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Numerical study of the effect of FRP sheets on the cyclic behavior of concrete columns exposed to fire

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Abstract

Despite the widespread and successful use of FRP sheets in improving the seismic behavior of structures, the effect of FRP sheets on the strength of structural members under lateral load (such as concrete columns), especially at high temperatures, has received less attention. Therefore, in this study, while making sure the accuracy of numerical simulations, then, by numerical modeling of three-dimensional finite element columns of reinforced concrete columns in both non-reinforced and reinforced conditions with CFRP sheets and thermal coupling-displacement analysis of this model during cyclic lateral loading at different fire temperatures, the effect of reinforcement of reinforced concrete columns with FRP sheets on the cyclic lateral behavior of these columns at different fire temperatures has been investigated. From the results of these studies, It has been observed that following the incre ase of fire temperature from 250 to 1000 °C in both reinforced concrete columns and reinforced with FRP sheets, on the amount of lateral force, anchorage and energy of these columns during lateral loading of the cycle, the amount of lateral force, anchorage and energy of these columns during cyclic lateral bearing has been increased, which this increase (as the result of the increase in fire temperature) of the mentioned responses in the columns is more significant than the temperature of 500 °C and especially in the reinforced concrete columns reinforced with FRP sheets.

Keywords: Reinforced concrete column, FRP sheets, Fire heat, Cyclic loading, Finite element method, Abaqus software
2020 MSC: 91G60

1 Introduction

Numerous environmental factors affect the structure life reduction, including high temperatures and fires that always threaten structures. The non-flammable nature of concrete structures is a positive advantage of these structures against heat increase. High temperatures lead to obvious chemical and physical changes in concrete and sometimes concrete degradation. On the other hand, the weakness of concrete in its relatively low tensile and ductility, especially against dynamic loads and local stresses caused by these loads, has made the need to strengthen concrete members against seismic loading more than ever. Now, the widespread use of concrete structures in the country and the importance of columns in structures (as the most important and critical structural members), has necessitated special attention to concrete columns. In fact, the columns play the important role in the power transmission chain in the

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structure, even after the breakdown of other structural members (and consequently the removal of other structural members) columns can hold the members of a structure together and maintain the stability of the structure. Therefore, it is important to pay attention to the seismic behavior of concrete columns at high temperatures and seismic reinforcement of these members in these conditions. One of the methods of seismic reinforcement of concrete columns is the use of FRP sheets on the lateral surface of these columns. In recent years, FRP sheets have been widely and successfully used to improve the seismic behavior of structures. The excellent resistance of these sheets against corrosion, along with their very high weight-to-weight ratio, has made the reinforcement of the structure with these sheets, contrary to traditional methods (using shotcrete, etc.), does not apply extra weight to the structure and change the dynamic properties of the existing structure. Fiber-reinforced polymers (FRPs) are produced using fiber-based composites in a polymer resin environment, so that the fibers and resins are used to make multi-layer composites (such as resins used to bond multi-layer composites). Conventional coatings used for aesthetic purposes are not considered as part of FRP sheets. FRP materials are lightweight, corrosion resistant and have high tensile strength. These materials are available in a variety of forms (from factory multilayer sheets to dry sheets that can be twisted onto various structural shapes before adding resin). In most cases, FRP sheets processed into relatively thin profiles are desirable in execution, especially when the appearance of the work is finished or accessibility is considered. There is a growing tendency to use FRP sheets for the reinforcement of structures, for various reasons, the most important of which are the following:

- Although the fibers and resins used in FRP sheets are more expensive than other conventional materials such as concrete and steel, often, the costs associated with wages and equipment for installing FRP sheets are cheaper.

- These sheets can be used in areas with limited access or places where the implementation of conventional methods is difficult.

- Studies on reinforced concrete structural members with FRP exterior cladding have been more focused on concrete beams and slabs, while less attention has paid to the effect of FRP sheets on the strength of structural members under lateral bearing (such as concrete columns), especially in high temperatures. Adelzadeh and Hajiloo by two-dimensional numerical simulations of a series of reinforced concrete slabs with FRP under high uniform thermal loading, examined the fire resistance of the slab regardless of the slip of FRP rebars in concrete [3]. So far, as the result of the widespread use of concrete structures in the country and the importance of observing the principles of optimal design of columns in these structures and despite extensive studies on the separate knowledge of thermal behavior and seismic behavior of columns in these structures, still, few studies have been conducted on the seismic behavior of various types of concrete columns at high temperatures, especially concrete columns reinforced with FRP sheets. Wang et al. reinforced polymer sheets) [15]. Gillie also numerically simulated a cross section of a Concrete- Filled Steel Tube (CFT) under uniform high thermal loading and evaluated the temperature-time curve at different points of the cross section, presents a simplified two-dimensional numerical model (instead of a three-dimensional numerical model) to measure the temperature of different cross- sections of a fire-exposed CFT, while comparing the results of the numerical model with the results of the laboratory model [7]. Rodrigues and Júnior presented a simplified numerical procedure for predicting the temperature of concrete-steel composite columns exposed to fire by simulating a three- dimensional numerical simulation of a CFT composite column under uniform thermal loading and temperature evaluation in the said column [14]. This paper, first, using the measured data from a loading experiment performed (by Haji et al. in 2018 [8]) on a reinforced concrete column in two conditions, non-reinforced and reinforced with CFRP sheets ensures the accuracy of the numerical simulations and the software used for this purpose (Abaqus finite element software). Then, with three- dimensional numerical modeling of these laboratory samples by the mentioned software and analysis of thermal coupling - displacement of this models during cyclic lateral loading (cyclic nonlinear dynamic method) at different fire temperatures, the effect of reinforcement of reinforced concrete columns with FRP sheets on the cyclic lateral behavior of these columns at different fire temperatures is investigated. In the following, first, the method of these simulations is described and validated, and then, the results of the mentioned simulations are presented.

2 Numerical simulations

Abaqus software is a finite element numerical software with the ability to simulate three-dimensional structural members such as concrete members, steel, etc. [2]. Therefore, this paper adopts three- dimensional numerical simulations by Abaqus software using laboratory samples specifications by Haji et al. [8]. In fact, the desired fire heat has been applied to the lateral surface of the column and a set cyclic lateral displacement (cyclic lateral loading) has been applied to the upper surface of the column to analyze the models thermal coupling-displacement. The laboratory samples included reinforced concrete columns with a length and diameter of 600 and 200 mm, respectively with fully Carbon Fiber Reinforced Polymer sheets (CFRP sheets) covered lateral surfaces in the reinforced condition. During the experiment, we applied a set of uniform lateral displacement of 57.75 mm on the upper surface of the samples after applying a set of uniform vertical displacement of 20.07 mm on the upper surface of the samples. The lower surface of the samples is restricted to transitional and rotational displacements to stabilize the samples during the loading [8]. This section also described the steps of these simulations. Similarly, the description provided the models other specifications, as well.

2.1 Samples' modeling

A homogeneous concrete mass (length and diameter 600 and 200 mm, respectively [8]) with elastoplastic behavioral model (using a combined plastic-failure model for definition of concrete plastic behavior) was used in numerical modeling of columns (Figures 3 and 4), so that the specific gravity, compressive strength and Poisson ratio of concrete mass are 23.5 kN/m3, 30.61 MPa and 0.15 [8], respectively. Moreover, the simulations modulus elasticity of concrete mass (E_c) is obtained from the following regulatory relationship (ACI 318 regulation), based on this specific gravity and compressive strength [5]:

$$E_c = 15000\sqrt{f_c'} \tag{2.1}$$

where, f_c' , is the characteristic compressive strength of concrete in kilograms per square centimeter. On the other hand, the specific heat capacity, thermal conductivity and thermal expansion coefficient are 970 $^{\mathrm{J}}/_{\mathrm{kg\,Kelvin}}$, and 1.14 wattmeter Kelvin and 0.0000117 units per degree Celsius [7, 10] is used for the concrete mass. The simulations, define the plastic properties and behavior of the concrete mass after defining the physical, thermal and elastic characteristics of mass. Hence, a plastic-failure model is used for concrete, which is a continuous plastic model for considering the concrete failure criteria (through the two main mechanisms of concrete rupture, namely tensile cracking and compressive crushing) [6, 12]. Now, first, it is necessary to establish the relationship between stress and compressive strain of concrete, for which the simulations used the following relation (Kent and Park relation in 1971) [9]:

$$\sigma_c = f_c'\left[2\left(\frac{\epsilon_c}{\epsilon_c'}\right) - \left(\frac{\epsilon_c}{\epsilon_c'}\right)^2\right] \tag{2.2}$$

where σ_c and ϵ_c are stress and compressive strain, respectively, and f_c' and ϵ_c' are the compressive strength of concrete (30.61 MPa in the simulations, respectively) and the corresponding strain (0.002 in the simulations and according to Park and Paulay report in 1975 [13]. This relation creates a parabolic in which the behavior of concrete becomes linear after reaching the compressive strength of concrete and continues until it reaches 20% of this strength, because concrete at high compressive strains, maintains about 20% of its strength pressure [9]. Thus, in these simulations, according to the mentioned parabolic relation, the compressive plastic strains have been calculated for the compressive yield stresses and have been used to define the compressive plastic behavior of the concrete mass. Furthermore, to establish the relationship between stress and tensile strain of concrete, it is necessary to define a percentage (about 7 to 10%) of the compressive strength of concrete as the tensile strength of concrete (f_t') and consider elastic and linear behavior for concrete (until reaching tensile strength) [9]. Therefore, in the simulations, the tensile strength of concrete is considered the 10% of the compressive strength of concrete. Structural members of Truss with diameters of 16 and 8 mm (for longitudinal and transverse reinforcements of the column) [8] have been used in numerical modeling of longitudinal and transverse reinforcements in concrete mass, for which a complete elastoplastic behavioral model (which is the elastic steel behavior until it reaches the yield stress) and its physical and mechanical properties are considered according to Table 1 [8]. On the one hand, the specific heat capacity,thermal conductivity and thermal expansion coefficient for the longitudinal and transversal buried reinforcements in concrete mass are 460 $^{\mathrm{J}}/_{\mathrm{kg\,Kelvin}}$, and 45 wattmeter Kelvin and 0.0000117 units per degree Celsius, [7, 10], respectively.

Table 1: Specifications of steel used in reinforcements [8]

Diameter (mm)	γ ($^{\mathrm{kN}}/_{\mathrm{m}^3}$)	E (MPa)	ν	f_y (MPa)	f_u (MPa)
8	78.5	201959.18	0.3	494.8	628.82
16	78.5	207779.17	0.3	498.67	658.48

In Table 1, γ, E, ν, f_y and f_u are the specific gravity, modulus of elasticity, Poisson ratio, yield strength and steel final strength applied on longitudinal and transverse reinforcements, respectively.

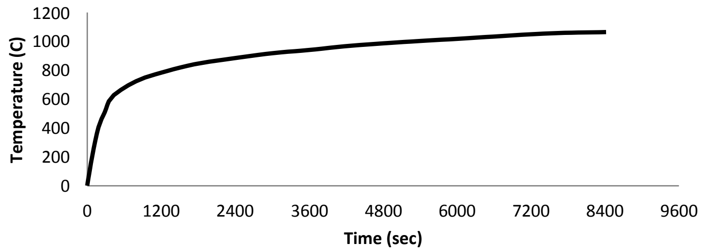

Figure 1: Time curve - standard fire temperature [1]

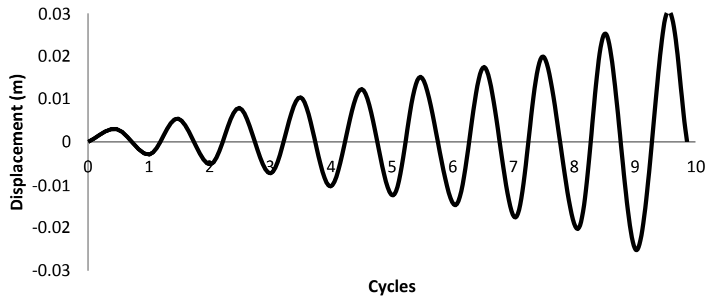

Figure 2: Cyclic lateral displacement curve applied to the upper surface of the column in models [11]

Homogeneous and dissimilar Shell structural member with a thickness of 5 mm was used in numerical modeling of CFRP sheets on the lateral surface of reinforced concrete mass. This member has an elastic-failure and physical and mechanical models according to Table 2 [8]. It is assumed that this member is completely attached to the lateral surface of the reinforced concrete mass (Figure 4). On the other hand, the specific heat capacity, thermal conductivity and thermal expansion coefficient are 1500 $^{\mathrm{J}}/_{\mathrm{kg\,Kelvin}}$, and 0.577 wattmeter Kelvin and 0.0000144 units per degree Celsius, [4] for CFRP sheets on the lateral surface of the reinforced concrete mass.

Table 2: Specifications of CFRP sheets in the reinforced laboratory sample

γ $(^{\mathrm{kN}}/_{\mathrm{m}^3})$	$E\,(\mathrm{MPa})$	ν	$\sigma_t(\mathrm{MPa})$
17.9	230000	0.22	3900

In Table 2, E and σ_t are the sheets modulus of elasticity and tensile strength, respectively, and γ and ν are the CFRP sheets specific gravity and Poisson ratio, respectively.

2.2 samples boundary conditions and thermal-cyclic coupling loading modeling

The prescribed cyclic lateral displacement (as shown in Figure 2 [11]) is also applied to the upper surface of the columns, while applying the desired heat (T) by the fire (based on ISO 834 according to Figure 1) [1] to the lateral surface of the columns during thermal-cyclic loading (during thermal - displacement coupling of models by cyclic nonlinear dynamic method) to achieve lateral force, flexural moment and energy of numerical models.

All transitional and rotational displacements in the bottom of the column are retrained for the stability of numerical models (Figures 3 and 4).

The 8-node thermal continuous three-dimensional solid mass elements (under the name C3D8T in Abaqus software [2]), 2-node three-dimensional thermal Truss linear structural elements (under the name T3D2T in Abaqus software [2]) and 4-node thermal Shell structural elements (under the name S4T in Abaqus software [2] were used in concrete mass meshing in models, longitudinal and transverse reinforcements meshing in this mass, and CFRP sheets on the lateral surface of the reinforced concrete mass meshing, respectively.

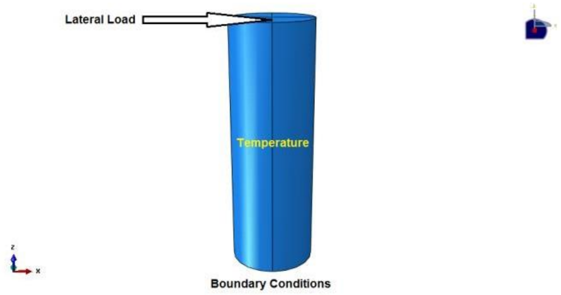

Figure 3: Geometry of non-reinforced column

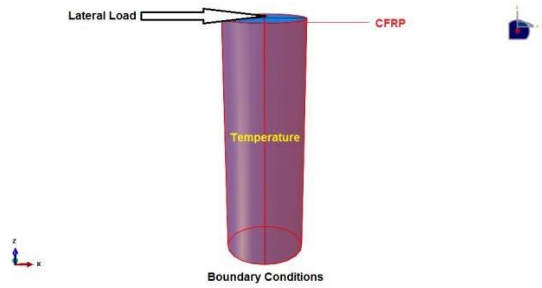

Figure 4: Geometry of CFRP sheets reinforced column

2.3 Numerical simulations validation

The lateral bearing of the samples was evaluated during the application of the uniform steady lateral displacement (during nonlinear static analysis) to the upper surface of the samples to validate the numerical simulations, in addition to the three-dimensional numerical simulations of the laboratory samples of Haji et al., and the results are compared with the bearing measured from the experiments (Figure 5).

Figure 5 shows the good agreement between the amount and trend of lateral bearing and finally the lateral behavior of both non-reinforced and reinforced samples with CFRP sheets (numerical overlay curve of lateral to vertical displacement ratio - lateral bearing of sample), with this bearing and the measured behavior of the experiments (laboratory cover curve of lateral to vertical displacement ratio - lateral bearing of the samples). This ensures the accuracy of the numerical simulations and the Abaqus software. This figure also shows a significant increase (about 162%) in the lateral bearing of CFRP sheets reinforced concrete columns (compared to unreinforced reinforced concrete columns).

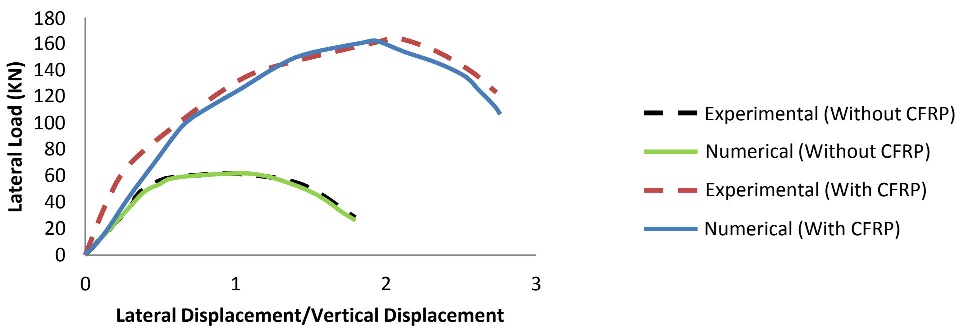

Figure 5: Comparison of numerical curves (present study) and laboratory [8] behavior of non-reinforced and reinforced samples with CFRP sheets (ratio of lateral displacement to vertical displacement - lateral bearing of specimens)

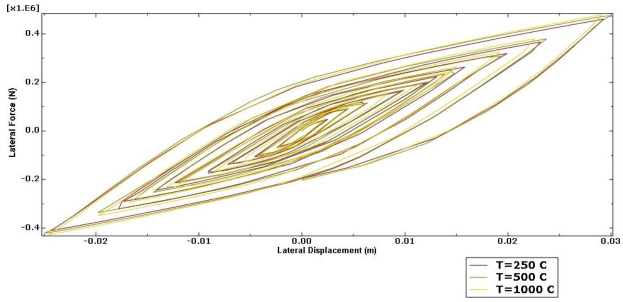

Figure 6: Effect of heat on the lateral force of the RC model during cyclic lateral loading

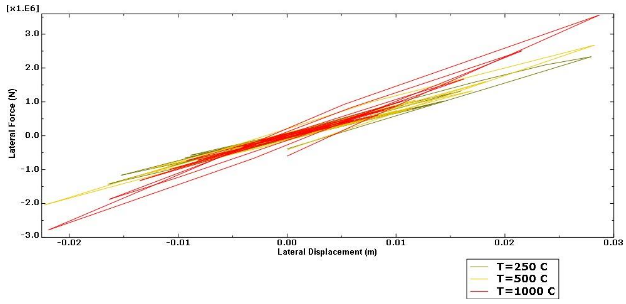

Figure 7: Effect of heat on the lateral force of the RC-CFRP model during cyclic lateral loading

3 Evaluate and review the results of numerical simulations

Now, we are assured about the accuracy of the numerical simulations. Thus, we examine the effect of reinforcement of reinforced concrete columns with FRP sheets on the cyclic lateral behavior of these columns at different fire temperatures, in accordance with Figures 6, 7, 9, 10, 12 and 13, by evaluating the lateral force, flexural moment and energy of the non-reinforced column (under the name of RC model) and the CFRP sheets reinforced column (under the name RC-CFRP model) during cyclic lateral loading of these models at standard fire temperatures of 250, 500 and 1000 °C and, according to Figures 8, 11 and 14, with the evaluation of dimensionless parameters of Percentage increase of lateral force $\left(\frac{\Delta F}{F250^\circ C}\right)$, percentage increase of flexural moment $\left(\frac{\Delta M}{M250^\circ C}\right)$, and percentage increase of energy $\left(\frac{\Delta E}{E250^\circ C}\right)$ models. It should be noted that in the mentioned parameters, F250°C, M250°C, and E250°C are the maximum amount of lateral force, flexural moment and energy of each model at standard fire temperature of 250 °C , respectively with ΔF, ΔM and ΔE as the maximum difference of the lateral force, flexural moment and energy of each model, respectively, following the increase of the standard fire temperature in the model from 250 to 500 and 1000 degrees Celsius.

Figure 6 shows that following the increase of the standard fire temperature in the reinforced concrete column (from 250 to 1000 °C), the lateral force of the colu mn increases slightly during the lateral cyclic loading (about 3% from 250 to 500 °C) and about 1% from 500 to 10 00 °C). This small increase (about 4% as the result of the increase in temperature from 250 to 1000 °C) of the cyclic lateral force of the reinforced concrete column, up to a temperature of 500 °C, is more noticeable (about 3%). Because the occurrence of volumetric strains as the result of heat increase (especially up to 500 °C) in the reinforced concrete column, leads to a small increase (about 4%) of stresses and finally the column forces during cyclic lateral loading.

Figure 7 shows that by increasing the standard fire temperature in FRP sheets reinforced concrete columns (from 250 to 1000 ° C), the lateral force of the co lumn during cyclic lateral loading increases by about 15% from 250 to 500 °C and about 38% from 500 Up to 1000 °C, which an increase of (about 53% as the result of the increase in temperature from 250 to 1000 ° C) of the cyclic lateral force of the FRP sheets reinforced concrete column, from the temperature of 500 degrees Celsius is more significant (about 38%). This is because the occurrence of volumetric strains as the result of heat increase (especially from 500 ° C) in FRP sheets reinforced concrete columns (as the result of the high coefficient of thermal expansion of FRP, ie 0.0000144 units per degree Celsius compared to 0.0000117 units (Degrees Celsius for concrete), leads to an increase (about 53%) in the stresses and ultimately the forces of this column during

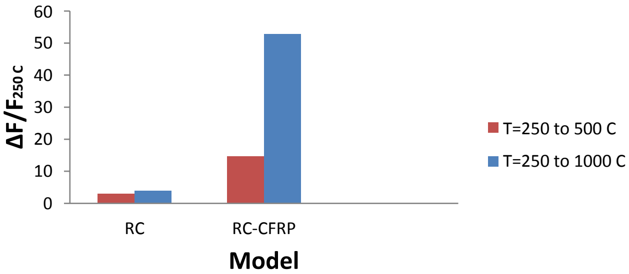

Figure 8: Comparison of percentage increase (as the result of heat increase) of lateral force of models during cyclic lateral loading

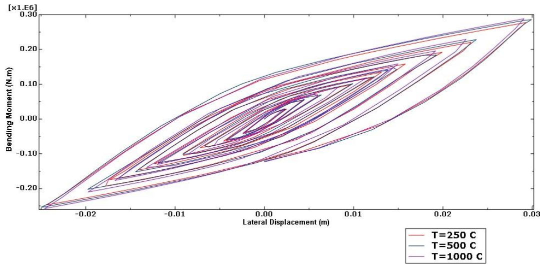

Figure 9: The effect of heat on the flexural moment of the RC model during cyclic lateral loading

cyclic lateral bearing. However, the effect of heat (especially temperatures below 500 ˚C) on increasing the lateral force of FRP sheets reinforced concrete columns during cyclic lateral bearing can be reduced by reducing the thickness of FRP sheets.

Figure 8 also shows that following the increase in standard fire temperature in both unreinforced concrete columns and FRP sheets reinforced columns (from 250 to 1000 ˚C), the amount of lateral force of these columns during cyclic lateral loading increases (about 4% for the RC model and about 53% for the RC-CFRP model); and increase in the cyclic lateral force of the column (as the result of increased heat) from 500 ˚C, is specifically significant in reinforced concrete columns (about 1% for the RC model and about 38% for the RC-CFRP model). Because the occurrence of volumetric strains as the result of heat increase (especially from 500 ˚C) in the column, leads to increased stresses and ultimately the column forces during the cyclic lateral loading in the FRP sheets reinforced concrete column (as the result of the high coefficient of thermal expansion of FRP, i.e. 0.0000144 units per degree Celsius compared to 0.0000117 units per degree Celsius for concrete), the percentage increase (as the result of increased heat) of stresses and finally the cyclic forces of the column (especially from 500 degrees Celsius), is also more significant (about 38%). Therefore, it can be said that the FRP sheets reinforced concrete columns reinforcement has significantly increased the sensitivity of reinforced concrete columns to heat during cyclic lateral loading (about 49% for the RC-CFRP model compared to the RC model). This increases (as the result of heat increase) on the cyclic lateral force of reinforced concrete columns is also more significant (about 38%) than 500 ˚C.

Figure 9 shows that following the increase in standard fire temperature in a reinforced concrete column (from 250 to 1000 ˚C), the flexural moment of the column during cyclic lateral loading is slightly increased (about 3% from 250 to 500 ˚C and about 1% from 500 to 1000 ˚C) that this small increase (about 4% as the result of the increase in temperature from 250 to 1000 ˚C) is more significant with reinforced concrete columns cyclic flexural moment at up to 500 ˚C (about 3 percent). Because the occurrence of volumetric strains as the result of heat increase (especially up to 500 ˚C) in the reinforced concrete column, leads to a small increase (about 4%) of stresses and forces and finally the moments of the column during cyclic lateral bearing.

Figure 10 shows that following the increase in standard fire temperature in FRP sheets reinforced concrete columns (from 250 to 1000 ˚C), the amount of column flexural moment is slightly increased during cyclic lateral bearing (about 15% of 250 to 500 ˚C and about 39% from 500 to 1000 ˚C) that this small increase (about 54% as the result of heat increase from 250 to 1000 ˚C) in cyclic flexural moment of FRP sheets reinforced concrete columns is more significant (about 39%) than 500 degrees Celsius. Because the occurrence of volumetric strains as the result of heat increase (especially from 500 ˚C) in FRP sheets reinforced concrete columns (as the result of the high coefficient of

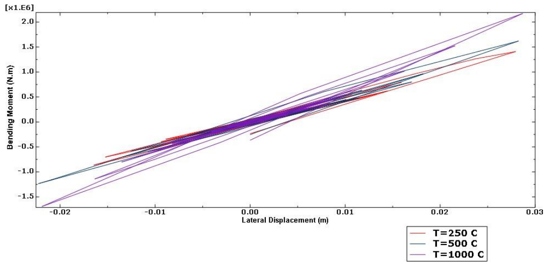

Figure 10: Effect of heat on the flexural moment of RC-CFRP model during cyclic lateral loading

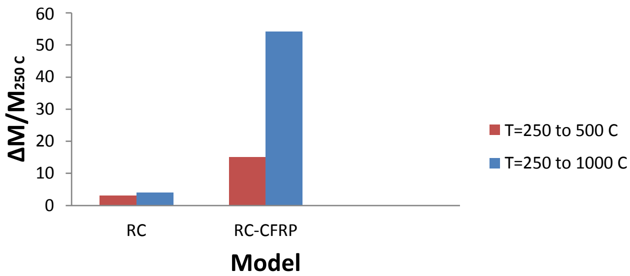

Figure 11: Comparison of percentage increase (as the result of heat increase) of flexural moment of models during cyclic lateral loading

thermal expansion of FRP, i.e. 0.0000144 units per degree Celsius compared to 0.0000117 units (Degrees Celsius for concrete), leads to an increase (about 54%) in the stresses and forces and finally the moments of this column during cyclic lateral loading. However, by reducing the thickness of FRP sheets, it is possible to reduce the effect of heat (especially temperatures below 500 ˚C) on increasing the flexural moment of FRP sheets reinforced concrete columns during uniform lateral loading.

Figure 11 also shows that following the increase in standard fire temperature in both unreinforced concrete and FRP sheets reinforced columns (from 250 to 1000 ˚C), the amount of flexural moment of these columns has increased during the cyclic lateral loading (about 4% for the RC model and about 54% for the RC-CFRP model), this increase is more significant on FRP sheets reinforced columns (about 1% for the RC model and about 39% for the RC-CFRP model). Because the occurrence of volumetric strains as the result of increased heat (especially from 500 ˚C) in the column, leads to an increase (about 4% for the RC model and about 54% for the RC-CFRP model) stresses and forces and finally the moments of the column during lateral bearing in the FRP sheets reinforced concrete column (as the result of the high thermal expansion coefficient of FRP, i.e. 0.0000144 units per degree Celsius compared to 0.0000117 units per degree Celsius for concrete), the percentage increase (as the result of the increase in temperature, the stresses and forces and finally the cyclic anchors of the column (especially from the temperature of 500 ˚C) are also more significant (about 39%). Therefore, it can be said that the reinforcement of FRP sheets reinforced concrete columns has significantly increased the sensitivity of heat-reinforced concrete columns during cyclic lateral bearing (about 50% for the RC-CFRP model compared to the RC model), which increases this percentage (as the result of the increase in temperature, the cyclic flexural moment of reinforced concrete columns is also more significant (about 39% for the RC-CFRP model) than 500 ˚C.

Figure 12 shows that following the increase in standard fire temperature in a reinforced concrete column (from 250 to 1000 ˚C), the energy of the column is slightly increased during the cyclic lateral bearing (about 6% from 250 to 500˚ C and about 4% from 500 to 1000 ˚C). This relatively small increase (about 10% as the result of the increase in temperature from 250 to 1000 ˚C) also increases the energy of the reinforced concrete column up to 500 ˚C (about 6%). Because the occurrence of volumetric strains and ultimately the stresses and forces as the result of the increase in flow (especially up to 500 ˚C) in the reinforced concrete column, leads to a relatively small increase (about 10%) of the column strain energy during cyclic lateral bearing.

Figure 13 shows that following the increase in standard fire temperature in a FRP sheets reinforced concrete column (from 250 to 1000 ˚C), the column energy is increased during cyclic lateral loading (about 29% of 250 Up to 500 ˚C and about 91% from 500 to 1000 ˚C) that this increase (about 120% as the result of heat increase from 250

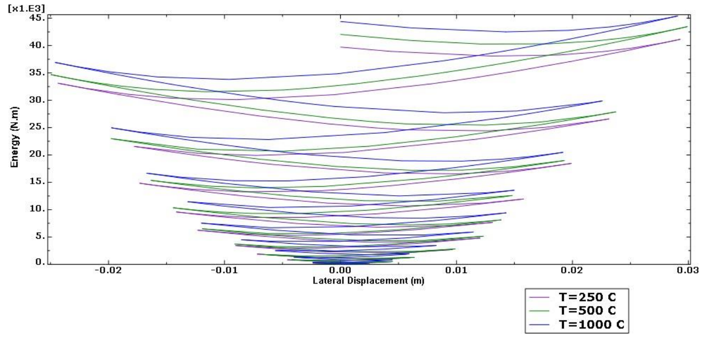

Figure 12: The effect of heat on the energy of the RC model during cyclic lateral loading

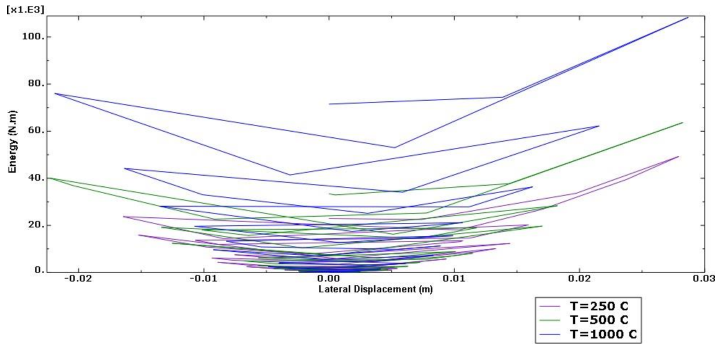

Figure 13: The effect of heat on the energy of the RC-CFRP model during cyclic lateral loading

to 1000 ˚C) is more significant in FRP sheets reinforced concrete column from 500 ˚C Celsius (about 91%). Because the occurrence of volumetric strains and finally stresses and forces as the result of heat increase (especially from 500 ˚C) in the FRP sheets reinforced concrete column (as the result of the high thermal expansion coefficient of FRP, i.e. 0.0000144 units per degree Celsius (0.0000117 units per degree Celsius for concrete), leads to an increase (about 120%) in the strain energy of this column during cyclic lateral loading. However, by reducing the thickness of FRP sheets, the effect of heat (especially temperatures below 500 ˚C) on increasing the energy of FRP sheets reinforced concrete columns during cyclic lateral bearing can be reduced.

Figure 14 also shows that following the increase in standard fire temperature in both unreinforced reinforced and FRP sheets reinforced concrete columns (from 250 to 1000 ˚C), the energy of these columns during cyclic lateral bearing (about 10% for the RC model and about 120% for the RC-CFRP model) has increased that this increase (as

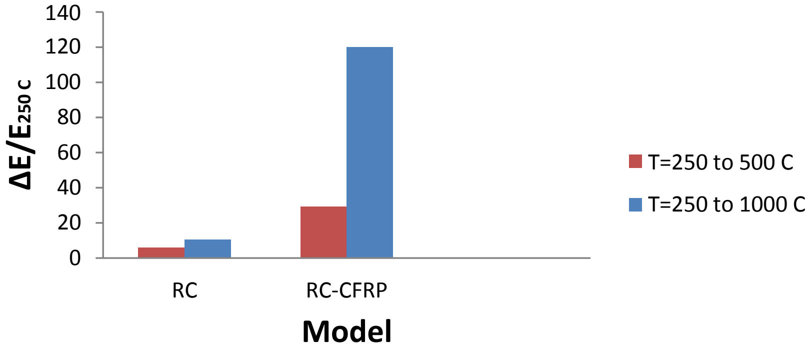

Figure 14: Comparison of percentage increase (due to heat increase) of models' energy during cyclic lateral loading

the result of increased heat) of the column energy is more significant than the temperature of 500 ˚C and especially in reinforced concrete columns (it is about 4% for the RC model and about 91% for the RC-CFRP model. Because the occurrence of volumetric strains as the result of heat increase (especially from 500 ˚C) in the column, leads to an increase (about 10% for the RC model and about 120% for the RC-CFRP model) stresses and forces and finally the strain energy of the column during lateral loading. This increase percentage is more significant in FRP sheets reinforced concrete column (as the result of the high thermal expansion coefficient of FRP, i.e. 0.0000144 units per degree Celsius compared to 0.0000117 units per degree Celsius for concrete), also the increased strain energy (as the result of increased heat) (especially from 500 ˚C) is also more significant (about 91%). Therefore, it can be said that the FRP sheets reinforced concrete columns has significantly increased the sensitivity of heat-reinforced concrete columns during cyclic lateral loading (about 110% for the RC-CFRP model compared to the RC model), which increases this percentage (as the result of the increase in heat) and energy of reinforced concrete columns is more significant (about 91%) than the temperature of 500 ˚C.

4 Conclusion

This paper evaluated the accuracy of numerical simulations followed by non-reinforced and CFRP sheets reinforced columns (under the name of the RC model). -CFRP) evaluations considering the lateral force, flexural moment and cyclic lateral loading energy of the models at standard fire temperatures of 250, 500 and 1000 ˚C. The following results are obtained:

- Following the increase of standard fire temperature (from 250 to 1000 ˚C), the amount of lateral force, flexural moment and energy of the columns are increased during the lateral cyclic loading in both non-reinforced concrete columns and FRP sheets reinforced concrete columns. This increase is more significant (as the result of the increase in heat) at the cyclic responses of the column, than the temperature of 500 ˚C, especially in reinforced concrete columns.

- Occurrence of volumetric strains as the result of heat increase (especially from 500 ˚C) in the column, leads to increased stresses and finally forces, moments and strain energy of the column during the cyclic lateral loading in the FRP sheets reinforced concrete column (as the result of the high thermal expansion coefficient of FRP), the percentage increase (as the result of heat increase) stresses and finally the forces, moments and strain energy of the column (especially from 500 ˚C), is also more s ignificant. Therefore, it can be said that the FRP sheets reinforcement of reinforced concrete columns greatly increases the sensitivity of reinforced concrete columns to heat during cyclic lateral loading.

- By reducing the thickness of FRP sheets, it is possible to increase the effect of heat (especially temperatures below 500 ˚C) on increasing lateral force, flexural moment and energy of FRP sheets reinforced concrete columns during cyclic lateral loading.

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