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FINITE ELEMENT ANALYSIS OF RETROFITTING OF RC BEAM WITH CFRP USING ABAQUS

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Abstract - *Concrete structures retrofitted with fibre reinforced plastic (FRP) applications have become widespread in the last decade due to the economic benefit from it. This paper presents a finite element analysis which is validated against laboratory tests of eight beams. All beams have the same rectangular cross-section geometry and all beams are loaded under four point bending, but different in the length of the carbon fibre reinforced plastic (CFRP) plate. The commercial numerical analysis tool ABAQUS has been used and different material models have been evaluated with respect to their ability to describe the behavior of the beams. Linear elastic isotropic and orthotropic models have been used for the CFRP and a perfect bond model has been use for the concrete–CFRP interface. A plastic damage model has been used for the concrete. The analysis results show good agreement with the experimental data regarding load–displacement response, crack pattern. There is no significant difference between the elastic isotropic and orthotropic models for the CFRP. The results showed that when the length of CFRP in flexural retrofitting increases, the load capacity of the beam increases as well.*

***Key Words*: RETROFITTING, FINITE ELEMENT ANALYSIS, ABAQUS, CFRP.**

1. INTRODUCTION

Reinforced concrete structures possess many advantages such as durability, strength and low maintenance, and reinforced concrete construction has been very popular all over the world. Reinforced concrete structures have to face modification and improvement of their performance during their service life. Reinforced concrete structures are subjected to structural deterioration, which might be caused by design and construction defects, environmental effects, and extreme loadings such as earthquake, impact load etc.

In such cases, to improve the load carrying capacity of the RC structures there are two possible solutions, first solution is replacement and second solution is retrofitting (strengthening). The replacement of full structures have disadvantages such as high costs for material and labour, limited working space and impact on nearby structures. When possible, it is often better to repair or upgrade the structure by retrofitting. Retrofitting of the structures is a cost efficient and more practical method than the replacement.

For the retrofitting and strengthening of concrete structures, the use of bonded steel plates was very common. However disadvantages of steel such as tendency to corrode, heavy weights, deterioration of the bonds at their steel-concrete interfaces and the requirement of massive scaffolding during installation.

There has been an increasing interest in the use of high strength composites for repair and rehabilitation of reinforced concrete components in recent decades. Fibre reinforced Polymers (FRPs) are being used increasingly as promising composite materials for the enhancing of reinforced concrete structures in civil constructions. The significant increase in use of FRP in construction industry, particularly for the retrofit and repair of concrete structure has started since 1990.

1.1 FRP MATERIAL

Fibre reinforced polymer (FRP) composites consist of high strength fibres embedded in a matrix of polymer resin as shown in figure 1.1, the fibres are usually glass, carbon, aramid, or basalt and polymer is usually an epoxy, vinyl ester, or polyester thermosetting plastic etc.

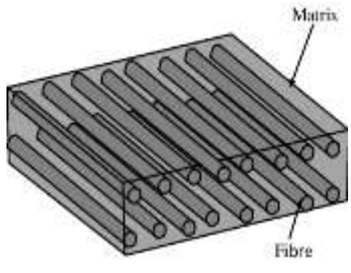


Figure 1.1: A schematic diagram showing a typical unidirectional FRP plate

These fibres are all linear elastic up to failure, with no significant yielding compared to steel. The primary functions of the matrix in a composite are to transfer stress between the fibres, to provide a barrier against the environment and to protect the surface of the fibres from mechanical abrasion.

The main characteristics of CFRP are follows:

a) High strength to weight ratio
b) Excellent corrosion resistance
c) Excellent fatigue resistance
d) Good durability, and
e) Cost effective fabrication.

In structural engineering, FRP can be used in different forms as listed below:

a) FRP strips and sheets for strengthening of structures
b) Reinforcing bars for reinforcing structures
c) Tendons for internal prestressing concrete
d) Tendons for external prestressing
e) Pultruded shapes.

1.2 FRP STRENGTHENED RC BEAMS:

Among various components of reinforced concrete structures, beam is one of the most basic structural elements as well as an indispensable part for most civil constructions, such as bridges and buildings. During the service life of RC elements, their stiffness and load carrying capacity are decreased since retrofitting or strengthen of those RC elements are required.

FRP has been used to strengthen RC beams externally, and this is the most common form of structure retrofitting or strengthening. FRP plates are usually glued to the bottom or tension side of a reinforced concrete beam to increase the flexural strength and FRP plates are applied on sides of a reinforced concrete beams to strengthen the reinforced concrete beam in shear. Many researchers found that the use of FRP plates increases the stiffness and load carrying capacity of reinforced concrete beam, consequently reducing the cracks. After retrofitting or strengthen the deflection of beam considerably reduced.

2. OBJECTIVE OF STUDY

The project work has been undertaken with the following objectives:

1. To develop model to simulate the behaviour of concrete and steel.
2. To simulate the behaviour of RC beam and validate it.
3. To develop simple finite element models which can emulate structural behaviour of CFRP strengthened RC beams under static load.
4. To study the effect of different length of CFRP on load carrying capacity of beam.

3. DEVELOPMENT OF MODELLING FRAMEWORK

The main objective of the study is to develop a modelling framework representing the flexure behavior of beams with retrofitted with FRP. This involves several aspects of practical and theoretical interest. Important issues such as material model, element type, various interface, meshing, convergence and boundary condition.

3.1 FEM PROGRAM

ABAQUS/standard has been used for the finite element modelling in this project. This FEM package includes a large variety of material models and elements as well as facilities necessary for this project.

At a minimum the analysis model consists of the following information:-

a) Geometry.
b) Element section properties.
c) Material data.
d) Loads and boundary conditions.
e) Analysis type.
f) Output requests.

Use the visualization module of ABAQUS/CAE (also licensed separately as ABAQUS/Viewer) to read the output database and view the results of analysis. The ABAQUS/Viewer provides graphical display of ABAQUS finite element models and results. It obtains the model and results information from the output database. We can control the output information displayed. For example, we can obtain plots such as undeformed shape, deformed shape, loads, x-y data, stress variation and time history animation from ABAQUS/Viewer.

In this work, ABAQUS/CAE 6.14 was used to simulate several test results from previous works. One of the major advantages of this software is the flexibility of implementing, revising, analyzing the model, and producing results.

3.2 MODELLING OF CFRP BONDED RC BEAMS

3.2.1 Experimental Technique

The results of the experimental work of retrofitted RC beams which was done by Yasmeen Taleb Obaidat, Susanne Heyden, Ola Dahlblom, Ghazi Abu-Farsakh and Yahia Abdel-Jawad has used for comparison and verification of the finite element analysis. Hence, the finite element model has been implemented based on the parameters and conditions in the laboratory tests made by Yasmeen Taleb Obaidat, Susanne Heyden, Ola Dahlblom, Ghazi Abu-Farsakh and Yahia Abdel-Jawad.

In this experimental work, eight RC beams are loaded with four point bending configuration with overall span of 1960 mm, and distance between loads of 520 mm. The distance between supports is 1560 mm. Beam have rectangular cross section of 150 mm width and 300 mm height. In this beam, tension reinforcement (2 ϕ12), compression reinforcement (2 ϕ 10) are tied together with 8 mm stirrups c/c 100 mm along the beam.

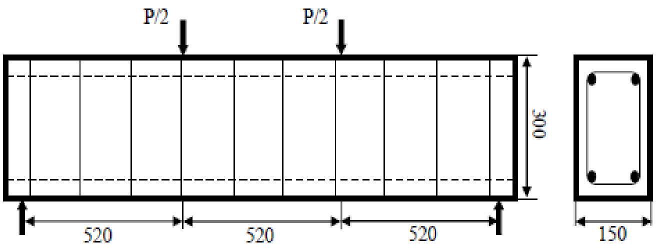
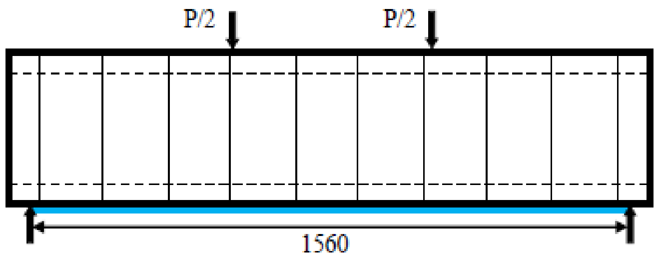
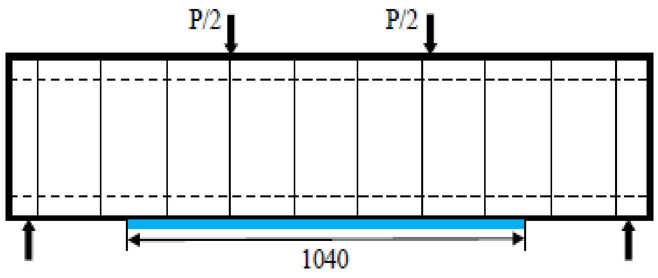


Figure 3.1: Geometry, reinforcement and load of the tested beams (Dimension in mm)

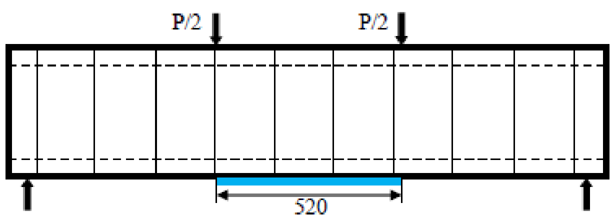
In this experimental work, two control beams are loaded to failure and other beams are loaded until cracks are appeared, then the soffit of beams are retrofitted with CFRP laminates 50 mm wide, 1.2 mm thick and three different lengths 1560 mm ,1040 mm, 520 mm as shown in figure. And retrofitted beams are retested and deflection and load are monitored.



(a) Retrofitted Beam RB1



(b) Retrofitted Beam RB2



(c) Retrofitted Beam RB3

(d)

Figure 3.2: Length of CFRP laminates in test series RB1, RB2, RB3

3.2.2 Constitutive models and material properties

1. Concrete

In the last decades, many constitutive models which can predict the behaviour of concrete, including cracks and crushing have been developed. Two approaches are available in ABAQUS to predict the behaviour of concrete: smeared crack and plastic damage models. The plastic damage model has been selected for this project, since it has higher potential for convergence compared to the smeared crack model. The concrete plastic damage model assumes that the two main concrete failure mechanisms are cracking and crushing.

The plastic damage model requires the values of elastic modulus, Poisson's ratio, the plastic damage parameters and description of compressive and tensile behaviour. The five plastic damage parameters are the dilation angle, the flow potential eccentricity, the ratio of initial equibiaxial compressive yield stress to initial uniaxial compressive yield stress, the ratio of the second stress invariant on the tensile meridian to that on the compressive meridian and the viscosity parameter that defines viscoplastic regularization.

2. Steel reinforcement

The constitutive model used to simulate the steel reinforcement was the classical metal elastic-perfectly plastic model. The steel have been assumed to be an elastic-perfectly plastic material and identical in tension and compression. The input for the steel model includes elastic modulus, Poisson's ratio and yield stress. The elastic modulus, Es, and yield stress fy, were measured in the experimental study and the values obtained were Es= 209 GPa, and fy= 507 MPa and Poisson's ratio have been assumed to be 0.3.

3. CFRP

Two know the actual behavior of CFRP, in this work two different models use for CFRP. In the first model, the CFRP material was considered as linear elastic isotropic until failure. In the second model, the CFRP was modeled as a linear elastic orthotropic material. Since the composite is unidirectional it is obvious that the behaviour is essentially orthotropic. In a case like this however, where the composite is primarily stressed in the fibre direction, it is probable that the modulus in the fibre direction is the more important parameter. This is why an isotropic model is considered suitable.

The elastic modulus in the fibre direction of the unidirectional CFRP material used in the experimental study has been specified by the manufacturer as 165 GPa and poisson ratio is 0.3. This value for E and ν = 0.3 is use for the isotropic model.

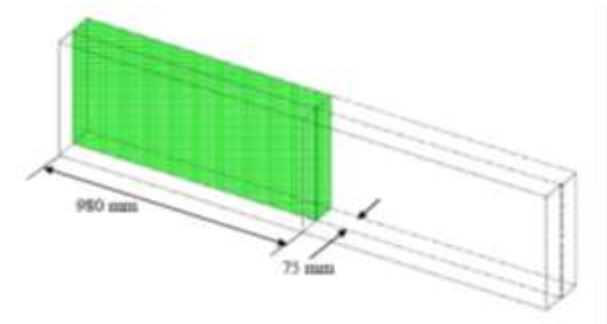
By using rule of mixture, E_{11} = 164.875 GPa, E_{22} = 9.66 GPa, E_{33} = 9.66 GPa, ν_{12} = ν_{13} = 0.3, G_{12} = 3.71 GPa and G_{13} = 3.71 GPa use for orthotropic model.

4. Interface between concrete and CFRP

The model for the interface between FRP and concrete is of essential importance. In this analysis the interface between concrete and CFRP is assumed to be perfect bond.

3.2.3 Boundary Conditions & meshing

One quarter of the specimen was modelled by taking advantage of the double symmetry of the beam in three-dimensions and fine mesh used as shown in figure 3.3. The boundary conditions are shown in figure 3.4. A fine mesh is providing to obtain accurate result.



(a) Quarter of the beam was modelled

(b) Finite element mesh of quarter of beam

Figure 3.3: Geometry and element used in FEM analysis

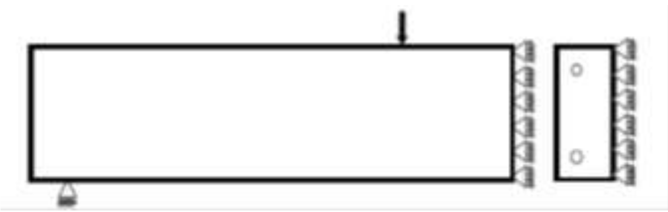


Figure 3.4: Boundary condition used in numerical analysis

3.2.4 Numerical Analysis:

In this project, C3D8R element is use for concrete, T3D2 element is use for reinforcement and S4R element is use for CFRP. To show the effect of CFRP on the RC beam, CFRP plate is apply on cracked beam. The pre-crack is modelled by providing 1 mm gap between CFRP plate and soffit of beam.

4. VERIFICATION OF FINITE ELEMENT MODEL

To verify the finite element model of the reinforced concrete retrofitted with CFRP, four beams from an experimental study (Obaidat 2007) has been simulated. The result obtain from the FEM analysis are compared to experimental result by Obaidat (2007) is shown in figure 4.1. The FEM results is slightly stiffer than the experimental results, because of the in this study assumed perfect bond between steel and concrete.

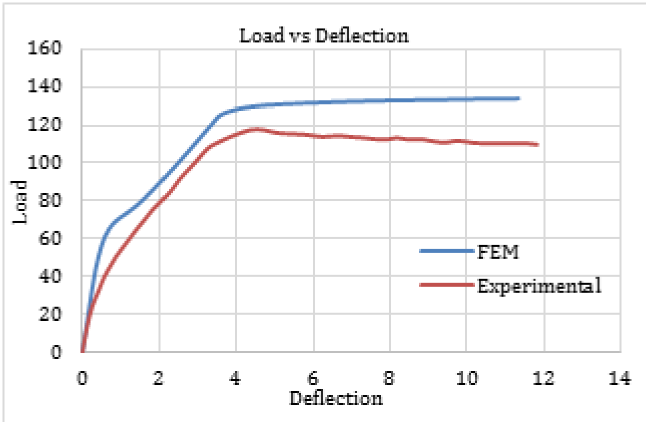


Figure 4.1: Load vs deflection curves of control beams obtained by experiment and FEM analysis

The above graph show the comparison of FEM analysis result and experiment result. In experimental result maxim um load is 117.52 KN and in FEM analysis result maximum load is 133.81 KN.

As the concrete damage plasticity model does not have a notation of cracks developing at the material integration point, it was assumed that cracking initiates at the points where the maximum principal plastic strain is positive, figure 4.2 shows a comparison between plastic strain distributions obtained from the finite element analysis and crack patterns obtained from the experiments for the control beam. The cracks obtained in the experiments and in the simulations are similar, which indicates that the model can capture the mechanisms of fracture in the beams.

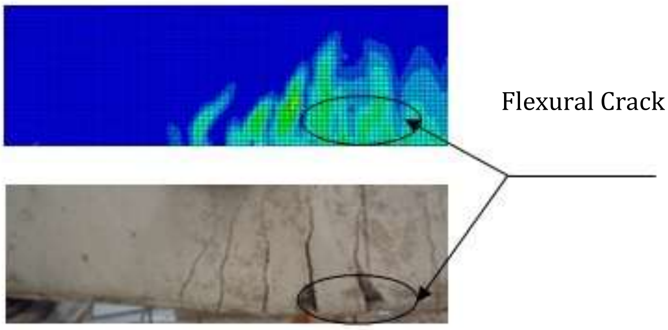
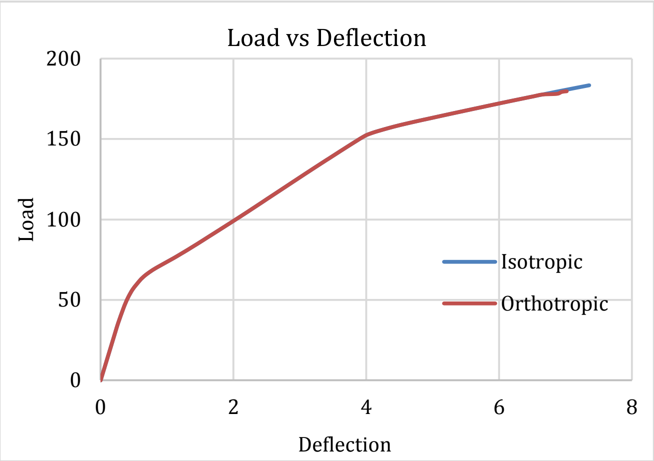


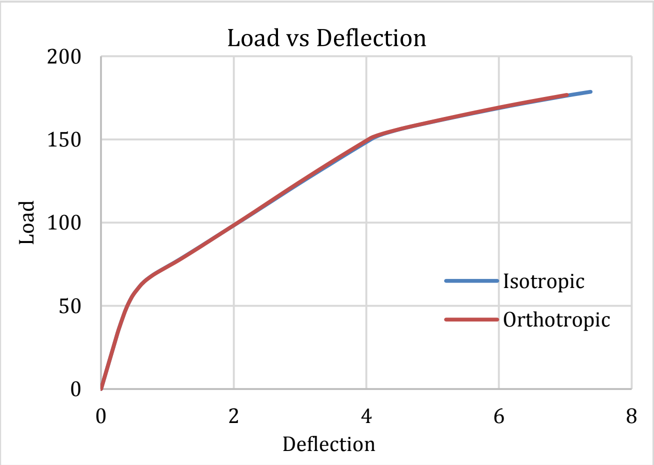
Figure 4.2: Comparison between plastic strain distribution from FEM analysis and crack pattern from experiments

5. RESULT & DISCUSSION

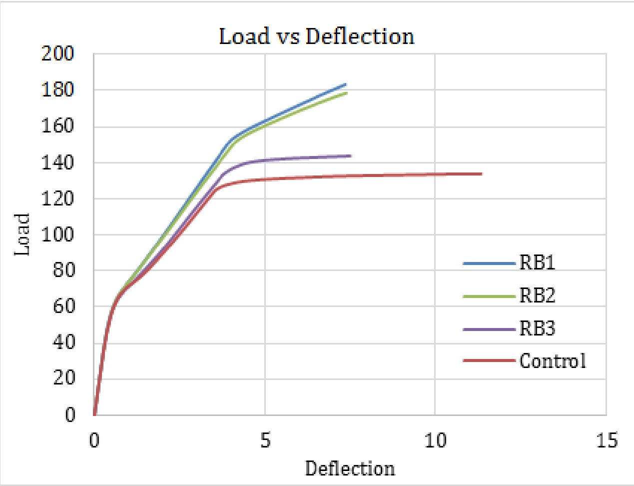
Retrofitting with CFRP to soffit of beam are shown in figure 5.1



(a) RB1



(b) RB2



(c) RB3

Figure 5.1: Load vs Deflection curve for retrofitting by CFRP on cracked beam

From the load vs deflection graph of RB1, the ultimate load taken by RB1 beam is 183.36 KN in isotropic model and 179.65 KN in orthotropic model. It is clear that the isotropic model takes more loads about 2.06% as compared to orthotropic model. This is possibly because of unrealistically high stiffness in the transverse direction and shear of the isotropic CFRP provides a strengthening confinement. The RB1 with isotropic model is compared with control model is found that the strength was increased about 37.03%.

From the load vs deflection graph of RB2, the ultimate load taken by RB2 beam is 178.63 KN in isotropic model and 176.76 KN in orthotropic model. It is clear that the isotropic model takes more loads about 1.05% as compared to orthotropic model. The RB1 with isotropic model is compared with control model is found that the strength was increased about 33.49%.

From the load vs deflection graph of RB3, the ultimate load taken by RB3 beam is 143.60 KN in isotropic model and 143.55 KN in orthotropic model. It is clear that the isotropic model and orthotropic model have nearly same strength. The RB1 with isotropic model is compared with control model is found that the strength was increased about 7.31%.

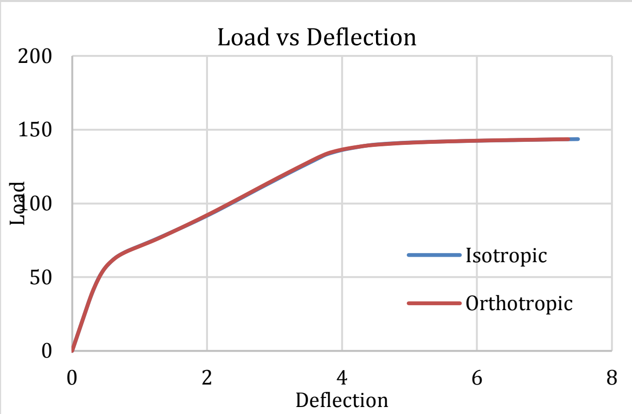


Figure 5.2: Comparison of load vs deflection of retrofitting beam and control beam

6. CONCLUSIONS

A finite element model was developed to analyse beams retrofitted or strengthen with CFRP plate. The finite element results show good agreement with the experimental results. Elastic orthotropic and isotropic behaviours have been used to represent the CFRP behaviour. The following conclusions can be drawn from this study:

1. The behaviour of the retrofitting of cracked beam is significantly influenced by the length of CFRP. The load carrying capacity increases 37.03%, 33.49%, 7.31%. with the length 1560 mm, 1040 mm, and 520 mm of the CFRP respectively.
2. Application of CFRP to uncracked beam provides greater strength as compared to cracked beam.
3. The stiffness of the CFRP-retrofitted beams is increased compared to that of the control beams.

7. FUTURE SCOPE FOR STUDY

1. In this project interface between concrete and CFRP plate is assumed as perfect bonding, for future work cohesive zone modelling is also used.
2. Many environmental factors such as seasonal temperature variation, degradation of material properties, creep etc. involved during the life span of a retrofitted structure that needs more attention. The durability of CFRP reinforced beams under these environmental conditions should be investigated.
3. Models based on extended finite element method (XFEM) may be developed to represent the cracks in the concrete.

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