Global Scientific JOURNALS

GSJ: Volume 10, Issue 1, January 2022, Online: ISSN 2320-9186
www.globalscientificjournal.com

ANALYSIS OF RC BEAMS WITH DURABLE GFRP SPIRAL REINFORCEMENT

Ahmed Gouda[1], Ahmed Ali[1], and Hamdy Mohamed[2]

[1] Department of Civil Engineering at Helwan University, Cairo, Egypt.

[2] Department of Civil and Architectural Engineering, College of Engineering, Applied Science University, Kingdom of Bahrain.

Abstract: This paper presents the results of an experimental and numerical programs that were carried out to investigate the effect of shear reinforcement ratio on the behaviour of circular reinforced-concrete (RC) beams. A total of three full-scale circular RC-beams with, the same GFRP longitudinal reinforcement ratio (1.5%) and, different spiral shear reinforcement ratios, ranging from 0.26% to 0.53%, were constructed and tested to failure. Afterward, numerical finite element models (FEM) were built to imitate the conduct of those beams. The beams had a diameter of 500 mm and a length of 3000 mm. The beams were subjected to a vertical shear force through two points. The test results showed that, increasing the shear-reinforcement by 35% and 104%, from 0.26% to 0.35% and 0.53%, increased the shear strength by 9% and 31%, respectively. The constructed FE models, also, were able to copy the characteristics of these beams in terms of load-deflection curve, and load-strain relationships for reinforcing bars as well, with excellent accuracy. Last but not least, the results from the FEM, showed that the average value for the experimental shear strength to the predicated one, by the FE program, (V_{exp}/V_{model}) for the beams is 0.99 with a 2.3% standard deviation.

1 INTRODUCTION

Circular RC bridge pier columns and waterfront structures include steel, concrete, and timber. Due to corrosion resulting from harsh marine environments, these structures' materials are subjected to limited-service life and high costs for maintenance. The high price associated with the corrosion of steel materials requires a solution that would solve the problem. In such structures, using fiber reinforced polymers (FRP) bars instead of conventional steel bars is an appropriate solution to overcome the corrosion problems. FRP materials, in general, give more advantages over the ordinary steel materials, such as FRP materials have less weight (one quarter to one fifth the density of steel), greater tensile strength, and no corrosion even in hard and harsh chemical environments, (Ali 2016).

The research studies, done so far, focused, mainly on reinforced concrete members with rectangular cross section (Tureyen and Frosch 2002, Razaqpur and Isgor 2006, and Jang et al. 2009). In addition, all the codes and guidelines provide flexural and shear design provisions and equations for the RC beams based on rectangular cross section (ACI 440-15, CSA S806-12, CSA S6-14, and JSCE 1997). Furthermore, experimental research on the shear strength and behaviour of circular RC components reinforced with FRP and stirrups is rare. Yet, no analytical study using finite element (FE)—on the shear behavior of circular concrete members reinforced with FRP—has been conducted to model the circular reinforced concrete members under shear loads, in a three-dimension space.

The purpose of this study is to use the specialized software package (Atena 3D), which is based on finite element method, to model circular RC member, in a three-dimension space. FE model was constructed to predict the shear strength and behavior of circular RC members reinforced with FRP bars. The analysis included tracing the load deformation response and the determination of FRP bars strain.

2 METHODOLOGY

Three circular beams, reinforced with longitudinal and transverse FRP reinforcement, were constructed and tested to failure. Each beam had a length of 3000-mm and diameter of 500-mm. All the specimens were tested using two-points load bending. The designation of each beam consisted of a letter and a number. The letter (B) represents a beam specimen and the number refers to the spiral reinforcement ratio (0.26, 0.35 and 0.53). The test variable was the spiral reinforcement ratio, with different spiral diameters and spacings, #4 spiral at spacing of 150-mm (B-0.26) and 200-mm (B-0.35) and #5 spirals at spacing of 150-mm (B-0.53). The dimensions and reinforcement details of the test specimens are shown in Figure 1.

2.1 Material Properties

The beams were cast using normal weight, ready mixed concrete from a local supplier. The target compressive strength was 35 MPa, while, the actual compressive strength was determined on the day of testing for each beam by performing standard cylinder test (CSA/A23.2-14). One type of GFRP bars and two types of GFRP spirals were used in this study. Table 1 lists the features of the used reinforcement.

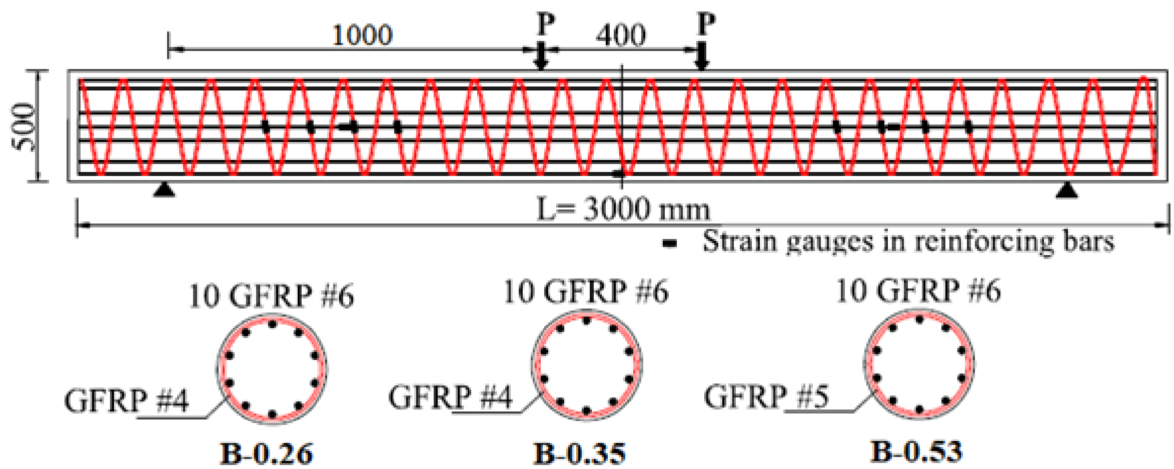


Figure 1: Reinforcement configuration

2.2 Instrumentation and Test Setup

6-mm strain gauges were used, in different locations, to measure the strains in the GFRP spirals and bars (Figure 1). Three, 60-mm, strain gauges were placed on the concrete surface to record the strain at the mid-span (D, D/8, and D/4). Deflection at the mid-span, under the point-load at the top of the concrete surface, was captured using linear variable differential transformers (LVDTs).

The test setup shown in Figure 2 was built, to test the specimens. The loads were applied to the specimens, using a hydraulic actuator attached to spreader beam, through two-points. A rate of 0.6 mm / min stroke-controlled was used to apply the shear forces. An automatic data-acquisition system monitored by a computer was used to record the readings of the LVDTs, the load cell, and the strain gauges.

2.3 Results

The observed failure modes of the tested circular GFRP-reinforced beams were diagonal tension failure, initiated by rupture in the spiral reinforcement. The concrete contribution to the shear strength of the circular RC beams was proportional to the spiral reinforcement ratio. Increasing the reinforcement ratio by, approximately, 35% and 104% (from 0.26% to 0.35% and 0.53%) increased the shear strengths by 9.0% and 31%, respectively. Also, Increasing the shear reinforcement ratio by 35% and 104%, reduced the captured deflection at the mid-span of the beams and increased the post-cracking stiffness, calculated as the slope of the load-deflection curve by 9% and 15% respectively. Table 2 shows the outcomes of the experimental tests.

Table 1: Properties of the reinforcement

Bar Size	Diameter (mm)	Nominal area (mm^2)	Area by immersion test (mm^2)	Tensile Modulus (GPa)	Ultimate Strength (MPa)	Ultimate Strain (%)
			GFRP bars			
#6	20	285	341	62.8	1103	1.75
			GFRP spirals			
#4	13	127	135	47.0	1050	2.23
#5	15	198	211	49.5	1003	2.02

Table 2: Test results

Specimen	Shear reinforcement		Failure Loads, $V_{exp.}$ (kN)	Ultimate shear, $V_{u\ exp.}$ (kN)	Post-cracking Stiffness (kN / mm)	FE Model Failure Load V_{Model} (kN)
	Spiral	$\rho_{fv.}$%				
B-0.26	#4@200 mm	0.26	769	385	22.2	761
B-0.35	#4@150 mm	0.35	837	419	24.2	848
B-0.53	#5@150 mm	0.53	1005	503	25.5	1016

Figure 2: Test setup

3 NUMERICAL PROGRAM

A software package ATENA (Cervenka et al. 2013) was preformed to simulate the shear behaviour of the circular concrete beams. Many factors had to be considered in modeling such as, dimensions for the models, types of elements, material properties, mesh sensitivity and generation, loading conditions, and boundary types. The elements used in the current study to simulate concrete, and the reinforcement in addition to the boundary conditions are briefly described in the following sections.

3.1 Concrete Properties

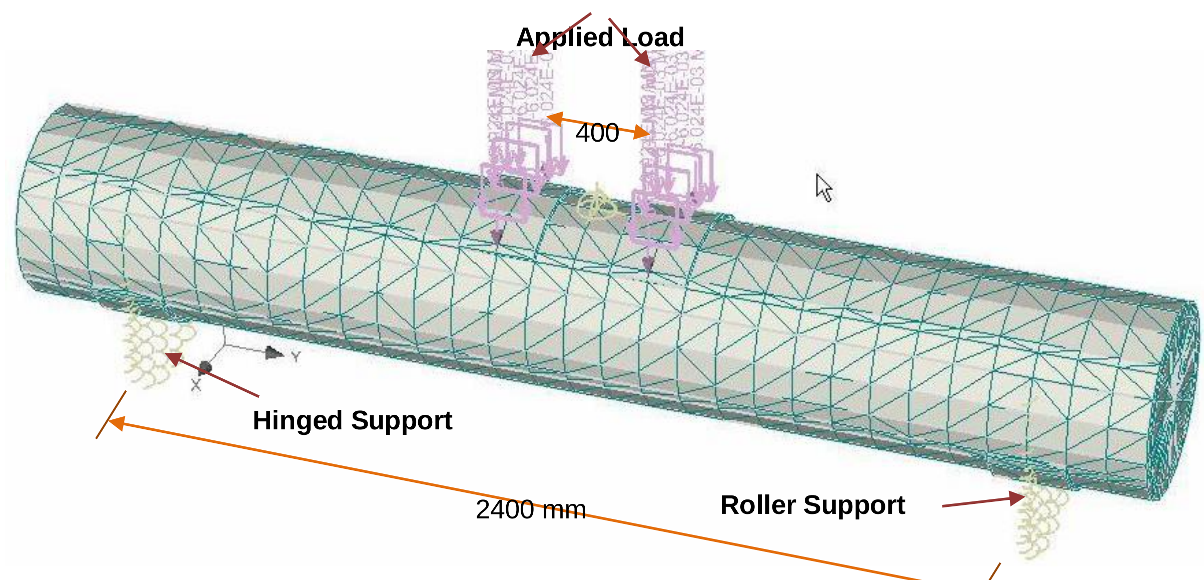
To mimic the influence of the concrete material, the finite-element programme employs many sorts of elements. The influence of concrete was modelled using CC3DNonLinCementitious2, a built-in fracture-plastic constitutive model. The Rankine failure criterion is employed in the fracture model, whereas the Menétrey-Willam failure surface (Cervenka et al. 2013) is used to determine the plastic failure surface. These fracture-plastic models were merged into one model to mimic cracking, crushing, and fracture mechanics for concrete material. Crushing, nonlinearity, plasticity, and cracking in the x, y, and z directions are all accounted for in this model.

3.2 Reinforcing Bars

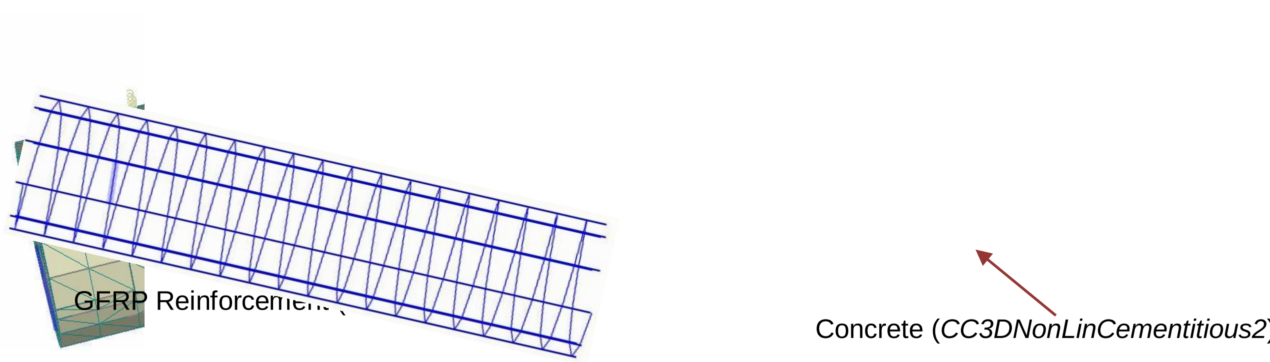
A truss element (*CCIsoTruss*) was used to model the reinforcing bars with transition degrees of freedom in *x*, *y*, *z* directions at the element's nodes. Perfectly linear elastic stress-strain curve was defined for the GFRP reinforcement using the mechanical properties documented in Table 1.

3.3 Concrete-Reinforcement Interface

The used bond-slip relationship, in the current study (Cervenka et al. 2013), is suggested for the unconfined concrete. This relationship consists of ascending branch in approximately a parabolic shape, a linear descending part in a linear form and finally the horizontal plateau in which the slip continues to increase at a constant bond stress.



(a) Model geometry



(b)

Element types

Figure 3: Model geometry of the circular reinforced concrete beams

3.4 Model Geometry, Loading, and Boundary Conditions

All length of circular beam specimen was modeled, and ring plates were modeled in order to accommodate the circular geometry at the loading and support points, as shown in Figure 3. The main purpose for those ringed plates was to distribute and transfer the stresses to the different elements of the circular concrete beam model. To imitate those plates, a tetra element (CCIsoTetra) with three translation degrees of freedom in the x, y, and z dimensions was employed at each node. The plates were also made of linear-elastic material with a modulus of elasticity of 200 GPa and a Poisson's ratio of 0.3. A roller was developed by modelling the support in this way. Constraints in the UX and UY directions were applied to a single line of nodes on the plate, with constant values of 0. The force P is applied across the entire centerline of the plate, to simulate the loading points in the experimental program.

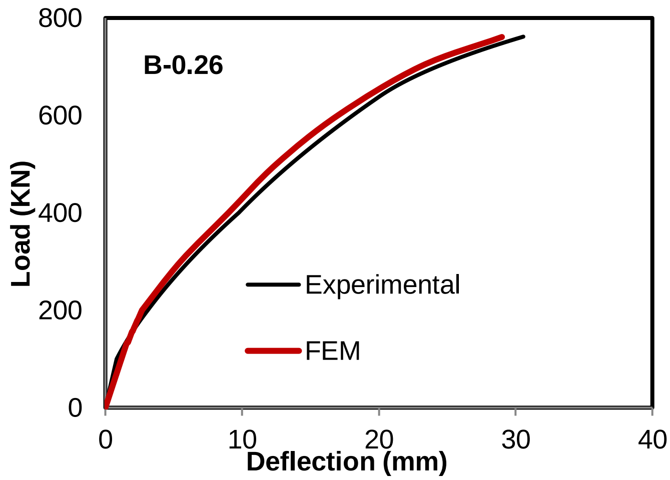
3.5 Numerical Results

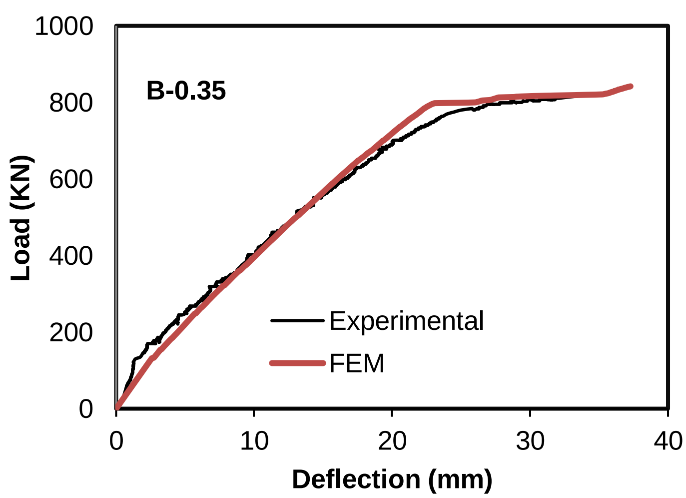
The results from the constructed FEM were verified against the experimental results of the tested circular RC beams. All specimens were used for the verification process of the FE model (B-0.26, B-0.35, B-0.53). The comparison was performed with respect to the load-deflection curve, the tensile strains in the FRP bars, and failure loads. The results show that the model accurately predicted the shear response up to cracking as well as between cracking and failure.

Figure 4 shows the load–deflection curves for the experimental and FEM results of the beams. It can be seen that the FE model was able to predict the load-deflection response of the experimental results with very reasonable accuracy. This applies to both the uncracked and cracked stages of the process. In addition, the model was able to anticipate the drop in stiffness following cracking.

Similarly, as shown in Figure 5, the GFRP longitudinal-bar’s strains measured in the FEM and the strains obtained experimentally are in good agreement. The strain was minimal in the longitudinal reinforcing bars until the concrete section cracked. After cracking occurred, the strains in FEM and experimental curves differed, from the pre-cracking ones, almost linearly with increasing load up to failure.

In term of load carrying capacity, the shear-load predicted by the FE model was within 5% from the one obtained experimentally as shown in Table 2. The average value for the experimental shear strength to the predicated one, by the FE program, (V_{exp}/V_{model}) for the beams is 0.99 with a 2.3% standard deviation.





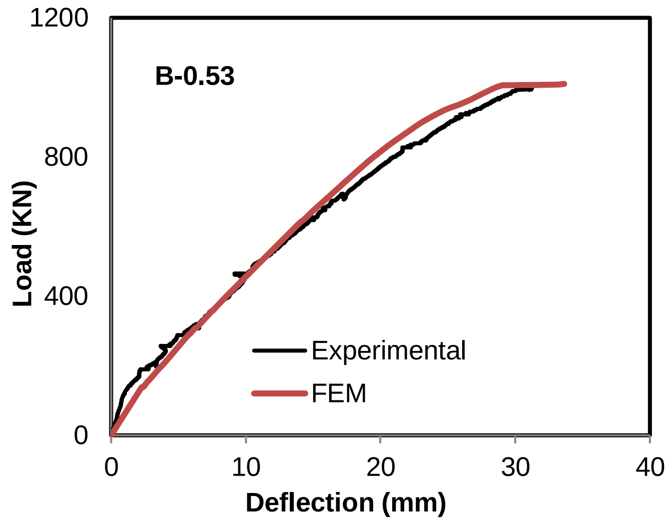
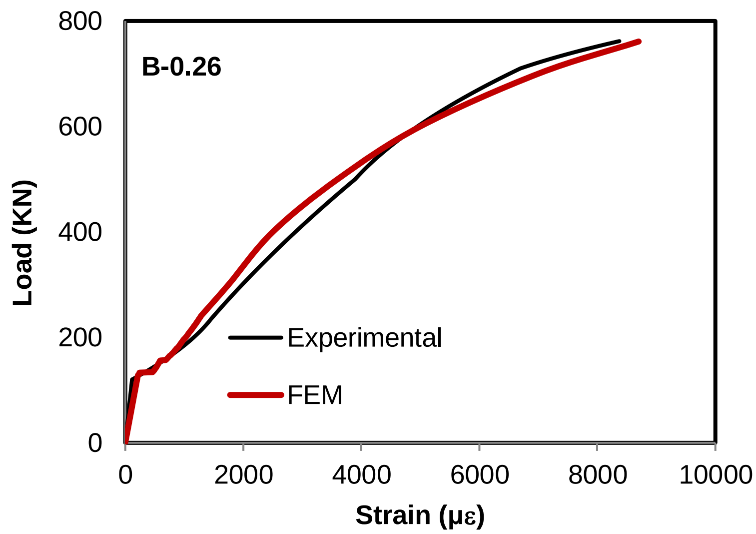
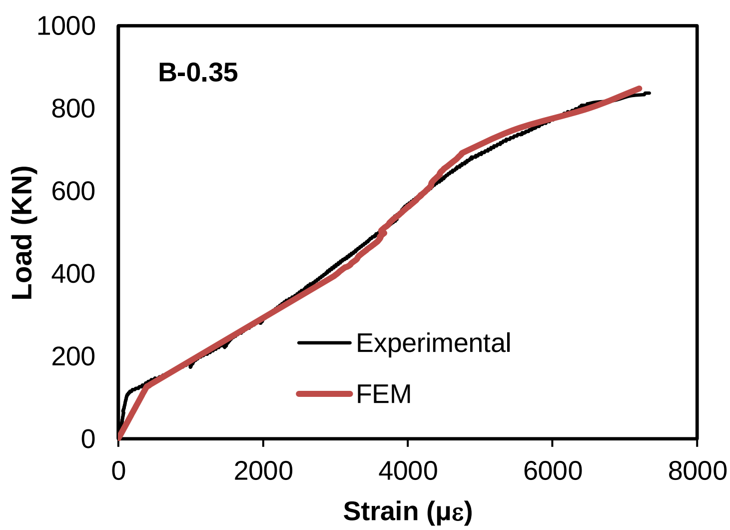


Figure 4: Load-deflection relationship





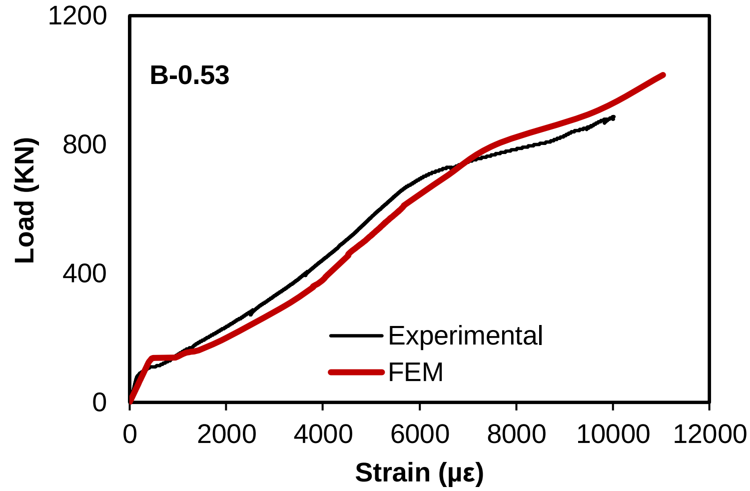


Figure 5: Load-strain relationship for the longitudinal-reinforcement

4 CONCLUSION

The behaviour of three full-scale GFRP circular beams, tested under shear-load, was evaluated. Based on the test results discussed herein, the following could be concluded.

1- All the beams failed due to GFRP spiral rupture.
2- Increasing the spiral shear reinforcement from 0.26 to 0.53% enhanced the shear contribution by 30.7% due to the confining of the concrete by the spirals.
3- The constructed model was able to predict the behaviour of the circular concrete beams, in terms of ultimate shear capacity, load-deflection curve and load-strain curve with a reasonable accuracy.
4- the average value for the experimental shear strength to the predicated one, by the FE program, (V_{exp}/V_{model}) for the beams is 0.99 with a 2.3% standard deviation.

5 REFERENCES

Ali, A. 2016. Shear Strength and Behavior of Circular Concrete Members Reinforced with FRP Bars and Spirals. Ph.D. thesis. University of Sherbrooke, Sherbrooke, QC, Canada.
American Concrete Institute (ACI) Committee 440. 2015. Guide for the design and construction of concrete reinforced with FRP bars. ACI 440.1R-15, Farmington Hills, MI.
CAN/CSA A23.2-14. 2014. Method of Test for Concrete. Canadian Standards Association, Rexdale, Ontario, Canada, 203 p.
CAN/CSA S806-12. 2012. Design and Construction of Building Components with Fibre-Reinforced Polymers. Canadian Standards Association, Rexdale, Ontario, Canada, 187 p.

Cervenka, V., Jendele, L. and Cervenka, J. 2013. ATENA Program Documentation Part 1: Theory. Cervenka Consulting Ltd., Prague, Czech Republic.

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

Japan Society of Civil Engineers JSCE. 1997. Recommendation for design and construction of concrete structures using continuous fiber reinforcing materials. Tokyo.

Razaqpur, A. G., and Isgor, O. B. 2006. Proposed shear design method for FRP-reinforced concrete members without stirrups. ACI Struct. J., 103(6): 93–102.

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