International Journal of Green Management and Business Studies
Vol. 2, No. 1. June 2022

Innovative FE Analysis to Investigate the Effect of Flexural Reinforcement on the Behaviour of Beams

Ahmed A. Gouda Sayed
Dept. of Civil Engineering, Helwan University, Egypt
Ahmed.Atef@m-eng.helwn.edu.eg
Ahmed H. Ali
Dept. of Civil Engineering, Helwan University, Egypt
Ahmed.Ali@usherbrooke.ca
Hamdy M. Mohamed
College of Engineering, Applied Science University (ASU), Kingdom of Bahrain
Hamdy.Mohamed@asu.edu.bh

Received: 22 April 2022 Revised: 28 April 2022 Accepted: 20 May 2022 Published: 1 June 2022
Correspondent Author: Hamdy.Mohamed@asu.edu.bh

Abstract

In this investigation, three circular beams reinforced with GFRP bars were modeled using nonlinear finite element program, ATENA 3D. The parameter adopted by the current study was the longitudinal reinforcement ratio (1.5, 2.5, and 3.5%). The numerical analysis results were verified by comparing them against the experimental results of these tested beams. The reinforced concrete beams were modeled in a three-dimension space, taking into account the material nonlinearity of concrete, the elastic-plastic behavior of concrete and the elastic behaviour of the GFRP bars. The analysis included tracing the load-deformation response of beams in addition to the strains in the GFRP bars. The numerical investigation showed a good representation of the experimental results.

Keywords: Concrete, Beam, GFRP, Experiment, Circular, Bars, FEM

1. Introduction

Circular beams reinforced with either steel or glass fiber reinforced polymer (GFRP) have many advantages over the, conventional, rectangular beams. Such as, circular beams have the same flexural and shear stiffnesses in all the directions, circular beams have better aesthetic shape. Nevertheless, rectangular beams reinforced with steel bars have been under investigation from many researchers (Collins & Kuchma, 1999) (Rebeiz et al., 2001). Which is to some degree the same case for the rectangular beams reinforced with FRP bars (Jang et al., 2009) (Tureyen & Frosch, 2002).. In terms of the shear behaviour of the circular beams, especially the ones reinforced with FRP bars, there is few or no research conducted, at all, to study that behaviour, other than the articles published by the writers presented in the current study.

Finite element (FE) analysis to explore the behaviour of reinforced-concrete (RC) elements is a good alternative to the studies that are being done in the lab. Finite element (FE) analysis is another way to look at the behaviour of many structural members, such as beams, slabs, walls, and columns. Numerical studies, when compared to experimental studies in the labs, would save money, space, and time that can be used to pursue more research areas.

2. Research Objectives

The aim of the current study is to investigate the behaviour of circular beams reinforced with GFRP bars, experimentally and numerically using Atena 3D, FE program. The studied parameter will be the longitudinal reinforcement ratio.

3. Experimental Program

Properties of Materials

Figure one shows the configuration of the beams in addition to the sand-coated GFRP bars that were used to reinforce the beams. All the reinforcement were provided by Pultral Inc. . (Inc, 2018). All the beams were reinforced with No. 6 GFRP bars. The properties, of this bar, are reported in Table 1. The Guaranteed tensile strength was calculated based on the recommendations of ACI 440.1R-15 standard for FRP material ("Guide for the Design and Construction of Concrete Reinforced with FRP Bars," 2015)..

All the beams were cast using ready mixed concrete. The beams were all cast at the same day, to try to minimize any variation in the concrete properties, between the beams. The targeted compressive-strength was 36 megapascal (MPa), the actual one, for each beam, was calculated at the day of testing by using the recommendations of the Canadian standard CSA/S806-12 (S806-12, 2012). Table 2 has the concrete properties of each beam.

©2022 Copyright The Science Publishing House LLC

Beams' configuration

Three full-scale circular beams were built. All the beams were designed using the Canadian standard CSA/S806-12 specifications (S806-12, 2012). The beams had a 500-mm diameter and 3000-mm length. The clear cover was kept equal to 40-mm in all the directions. The beam's definition had two symbols, "BG" to account for the reinforcement type (GFRP bars), the second is a number for the flexural reinforcement ratio.

Test setup

The different components of the test setup are shown at Fig. 2. The shear load was applied to the beams using 1000 kN hydraulic actuator connected to a spreader beam. The load from the actuator was divided into two-point loads as shown in the figure. Computerized displacement control system at a rate equal to 0.6mm/min was used to generate the applied shear force. Each beam was simply supported at two locations that were 300-mm away from the edges of the beam. To ensure equal distribution of the shear stresses, rubber strips were provided where necessary, such as between the beam's surface and the steel supports.

Instrumentations

Several instruments were used to capture the behaviour of the beams. For the compressive strain in the concrete, three 60-mm strain gauges were fixed on the surface of beam at the mid span at three different locations (D, D/8, and D/4). The diagonal concrete strains at the shear span were also observed using three strain gauges (S1, S2, and S3) as shown in Fig. 1. For the GFRP bars, 6-mm strain gauges were placed at the bar at the extreme tension side. Three LVDTs were used to capture the mid and shear spans deflections.

Main findings of the experimental phase

All the beams failed in diagonal shear failure mode. Increasing the reinforcement ratio would result in lower strain values in the GFRP bars, causing fewer cracks in the beams and increasing the shear capacity of those beams in terms of un-cracked concrete and aggregate interlock. Increasing the flexural reinforcement ratio by 66 and 133% enhanced the shear capacity of the circular beams by 6 and 32%, respectively. The strains in the GFRP bars as well as the concrete surface improved to some extent. The decrease in the ultimate captured compressive strains on the concrete surface was 12 and 18%, respectively. As shown in Table 2, the maximum measured deflection for BG1.5 was greater than that of BG2.5, which was greater than that of the beam reinforced with the highest reinforcement ratio (BG3.5).The deformability of the beams was reduced, significantly, by 23 and 29%, respectively.

Available online: www.scipubhouse.com *ISSN: 2771-1404*

Fig. 1. Beams' configuration

Table 1: GFRP bar's properties

Diameter (mm)	Cross-Sectional Area (mm^2)	Strength* (MPa)	Modulus of Elasticity (GPa)	Strain (με)
20 (#6)	285	1105	63.7 $\pm$ 2.5	1730

*Guaranteed tensile strength: Average value – 3 x standard deviation (ACI 440.1R-15)

Table 2: Beams' details

Beam ID	f_c' (MPa)	Reinforcement ratio %	Failure Load (kN)	Ultimate Shear Load V_{exp} (kN)	Strain (με) Bars ε_u	Strain (με) Concrete ε_{cu}	Deflection (mm) Δ_{mid}	FE Model Shear Load (kN)
BG1.5	38.1	1.5	457	229	4340	2000	15.1	222
BG2.5	38.1	2.5	489	245	3325	1752	11.6	241
BG3.5	38.1	3.5	603	301	3802	1644	10.7	295
V_{exp}/V_{Model}			--	--	--	--	--	**1.02**
S.D (%)			--	--	--	--	--	**0.47**
COV (%)			--	--	--	--	--	**0.5**

©2022 Copyright The Science Publishing House LLC

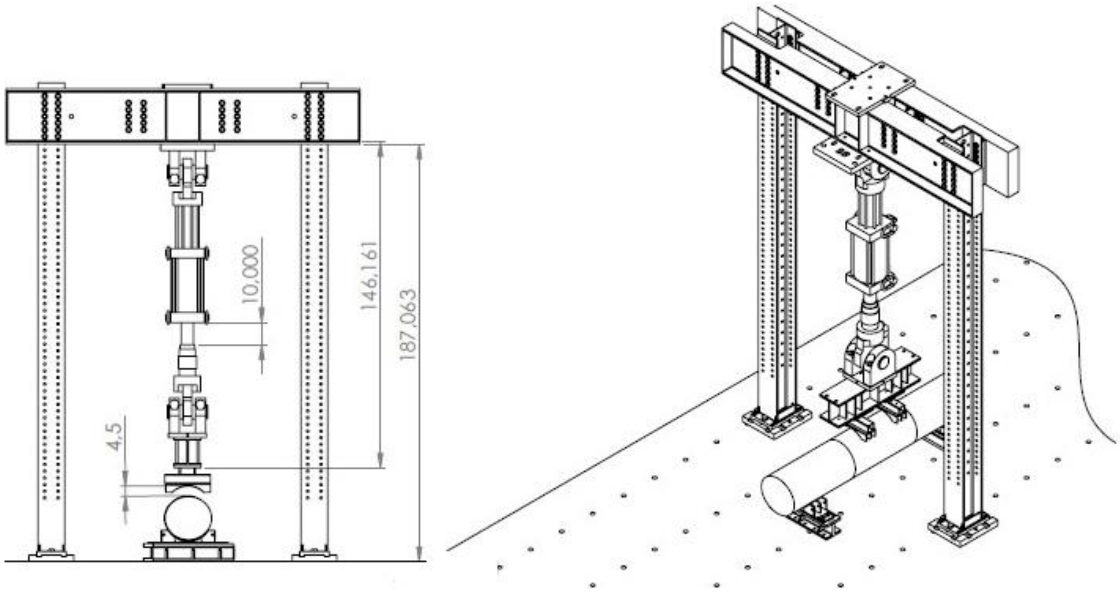


Fig. 2. Beams' setup

To simulate the shear behaviour of the circular concrete beams, the software package ATENA (Cervenka et al., 2013) was used. Modeling has to take into account a variety of aspects, including model size, elements' types, material characteristics, mesh sensitivity and generation, loading circumstances, and boundary types. The next sections briefly detail the elements employed in the current work to replicate concrete, as well as the reinforcing and boundary conditions.

Concrete

The finite-element programme uses a variety of elements to simulate the influence of the concrete material. CC3DNonLinCementitious2, a built-in fracture-plastic constitutive model, was used to simulate the influence of concrete. The fracture model uses the Rankine failure criterion, while the plastic failure surface is determined using the Menétrey-Willam failure surface (Cervenka et al., 2013). To simulate cracking, crushing, and fracture mechanics in concrete, these fracture-plastic models were combined into one model. This model takes into account crushing, nonlinearity, plasticity, and cracking in the x, y, and z directions.

Reinforcement

The reinforcing bars were modelled using a truss element (CCIsoTruss) having transition degrees of freedom in the x, y, and z directions at the element's nodes. Using the mechanical parameters listed in Table 1, a perfectly linear elastic stress-strain curve for the GFRP reinforcement was created.

Bond model

In the current study, the bond-slip relationship is given for unconfined concrete. This relationship has an ascending branch that is roughly parabolic in shape, a linear descending section, and

eventually a horizontal plateau where the slip continues to grow at a constant bond stress.

Model's geometry

As illustrated in Figure 3, the whole length of the circular beam was modelled, as were ring plates to suit the circular geometry at the loading and support points. The primary function, of the ringed plates, was to distribute and transfer stresses to the various elements of the circular concrete beam. A tetra element (CCIsoTetra) with three translation degrees of freedom in the x, y, and z dimensions was used at each node to mimic those plates. The plates were also built of a linear-elastic material with a Poisson's ratio of 0.3 and a modulus of elasticity of 200 GPa. By modelling the support in this way, a roller was created. Constraints were applied to a single line of nodes on the plate in the UX and UY directions, with constant values of 0. To replicate the loading locations in the experimental programme, the force P is delivered across sections of the loading plates

Results

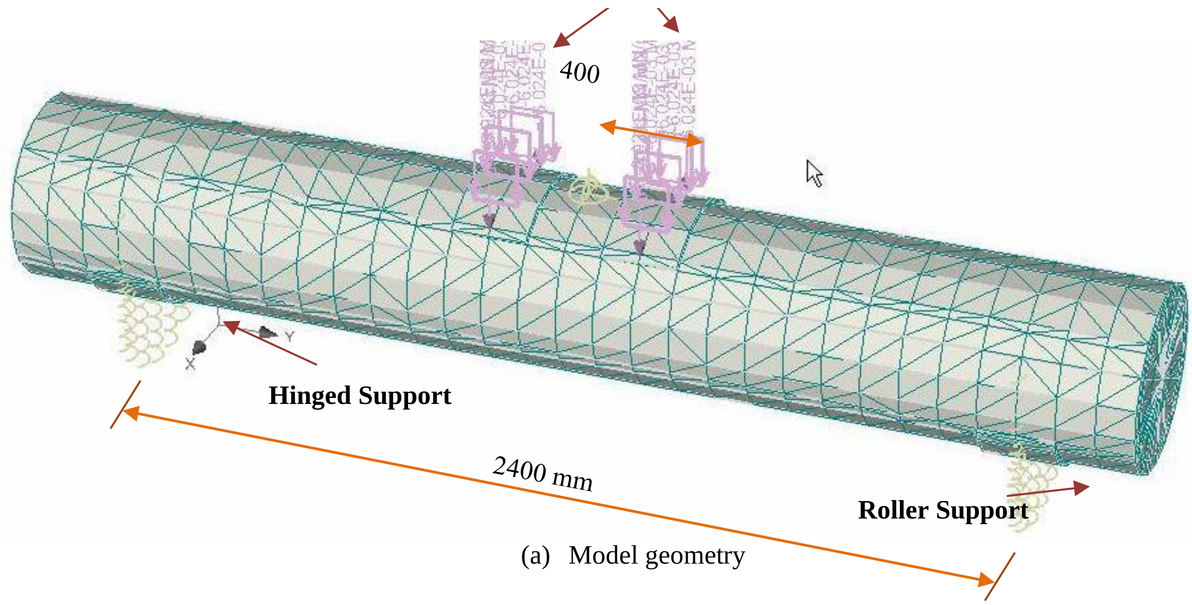
The findings of the developed FEM were compared to the experimental results of the circular RC beams that were tested. All specimens were used in the FE model's verification process (BG-1.5, BG-2.5, BG-3.5). The load-deflection curve, tensile strains in the FRP bars, and failure loads were all included in the comparison. The results show that the model correctly anticipated the shear response both before and after cracking, as well as between cracking and failure.
Figure 4 shows the, experimental and numerical, cracking pattern for one of the beams. The figure clearly shows the good mimic of the model to the beams tested experimentally in the lab.
The load–deflection curves for the experimental and FEM results of the beams are shown in Figure 5. The FE model was able to predict the load-deflection response of the experimental data with a high degree of accuracy, as can be observed. This holds true for both uncracked and cracked stages of the process. In addition, the model was able to predict the stiffness loss after breaking.
The GFRP longitudinal-bar strains measured in the FEM and the strains obtained experimentally are in good agreement, as illustrated in Figure 6. The longitudinal reinforcing rods were only slightly strained until the concrete section cracked. After cracking, the strains in FEM and experimental curves diverged virtually linearly with increasing load up to failure, compared to the pre-cracking ones. Table 2 shows that the shear-load predicted by the FE model was within 3% of the one observed experimentally. The average value for the experimental shear strength to the predicted one (Vexp/Vmodel) for the beams is 1.02, with a standard deviation of 0.47 percent.

©2022 Copyright The Science Publishing House LLC

International Journal of Green Management and Business Studies

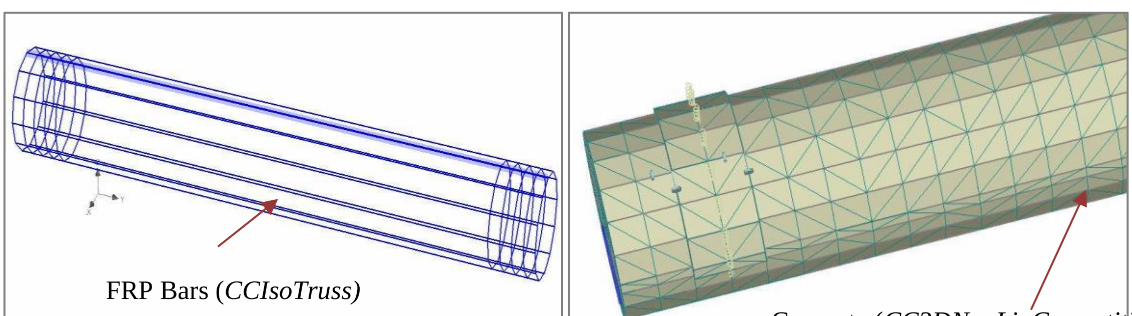
Vol. 2, No. 1. June 2022

THE SCIENCE PUBLISHING HOUSE



(a) Model geometry

(b) Model geometry



(b) Element types

Figure 3: Model’s geometry

Available online: ***www.scipubhouse.com*** ***ISSN***: *2771-1404*

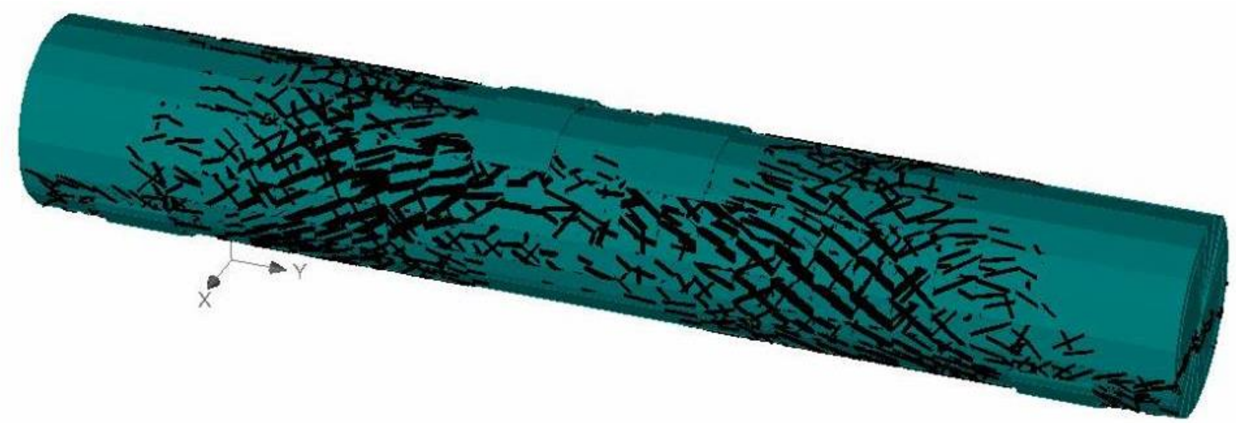
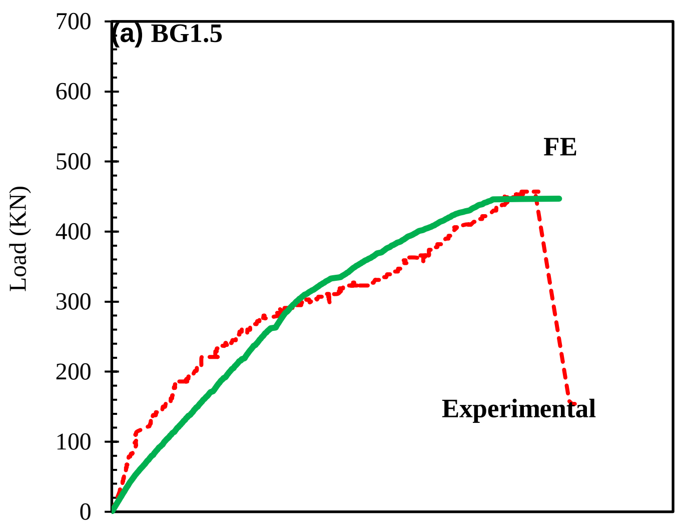
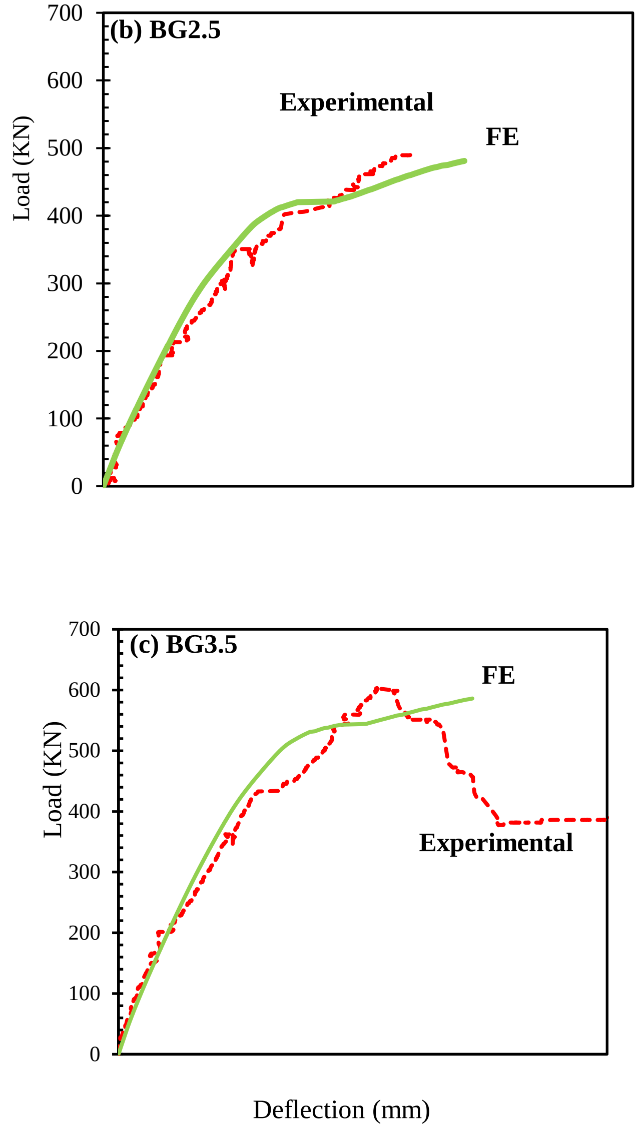
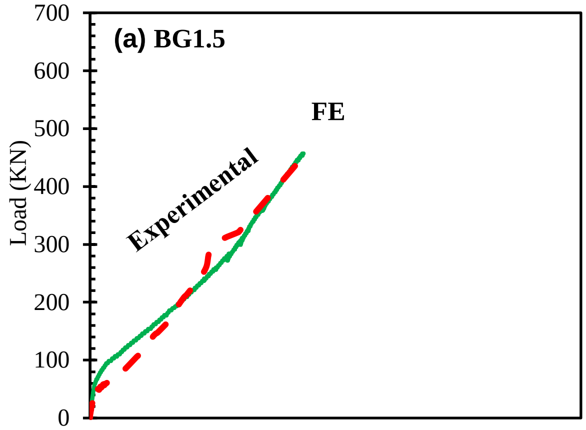


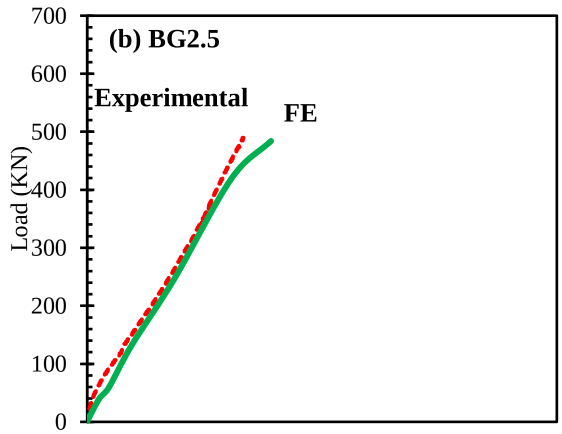
Figure 4: Cracking patterns



©2022 Copyright The Science Publishing House LLC


(b) BG2.5
Experimental
FE
Load (KN)
0
100
200
300
400
500
600
700
(c) BG3.5
FE
Experimental
Load (KN)
0
100
200
300
400
500
600
700
Deflection (mm)





©2022 Copyright The Science Publishing House LLC

International Journal of Green Management and Business Studies
Vol. 2, No. 1. June 2022

THE SCIENCE PUBLISHING HOUSE

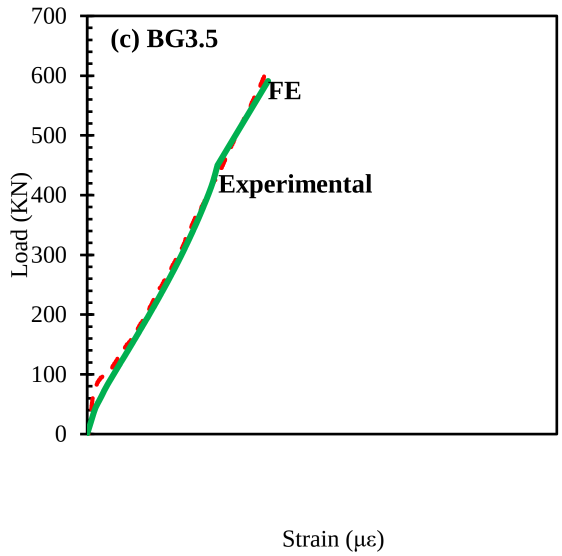


Figure 6: Load-strain relationship for the longitudinal-reinforcement

4. Conclusion

The behaviour of beams reinforced longitudinally with GFRP bars and subjected to pure shear force was examined. The following are the study's principal conclusions.

1- Diagonal tension failure, was the failure mode for all the beams.

2- The flexural reinforcement ratio has a great impact on the behaviour of the beams. Increasing the flexural reinforcement ratio by 66 and 133% enhanced the shear capacity of the circular beams by 6 and 32%, respectively.

3- The FE beams were able to accurately replicate the experimentally tested beams' characteristics in terms of cracking patterns, load-deflection relationship, load-strain relationship for reinforcing bars, and carrying load-capacity.

4- The average value of the shear capacity obtained experimentally to the shear strength obtained by the FE model, (V_{exp}/V_{Model}), is " 1.02±0.01 " with 0.5 percent COV.

Available online: *www.scipubhouse.com* *ISSN: 2771-1404*

5- Acknowledge

The authors would like to thank the technical staff of the structural laboratory at the University of Sherbrooke's Department of Civil Engineering. The authors would like to express their heartfelt gratitude to Pultrall Inc. for donating GFRP materials

5. References

Cervenka, V., Jendele, L., & Cervenka, J. (2013). *ATENA Program Documentation Part 1: Theory*. Cervenka Consulting Ltd.

Collins, M. P., & Kuchma, D. (1999). How safe are our large, lightly reinforced concrete beams, slabs, and footings? *ACI Structural Journal*, *96*(4), 482–491.

Guide for the design and construction of concrete reinforced with FRP bars. (2015). In *American Concrete Institute (ACI) Committee 440*.

Inc, P. (2018). *Composite Reinforcing Rods Technical Data Sheet*.

Jang, H. S., Kim, M. S., Cho, J. M., & Kim, C. H. (2009). Concrete shear strength of beams reinforced with FRP bars according to flexural reinforcement ratio and shear span to depth ratio. In *FRPRCS-9*.

Rebeiz, K., Fente, J., & Frabizzio, M. A. (2001). Effect of variables on shear strength of concrete beams. *Journal of Materials in Civil Engineering*, *13*(6), 467–470.

S806-12, C. A. N. /C. S. A. (2012). *Design and Construction of Building Components with Fibre-Reinforced Polymers*. Canadian Standards Association, Rexdale.

Tureyen, A. K., & Frosch, R. J. (2002). Shear tests of FRP-reinforced concrete beams without stirrups. *ACI Struct. J*, *99*(4), 427–434.

©2022 Copyright The Science Publishing House LLC