Ultimate Capacity of Bonded-Bolted GFRP Connection in GFRP Members

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1. Introduction

The use of fiber-reinforced composite materials for strengthening and rehabilitation of civil engineering structures is relatively new. Steel structural members are routinely joined by bolted connections. Due to the stress concentration around the holes of the bolted connections, the tensile capacity of pulturded glass fiber-reinforced plastic (GFRP) structural members decreases, which in its turn reduce the efficiency of using the GFRP members as a strengthening or rehabilitation materials for existing structures. This paper is an attempt to investigate the appropriate method to enhance the tensile capacity of GFRP bolted connection. Nine specimen types were prepared. General specification for design FRP bolted connections were considered when preparing the specimens. The experimental results are introduced and the conclusions are presented.

2. Specimens and Test Procedure

The behavior of bolted joints is highly dependent on the geometric dimensions of the connections. The geometric dimensions of the specimens were selected taking into account general specifications for design FRP bolted connections. Recent papers on design recommendations of FRP bolted connections indicate that the ultimate load capacity of single-bolt connections increases by increasing the geometric dimensions of the connection. However, increasing the width-to-hole-diameter ratio (w/d) beyond five or the edge-distance-to-hole ratio (e/d) beyond five have an insignificant effect on the ultimate capacity of the connection. Therefore, the ratios e/d and w/d were equal to 4 and 5, respectively. Figure 1 shows the geometric dimensions of the specimens.

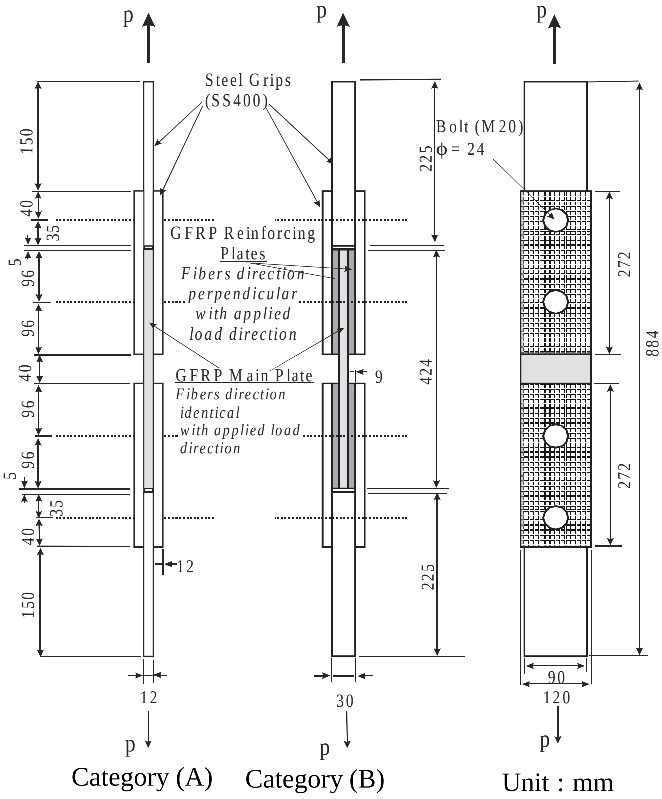

Fig 1. Details of GFRP Joints

Nine different specimen types were examined to achieve the main goal of this study. These specimen types were divided in two main categories (A) and (B). Category (A) includes all the specimens without GFRP reinforcing plates, while category (B) includes the specimens with GFRP reinforcing plates. Table 1 lists details about the tested specimens. The nominations used in table 1 are:
(I) *Bo* indicates the use of only bolts to construct the specimen, (II) *Ad* indicates the use of only epoxy adhesive to construct the specimen, (III) *Co* indicates the use of bolts and adhesive combination to construct the specimen.

3. Test Results and Discussion

Different failure modes occurred in the GFRP main plate (GMP) and GFRP reinforcing plates (GRP). Three basic failure modes were observed, They are net tension failure (NTF), shear off failure (SOF) and adhesive shear failure (ASF). Table 2 lists the failure modes of all the tested specimens. Figure 2 shows the ultimate loads and the loads associated with the initial cracking or initial adhesive slippage of each specimen.

Table 1. Details of Specimen Types

Specime Type	Construction Method	GFRP Reinfocing Plate	Torque (kN.m)
A-Bo	Bolts only	No	0
A-Ad	Adhesive only	No	0
A-Co	Combination	No	0
B-Bo	Bolts only	Yes	0
B-Co-0	Combination	Yes	0
B-Co-7.2	Combination	Yes	70.5
B-Co-14.4	Combination	Yes	141.1
B-Co-28.8	Combination	Yes	282.2

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3.1 Category (A)

Figure 3 shows the load-displacement relationships for the specimens of category (A), in which the displacement is the increase of the distance between the side steel grip plates. A comparison for the experimental results among the specimens of category (A) shows that the tensile capacity of Type A-Ad was 3.9 times bigger than that in Type A-Bo. The tensile behaviors of Type A-Ad and A-Co were approximately the same up to 60% of ultimate load of Type A-Ad. In this loading stage the stress around the bolthole in Type A-Co was highly concentrated, which caused shear out initial failure in the GFRP main plate before the occurrence of the adhesive shear failure between the side steel grips and the GFRP main plate.

3.2 Category (B)

Figure 4 shows the load-displacement relationships for the specimens of category (B).The tensile behaviors of the specimens were approximately the same up to a certain limit. Applying torque equal to 70.5 kN.m , which produced a tensile load in the bolt equal to 35% of the bolt design load, enhances significantly the tensile capacity of Type B-Co-7.2 over that of Type B-Bo. Increase the applied torque value over than that of Type B-Co-7.2 has a negative effect on the cracking pattern of the GFRP reinforcing plate, which suffered from severe cracks by the end of the loading procdure.

4. Conclusions

The exploratory study has presented the feasibility of enhancing the tensile capacity of GFRP bolted connection.

According to the experimental study, the following conclusions can be made;

1. The concentration of the stress around the bolthole in Type A-Co was a major factor in reducing the ultimate tensile load to be less than that of Type A-Ad.
2. Type B-Co-7.2 showed the best loading behavior, as the initial cracking and the complete failure occurred simultaneously.
3. Increase of the applied torque over a certain limit, which produces a tensile load in the bolt exceed 35% of the bolt design load, negatively resulted in effect on the tensile behavior of the connection.

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Reference

Charles N. Rosner , Sami H. Rizalla., *Bolted Connections for Fiber Reinforced Composite Structural Members: Analytical Model and Design Recommendations*, ASCE, Journal of Materials in Civil Engineering, November 1995.

Table 2. Failure Modes

Specime Type	Load of Initia Cracking (kN)	Initial Cracking	Ultimate Load (kN)	Failure Mode
A-Bo	-----	-----	27.7	SOF
A-Ad	-----	-----	108.7	ASF
A-Co	63.2	GMP : SOF	75.2	ASF
B-Bo	-----	-----	88.4	SOF+NTF
B-Co-0	92.6	GRP : Cracks	110.2	ASF+NTF
B-Co-7.2	127.4	AS*	128.3	SOF+NTF
B-Co-14.4	124.4	AS*	145.6	SOF+NTF
B-Co-28.8	110	GRP : Cracks	211.4	SOF+NTF

AS* : Adhesive Initial Slippage

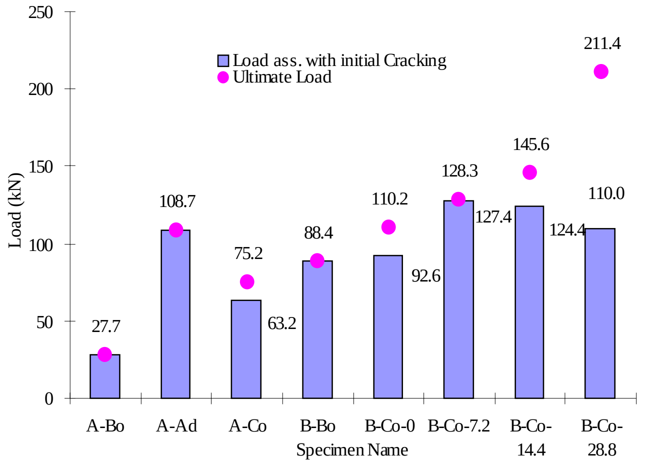

Fig 2. Ultimate Load of Specimens

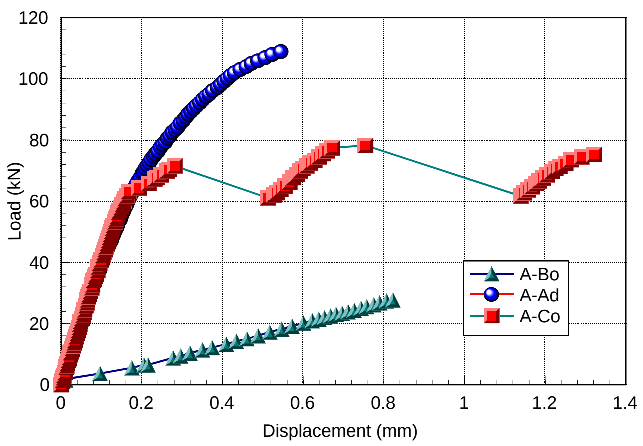

Fig 3. Load-Displacement Relationship for Specimens of Category (A)

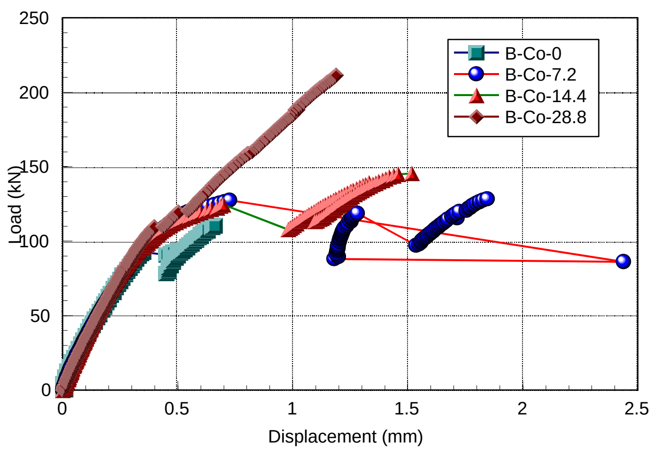

Fig 4. Load-Displacement Relationship for Specimens of Category (B)