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NONLINEAR BEHAVIOR ASSESSMENT OF REINFORCED CONCRETE FRAMES BY CARBON FIBER REINFORCED POLYMERS UNDER BLAST LOADING USING FINITE ELEMENT METHOD

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Abstract: This paper focuses on the numerical nonlinear analysis of blast pressure wave propagation on CFRP reinforced buildings. The frequency and severity of missile attacks and terrorist operations have led to the need for building strengthened structures against these danger. The implementing of extreme and immediate explosive energy imposed to buildings needs special requirements. Also, the CFRP reinforced structures shows their ability in facing to various types of dynamic loads such as earthquakes, winds and waves. Their ability to respond to such intense loads is evaluated in this research.
A fully nonlinear 2-span, 3-story ordinary and CFRP reinforced frame is modelled then subjected to three different intensity of blast loadings (explosive material's weight). Then the nonlinear responses of models (maximum stress, displacements and maximum reflectivity pressure based on UFC code) are compared to show the performance of these structural reinforcement member. In the following, the effect of the member's coverage rate by CFRP is investigated.
The carbon fiber in CFRP composites shows the great strength and stiffness during stretching [1]. The concrete nonlinearity is explicitly implemented and its behavior is expressed using elastic damaged isotropic and tensile stresses [2]. Also, the nonlinearity of steel is modelled using the Von Misses failure criteria and the ASTM A572 [3, 4]. Finally, the blast loads are calculated based on a presented principle equation proposed by [9] according to atmosphere pressure, scaling factor and mass of blasting substance.
The wave propagation of blast loads on the concrete frame was simulated using a three-dimensional model of finite element in ABAQUS/CAE 6.10-1 software. For the modelling concrete, a solid element is used from software library. The C3D8R Element is selected for properly applying concrete nonlinearity, ordinary and CFRP reinforcing. For longitudinal and transverse reinforcement of frame, the B31 two-node truss element is selected. Finally, the S4R, 4-node shell element used for modelling the CFRP parts.

1 INTRODUCTION

Explosion is a very fast release of energy in the form of light, heat, sound and shock wave. The shock wave consists of a very dense air that moves quickly from the center of explosion outward with ultrasonic velocity. By the expansion of the shock wave, the value of pressure decreases rapidly (proportional to distance, the third factor) and reflects after reaching a rigid surface, and its amount may increase up to thirteen times. The magnitude of the reflection coefficient is in close proximity of the explosive and the angle of the hitting wave. Pressure also decreases exponentially.

In loading of an explosive, the loading time is very short and it is usually expressed in terms of milliseconds.

These days, due to the unpleasant spread of the threat imposed to human life by explosion, the analysis and designating of important structures such as military, governmental and fundamental, and utilities against these loads are not anymore a costly conservatism but an inevitable necessity. Regarding explosive analysis and designing, due to the nature of these charges and applications of the building and also observing economic issues, different levels of performance for the structure under the explosive load are considered. On the other hand, using modern approaches and efficient materials the structure can be reinforced [1].

Structure of the buildings can be effective in minimizing or reducing damage, in terms of behavior, against the effects of explosions. Reinforced concrete buildings can be better in large explosions, because they have a massive capacity to absorb more energy than steel buildings; other advantage of concrete is that it can also resist alone against compressive loads. On the other hand, the strain is tolerated by the bars, while in steel buildings; steel has the same capacity for pressure and tension [2].

The explosion wave results from the rapid rise in air pressure from the atmospheric point to the peak explosion pressure, which results in a rapid reduction in the atmospheric pressure of the substrate and ending with a gradual increase in atmospheric pressure. Therefore, the explosive wave has two phases. The rapid rise in pressure that results in an atmospheric increase is called positive phase or pressure phase and a decrease in atmospheric pressure that leads to a return to the atmospheric state is called negative phase or suction phase. At a certain distance from the site of the explosion, through time, the pressure of that place suddenly rises to reach its peak. Then, the pressure drops too slowly and goes down to the normal pressure and even lower [3].

The massive loads imposed to the materials for a short period of time do not fall under the category of the static and dynamic loadings. Due to the impossibility of gaining comprehensive knowledge of the explosion, in many cases, computer-based solutions are well-suited for precise simulation. Knowledge of these cases is useful in analyzes and studies performed in this field [4].

In order to increase the strength of the structure against the explosion-induced loads, there are some commonly applied solutions, among which the most important are the use of local reinforcement such as steel covers and concrete covers for structural sections, as well as adding new structural systems such as a composite cutting steel wall. One of the disadvantages of such methods is that, it imposes significant gravity loads on the structure and ultimately on the foundation, and on the other hand, it requires a lot of time to install, thus it will not be financially favorable. An effective and economical approach to this goal is applying CFRPs to strengthen parts. CFRP composites have been used for about 50 years in structural engineering in the fields of fabrication, retrofit, reinforcement, restoration and refurbishment of existing structures. Over the last decade, a significant growth has been observed in the use of CFRP materials, which are an advanced form of composites. CFRP materials are composite materials which include highly resistant fibers that are put in a polymeric area [5].

The fibers in a CFRP composite are the main bearer and they exhibit very high strength and stiffness while stretching. CFRP composites are nowadays proposed as a substitute for steel due to their higher resistance, increased corrosion resistance and the convenience of carrying and installing them. Many composites have a very high resistance to fatigue. Unlike steel, CFRP composites do not suffer a gradual softening compared with reciprocating loads or a reduction in hardness prior to any cracking. As a very important advantage, unlike steel, CFRP composites have a high corrosion resistance. Composite materials acts auto tropically under thermal loading due to different thermal expansion coefficients in the same direction with fibers and perpendicular to the fibers. Thus, they stand safe against the thermal activities. But in materials like steel due to their anisotropic nature severe destructions take place under thermal pressures. These materials are capable of adapting themselves with the circumstances and they indicate appropriate reaction. Making use of these materials also can lead to considerable increase in the strength of the structure against explosion and decrease of cracking effects by increasing the resistance of the structure [6].

In this study, the issue of the effect of explosion on a concrete frame was simulated using a three-dimensional of finite element model. Then, the effects of explosions on CFRP composite fibers and their dynamic response, was investigated based on their features and characteristics. In this model, the beam is modeled using a Wire element. Shell reinforcement sheet with four-sheathed elements, and concrete frame with three dimensional element of Solid were modeled. In this model, the effect of the explosion is put on the frame surface as an external pressure.

Crawford et al. (1997) studied the columns reinforced by CFRP sheets. In this experimental study, they studied the effect of reinforcing method of concrete columns on CFRP sheets [1]. In 2009, Shie et al. reviewed the pressure-shock diagram and predicted the damage rate of concrete columns under explosive loading and they presented their proposed method for predicting damages [6].

Zhou et al. (2009) has also studied the behavior of steel and concrete structures with different shapes and conditions under the influence of explosive loading. By comparing concrete and steel structures under explosion, they found that the performance of concrete structures is better. Also, in the case of the effect of the shape of structures, the structures that have lower perpendicular surfaces to the explosion, the performance of spherical structures is better than cubic structures [7].

Astari et al. (2007) studied the behavior of reinforced concrete columns under axial and transverse burst loads. He has introduced a model with single degree of freedom which is developed to examine the behavior of explosive-reinforced concrete pillars under explosion. According to the results, the magnitude of the axial load on the behavior of the reinforced concrete column under the explosion is so important that even if the axial load is half of the critical axial load of the column, it reduces its capacity against the side load of the explosion [15].

In 2008, Arlree et al tried to simulate the columns of concrete numerically and examined the rate of damage and reduction of load capacity of the column under the explosion load. In this study, a numerical method was proposed to simulate the behavior of concrete artillery columns under the close explosion field and the remaining cargo capacity was estimated. Using ABAQUS software, they showed that among the changed parameters of the column, thickness, the radius of explosion charge and the ratio of the distance to this radius had the most important effects; the height, width and compressive strength of the concrete in the column had less effect on the Explosive response. Also, by providing an empirical formula, they predicted the amount of damage inflicted on concrete [16].

In 2010, Li et al, carried out a numerical study on crushing of the concrete columns under the explosion load. In this study, a three-dimensional model was simulated and validated in comparison with laboratory samples. With a strong simulation, they dealt with various parameters of the column under the explosion and they observed that the amount of crushing of the concrete depends on the distance of the explosion, the strength of the concrete column and the boundary conditions. Although the depth of the column and the type of rearmament also has a significant impact on the rate of destruction, by increasing the depth of the column and the reinforcement, destruction rate decreases [17].

Ghani et al. Have studied the behavior of concrete slabs reinforced with polymeric composite under explosive loading [19] and used CONWEP software to calculate explosion loading parameters. In all conducted laboratory and numerical studies, reinforcement of concrete slabs with FRP sheets has led to increased load capacity, reduced sample deformation after the explosion and improved performance of the reinforced sample.

Pedro and Hao showed in laboratories that reinforcement in both the tensile and compression sides is essential under the explosion in composite sheets [20]. However, the conducted studies have been more of a tentative laboratory test. Therefore, the present study attempts to carry out a numerical evaluation of the reinforcement of concrete slabs with FRP sheets. Parametric studies also include the effect of increasing the strength of concrete, FRP strength, the age of steel bars and thickness FRP beams.

2 METHODOLOGY

2.1 Explosive loads

Buildings can be effective in decreasing or minimizing damages in terms of behavior against the effects of explosions. Because concrete Reinforced buildings have a massive capacity to absorb more energy than steel buildings, they can indicate better reaction in large bursts; the other advantage of concrete is that it can also withstand compressive loads by itself. On the other hand, the stretch is tolerated by the bars, while in steel buildings steel has the same capacity for pressure and strain.

The explosion wave results from the rapid rise in air pressure from the atmospheric point to the peak explosion pressure, which results in a rapid reduction in the atmospheric pressure of the substrate and then a gradual increase in atmospheric pressure. Therefore, the explosive wave has two phases. The rapid rise in pressure that results in an atmospheric increase in the name of a positive phase or a pressure phase and a decrease in pressure to the atmospheric pressure that leads to a return to the atmospheric state called the negative phase or suction phase.

At a certain distance from the site of the explosion, through time, the pressure of that place suddenly rises to reach its peak. After that, the pressure drops too slowly and goes down to the ambient pressure and even lower.

In the explosion, a law is called the scaled interval is used to find other parameters of these values. The amount of pressure and impact released from the explosion on structures is comparable to empirical formulas, all of which are derived according to the scaled interval law. The relationship between the maximum pressure and the explosion at a given distance is given by the following formula [8, 11].

When the explosion wave reaches a level that is in the direction of the explosion, it is reflected that, as a result, the pressure from the explosion will be multiplied. Unlike pink waves with a magnification of about 2%, the shockwaves can be amplified by up to 20 times due to the ultrasound velocity of the shock. The features of the buildings which have already been subject to explosion can be summarized in FEMA 427 under the following three cases [2].

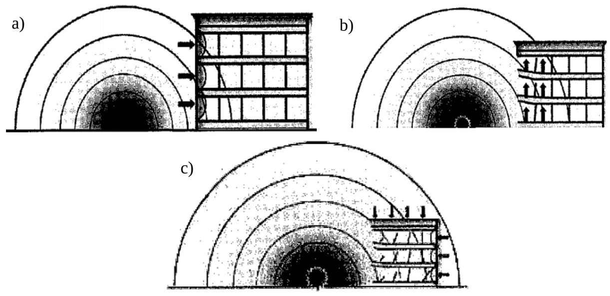

Figure 1: Damage to building resulted from the blast in mode a) 1, b) 2 and c) 3 [2]

Mode 1. When the explosion wave collides with the closest external side of the building, all of the glasses are crushed and the columns are deformed under the influence of the return waveform (figure 1-a). Mode 2. by the expansion of the explosion wave around the building, an additional pressure is imposed on the roof, the perimeter walls and the walls far away from the explosion site. The internal pressure penetrating from the openings typically enters downward pressure and an upward pressure on the floor slabs (figure 1-b). Mode 3. The frame of the building is the last part that reacts to the explosion. The following figure shows the further deformation of the frame against the explosive charge. Prefabricated concrete buildings should be designed in such a way that they do not act in the explosion phenomenon, such as picking up of a number of cards (figure 1-c). The failure is mainly due to the loading caused by the rubble of other floors. Therefore, the designer should pay special attention to the design of fittings, compression tension reinforcement and shear and bending steel.

Also, the following figure shows how the explosion-induced waves are propagated on the ground (figure 2).

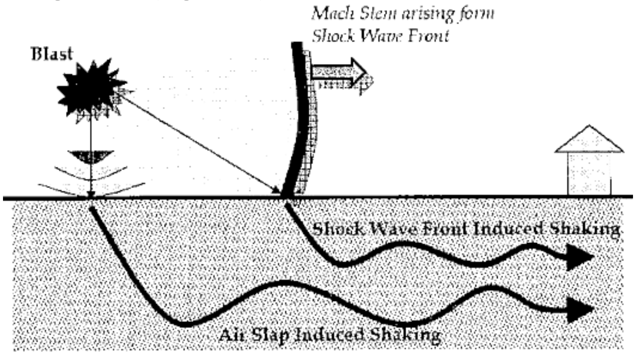

Figure 2: The emission of waves from the explosion on the ground [9]

The first mechanical effect of the explosion is the sudden jump of ambient air pressure to a higher value and producing strong winds. As a result of the explosion, the environmental pressure has risen to a maximum within a short time. This value is called the maximum overpressure (Pso). The overpressure is gradually reduced and the pressure of the medium returns to its initial pressure. Following the reduction of pressure, suction or negative pressure in the environment, the pressure finally returns to its normal state. Thus, the characteristic of an explosive wave is a sudden jump of air to a level above the pressure of the atmosphere, then a gradual reduction of pressure to the extent which results in loss of excessive pressure. This process continues, and the pressure becomes a negative pressure (suction), and therefore the air pressure falls below the atmospheric pressure. The pressure variations in terms of time are given in the following figure [10, 12, and 13].

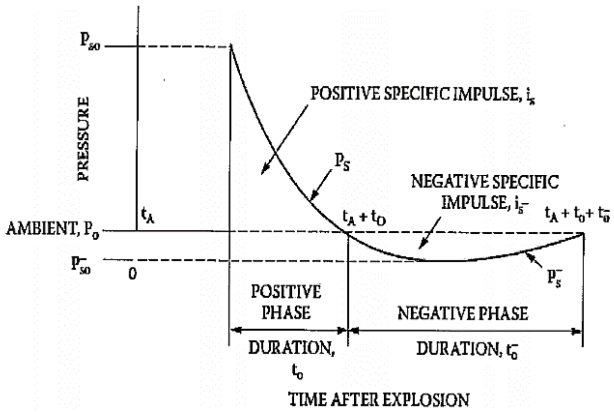

Figure 3: Sudden rise of ambient air pressure and its gradual reduction due to explosion [10]

The period of time during which the air pressure is above the atmospheric pressure is called the durability period or the durability of positive phase and is displayed with td. Typically, the maximum value of the negative pressure generated is less than the maximum permissible pressure and the type of explosion, the height of the point of the ground (HOB) for bombs that explode in space, and the distance from the measured location from the center of explosion site. After the explosion wave moves from the explosion to the surrounding area, the mass flow of the air behind the wave of the explosion forms as intense winds. These winds are expanded rapidly in the direction of explosion wave. Thus, the concept of dynamic pressure is formed. Dynamic pressure is indicated by q0 symbol. The amount of dynamic pressure is firstly the dependent on of the density of air that the explosion wave passes through and, secondly, it depends on the velocity of the wind coming from the pressure side [11, 18].

The explosion-induced loads on building surfaces are given bellow as diagrams of variations of explosion pressure trough time consistent with TM-855-1 regulation [21].

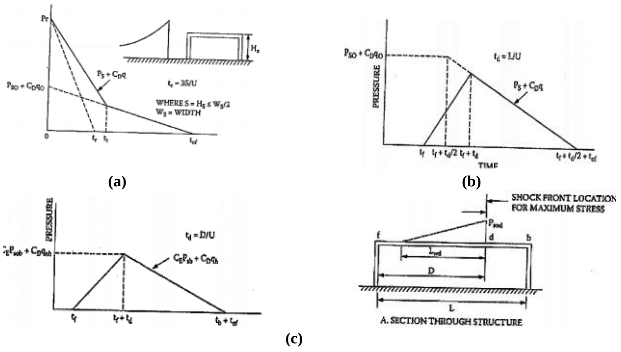

Figure 4: Typical loading types on the structural components, (a) installations of the Front wall, (b) Roofing and side walls (direction of the span parallel to the explosion wave), (c) Loading the roof and side wall (vertical direction of the span Explosion) [21]

In the explosion, a law called the scaled interval is used to find other parameters. The purpose of the simulation of concrete reinforced frame with the columns reinforced by composite fibers is to simulate the behavior of this structure under an explosive charge of 20 kilograms of TNT at a distance of 10 meters from it [14]. So.

$$Z_G = \frac{R}{\sqrt[3]{W}} = \frac{10 \times 3.28}{\sqrt[3]{(20 \times 2.2)}} = 9.3\ ft/lb^3 \qquad (1)$$

Where R is the distance from the explosion and W is the explosive material equivalent to TNT.

The amount of pressure and hit released from the explosion on structures is comparable in empirical formulas, all of which are derived according to the law of scaled interval. The relationship between the maximum pressure and the explosion at a given distance is given by the following formula [12].

$$P/P_a = \frac{808\left[1+\left(\frac{z}{4.5}\right)^2\right]}{\sqrt{1+\left(\frac{z}{0.048}\right)^2}\sqrt{1+\left(\frac{z}{0.32}\right)^2}\sqrt{1+\left(\frac{z}{1.35}\right)^2}} \qquad (2)$$

Where P is the pressure of the explosion and pa is the pressure of the atmosphere. Z is also a scale parameter calculated from the following equation.

2.2 Concrete nonlinearity

In this model, nonlinear behavior is expressed using elastic damaged isotropic and tensile stresses. This model can be applied in static and dynamic computing.

2.2.1 Tensile cracks

Completion of the stretch level is controlled using and the hardening variables $\varepsilon_t^{pl}, \varepsilon_c^{pl}$ which are related to the failure mechanisms under compressive and tensile loading, respectively. In fact, $\varepsilon_t^{pl}, \varepsilon_c^{pl}$ are equivalent to plastic. The concrete stress-strain diagrams are presented in single axis stretching and pressure bellow. Due to uniaxial stretching, the stress-strain curve varies linearly which is associated with the onset and expansion of tiny cracks in concrete. Passing through that point, they appear as visible cracks, which are represented by a softening curve in the strain stress space (figure 5).

2.2.2 Pressure crackups

Under the uniaxial pressure, the response will be elastic to the point of flow, and the behavior in the plastic region is generally expressed as a hardening curve, which ultimately becomes a curvilinear curve by reaching the final stress. In spite of its relative simplicity, this model satisfies the basic concrete properties [21].

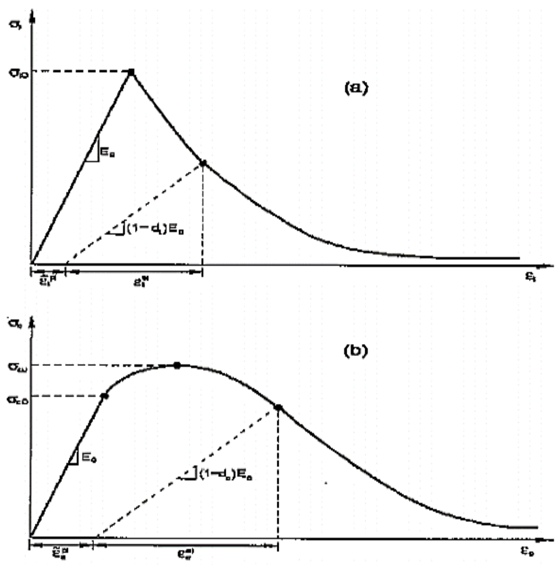

Figure 5: Concrete response under uniaxial loading (a) at strain elasticity, (b) at pressure [7]

Stress-strain diagrams under uniaxial

loading have the ability to convert to plastic stress-strain curves, which is done automatically by ABAQUS software using given stresses and non-elastic strains inserted into the software [8].

$$\sigma_t = \sigma_t\left(\varepsilon_t^{pl}, \dot{\varepsilon}_t^{pl}, \theta, f_i\right) \quad (3)$$

$$\sigma_c = \sigma_c\left(\varepsilon_c^{pl}, \dot{\varepsilon}_c^{pl}, \theta, f_i\right) \quad (4)$$

Where $(\varepsilon_t^{pl}, \varepsilon_c^{pl})$ are the plastic strain equivalent to pulling and pressing. $\varepsilon_t^{pl}, \varepsilon_c^{pl}$ Are the rate of plastic strain equivalent to tension and pressure, as well? Temperature and other field variables are defined [8].

2.2.3 Mechanical features of Concrete

Here, the density of concrete is 2450 kg/m3, the modulus of elasticity and the Poisson coefficient for mechanical properties in the elastic state are 0.64 and 2.64 MPa, respectively. Also, regarding the definition of the behavioral model of plastic damage model of the concrete, the nonlinear behavioral model of concrete obeys the following figure [12].

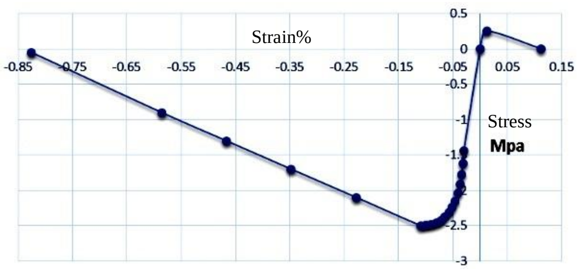

Figure 6: Nonlinear Behavioral Model of Concrete [12]

2.3 Mechanical features of Steel

Nonlinear behavior with kinematic hardening is selected for all species. The plastic behavior of the model is selected based on the Von Misses fluctuation test and the ASTM A572 stress-strain chart. According to Fig. 5, Young's modulus, the Poisson coefficient of 0.3 and density of 7850 are considered [10]. And nonlinear behavioral model of steel is consistent with figure (7).

Table 1: Mechanical features of steel

density	modulus of elasticity	poison's ratio
$7850\,{kg}/{m^3}$	$2.1\times10^6\ kg/cm^2$	0.3

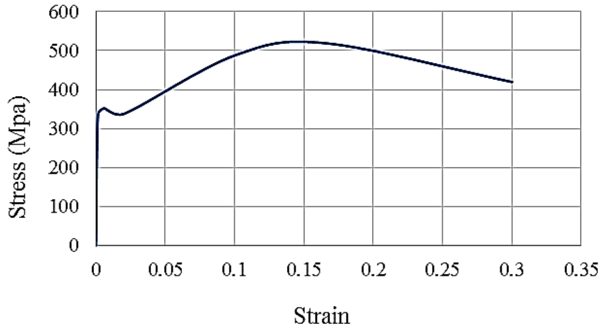

Figure 7: Non-linear behavioral model of steel [11]

2.4 Mechanical features of CFRP Composite

The mass of the volume unit of composite fibers is 1200, the modulus of elasticity and its Poisson coefficient are 22GPa and 0.3 respectively, and its behavior is considered to be linear [12].

2.5 Finite element model

The selected model is a reinforced concrete frame with two spans and three floors. Its columns are 40 cm in size. Dimensions of beams like columns are square and dimensions are 40 in 40 cm. The height of the floors is 3 meters and the length of the span is 4 meters.

Table 2: Geometric Specifications of Concrete Frame

D of the column (cm)	L of the bar (cm)	H of the story	L of the opening	slabs of the column	bars	strip
40*40	40*40	3	4	16 P	20 P	10 P

The concrete frame is equipped with longitudinal and transverse reinforcements. The longitudinal reinforcement of the column is of a graded one of size 16, the number of which is 8 at the cross section. The longitudinal reinforcements of the beams were of a size 20, with four armatures placed in four corners of the section. Rebar size is 10, which are located in interval of 10 cm in beams and frame pillars. The columns of Concrete frame are reinforced by 0.44 mm thick CFRP fibers, and in order to ease numerical modeling, they have been considered in integrated forms and completely covered around the pillars. The purpose of this chapter is to investigate the effects of explosions in this strengthened reinforced concrete frame.

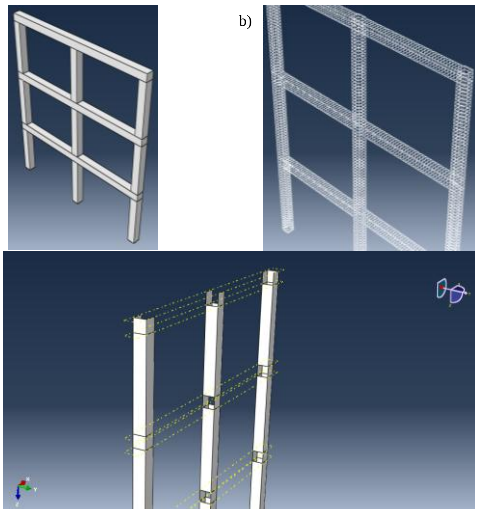

Figure 8: Geometric view of a) concrete frame, b) reinforcements and c) CFRP

3 ANALYZING THE NUMERICAL MODEL

3.1 Investigating explosion rates

In Fig. 7, the results of the tensile stress are shown in the last analysis time, and the numerical results are presented below.

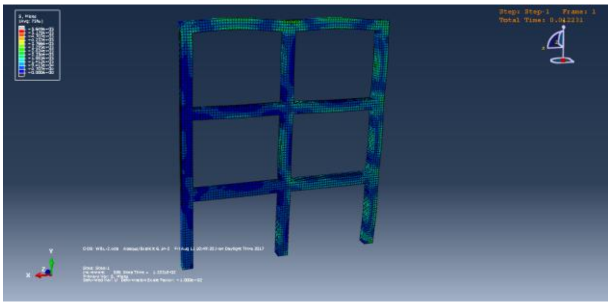

Figure 9: Tension contour in the modeled frame

In order To evaluate the retrofitting method with CFRP sheets, reinforced and non-reinforced concrete columns are evaluated. In this study, according to the UFC regulations the values of 1.2 for concrete and steel yield stress and 1.05 for the final stresses of steel, the behavior of the columns under bending explosion loading was determined based on the dynamic increase frequency (DIF) [12] .

Table 3: The three explosion rates considered in this research

Number of the explosion	TNT (kg)	Z (m/kgl/3)	P_r (Mpa)	T_0
1	15	1.7	2.1	4.8
2	30	1.2	3.5	6.4
3	65	1	6.9	7.1

The values of P_r and t_0 are the maximum reflectivity pressure of the explosion and its time length, which are adopted from UFC Code. Performing nonlinear dynamic analysis on non-reinforced and reinforced samples under these three loading rates, it is observed that the column without reinforcement of these three explosive loading rates in the explosion number 2 enters completely into the plastic zone, and it could not bear the explosion number 3. However, the reinforced pillar tolerated all three explosion rates and had acceptable forms. The maximum value of displacement (Xm) and maximum tensile stresses in the longitudinal and transverse grooves of the species are shown in Table 4.

Table 4: Maximum values of displacement and maximum stresses of the steel

Number of the explosion	Maximum strain tension (MPa)		Xm
	Longtudinal steel	Traverse steel	
Not reinforced column			
1	167	247	27
2	495	370	177
3	-	-	-
Reinforved column			
1	60	15	2
2	67	51	5
3	315	294	16

The results above are derived from nonlinear dynamic analysis by the ABAQUS finite element software. The positive effect of retrofitting RC columns with CFRP sheets is clearly observable.

3.2 Investigation reinforcing rates

For the frame concrete, a library Element of Solid is used; since the shape is geometrically considered irregular, or by applying appropriate partitions, it is split into regular shapes so that a neat meshing pattern can be obtained. The result of this partitioning is generating a layout with features; Sixteen-Node Element shape, Structured Technique, the Standard Library Element from the 3D Stress Family, and finally the C3D8R Element Selection. For longitudinal and transverse reinforcement of beams and columns, a Beam element and a two-node truss type are used, which is part of the software known as the B31 Element. For the CFRP part, the 4- knot Shell element is also used. This element is known as the S4R Element in ABAQUS software.

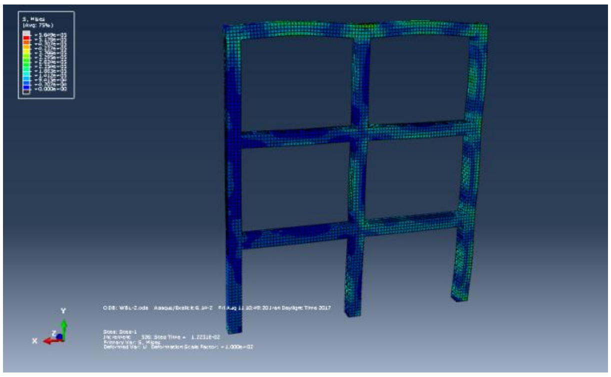

Figure 10: Tension contour in the modeled frame

To strengthen the columns, the four layout modes of the fibers are considered as the percentage of covering area and two frame-level two-story and four-story frameworks, which provide a total of 8 different modes. As it is clear in the research, with the increase of CFRP, the circumference of the columns, displacement and shear force decreased significantly. The models performed in the software are in the following form, some of which are visible in the following pictures.

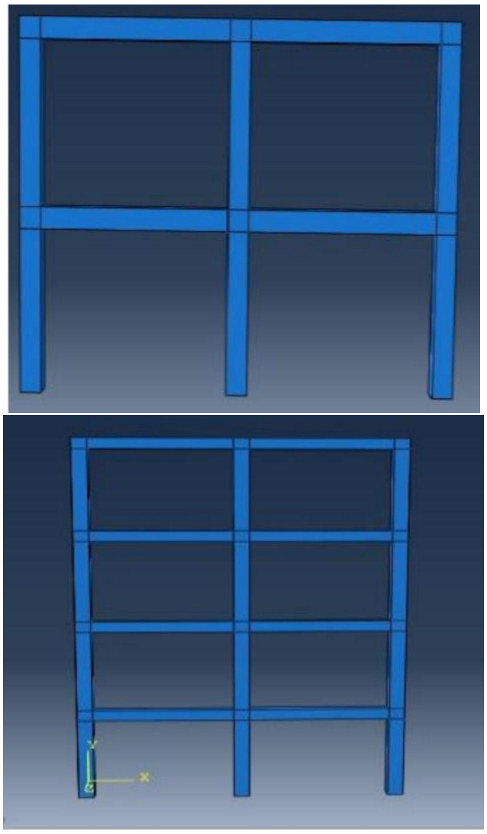

Figure 13: Modeling of two-story and four-story concrete frame

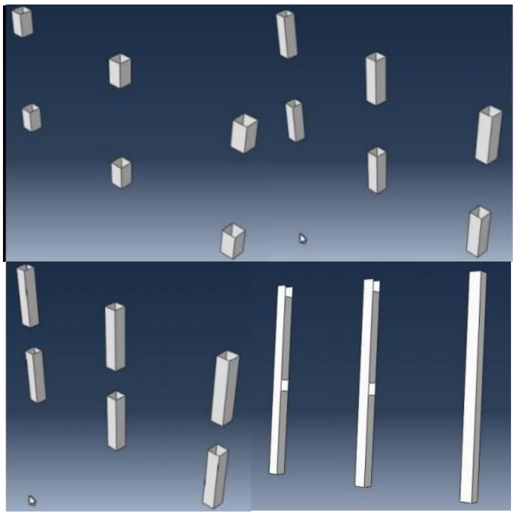

Figure 14: The alignment of the CFRP columns in four modes. 25%, 50%, 75%, and 100%

The results of numerical analysis for the two-story and four-story models can be seen in the following tables and figures.

Table 4: Results of analysis for two-story and four-story models

Number of story	Peripheral % of Columns with Fiber CFRP	Max Disp of the frame (cm)	Maximum tension of Long steel (MPa)	Maximum cutting base (KN)
2 story	25%	2.82	450	420
	50%	1.32	380	690
	75%	0.87	360	970
	100%	0.20	280	1200
4 story	25%	5.1	486	560
	50%	2.98	4.1	745
	75%	1.75	390	1115
	100%	0.98	310	1500

4 CONCLUSION

In this study, by using finite element modeling, the behavior of the column and reinforcement with CFRP sheets under explosive loading were studied. According to the numerical results, it can be concluded that the reinforcement using CFRP sheets has had a significant effect on the reduction and displacement of the column and tension in steel bars. This value for the maximum displacement is about 30%. Also, by the increase of loading values, the effect of improving the performance of reinforced columns increases. It was observed that the maximum tension was in the longitudinal columns, where, after loading, the tension reduced by about 43%. Among the different levels of the column under the explosion, side of the structure facing the explosion is of particular importance and the back sides and left and right sides of the explosion are respectively of less importance.

In the third model that the weight of the explosive of 65 kg and the scale factor of 1, due to the proximity of explosive materials and its high weight, the frame without the fibers is completely destroyed, while in the equipped state, the frame has been able to maintain its function . The loading significant in the 4-story frame is more than two-story frame. In this comparison the increase in the sheer force of the two-story building to four story building increases by about 25%. But it is expected that the increase in the number of stories should not have a completely direct relationship with the increase in the basic cutoff points in the explosion phenomenon.

The higher rate of the reinforcing surface with the fibers concluded the more absorbing energy. So, as expected, for a 25-% increase in the equipped surface, in both the 2 and 4 story frames, 30% increase in the base cutting force is seen. This issue, conversely, occurs at the maximum displacement of the crown of the frame and the maximum tension. As the rigidity of the columns increases due to the increase of the illustrated surface, the deformation decreases and the strain decrease in proportion to that. This decrease in the values for maximum displacement and tension outputs increases up to 30% and 20% respectively by increasing 25 % of the enclosed level.

Finally, in the 4-story model, the maximum displacement of the frame crown increases because of the higher height of the 2-story model and the increase in the loading surface. This increase is about 100 %. This means that these changes are almost linear in relation to the height of the frame.

REFERENCES

[1] J. E. Crawford, L. J. Malvar, J. W. Wesevich, J. Valancius, and A. D. Reynolds. 1997. Retrofit of reinforced concrete structures to resist blast effects. *ACI Structural Journal*. 94:371–377.

[2] UFC 3-340-02. 2008. *Structures to resist the effects of accidental explosions*. US army corps of engineers, naval facilities engineering command, Air force civil engineer support agency, United States of America.

[3] DoD 6055.09-STD. 2008. *Ammunition and explosives safety standard*. US Department of Defense. USA. US.

[4] W. Kravfsourd, D. Zhang, F. Lu, S.C. Wang, F. Tang. 2012. Experimental study on scaling the explosion resistance of a one-way square reinforced concrete slab under a close-in blast loading.

International Journal of Impact Engineering. 49:158-164.

[5] G. Louchinie, J. Hetherington, T. Rose. 1999. Response to blast loading of concrete wall panels with openings. *Journal of Structural Engineering*. 125:1448-1450.

[6] P.F. Shie, B. Lu. 2009. Blast resistance capacity of reinforced concrete slabs. *Journal of Structural Engineering*. 135:708-716.

[7] X. Zhou, V. Kuznetsov, H. Hao, J. Waschl. 2008. Numerical prediction of concrete slab response to blast loading. *International Journal of Impact Engineering*. 35:1186-1200.

[8] H. Hibbitt, B. Karlsson, P. Sorensen. 2012. *ABAQUS Theory Manual: Version 6.12*. Pawtucket, Rhode Island, USA.

[9] J. Li and H. Hao. 2014. Numerical study of concrete spall damage to blast loads. *International Journal of Impact Engineering*. 68:41–55.

[10] Smith, S. T. and Teng, J. G. 2001. FRP strengthened RC Structure. *Engineering Structures*. 94:158–171.

[11] Baker, J.F., Leader Williams, E. and Lax, P. 1948. *The design of framed buildings against high explosive bombs, The Civil Engineer in War*. UK Institution of Civil Engineers, London.

[12] Khalid M. Mosalam, Ayman S. Mosallam. 2001. *Nonlinear transient analysis of reinforced concrete slabs subjected to blast loading and retrofitted with CFRP composites*. University of California, Berkeley.

[13] P. Kmiecik and M. KamiŃSki. 2011. Modelling of reinforced concrete structures and composite structures with concrete strength degradation taken into consideration. *Archives of Civil and Mechanical Engineering*. 11:623-636.

[14] P.F. Fiuze, B. Lu. 2007. Improving the blast resistance capacity of RC slabs with innovative composite materials. *Composites Part B. Engineering*. 38:523-534.

[15] A. Astari, A. Tolba, E. Contestabile. 2007. Blast loading response of reinforced concrete panels reinforced with externally bonded GFRP laminates. *Composites Part B. Engineering*. 38:535-546.

[16] A. Arlree, I. Anteby, E. Gal, Y. Kivity, E. Nizri, O. Sadot. 2008. Full-scale field tests of concrete slabs subjected to blast loads. *International Journal of Impact Engineering*. 35:184-198.

[17] Y. Li, Z.X. Shie, H. Hao. 2010. A new method for progressive collapse analysis of RC frames under blast loading. *Engineering Structures*. 32:1691-1703.

[18] J. Khaled, H. Hao. 2011. A two-step numerical method for efficient analysis of structural response to blast load. *International Journal of Protective Structures*. 2:103-126.

[19] R. Ghani, D. P. Thambiratnam, N. J. Perera, V. Kosse. 2011. Blast and residual capacity analysis of reinforced concrete framed buildings. *Engineering Structures*. 33:3483-3495.

[20] X. Pedro, H. Hao. 2009. Mesoscale modelling and analysis of damage and fragmentation of concrete slab under contact detonation. *International Journal of Impact Engineering*. 36:1315-1326.

[21] Army Technical Manual. 1998. *TM5-855-1: fundamentals of protective design for conventional weapons*. Department of the Army.