

## **Use of TUF-BAR GFRP Rebars in Circular Concrete Beams and Columns**

### **Progress Report**



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# **Shear Strength of Full-Scale Circular B.P GFRP-Reinforced Concrete Beams as Pile Applications**

## **Summary:**

Traditional pile materials for bridge foundations and waterfront structures include steel and reinforced concrete. These pile materials have limited service life and high maintenance costs when used in harsh marine environments due to corrosion. The high cost associated with the corrosion of steel reinforcement command a solution that will attack the problem from its root cause. The use of fibre-reinforced polymers (FRP) has increased during the last decade. Known to be corrosion resistant, FRP reinforcing bars provides a great alternative to steel reinforcement. Considerable research efforts have contributed to the understanding of concrete members internally reinforced with FRP bars. These efforts, while greatly improving our knowledge of how concrete slabs and beams reinforced with FRP bars should be analyzed and designed, have not yet investigated the analysis or design of circular concrete piles (CCPs) reinforced with FRP-bars and spiral stirrups. This is partly due to a lack of experimental data, which can describe the behaviour of members reinforced with such materials. The lack of information relevant to this area is also addressed in the FRP-North American code design provisions as one of the areas remains to be researched to further develop strength design guidelines for such members. This research project is intended to investigate the shear strength behavior of FRP-reinforced concrete beams for pile applications.

To fulfill the objectives of this research, an experimental program has been designed including flexural-shear tests. The experimental program consists of testing 6 full-scale circular concrete beams with a total length 3000 mm and cross sectional diameter equals 500 mm. The effect of five parameters and their interaction on the shear behaviour will be investigated for these specimens; namely, shear span to depth ratio, shear reinforcement ratio, spacing between FRP stirrups, and type of shear reinforcements. In addition, the contribution of FRP stirrups to the shear strength of concrete beams will be investigated.

## **Objectives:**

The present study attempts to enrich the database of shear behaviour of FRP-RC beams. The main objective of the experimental program is to investigate and evaluate the performance of concrete beams reinforced with FRP bars and stirrups under shear loads for pile applications. The specific objectives of this study can be summarized as follows:

1. To evaluate the shear behaviour of concrete beams reinforced with B.P GFRP bars and stirrups compared to a control beams reinforced with steel.
2. To compare the experimental results with design equations provided by the three different North American codes and design guidelines ACI Committee 440, CAN/CSA-S6-06, and CAN/CSA-S806-12, for the predictions of the shear strength of circular concrete beams.

### **Parameters:**

1. Type of reinforcement, (GFRP versus steel),
2. Spacing between FRP stirrups,
3. Shear span to depth ratio,
4. Diameter of shear stirrups,

### **Test matrix**

No.	a/d	Stirrups Size No.	Stirrups spacing	Type of stirrups	(a) mm	Type of Longitudinal bars	Longitudinal bars
1	2.4	4	150	spiral	850	B.P GFRP	10 No. 6
2	2.4	4	200	spiral	850	B.P GFRP	10 No. 6
3	2.4	5	150	spiral	850	B.P GFRP	10 No. 6
4	1.43	4	150	spiral	500	B.P GFRP	10 No. 6
5	2.0	4	150	spiral	700	B.P GFRP	10 No. 6
6	3.0	4	150	spiral	1050	B.P GFRP	10 No. 6



**Figure 1.** B.P GFRP bars



**Figure 2.** B.P GFRP stirrups





**Figure 3.** Preparing of B.P GFRP cages.



**Figure 4.** Overview for the B.P GFRP cages with strain gages.





**Figure 5.** The B.P GFRP cages inside Sonatubes.



**Figure 6.** The B.P specimens on the formwork.





**Figure 7.** Casting of circular beams.



**Figure 8.** Curing of circular specimens





**Figure 9.** Specimens after casting

## **Behaviour of circular concrete columns reinforced with B.P GFRP bars and stirrups'**

### **Summary:**

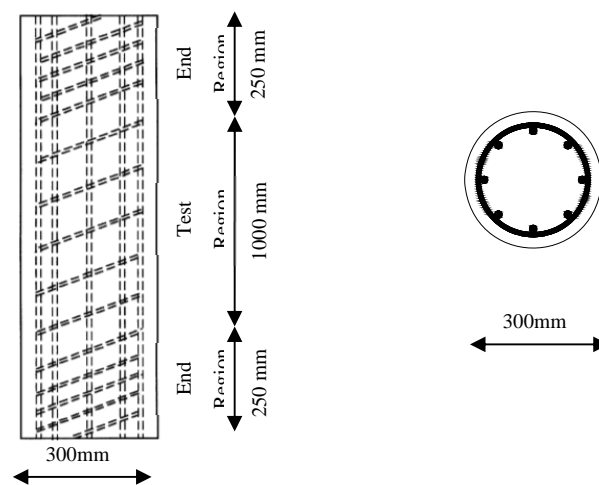
Fibre Reinforced Polymer (FRP) bars are a valuable competitive option as internal reinforcement for concrete structures; especially for structures subjected to aggressive environments when corrosion resistance is sought. Considerable research efforts have contributed to the understanding of concrete members internally reinforced with FRP bars. These efforts, while greatly improving our knowledge of how concrete members reinforced with FRP bars should be analyzed and designed in flexure and in shear, have not yet led to a rational approach for the analysis or design of FRP-reinforced concrete compression members. On the other hand, there are no yet applications concerning the use of FRP stirrups as confinement elements for concrete columns, pier columns and piles. This is partly due to a lack of experimental data, which can describe the behaviour of members reinforced with such materials. This study presents the second phase of an on-going experimental program conducted at the Sherbrooke University to investigate the performance of short columns reinforced with FRP bars and stirrups. In the first phase, rectangular FRP-concrete columns have been investigated, while the present phase is oriented towards the behaviour of circular columns. A total of 6 columns reinforced with FRP bars and stirrups in the vertical and transverse directions, respectively, will be prepared and tested with 300 mm diameter and 1500 mm height. The main objective is to investigate the contribution of longitudinal FRP bars to the column capacity under pure axial load. In addition, the contribution of FRP stirrups to the confinement of the concrete core and to prevent instability of the longitudinal reinforcement will be investigated.

### **Objectives:**

The present study attempts to enrich the database of axial behaviour of circular FRP-reinforced concrete columns. The main objective of the experimental program is to investigate and evaluate the performance of concrete columns reinforced with FRP bars and stirrups under pure axial load. Also, it aims to propose design guidelines that include new strength factors to account for the nature of FRP reinforcements. The specific objectives of this study can be summarized as follows:



1. To evaluate the compression behaviour of circular concrete columns reinforced with FRP bars and stirrups under pure axial load.
2. To investigate the impacts of GFRP bar reinforcement in the longitudinal direction to the axial capacity of the concrete columns.
3. To evaluate the contribution of FRP spiral and tie stirrups to the axial capacity compared to conventional RC columns with steel spiral reinforcement.
4. To compare the experimental results with design equations provided by the three different North American codes and design guidelines ACI Committee 440, CAN/CSA-S6-06, and CAN/CSA-S806-02, for the predictions of the confined concrete compressive strength and the ultimate load capacities of FRP circular reinforced concrete columns.
5. To propose new model and appropriate modifications to the existing design equations for the FRP-circular reinforced concrete columns.
6. To develop an analytical model using non-linear finite element analysis to be implemented in a computer software to predict the behaviour of FRP-circular concrete columns.



**Figure 10.** Dimensions of column.

### **Parameters:**

1. Type of reinforcement, (GFRP versus steel),
2. Spacing between FRP stirrups,
3. Vertical reinforcement ratio,
4. Stirrups configuration, (Spirals and Hoops).

**Test Matrix:**

Specimen ID	Vertical Reinforcement		Horizontal Reinforcement		
	$\rho_s$ %	Number of bars	$\rho_{st}$ %	bar No.	pitch (mm)
G8V-3H80	2.2	8 No.5	1.5	3	80
G4V-3H80	1.1	4 No.5	1.5	3	80
G12V-3H80	3.2	12 No.5	1.5	3	80
G8V-3H40	2.2	8 No.5	3.0	3	40
G8V-3H120	2.2	8 No.5	1.0	3	120
Hoops with 400 mm over lab	2.2	8 No.5	1.5	3	80
Hoops with 400 mm over lab	2.2	8 No.5	1.5	3	120



**Figure 11.** Overview for B.P GFRP cages





**Figure 12.** Overview of the columns formwork



**Figure 13.** Overview for cages inside formwork



**Figure 14.** Casting of columns



**Figure 15.** The columns after casting