LOAD DISTRIBUTION IN MULTI-ROW BOLTED CONNECTIONS FOR FRP COMPOSITE STRUCTURES WITH VARYING COVER PLATE STIFFNESS

Nagoya University, Student Member, Mohammad Abdul Kader
Nagoya University, JSCE Member, Yasuo Kitane
Nagoya University, JSCE Fellow Member, Yoshito Itoh

1. Introduction

Fiber reinforced polymer (FRP) composite is an excellent material when compared to other conventional structural materials. The material has superior mechanical properties such as high strength-to-weight ratio, high stiffness-to-weight ratio, good durability and corrosion resisting capacity. However, its applications in the civil engineering field are limited so far due to several factors including lack of standards and design guidelines, lack of experience of designing structures with anisotropic and viscoelastic properties, and most importantly the lack of proper and reliable joining details.

Since the capacity of the structure is often limited by the capacity of its connections, understanding of the mechanical behavior of connections in FRP structural members is extremely important. The capacity of a connection is influenced by many factors. In bearing type bolted connections with multiple rows of bolts, bolts in different rows carry different amounts of load, which depends on clearance of hole [1], cover plate stiffness [2-5], and other factors. Feo, Marra, and Mosallam [2] investigated the load distribution among rows of bolts up to four rows of bolts, where one cover plate has a half of the stiffness of the main plate. The LRFD Pre-Standard [3], EUROCOMP [4] and CNR [5] codes specify load distributions for up to four rows of bolts where a steel cover plate or an FRP cover plate with half the stiffness of the FRP main plate is used. However, how cover plate stiffness affects the load distribution in the multi-row connection has not yet been studied.

The objective of this paper is to carry out a numerical study of multi-row bolted connections of FRP structural members to examine the effect of cover plate stiffness on load distributions among bolt rows.

2. Material Properties and Model Description

In this study, a bearing type bolted connection with a double-lap configuration is examined. The modeled connection consists of one line by three or four rows of bolts. The main plate is a GFRP composite plate with a thickness of 12 mm. The bolt diameter of 16 mm and the bolt hole diameter of 17.6 mm are used, resulting in a clearance of 1.6 mm. Two types of cover plate are considered i.e. GFRP and steel. To examine the effect of different cover plate stiffnesses, 6, 9 and 12 mm FRP cover plates, and 3, 4.5, and 6 mm steel cover plates are used, which corresponds to stiffness ratios of cover plate to main plate of 1.0, 1.5, and 2.0 for FRP cover plates and 5.2, 7.8, and 10.4 for steel cover plates, respectively. Geometric parameters of bolted connections are set to satisfy code-specified minimum requirements, where a pitch to bolt diameter ratio, a width to bolt diameter ratio, and an end distance to bolt diameter ratio are 4, 4, and 2, respectively.

For FRP plates, quasi-isotropic glass-fiber laminates is used. A thickness of each ply is 0.375 mm, and a stacking sequence is symmetric in each laminate. Material properties of unidirectional lamina used in this study are given in Table 1. Material properties of steel are Young's modulus $E = 200$ GPa and Poisson's ratio $\nu = 0.3$.

Table 1 Material properties of unidirectional GFRP

E_{11} (MPa)	E_{22} (MPa)	E_{33} (MPa)	ν_{12}	ν_{13}	ν_{23}	G_{12} (MPa)	G_{13} (MPa)	G_{23} (MPa)
26,000	6,000	6,000	0.3	0.3	0.5	3,120	3,120	2,000

Finite element models are created using general purpose finite element software, ABAQUS, with solid composite elements, C3D8R. Contact pairs are defined between faces of bolts and plates, and a main plate and a cover plate. Due to symmetry conditions, a quarter of a connection is modeled, and symmetry boundary conditions are applied in the planes defined in Fig. 1. An elastic analysis is performed, and material failure is not included in this study.

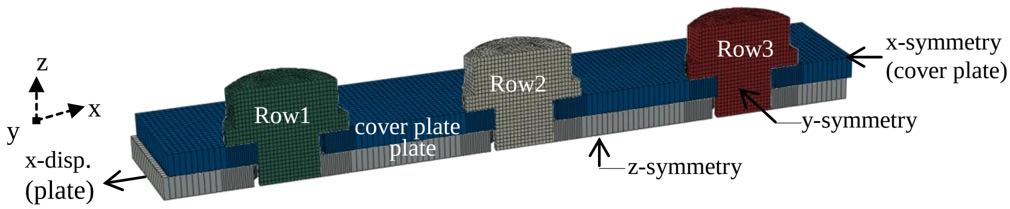

Fig. 1 Finite element model of three row bolted connection

3. Results and Discussions

For a connection with an FRP cover plate that has half the stiffness of an FRP main plate, the load distribution coefficients are given in Table 2 for comparison. Load distribution coefficients from the present finite element analysis (FEA) are in very good agreement with those of Refs. [2-5], which validate the finite element model of this study.

Table 2 Load distribution coefficients of FRP/FRP bolted connections

	Materials	Three rows of connection			Four rows of connection			
		Row1	Row2	Row3	Row1	Row2	Row3	Row4
FEA of this study		0.37	0.27	0.37	0.32	0.18	0.18	0.32
Feo, Marra [2]		0.36	0.28	0.36	0.31	0.19	0.19	0.31
LRFD [3]	FRP/FRP	0.40	0.20	0.40	-	-	-	-
EUROCOMP [4]		0.37	0.27	0.37	0.30	0.20	0.20	0.30
CNR [5]		0.41	0.17	0.41	0.29	0.21	0.21	0.29

Load distribution coefficients among rows of bolts are presented in Fig. 2 for cases with different cover plates. In legends of the figure, S6.0 indicates the case of a steel cover plate with a thickness of 6.0 mm, and F9.0 is the case of an FRP cover plate with a thickness of 9.0 mm.

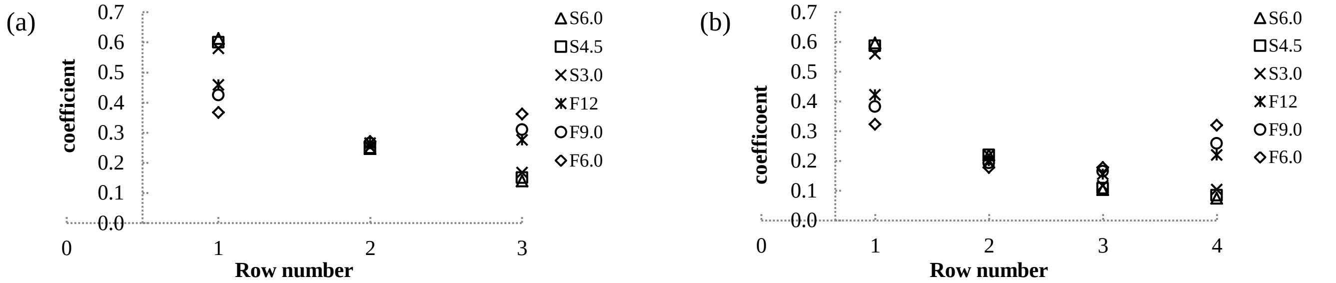

Fig. 2 Load distribution coefficients amomg the rows: (a)Three rows of bolts and (b) Four rows of bolts

It is seen that load distributions depend on the stiffness of cover plate. The distribution coefficients increase in the first row and decrease in the last row with increase cover plate stiffness. For the second row, the coefficients increase by negligible amount with increased cover plate stiffness, but for the third row of a four-row connection they slightly decrease.

Relations of the load distribution coefficients in each row with a stiffness ratio are shown in Fig. 3. It is observed that a rate of change of coefficients for the first and last rows decreases with the increased stiffness ratio. When the stiffness ratio becomes greater than 5, the rate of change becomes nearly zero.

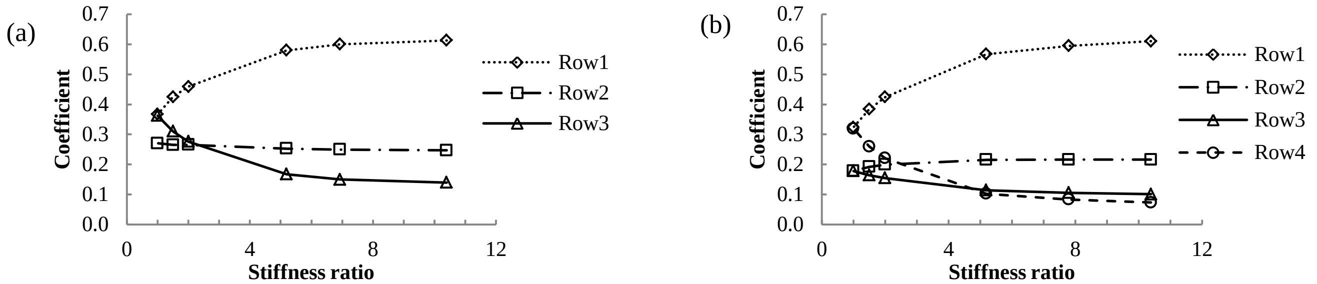

Fig. 3 Effect of stiffness ratio of cover plate to main plate: (a)Three rows of bolts and (b) Four rows of bolts

4. Conclusions

In multi-row bolted connections of FRP structural members, load distributed coefficients vary with a change of cover plate stiffness. Coefficients of the first and last rows will be affected significantly, while those of intermediate rows are insensitive with the change of cover plate stiffness. However, the stiffness ratio of cover plate to main plate becomes more than 5, distribution coefficients do not change any more, implying that when a steel cover plate is used, the cover plate stiffness does not affect the load distribution. In conclusion, for a double-lap configuration, when an FRP cover plate with a higher stiffness than the half of the main plate stiffness is used in a bearing type multi-row bolted connection, a designer has to use appropriate load distribution coefficients which are not shown in the current design codes.

Reference

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