Numerical Modeling of Time Effects of Two-Way Reinforced Concrete Slabs Strengthened by FRP Sheets

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Abstract. This paper deals with numerical investigations to develop new a nonlinear viscoelastic model to study the behavior of long-term deflection (considering the creep) of the strengthening two-way slab by FRP sheets. Creep is always related to damages, and it's one complex phenomenon that is set up differently in each program, so computations are done using the Finite Element Method (FEM) by using the ANSYS/ APDL Ver19.2 program. In the ANSYS program, creep analysis can be done in a variety of ways. One of these is the Prony series' definition of creep function. The investigates include some important parameters' effect on the behavior of strengthening two-way slab. Four parameters were studied in this research consisted; the sustained load magnitude, compressive strength, length to thickness of the slab, and FRP sheet type. Where analyzed seventy-two models and noticed that the deflection decreased when increased the compressive strength and elasticity modulus of FRP (with remaining other parameters constant) but the deflection increased when increased the sustained load magnitude and decreasing the length of the slab.

INTRODUCTION

Fiber-reinforced polymers (FRPs) was being used throughout the recent decade. FRP plates and sheets appeared like promising alternative materials to strengthen (i.e. steel) due to their advantages such as high corrosion resistance, high strength to weight ratio, and durability (1). In the long term, the FRP materials don't have corrosion and rust (2). Although much of the research had directed to study the external strengthening slab by FRP (3–6), most of these works covered mainly a short term behavior which can't be used to model the behavior of long-term concrete structures external strengthening by FRP (7). In fact, there was some research was conducted to investigate the behaviour of long-term external strengthening by FRP for beam, column, and one-way slab (8–14). However, there're very limited studies available of the (long-term) behavior of external strengthening two-way slab with FRP that has been mentioned in the literature. Through the numerical investigation conducted by A. S. Mahmoud and Z. T. Salih (13), the result of the strengthened column with FRP sheet were used the nonlinear viscoelastic model by using ANSYS to calculate the viscoelastic behavior strengthened column by FRP. the actual parameter of the model was determined with low sustained stresses. the model can determine the creep behavior of viscoelastic FRP-strengthen concrete. viscoelasticity is a topic of interest to model the time dependent materials behavior. therefore, many researchers used viscoelasticity to predict time-dependent behavior (15). In this study, using of viscoelasticity by means of the Prony series in the ANSYS is explained first.

The objective of this study is to achieve a numerical investigation of the time dependent behavior of reinforcement concrete two-way slabs subjected to sustained load. this aim is achieved using the FE method utilizing (ANSYS) software**.**

FINITE ELEMENT MODELING

Material Modelling

The creep response of external strengthening RC slabs with FRP sheets was studied using a non-linear numerical model. were conducted by using the ANSYS FE analysis software. The SOLID186 element was used to model the concrete (the concrete assumed isotropic and homogenous) (16) the element SOLID186 represent the viscoelastic behaviour for concrete, it is defined by 20-nodes with three freedom degrees for each node and translation in (x), (y), and (z-directions). The supports plasticity of element, creep, hyperelasticity, large strain, stress stiffening, and large deflection capabilities (17). The element geometry and node locations are shown in “Fig.1a”. A (Link180) element was used for modelling the steel reinforcement bar (16) The element had two-node and 3-degrees of freedom at each node as illustrated in “Fig.1b”. The loading and supports application are modelled by using a 3D solid element SOLID185 (18), the element geometry shown in “Fig.1c”. The SHELL181 element is used for the model FRP sheet having four-node with six degrees of freedom at each node (19) as shown in “Fig.1d”.

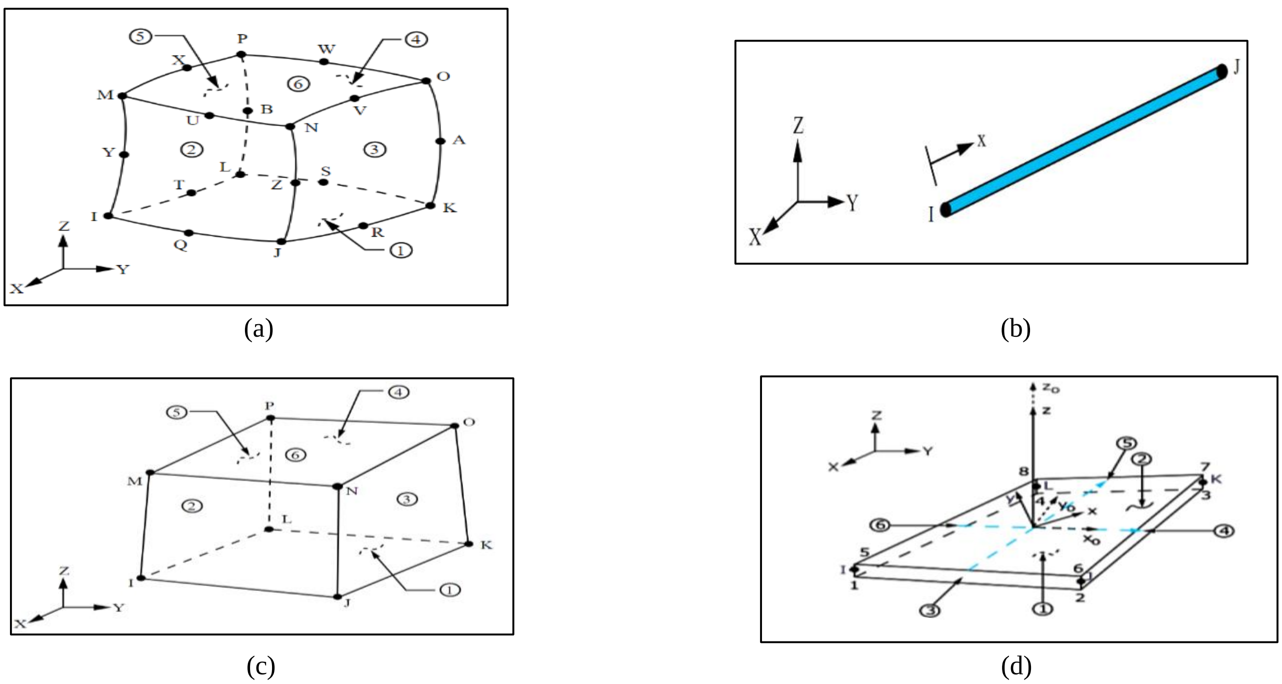

FIGURE 1. (a) SOLID186 Geometry, (b) LINK180 Geometry, (c) SOLID185 Geometry, and (d) SHELL181 Geometry (17).

Viscoelasticity in The ANSYS Program

In this section, the viscoelastic equations used by ANSYS is explained. ANSYS employs the Prony series to represent the viscoelastic material behavior. The creep test results were used to indicate the series of Prony validity for viscoelastic analysis. The model consists of (n + 1) elements in parallel, where n is the Maxwell model with a spring. For the series of Prony the expressions of shear modulus and bulk modulus are given as:

$$G(t) = G_\infty + \sum_{i=1}^{nG} G_i \exp(-\frac{t}{\tau_i^G}) \tag{1}$$

$$K(t) = K_\infty + \sum_{i=1}^{nK} K_i \exp(-\frac{t}{\tau_i^K}) \tag{2}$$

Where: $G\infty$, Gi is shear elastic moduli, $K\infty$, Ki is bulk elastic moduli, τ_i^G, τ_i^K is relaxation times of each Prony component. The relative moduli are introduced as follows:

$$\alpha_i^G = \frac{G_i}{G_0} \quad , \quad \alpha_i^K = \frac{K_i}{K_0} \tag{3}$$

Where: $$G_0 = G_\infty + \sum_{i=1}^{nG} Gi \, , \qquad K_0 = K_\infty + \sum_{i=1}^{nK} Ki \tag{4}$$

The kernel functions would be written as follows:

$$G = G_0 \left[\alpha_\infty^G + \sum_{i=1}^{nG} \alpha_i^G \exp(-\frac{t}{\tau_i^G} \right] \tag{5}$$

$$K = K_0 \left[\alpha_\infty^K + \sum_{i=1}^{nK} \alpha_i^K \exp(-\frac{t}{\tau_i^K} \right] \tag{6}$$

Finite Element and Material Properties

The concrete creep for (360 days) that is used in this model from [20] was selected the concrete mixture (NC 3) while after (360 days) the value of the coefficient of the ultimate creep assumed of (1.3). By considering the symmetry of the quarter slab for each specimen were modelled with related boundary conditions, a symmetric was restrained on their perpendicular directions where the bottom part was restrained on vertical direction using constraints in the FE analysis. The load was put as a quarter of the load and distributed over all nodes of the upper plane surface of the steel plate. The Prony series fitting curve from the ANSYS Program are shown in "Fig.2". Modulus of shear (G) and modulus of bulk (K) was calculated from ACI equations:

$$G = \frac{E}{2(1+\upsilon)} \, , \quad K = \frac{E}{3(1-2\upsilon)} \, , \quad E = \frac{E_0}{(1+\varphi(t,\tau))} \tag{7}$$

Where τ is a time of the start of loading, t is concrete age at the moment measured in (days), φ (t, τ) is the coefficient of creep and is defined as the creep strain ratio at (t) day from loading to the strain of initial instantaneous at loading at the time (τ), v is the Poisson ratio of concrete.

The designed slabs in this section have a square cross-section with a thickness of (90 mm) and four varied lengths of (1350, 2025, 2700, and 3375) mm according to the original experimental model to have a four-length to thickness ratio (15, 22.5, 30, and 37.5). The flexural steel reinforcement ratios are the same in all slab models were shown in "Fig.3". The steel reinforcement was used in the specimens is shown in "Table.1". The steel bars yield strength and elastic modulus were (500MPa), and (200GPa) respectively, the concrete material properties and FRP properties that used in the specimens are shown in "Table.2". and "Table.3". respectively.

TABLE 1. Steel Reinforcement Details and Element Dimension of the Slabs Model.

Slab Size (mm)	Element size in (x, y, and z) (mm)	Steel Reinforcement Details
1350 × 1350 × 90	28.125 × 28.125 ×22.5	8 Ø 10 @ 168.75 mm
2025 × 2025 × 90	28.125 × 28.125 ×22.5	12 Ø 10 @ 168.75 mm
2700 × 2700 × 90	84.375 × 84.375 ×22.5	16 Ø 10 @ 168.75 mm
3375 × 3375 × 90	84.375 × 84.375 ×22.5	20 Ø 10 @ 168.75 mm

TABLE 2. Concrete Material Properties.

Compressive Strength fc′(MPa)	Initial Elastic Modulus E_o (MPa)	Shear Modulus G (MPa)	Bulk Modulus K(MPa)
30	25743	10726	14302
45	31529	13137	17516
60	36406	15169	20225

TABLE 3. FRP Sheet Properties

FRP Sheet Type	Properties
CFRP	Exy= 62000 (MPa)* Eyz=4800 (MPa)* Exz=4800 (MPa)* Gxy=3270 (MPa)* Gyz=1860 (MPa)* Gxz=3270 (MPa)* υxy=0.22* υyz=0.3* υxz=0.22* t=1 (mm)*
GFRP	Ex=72395 (MPa)*** ft= 1517 (MPa)*** υ=0.22** t=1 (mm)**

* From reference (18)
** Assumed
*** From reference (20)

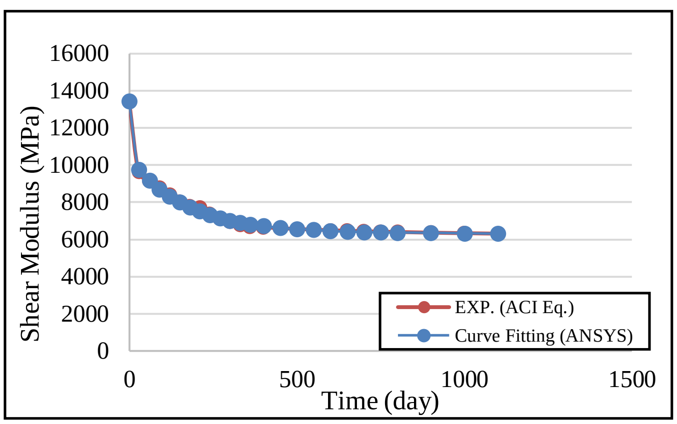

FIGURE 2. Comparison of the shear modulus results from reference (21) for the concrete mixture (NC3) with ANSYS results.

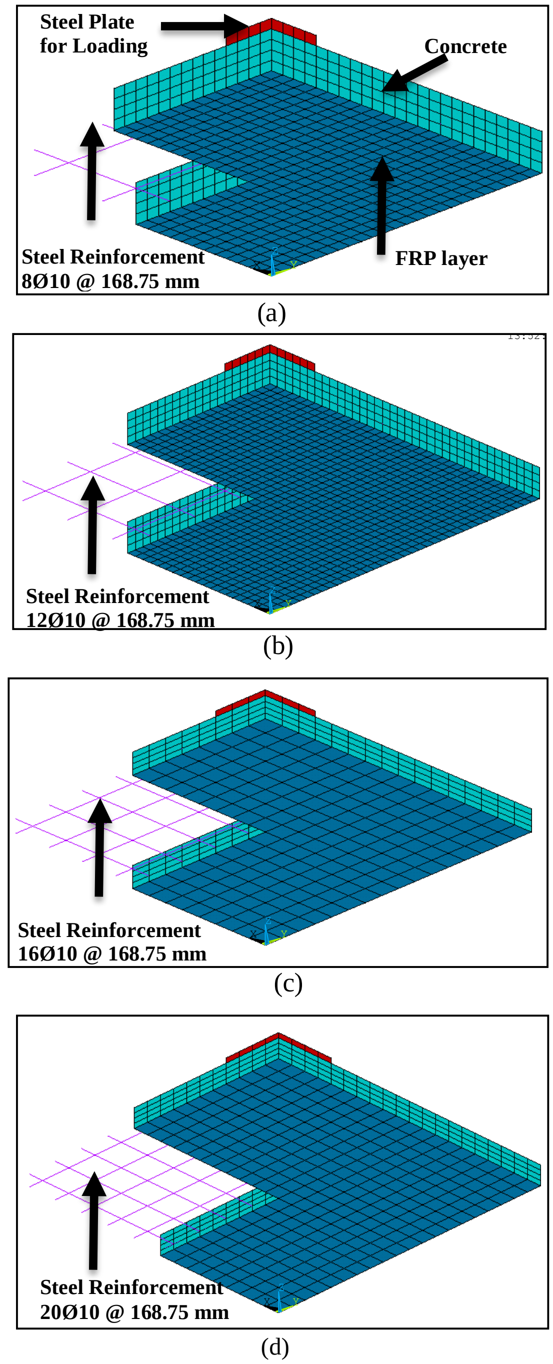

FIGURE 3. 3D Finite Element Model of Quarter Slab with (a)l/h=15, (b) l/h=22.5, (c) l/h=30, and (d) l/h=37.5

Parametric Analysis and Discussions

The parametrical analysis considers included seventy-two models which are divided into four main groups of parameters (L/h); (15, 22.5, 30 and 33.5). All groups content of three models of the concrete compressive strength (f'c); (30, 45, and 60 MPa), each one was applied to a different load (20, 40, and 60%) of the ultimate load with two types of FRP sheet (CFRP and GFRP). The analysis establishes that the maximum load in the short-term was equal to 215 kN Therefore, the load applied value is equal to (43,86, and 129) kN according to the ultimate load Pu percentage (20, 40, and 60%). The model's short name contains four symbols were illustrated in “Fig.4”.

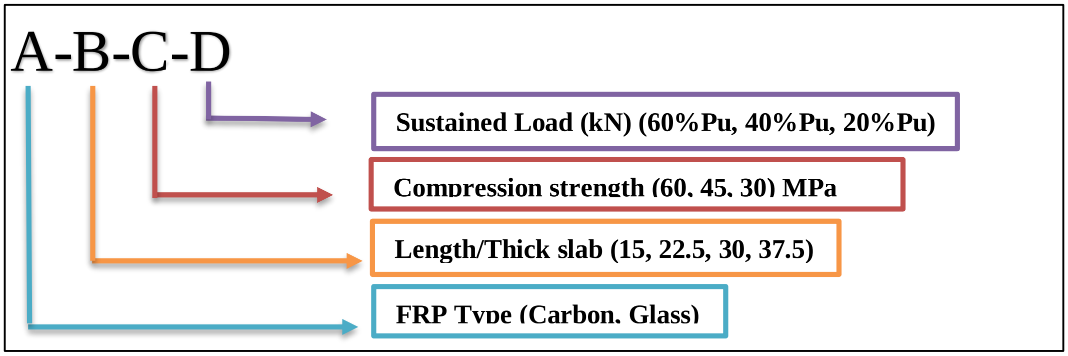

FIGURE 4. Short-Name of The Models.

For example, a model (C-15-60-6P) represents Carbon FRP - length to thick slab ratio of 15- 60 MPa compression strength- 60% of the ultimate sustained load (kN). Figures 5 to 22 show the results of the paramedic's effect.

Sustained Load Magnitude Effect

The sustained load magnitude is the main parameter that affects the creep, it was observed from analysis that when increases the load lead to an increase in the slab deflection, whereas sustained load increases from (20%Pu to 40%Pu) kN and from (40%Pu to 60%Pu) kN increase in deflection about (2 and 0.5) times respectively.

Length to Thickness Ratio Effect

To study the slender ratio of slab (length to thickness) effect on the behavior of the RC slab strengthening by FRP sheet, four values (15, 22.5, 30 and 37.5) of (l/h) ratio were selected. The thickness for all specimens was a constant 90 mm, while the cross section was different according to length (1350, 2025, 2700 and 3375) mm for (15, 22.5, 30 and 37.5) ratio respectively. Increasing of (l/h) ratio lead to an increase in the deflection at the same load, FRP type, and compressive strength. Increasing this ratio from (15 to 22.5), (22.5 to 30) and (30 to 37.5), lead to an increase in the slab deflection by (2, 1.79 and 1.54) times, respectively. This means that decreasing the length of the slab from (3375mm) to (1350mm) lead to an increase in the deflection of the mid slab by (5.615) times.

Compressive Strength Effect

To study the compressive strength effect three compressive strength values of (30, 45 and 60) MPa were selected to evaluate the behavior of strengthening RC slabs by FRP under the different values of the compressive strength with the same FRP type, applied load, and length to thickness ratio. Increasing the compressive strength of the specimen leads to a decrease in the specimen deflection at the same applied load and length to thickness ratio. Where when increasing the compressive strength by (50%) and (100%) leads to a decrease in the mid deflection by (12.56%) and (17.9%) for strengthening by CFRP, as well for strengthening by GFRP the decrease in the mid deflection (11.48%) and (16.24%) respectively.

FRP Sheet Type Effect

CFRP and GFRP were selected to evaluate the behavior of strengthening RC slabs under different FRP types with the same compressive strength, applied load, and length to thickness ratio. The increase in the elastic modulus leads to a decrease in creep. Where the creep has in deflection, the model with high elastic modulus has a lower creep as a result of a lower deflection. The models strengthening with GFRP have a greater elastic modulus than the models strengthening with CFRP that used in this research, so the models strengthening with CFRP have a higher deflection than the models strengthening with GFRP by 14.23%.

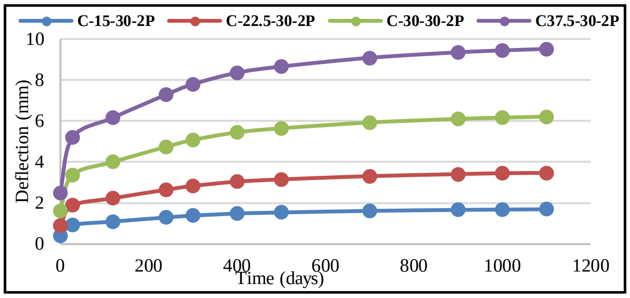

FIGURE 5. Time vs Deflection for Models (C-#-30-2P)

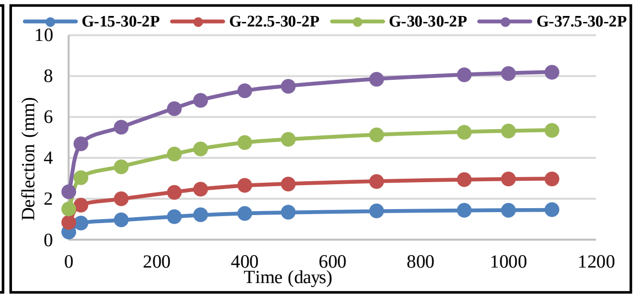

FIGURE 6. Time vs Deflection for Models(G-#-30-2P)

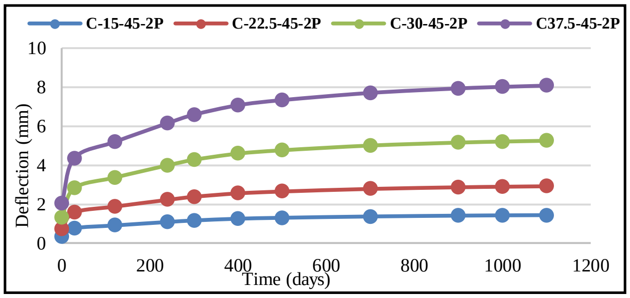

FIGURE 7. Time vs Deflection for Models (C-#-45-2P)

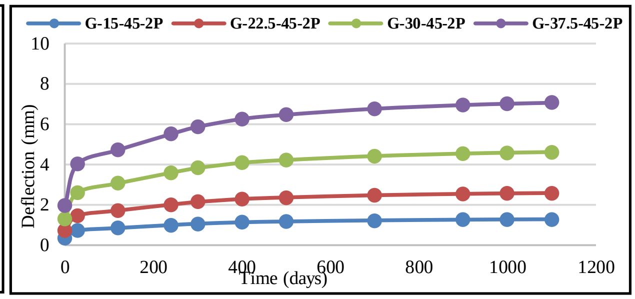

FIGURE 8. Time vs Deflection for Models(G-#-45-2P)

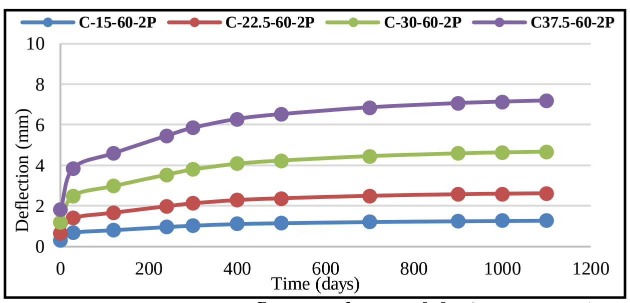

FIGURE 9. Time vs Deflection for Models (C-#-60-2P)

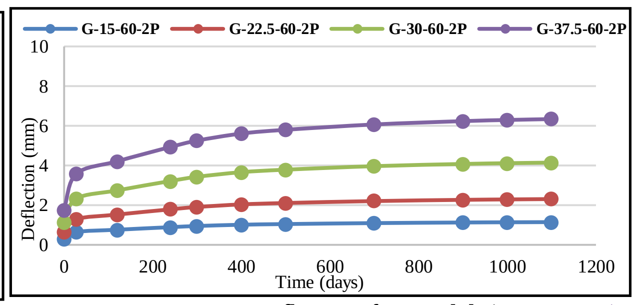

FIGURE 10. Time vs Deflection for Models(G-#-60-2P)

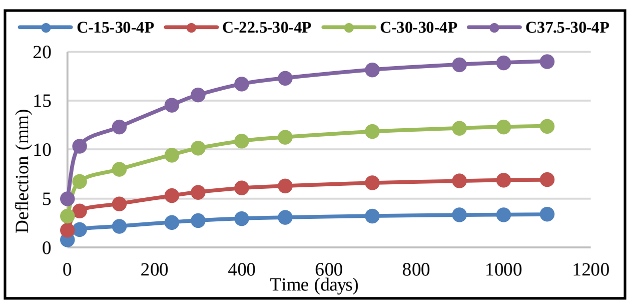

FIGURE 11. Time vs Deflection for Models (C-#-30-4P)

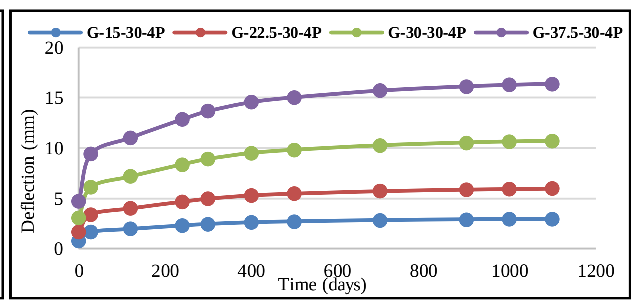

FIGURE 12. Time vs Deflection for Models(G-#-30-4P)

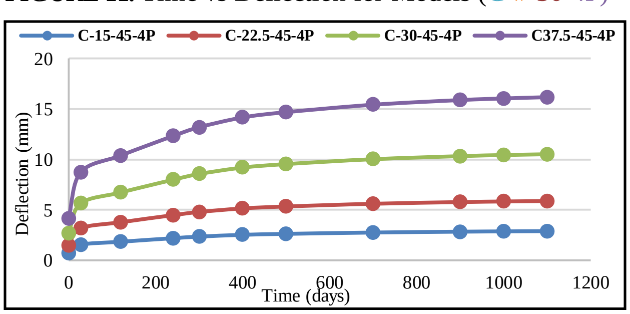

FIGURE 13. Time vs Deflection for Models (C-#-45-4P)

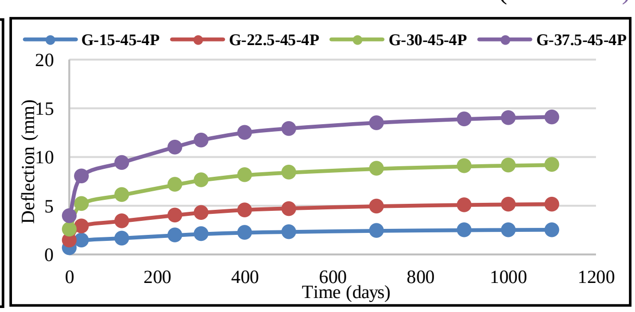

FIGURE 14. Time vs Deflection for Models(G-#-45-4P)

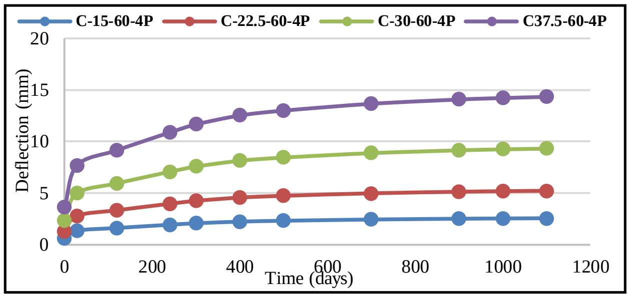

FIGURE 15. Time vs Deflection for Models (C-#-60-4P)

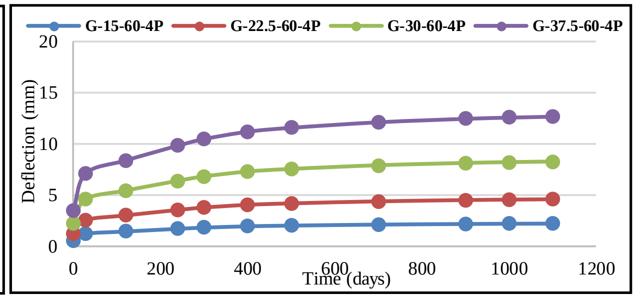

FIGURE 16. Time vs Deflection for Models(G-#-60-4P)

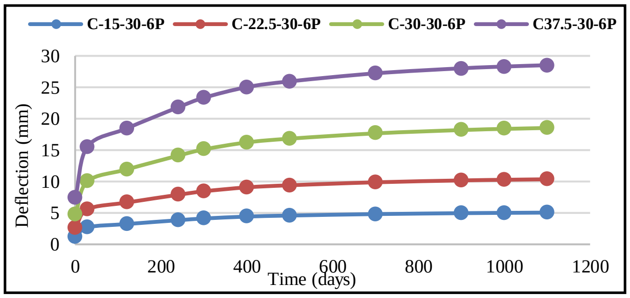

FIGURE 17. Time vs Deflection for Models (C-#-30-6P)

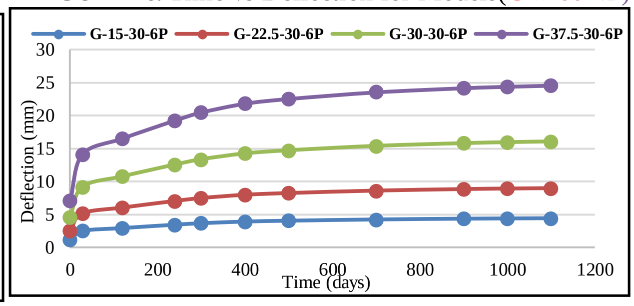

FIGURE 18. Time vs Deflection for Models(G-#-30-6P)

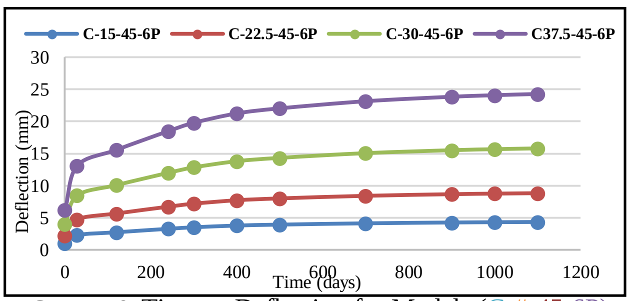

FIGURE 19. Time vs Deflection for Models (C-#-45-6P)

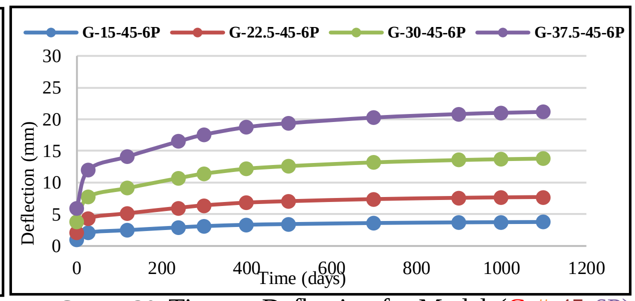

FIGURE 20. Time vs Deflection for Models(G-#-45-6P)

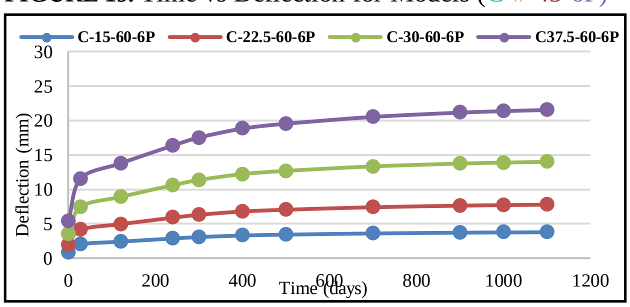

FIGURE 21. Time vs Deflection for Models (C-#-45-6P)

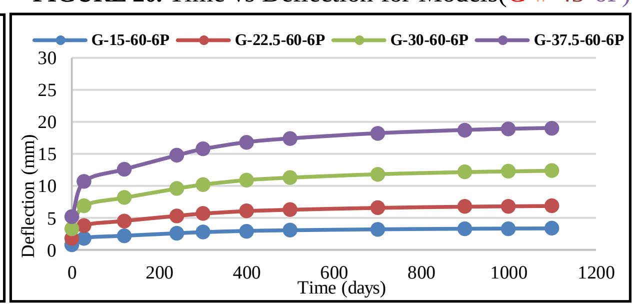

FIGURE 22. Time vs Deflection for Models(G-#-45-6P)

CONCLUSION

A non-linear viscoelastic model is presented in this paper for studying the time-dependent deflection (consider the creep) of the strengthening RC two-way slab using FRP under sustained load. The Prony series is used to solve the creep problem using finite element modelling by using (ANSYS) software. The numerical results indicate that; increasing the applied load leads to a decrease in the strengthening slab efficiency in the long term where it increases the deflection due to increasing the creep, which the creep have in deflection. As increases the span, the flexural stiffness decreases as l/h increases for a given loading, as a result, the deflection would decrease. As well the (long-term) deflection is reduced by increasing the concrete compressive strength. Finally, the deflection decrease by using the strengthening FRP with a high modulus of elasticity.

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