.93
G-30-100-9Pu	+15	20.015	S-25-150-5Pu	-25	50
G-30-100-5Pu	-25	50	C-25-150-9Pu	+15	20.11
S-30-50-9Pu	+15	20.03	C-25-150-5Pu	-25	50
S-30-50-5Pu	-25	50	G-25-150-9Pu	+15	20.021
C-30-50-9Pu	+15	20.016	G-25-150-5Pu	-25	49.91

7. Conclusions

Based on the research's numerical analysis of reinforced concrete two-way slabs reinforced by steel bars or fiber polymer bars, the following findings and observations can be drawn:

1. There is no significant difference in the behavior of the materials when used as reinforcing bars for concrete, whether they are steel bars, steel bars, or FRP bars. This is because the tensile surface in the concrete undergoes stress of the same amount under the influence of the same load for a certain period of time.
2. Analysis using the Analytics program simulates laboratory work and gives similar results, sometimes more accurate, and this is better in several aspects, including cost, effort, and time.

3. The results showed what was agreed upon by the structural design codes, as the stiffness of the structure decreased with age and the strain increased under the influence of the load. This was proven for the structures reinforced with steel bars, and here it was proven for the structures reinforced with FRP bars.
4. It can be seen that the strain in the steel model increases with a ratio of 19.98% when the load increases from 75% to 90% and decreases with a ratio of 50% when the load decreases from 75% to 50%. That is, the change by increasing the strain is less and slower than the change by decreasing the strain, since the strain when dropping the load is less than the strain when lifting the load because the structure has not undergone any changes, its stiffness is still high, and it is trying to recover its original shape.

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