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The Efficiency of Using FRP Composites as a Strengthening Technique for Reinforced Concrete Beam Subjected to Blast Loading

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Abstract: Some structures may be subjected to blast loading while in service. Terrorist attacks have been destabilizing threat around world. This may cause damage or failure to the structural elements. This paper examines the use of new and innovative materials that can improve strength and ductility of reinforced concrete beam under blast loading. The experimental data including damage and deflection were collected from a previous investigation and numerical analysis was then performed using ANSYS software. The focus of the present study is on applicability of FRP composites in improving and extending life span of RC beam from different structural aspects. In this study, the conventional Finite Element Method using ANSYS is used to study the dynamic behavior of Reinforced Concrete beams strengthened with Fiber Reinforced Polymer composites (such as CFRP, GFRP, AFRP). A comparative study is conducted by providing fully wrapped FRP composites on Reinforced Concrete beam and also by providing 20 mm wide strips of FRP composites on Reinforced Concrete beams. This paper presents numerical investigation of blast load performance of steel reinforced concrete beams retrofitted with externally bonded fiber reinforced polymer sheets. The modeling and analysis of different FRP composites must be carried out to find out the most effective method of retrofitting RC beam against blast loading.

Keywords: *ANSYS, Blast, Fiber Reinforced Polymer, Reinforced Concrete Beam.*

1. Introduction

In recent years, the explosive loads have received considerable attention by different events, accidental or intentional, over important structures all over the world. In consequence, in the last decade there was an important activity in the research of explosive loads. Initially, these works were mostly empirical, but, in the last few years, important researches have begun to develop. The study of blast effects on structures has been an area of formal technical investigation over 60 years. The blast explosion nearby or within structure is due to pressure or vehicle bomb or quarry blasting. Due to different accidental or intentional events, the behavior of structural components subjected to blast loading has been the subject of research effort in recent years. It is becoming increasingly important to ensure that critical infrastructure is blast resistant. One particularly important failure mode of structures subjected to blast loading is progressive collapse. This is typically initiated by the abrupt failure of load bearing columns and beams, which are extremely vulnerable during close-in blast loading. Fiber reinforced polymers (FRPs) have become widely used in civil engineering applications to increase the load bearing capacity of shear walls, columns and beams due to their high strength-to-weight ratio, tensile strength, and durability. Thus strengthening reinforced concrete beam with FRP composites against blast loading .FRP composites used for retrofitting are Carbon Fiber Reinforced Polymer (CFRP), Aramid Fiber Reinforced Polymer (AFRP) and Glass Fiber Reinforced Polymer (GFRP).

There are many methods to analyze blast loads. Some of them are related to finite element modeling programs (Hibbitt et al. 2011), and the other related to dynamic analysis theory such as single degree of freedom analysis (SDOF) and multi-degree of freedom analysis (MDOF) (Temsah et al. 2017). This paper will present both finite element and dynamic analysis procedure. Ali Jahami and Yehya Temsah (2020). The efficiency of using CFRP as a strengthening technique for reinforced concrete beams subjected to blast loading. The prediction of the response of blast loaded reinforced concrete beams using a finite element program such as ABAQUS is possible. The built-in concrete damage plasticity model (CDP) was simulated successfully the nonlinear behavior of concrete under impact loading. It requires taking into consideration the strain rate effect on the concrete dam- age plasticity parameters to get an acceptable response with minimal error. Using CFRP reduced the extent of damage of the reinforced concrete beams when subjected to blast loads. As the number of layers of CFRP increased as demonstrated by the mid-span deflection. The mid-span deflection for beams with 4 layers of CFRP is 30% lower than that of a beam without CFRP. However, using more than 2 layers does not cause a further decrease in deflection. Zhen Li et.al (2020). Experimental and numerical analysis of CFRP strengthened RC columns subjected to close-in blast loading. In this paper, several field tests were performed to investigate the blast response of RC columns retrofitted with CFRP sheets. The parameters considered in this experiment include the CFRP thickness and the retrofitting method. The results demonstrate that CFRP sheets significantly improve the blast performance of RC columns by reducing the maximum and residual displacements and enhancing the spalling effect. Increasing the thickness of the CFRP can further reduce the bending deformation and spalling damage of reinforced concrete columns. Retrofitting RC columns with CFRP reinforcement on both faces may increase the diagonal shear damage. The damage mode of the RC columns shifted from flexural failure to shear failure; therefore, the blast resistance performance of columns with CFRP on both faces might be disadvantaged.

2. Objectives

(1) To validate and check the possibilities of implementation of ANSYS workbench 18.1. (2) To evaluate the behavior of FRP strengthened RC Beam under blast loading using ANSYS. (3) To find out the most efficient retrofitting composite material. (4) Detailed parametric analysis by varying FRP composites as spacing between the strips and fully wrapping.

3. Numerical Modelling

The modeling and analysis of reinforced concrete beam is done in this thesis using ANSYS 18.1.The model is a beam having a span of 1100 mm. The width and depth of beam is 100 mm. Elastic modulus is 25000 N/mm^2 and f_{ck} is 40 N/mm^2 .The blast load (TNT) of weight 0.36 Kg is placed at a standoff distance 400 mm from the mid span of beam. The concrete had strength of 40 MPa. The yield and ultimate stresses of the reinforcing steel were 395 MPa and 501 MPa, respectively.

4. Explicit Analysis

Dynamic analysis can be used to find dynamic displacements, time history, and modal analysis. Dynamic loads include people, wind, waves, traffic, earthquakes, and blasts. Dynamic analysis for simple structures can be carried out manually, but for complex structures finite element analysis can be used to calculate the mode shapes and frequencies. In this thesis finite element analysis were done by ANSYS software. For explicit analysis TNT explosive is used. It is a standard high explosive which is chemically safe and easy to cast. TNT mass were set at 0.36 Kg to examine the influence of explosive mass to damage degree of RC beam. TNT is placed at a standoff distance of 400 mm above center of RC beam. Analysis was done in order to find out most effective retrofitting material against blast loading. Strengthening materials such as CFRP, GFRP and AFRP in fully wrapped form and strip form were analysed.

4.1. Strengthening Beam Using CFRP

A numerical analysis of reinforced concrete beam strengthened with fully wrapped and 20 mm wide strips of Carbon Fiber Reinforced Polymer (CFRP) were conducted by using ANSYS Workbench 18.1. The analysis included modelling of specimen in ANSYS workbench 18.1, followed by meshing and then analyzing.

Fig.1 shows deformation of a beam fully wrapped with carbon fiber subjected to blast loading. The deformation obtained from ANSYS software is 23.185 mm. Fig.2 shows deformation of beam strip wrapped with carbon fiber and the deformation obtained from ANSYS software is 24.557 mm.

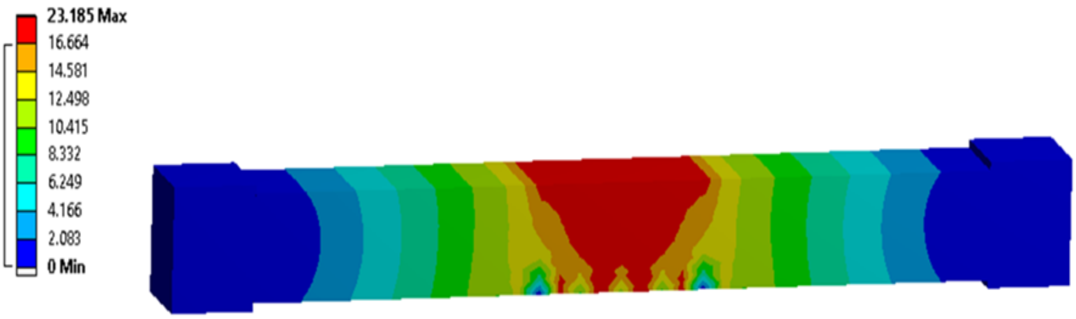

Fig.1. Deformation of fully wrapped CFRP beam subjected to blast loading

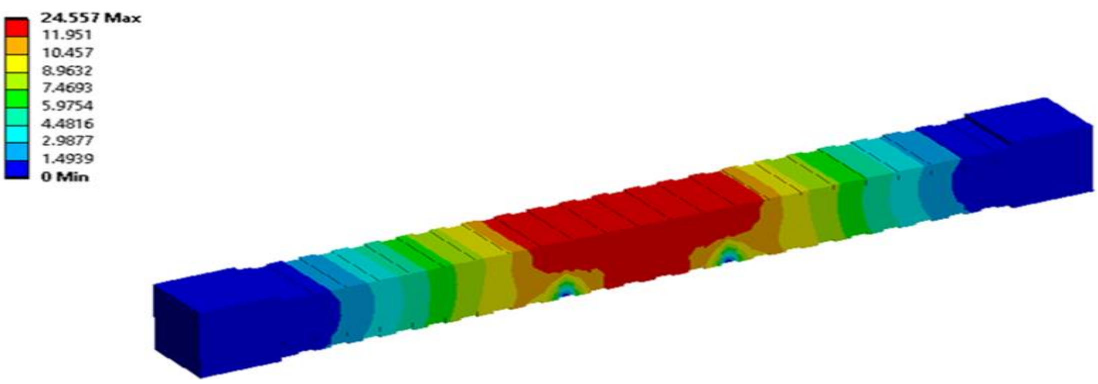

Fig.2. Deformation of beam with 20 mm wide strips of carbon fiber

4.2. Strengthening Beam Using GFRP

Numerical analysis of reinforced concrete beam strengthened with fully wrapped and strip wrapped GFRP were conducted. Fig.3 shows deformation of a beam fully wrapped with glass fiber subjected to blast loading. The deformation obtained from ANSYS software for fully wrapped is 20.345 mm and strip wrapped is 21.747 mm.

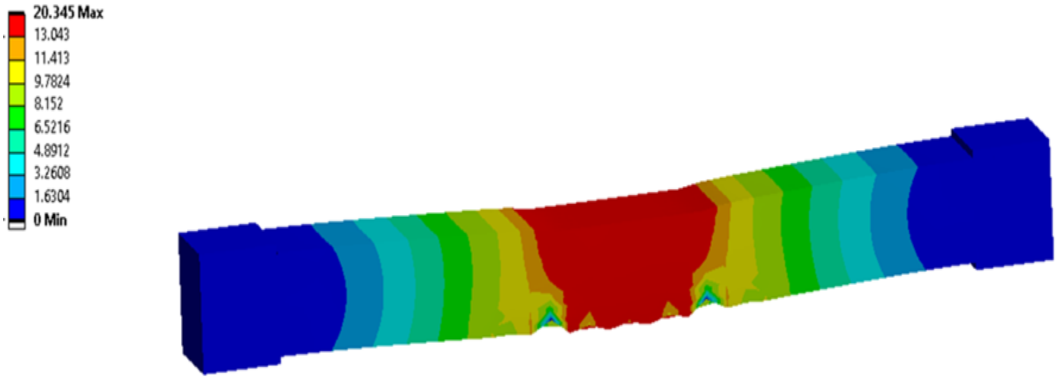

Fig.3. Deformation of fully wrapped GFRP beam subjected to blast loading

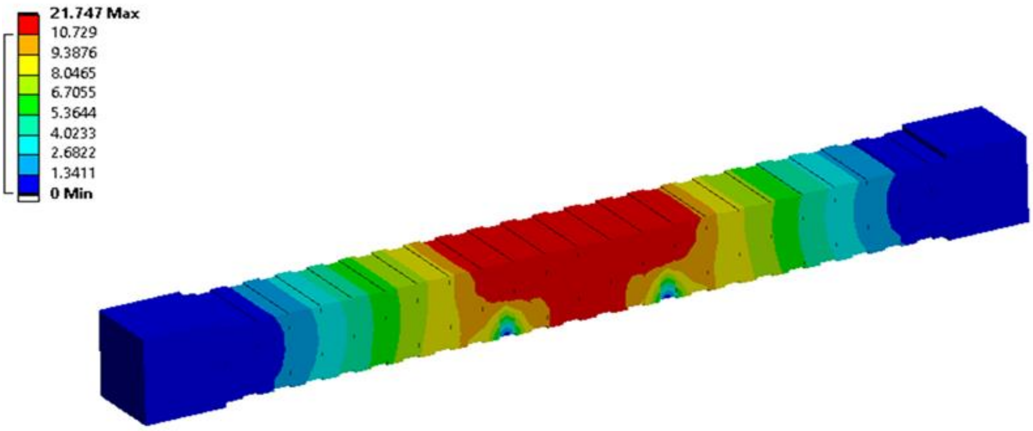

Fig.4. Deformation of beam with 20 mm wide strips of Glass fiber

4.3. Strengthening Beam Using AFRP

Numerical analysis of reinforced concrete beam strengthened with fully wrapped AFRP were conducted. Fig.5 shows deformation of a beam fully wrapped with aramid fiber subjected to blast loading is 18.116 mm. Fig.6 shows deformation of a beam strip wrapped with aramid fiber subjected to blast loading is 20.04 mm.

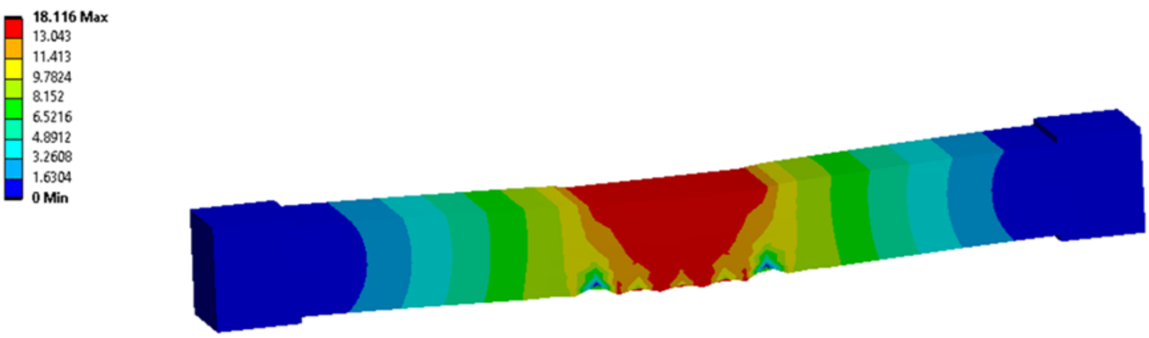

Fig.5. Deformation of fully wrapped AFRP beam subjected to blast loading

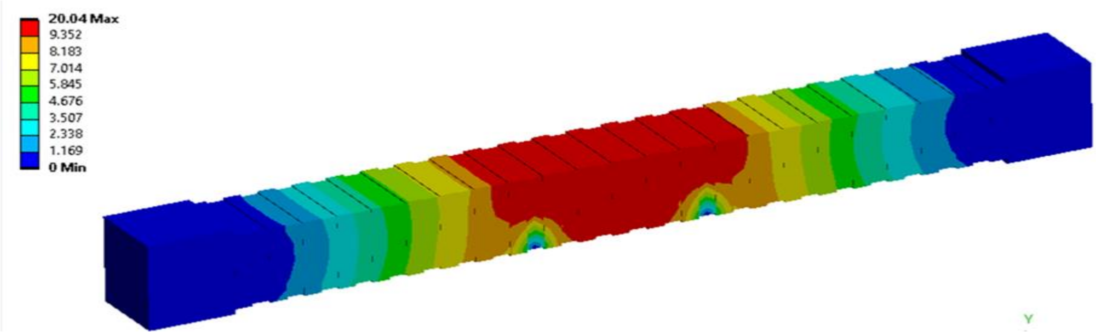

Fig.6. Deformation of beam with 20 mm wide strips of Aramid fiber

5. Results and Discussions

In this thesis, the conventional Finite Element Method using ANSYS is used to study the efficiency of using Fiber Reinforced Composites as a strengthening technique for reinforced concrete beam subjected to blast loading. A comparative study were conducted by providing fully wrapped FRP composites (such as CFRP,GFRP & AFRP) and also by providing 20 mm wide strips of FRP composites on Reinforced Concrete beams subjected to blast loading.

Table 1. Comparison of results

SPECIMEN	TNT (Kg)	STANDOFF DISTANCE (mm)	DEFORMATION (mm)
Beam without wrapping	0.36	400	9.176
Fully wrapped CFRP beam	0.36	400	23.185
Fully wrapped GFRP beam	0.36	400	20.345
Fully wrapped AFRP beam	0.36	400	18.196
Strip wrapped CFRP beam	0.36	400	24.557
Strip wrapped GFRP beam	0.36	400	21.747
Strip wrapped AFRP beam	0.36	400	20.04

Table 1 listed out the overall deformation of reinforced concrete beam strengthened with or without FRP composites (such as CFRP, GFRP & AFRP) subjected to blast loading. Here it is evident that reinforced concrete beam strengthened with fully wrapped CFRP provides effective protection than other composite materials against blast.

5.1. Energy versus Time Graph

It is the amount of energy absorbed during blast. Higher the value of dissipation lower is the deformation.

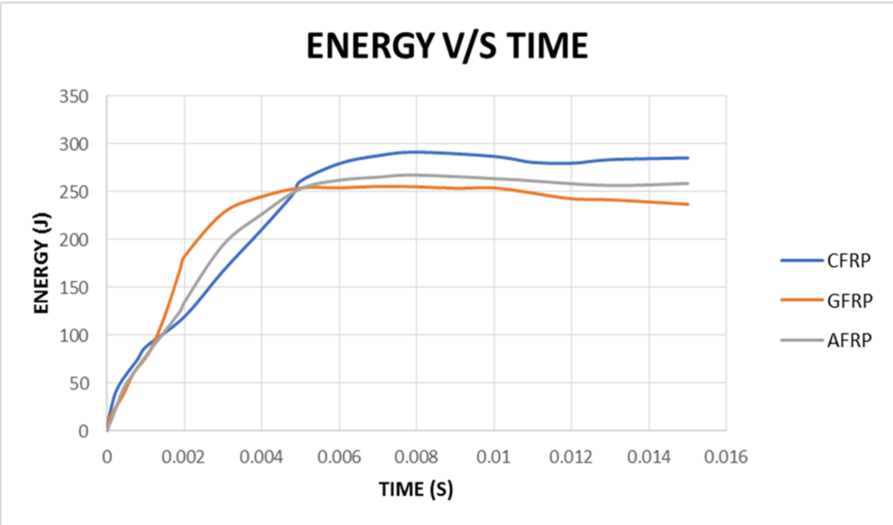

Fig.7. Comparison of dissipated energy in fully wrapped composites under blast loading

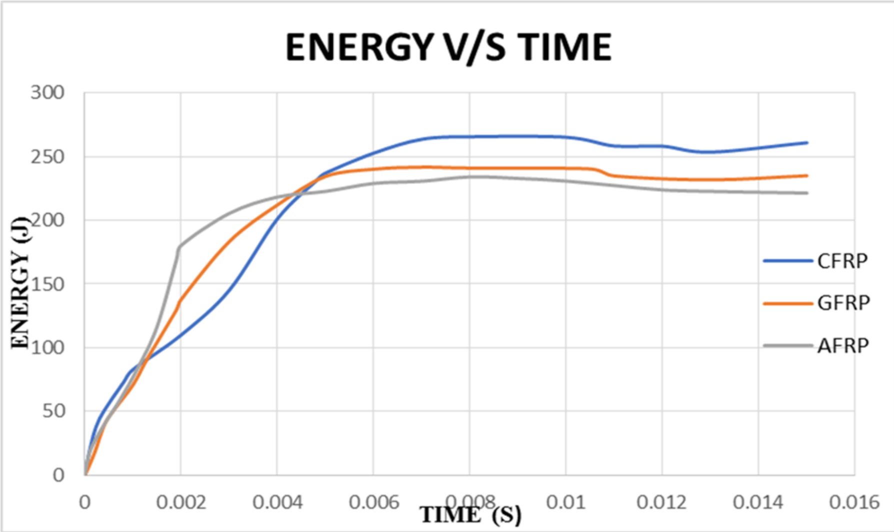

Fig.8. Comparison of dissipated energy in strip wrapped composites under blast loading

6. Conclusion

A numerical investigation were conducted to find out the effectiveness of FRP composites such as CFRP, GFRP,AFRP as a strengthening technique to RC beam subjected to blast loading. Based on the analysis, the following conclusions were drawn:

- ✓ The RC beam strengthened with FRP composites shows superior performance when compared to RC beam without strengthening.
- ✓ The external confinement of FRP wrapping reduces the deflection and it will be enhancing blast resistance.
- ✓ The deformation of RC beam strengthened with fully wrapped and stripped CFRP shows deformation of 23.178 mm and 24.557 mm under blast loading.
- ✓ The deformation of RC beam strengthened with fully wrapped and stripped GFRP shows deformation of 20.345 mm and 21.747 mm under blast loading.
- ✓ The deformation of RC beam strengthened with fully wrapped and stripped AFRP shows deformation of 18.196 mm and 20.04 under blast loading.
- ✓ A reinforced concrete beam is able to resist higher blast load in the presences of CFRP.
- ✓ Using CFRP sheets in reinforced concrete beams increased the absorbed energy of the beam.
- ✓ Higher absorption energy is associated with a reduced number and propagation of cracks.
- ✓ So, it can be concluded that Carbon Fiber Reinforced Polymer (CFRP) is the best FRP composite for strengthening reinforced concrete beam against blast loading. Also fully wrapped carbon polymer shows more efficiency than strips.

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