American Journal of Engineering Research (AJER)
e-ISSN: 2320-0847 p-ISSN : 2320-0936
Volume-10, Issue-01, pp-79-84
www.ajer.org
Research Paper Open Access

Numerical Analysis of FRP Reinforced Concrete Flat Slabs under Elevated Temperature

Mariet ABD-MARIAM[1], Osama ALI[2] and Mohamed ZAKARIA[3]
[1] M.Sc. Student, Civil Eng. Dept. Faculty of Engineering, Aswan University, Egypt.
[2] Assistant Professor, Civil Eng. Dept. Faculty of Engineering, Aswan University, Egypt.
[3] Associated Professor, Civil Eng. Dept. Faculty of Engineering, Aswan University, Egypt.

ABSTRACT : *The use of Fiber Reinforced Polymers (FRP) bars in concrete members as a steel reinforcement alternative to prevent corrosion actions that reduce the capacity of elements employing steel bars. However, properties of FRP bars are highly temperature dependent. The present study aims to obtain the structural behavior of FRP reinforced slab-column connection at elevated temperature using a 3D nonlinear Finite Element (FE) analysis. Herein, the considered structural behavior is the punching shear capacity. The Concrete Damage Plasticity CDP model available in Abaqus software was used to investigate the proposed FE model. The parameters of concrete damage plasticity were calibrated by using 6 specimens were collected from experimental studies. The Effect of increasing the concrete cover thickness on the ultimate capacity of the slab-columns connection at elevated temperature was studied. Results have shown that the performance of the slab-column connection under elevated temperature increases by increasing the thickness of the concrete cover.*

KEYWORDS *Finite element method, ABAQUS program, FRP bars, CDP model*

Date of Submission: 29-12-2020 Date of acceptance: 10-01-2021

I. INTRODUCTION

FRP reinforcing bars are used as internal reinforcement for concrete structures in the late 1980 because of their advantages including extremely high corrosion resistance, low stiffness/weight ratio, high tensile strength, easy in fabrication, light weight and good resistance to fatigue [1]. One of the big challenges in using fiber reinforced polymer (FRP) materials in civil engineering and limiting the wide application of it, is the lack of understanding the behavior of FRP materials at elevated temperatures because of the early loss of strength and stiffness at elevated temperatures. ACI 440 guideline [2] demonstrated that more researches are required to understand the behavior of concrete structures that reinforced with FRP in fire. An experimental study was presented by Mohamed Hassan *et a*l (2013) [3] about punching shear behaviour of slabs column connection reinforced with GFRP bars. A total of 17 specimens 2500 mm × 2500 mm reinforced with steel and GFRP bars were tested under concentric loads until failure. The results were represented in terms of strains in FRP-reinforcement/concrete, cracking behavior, mode of failure, deflection and punching shear capacity. Furthermore, the results assess the equation precision of the punching shear capacity including the equations of Canadian Standards CAN/CSA S806-12 [4].

Y.C Wang *et al* (2007) [5] studied the mechanical properties of FRP bars that used as an internal reinforcement in concrete structures at elevated temperature. Authors found that the stress-strain relationship remains almost linear at high temperature until failure. A numerical modelling was proposed by Adelzadeh *et al* (2014) [6] to investigate one way concrete slabs that reinforced with GFRP bars at elevated temperature and their results showed that the fire endurance of the slabs increases by increasing the thickness of the concrete cover and by changing the distribution of the reinforcement from one layer to two layer (using the same amount of GFRP bars). Kodure and Baingo (1999)[7] presented a numerical study to understand the behavior of concrete slab reinforced with FRP bars in fire and they found that the main factors that delay the failure of slabs reinforced with FRP bars under high temperatures are the thickness of the concrete cover and the type of the aggregate in concrete.

Abdolkarim Abbasi *et al* (2005) [8] proposed a model to predict the lifetime of concrete beams reinforced with GFRP bars at high temperature. Two beams were tested, and the model was found able to provide reasonable behavior in a good agreement with the experimental behavior. Hui Wang *et al* (2009) [9] presented a numerical study to predict thermal distribution and mechanical behaviour of FRP reinforced concrete columns under fire conditions. A finite element method was used to study the effect of section size and concrete cover thickness. Authors had found that, the concrete cover thickness plays an important role compared with the section size.

This study presents a temperature dependent Finite Element (FE) prediction of punching shear capacity of FRP reinforced flat slab at elevated temperature. Concrete Damage Plasticity CDP model available in Abaqus software was used to represent concrete material. Experimental behavior of six FRP reinforced flat slabs specimens collected from the literature, were used to calibrate the parameters of the CDP model. Then after, two cases of studies was chosen and numerically simulated fire conditions. Different values of concrete covers ranges between 20-40mm considered.

II. FINITE ELEMENT MODELLING

1. Meshing and simulation technique

The FE Abaqus Software was used to investigate the temperature dependent analysis throughout sequentially thermo-mechanical procedure. The proposed procedure consists of two main steps: First, a heat transfer analysis of the FRP reinforced concrete slab-column connection. Fire was assumed to affect the tensioned surface of the column slab connection. Second, the mechanical properties to evaluate the punching shear capacity by applying monotonic load at column area as shown in **Fig. 1.A** square slab with central square column is used for simulation. Due to the advantages of symmetry, one quarter of the specimen is used for this simulation as shown in **Fig. 1.** Three dimensional with eight nodes hexahedral element (DC3D8) and (C3D8) were used in the FE modelling to simulate the concrete in the thermal and mechanical analyses respectively. A Three dimensional with two nodes tie element (T3D2) was used to represent FRP bars in the mechanical FE modelling. In the mechanical modelling, a rigid element (R3D4) was used to represent supports at slab column connection.

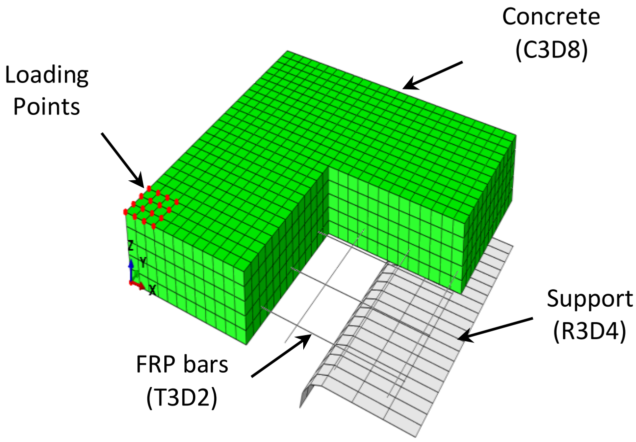


Fig. 1. Meshing elements of a slab-column connections

2. Materials

2.1 Concrete

Modelling of concrete media was performed using Concrete Damage Plasticity (CDP) model included in Abaqus software [10]. Hognestad parabola [11] was used to represent the uniaxial stress–strain behavior of concrete under compression which can be expressed as **(see Fig. 2a)**:

$$\sigma_c = f_c' \left(\frac{2\varepsilon_c}{\varepsilon_o} - \left(\frac{\varepsilon_c}{\varepsilon_o} \right)^2 \right) \qquad \textbf{Eq. 1}$$

Where $\varepsilon_o = 2f_c/E_c$, fc is the concrete compressive strength, Ec is the concrete modulus of elasticity; $E_c = 4700\sqrt{f_c}$ in MPa. Concrete was considered elastic until cracking initiation stage at the tensile strength f_{ct}; i.e. fct=0.33$\sqrt{f_c}$ in MPa [12]. Then after, cracking softening stage starts to take place. Two options available in Abaqus software to represent concrete tensile behavior [10]. Herein, stress-crack opening σ_t-w relationship was used instead of a stress–strain σ_t-ε_t..An exponential decay function was considered to describe the post cracking behavior (σ_t-w) of concrete, as shown in Fig 2b [13]. The fracture energy (G_f) was obtained as [14]:

$$G_f = 73 f_c^{0.18}/1000 \qquad \textbf{Eq. 2}$$

CDP model enables to evaluate degradation of concrete compression and tensile stiffnesses throughout d_c and d_t (≈0→1) damage parameters respectively [13]; d_c=1- σ_c/f_c & dt=1- σ_t/f_{ct}. Generally, CDP involves five main parameters which should be calibrated to provide accurate definition of concrete failure surface. These parameters are viscosity υ, dilation angle ψ, eccentricity of concrete ϵ, yield surface shape Kc and the ratio of equal-biaxial to uniaxial compressive yield stress σ_{bc}/σ_{uc} [15]. According to Abaqus user's manual, the default values of these parameter are; ψ=37, υ=0.0, Kc=2/3, ϵ=0.1 and σ_b/σ_u=1.16.

The specific heat and thermal conductivity of concrete were considered according to EN 1992-1-2[16] and as shown in Fig. 3a and 3b respectively, and the reduction of concrete compressive strength at elevated temperatures has been taken into consideration due to its highly temperature dependent[17] (see Fig. 4.). The density of concrete is a constant value of 2300 kg/m³.

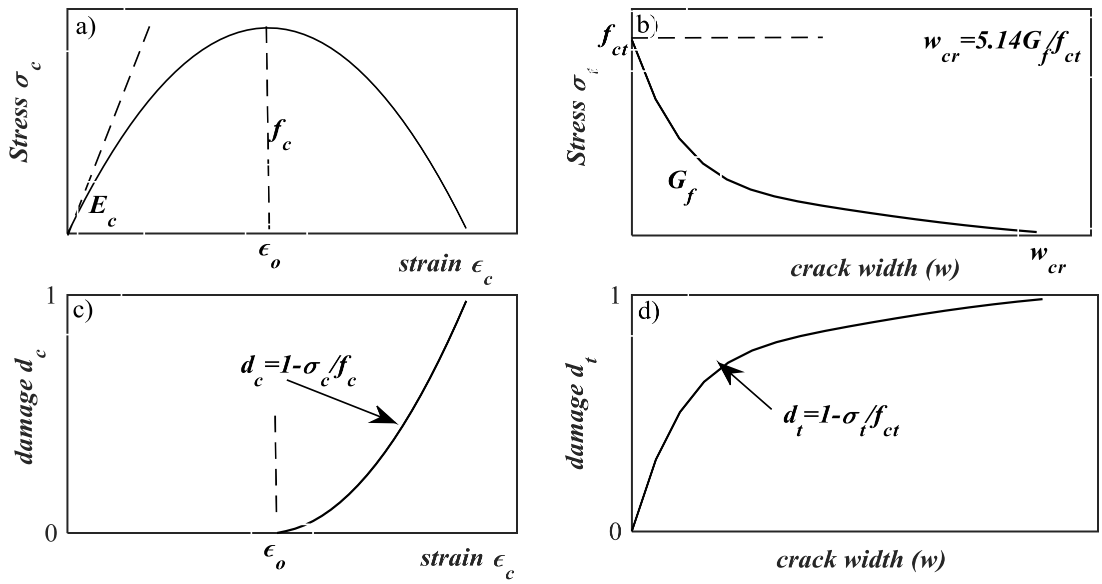


Fig. 2. Concrete compressive and post-cracking behavior.

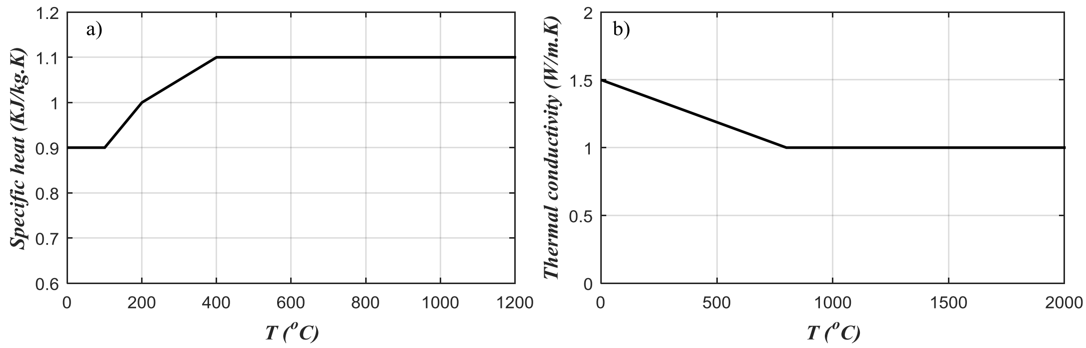


Fig 3. Thermal properties of concrete versus temperature [20, 21].

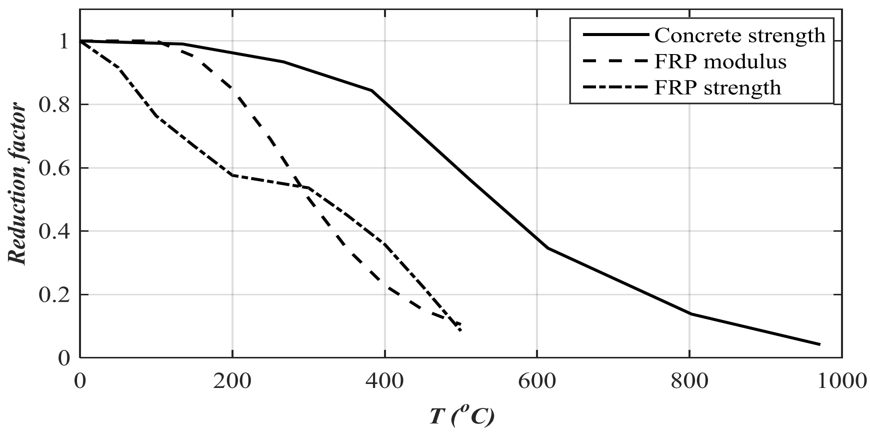


Fig. 4. Temperature reduction factor for the mechanical properties of concrete [17] and FRP bars [22, 5].

2.2 FRP

FRP bars were assumed linear elastic until failure. FRP bars was considered to have no effect on the heat transfer analysis. This due to the fact that, FRP bars were modelled as a line element and with an alignment perpendicular to temperature diffusion direction. Thus, there is no need to define their thermal properties (e.g. thermal conductivity and specific heat) in the numerical model. The variation in the FRP properties (modulus and tensile strength) in mechanical model were defined according to Nigro *et al* [22] and Y.C Wang *et al* (2007) [5] respectively and shown in Fig.5.

III. VERIFICATION

In order to validate the accuracy of FE analysis, 6 experimental specimens of concrete flat slabs reinforced with FRP bars tested by [3] were used. Specimens are of full-scale size and contain a variety of dimensions and reinforcement ratios. Table 2. presents all the details of used experimental dataset. An extensive try and error calibration procedure were carried out to obtain optimum values of CDP parameters that minimize the error between the experimental and the numerical load-deflection curves for the slabs in the experimental dataset. The key parameters in the calibration procedure are the υ, ψ, ϵ, Kc and σ_{bc}/σ_{uc}. Results of the calibration have indicated that υ and ψ affect significantly the structural behaviour of modelled slabs. Values of υ and ψ that could minimize the error were found equal to 0.00001 and 42 ^{o}C respectively. On the other hand, optimum values of the other CDP parameters were found equal to their default values recommended by Abaqus software. Fig. 5 show the load deflection curves based the calibration parameters. It can be noted that the numerical behavior matches well the experimental behavior. In addition, the bias ratio λ between the ultimate numerical $P_{u,n}$ and the experimental $P_{u,exp}$ loads was calculated for all specimens as shown in Fig 4. The CDP model could achieve a mean value and standard deviation of bias value λ of 0.99 and 0.042 respectively.

Table 2. Experimental data set collected from [3]

Current name	Ref name.	Concrete dimensions						Main reinforcement				Compression reinforcement			
		L (mm)	*S* (mm)	t_s (mm)	*cover* (mm)	*C* (mm)	f_c (MPa)	No	Φ	Fy (MPa)	Es (GPa)	No.	*Φ* (mm)	f_y (MPa)	E_f (GPa)
S1	G(0.7) 30/20	2500	2000	200	50	300	34.3	12	15	769	48.2	--	--	--	--
S2	G(0.7) 30/20-B	2500	2000	200	50	300	38.6	12	15	769	48.2	2	25	660	46.1
S3	G(1.6) 30/20	2500	2000	200	50	300	38.6	18	20	765	48.1	--	--	--	--
S4	G(1.6) 30/20-B	2500	2000	200	50	300	32.4	18	20	765	48.1	2	25	660	46.1
S5	G(1.2) 30/20	2500	2000	200	50	300	37.5	14	20	1334	64.9	--	--	--	--
S6	G(0.7) 45/20	2500	2000	200	50	300	45.4	12	15	769	48.2	--	--	--	--

Where *L* is the slab dimensions. *S* is the connection dimensions from support. T_s is the depth of the slab. C is the square column dimensions. F_c is the compressive strength of concrete. F_y is tensile strength of FRP. Es is the modulus of elasticity of FRP.

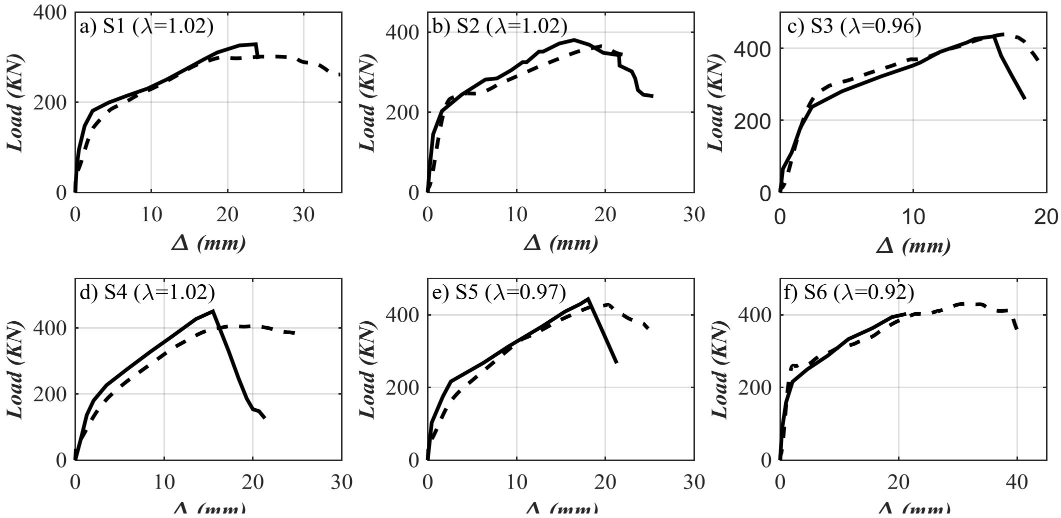


Fig. 5. Numerical and experimental results

IV. CASES OF STUDY

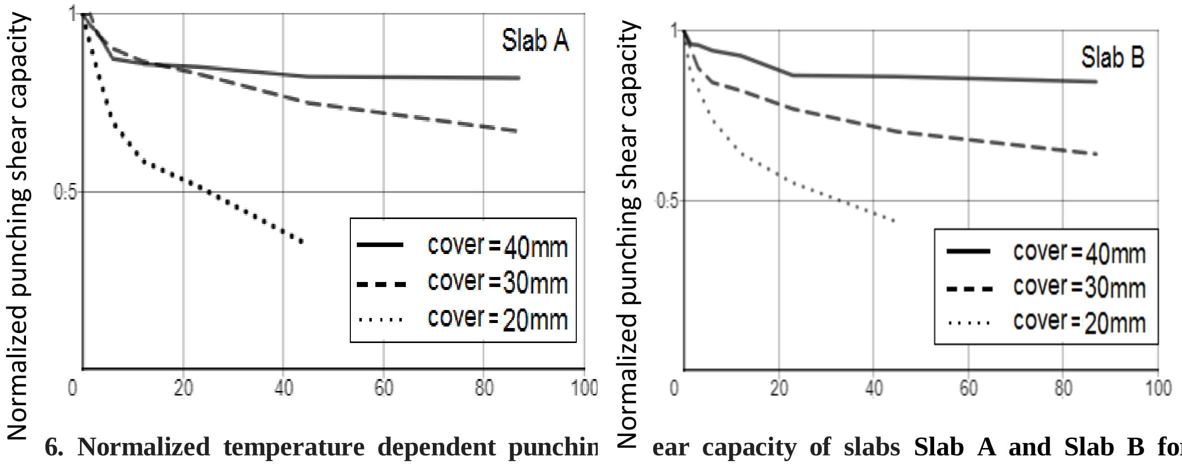
In order to study the effect of high temperature effect on a slab-column connection reinforced with FRP bars, two slabs were used in this study A and B (table 2). The influence of slab concrete cover at high temperature was studied because of the major effect of concrete cover thickness on the fire resistance of FRP-reinforced slabs [8]. Three values of concrete cover thickness were used 20, 30 and 40 mm and the results of the ultimate load were compared for each slab after exposed to temperatures from 0 to 1000˚.

Table 2. Details of slabs column connection used in the parametric studies

	Concrete dimensions						Main refinement		
	L (mm)	*S* (mm)	t_s (mm)	C (mm)	f_c (MPa)	No.	*Φ*	f_y (MPa)	E_s (GPa)
Slab A	2500	2000	200	300	34.3	12	15	769	48.2
Slab B	2500	2000	150	200	39	23	12	582	48

V. RESULTS

The modelling results showed that slabs fire performance increases by increasing the concrete cover thickness because increasing the concrete cover thickness delays the temperature transmission to reinforcement bars. As can be shown in Fig. 6.



6. Normalized temperature dependent punchin ear capacity of slabs Slab A and Slab B for different concrete covers.

VI. CONCLUSION

Predict the bunching shear capacity of two-way concrete flat slabs reinforced with FRP bars under elevated temperature. The general finite element (FE) software ABAQUS was used to perform the numerical modelling. Concrete damage plasticity model available ABAQUS software was used to represent concrete material. The parameters of numerical model were adopted using an experimental dataset to provide failure prediction of the desired behavior. In addition, the effect of increasing the thickness of the concrete cover at elevated temperature were studied. Results have shown that the concrete cover is a key parameter in delaying fire effects.

REFERENCES

[1]. Robert, M., & Benmokrane, B. (2010). Behavior of GFRP Reinforcing Bars Subjected to Extreme Temperatures. Journal of Composites for Construction, 14(4), 353–360.

[2]. ACI Committee 440. Guide for the design and construction of concrete reinforced with FRP bars. ACI 440.1R-06, American Concrete Institute, Farmington Hills, MI, USA; 2006.

[3]. Hassan, M., Ahmed, E. A., & Benmokrane, B. (2013). Punching shear strength of glass fiber-reinforced polymer reinforced concrete flat slabs. Canadian Journal of Civil Engineering, 40(10), 951–960.

[4]. Canadian Standards Association (CSA). 2012. Design and construction of building structures with fibre reinforced polymers (CAN/CSA S806-12). Rexdale, Ont., Canada.

[5]. Wang, Y. C., Wong, P. M. H., & Kodur, V. (2007). An experimental study of the mechanical properties of fibre reinforced polymer (FRP) and steel reinforcing bars at elevated temperatures.Composite Structures, 80(1), 131–140.

[6]. Adelzadeh, M., Hajiloo, H., & Green, M. (2014). Numerical Study of FRP Reinforced Concrete Slabs at Elevated Temperature. Polymers, 6(2), 408–422.

[7]. Kodur, V. K. R., and Baingo, D. _1999_. "Fire resistance of FRP reinforced concrete slabs." Technical Rep. No. IR758, National Research Council, Ottawa, Canada.

[8]. Abbasi, A., & Hogg, P. J. (2005). A model for predicting the properties of the constituents of a glass fibre rebar reinforced concrete beam at elevated temperatures simulating a fire test. Composites Part B: Engineering, 36(5), 384–393.

[9]. Hui Wang, Xiaoxiong Zha, and Jianqiao Ye (2009). Fire Resistance Performance of FRP Rebar ReinforcedConcrete Columns.

[10]. Nigro, E., Bilotta, A., Cefarelli, G., Manfredi, G., & Cosenza, E. (2012). Performance under Fire Situations of Concrete Members Reinforced with FRP Rods: Bond Models and Design Nomograms. Journal of Composites for Construction, 16(4), 395–406.

[11]. Genikomsou, A. A. and Polak, M. A. "Finite element analysis of punching shear of concrete slabs using damaged plasticity model in ABAQUS". *Journal of Engineering Structures* 98, 2015, pp38-48.

[12]. ACI 318 Committee. "Building code requirements for structural concrete". Farmington Hills. American Concrete Institute, 2014.

[13]. Coronado, C. A. and Lopez, M. M. "Sensitivity analysis of reinforced concrete beams strengthened with FRP laminates". Journal of Cement & Concrete Composites, 28, 2006, pp102–114.

[14]. Aikaterini Genikomsou (2015). Nonlinear Finite Element Analysis of Punching Shear of Reinforced Concrete SlabColumn Connections

[15]. Chanthabouala, K. and Teng, S. "Failures of Slabs Having Low Flexural Steel Ratios Subjected to Punching Loads". The 15 world congress on Advanced in structural engineering and mechanics ASEM15, Korea, 2015.
[16]. EN 1992-1-2. Eurocode 2: design of concrete structures. Part 1-2: general rules --- structural fire design. Brussels (Belgium): European Committee for Standardization; 2004.
[17]. Arna'ot, F. H., Abid, S. R., Özakça, M., & Tayşi, N. (2017). Review of concrete flat plate-column assemblies under fire conditions. Fire Safety Journal, 93, 39–52.
[18]. Elghazouli AY, Izzuddin BA. Analytical assessment of the structural performance of composite floors subject to compartment fires. Fire Saf J 2001; 36(8): 769-93.
[19]. Marechal JC. Variations of the modulus of elasticity and Poisson's ratio with temperature. In: Concrete for Nuclear Reactors. Detroit (MI): American Concrete Institute; 1972. p. 495-503 [Special publication].SP-34.
[20]. Guoqiang Wang, Peter J. Moss and Rajesh Dhakal (2006). Performance of reinforced concrete flat slabs exposed to fire.
[21]. Ershad Ullah Chowdhury (2009). Behavior of fibre reinforced polymer confined reinforced concrete columns under fire condition.
[22]. Nigro, E., Cefarelli, G., Bilotta, A., Manfredi, G., Cosenza (2014). Guidelines for flexural resistance of FRP reinforced concrete slabs and beams in fire. Composites Part B: Engineering, 58, 103–112.

Mariet ABD-MARIAM, et. al. "Numerical Analysis of FRP Reinforced Concrete Flat Slabs under Elevated Temperature."*American Journal of Engineering Research (AJER)*, vol. 10(1), 2021, pp. 79-84.