Integrated Solutions for Infrastructure Development
Edited by Lau, H. H., Tang, F. E., Ng, C. K., and Singh, A.

ISBN: 978-0-9960437-3-1

A STUDY ON THE PUSHOVER TEST AND NUMERICAL ANALYSIS OF GFRP FRAMES

YEOU-FONG LI, BO-SHIANG WANG and JIAN-YU LAI

Dept of Civil Engineering, National Taipei University of Technology, Taipei, Taiwan, R.O.C.

This paper presents the use of glass fiber reinforced plastic (GFRP) composite material to produce a structure frame; the behaviors of the GFRP frames were analyzed by using pushover test and a numerical analysis software. Double-web FRP I-beams are used for the beams and columns of the frame, and joints made from metal and FRP. Three types of frame specimens were involved: an un-braced frame, a compression-braced frame and a tension-braced frame for each joint type. The joints were bonded to the frame components using epoxy resin but also adding bolts in the beam-column joint. The pushover test was used to investigate the mechanical behaviors and failure modes of the GFRP frames. The analysis software SAP2000 was used for the pushover analysis of the GFRP frames, and it was shown that the ultimate strength and force-displacement relationships of the analytical results were similar to that of the experimental ones.

Keywords: Composite material, Brace, Experiment, Joint.

1 INTRODUCTION

FRP material, because of its high strength, high durability and light weight, can be advantageous when used to construct prefabricated houses in the mountain areas or seaside without being affected by corrosion. This study focuses on assembled GFRP Building frame specimens with related experiments and analysis.

This study collected previous related research achievements which are summarized as follows. Ascione *et al*. (2010) proposed bolt opening of porous GFRP deck experiments; and the establishment of numerical model, the experiment results of the bolts were compared with analysis results from the numerical model. Al-Kharat and Rogers (2007) describe the use of cold-formed steel to build a frame model. The model was used to estimate the performance of inelastic structural element, to determine the frame ductility, plastic strain concentration or possible position in the component and weld seam damage results. Bao *et al*. (2011) uses 3 groups of displacement meters to measure vertical displacement of beams and then calculate the rotation angle. Davalos *et al*. (1996) for different types of types I and box section member for three points and four points bending test, using the hierarchical systems theory, the mechanics of laminated beams and finite element analysis model to predict the deformation and strain of FRP components. In addition to the above references, several other literatures provide vital information relevant to this topic but cannot be covered in this text for the sake of brevity. Literature from previous studies is helpful to understand content and experiment planning for this paper. The analysis results were compared with experimental results and finally submit conclusions.

2 EXPERIMENTAL PROCEDURES

2.1 Materials of GFRP

In this study, GFRP frames are assembled with beams and columns using pultruded GFRP double web I type components. Bracing members are pultruded GFRP rectangular section components. Metal joints and FRP joints are used to connect and configure the members into a frame after which the members are bolted in place. The bracing also uses metal pieces to connect to the frame joint. GFRP member parameters are shown in Table 1.

Table 1. GFRP component parameters.

Elastic Modulus (kN/cm^2)	Poisson's Ratio	Shear Modulus (kN/cm^2)
E_x = 1,722	ν_{xy} = 0.11	G_{xy} = 310
E_y = 551	ν_{yz} = 0.33	G_{yz} = 310
E_z = 551	ν_{xz} = 0.11	G_{xz} = 310

2.2 Experimental Setup

The experimental setup details of single-span GFRP frame was shown in Fig. 1. A displacement controlled pushover test was done with unidirectional loading. In order to avoid external deformation of the GFRP, two lateral supports were provided along with pulley rollers attached to them to reduce the in-plane deformation from friction. Rotation was calculated according to the literature Bao *et al*. (2011). The specimen names and configurations can be seen in Table 2 and Table 3, respectively.

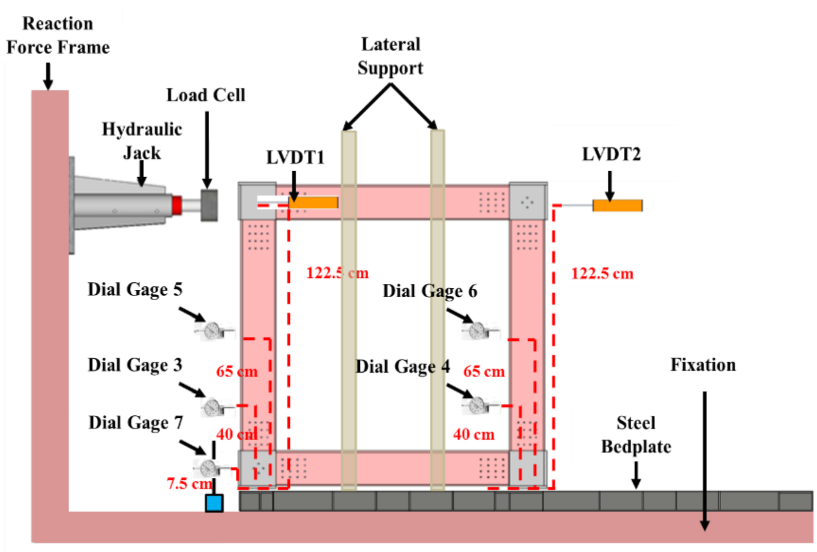


Figure 1. The schematic diagram of single-span specimen.

In this study, the single-span GFRP frame height and width are both 130 cm. The double-span GFRP frame height is 130 cm and width is 245cm. GFRP members clear height is 100 cm. The metal joints are 15 cm deep and 3.3 cm wide. GFRP components are bolted to the metal joints using M6 bolts. The bracing is attached to the joint by using a steel block and at the tip of the bracing member is inserted a small steel block which is bolted to the member to prevent shearing damage to the bracing member from the bolts.

3 TEST RESULTS AND DISCUSSIONS

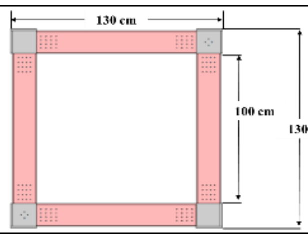
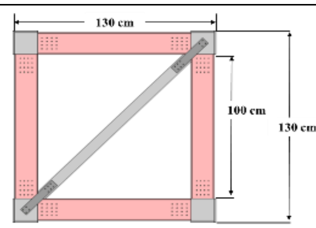
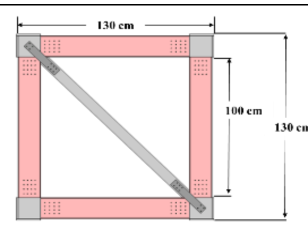
The experimental results of single-span frame of metal joints and FRP joints with bolts were discussed as the following.

3.1 The Experimental Results of Single-Span Frame of Metal Joints

FP1T and FP1C had better stiffness and ultimate strength at the initial stages than the prototype specimen FP1. This proves that adding a brace can improve the overall stiffness and strength of the frame. GFRP has higher tensile than compressive strength, therefore the ultimate strength of FP1T is even higher than that of FP1C.

For specimens with bracing, the bracing member becomes the first casualty whether in tension or compression damage. Tension damage (FP1T) occurs in the form of bolt hole tearing by the bolts due to high concentration of force whilst compression damage (FP1C) is visible when the bracing member buckles. The overall experimental results were compared and shown in Table 2.

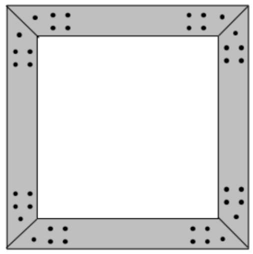
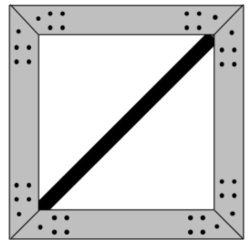
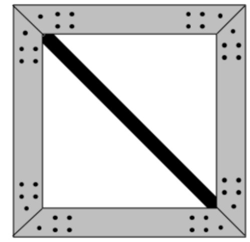
Table 2. Comparing experimental results of single-span frames with metal joints.

Specimen Name	FP1	FP1T	FP1C
Configuration			
Linear Stiffness (kN/cm)	15.9	42.2	26.2
Maximum Load (kN)	33.3	56.4	36.9
Energy Dissipation (kN.cm)	154.51	216.96	192.32

3.2 The Experimental Results of Single-Span Frame of FRP Joints

FB1T and FB1C had better stiffness and ultimate strength than the prototype specimen FB1 at the initial stages. This proves that adding a brace can improve the overall stiffness and strength of the frame. The ultimate strength of FB1T is even higher than that of FB1C. The overall experimental results were compared and shown in Table 3.

Table 3. Comparing experimental results of single-span frames with FRP joints.

Specimen Name	FB1	FB1T	FB1C
Configuration			
Linear Stiffness (kN/cm)	17.8	59.7	50.7
Maximum Load (kN)	17.75	30.24	24.7
Energy Dissipation (kN.cm)	88.6	161.54	117.71

4 NONLINEAR PUSHOVER ANALYSIS

Two-dimensional models of the frames were numerically analyzed using SAP2000 Version 14. Plastic hinges were manually defined for each column member, one in the upper part and one in the lower end. A plastic hinge was also defined at the middle of each bracing member.
The nonlinear nature of the problem requires the use of plastic hinges to simulate the behavior of the frame after yielding. Before yielding, the frame is in an elastic state and elastic behavior takes place over the entire length of the member but once the yielding point is reached, deformation behavior is propagated from the hinges. The Hinge-overwrite settings allow for proper simulation of plastic hinge locations. The plastic hinge parameter was set by using a single-column force-displacement relationship diagram and converting it into a moment-rotation relationship. The comparison of the experimental and numerical results of the force-displacement relationships of the GFRP frames were shown in Fig. 3.

As seen from Fig. 3, the analysis results compared with the experimental results, showing good correlation at the maximum load for all specimen, with absolute error rate less than 4 %. The analysis results can also predict experimental initial failure of the braces for specimens FP1T, FP1C, FB1T and FB1C correctly.

5 CONCLUSIONS

Based on this study, the following conclusions can be drawn:

1. Single-span of metal joints FP1T with tension bracing had a 165 % increase in initial stiffness and 69 % increase in maximum load. FP1C had 65 % increase in initial stiffness and 11 % increase in maximum load.

2. Single-span of FRP joints FB1T with tension bracing had a 235 % increase in initial stiffness and 70 % increase in maximum load. FB1C had 33 % increase in initial stiffness and 39 % increase in maximum load.

3. GFRP frames with FRP joints increase higher initial stiffness compare to those with metal joints, because the rigidity of FRP joint is higher than metal joint. GFRP frames with metal joints increase higher maximum load compare to those with FRP joints, because the strength and ductility of metal joint is higher than FRP joint.

4. Analysis results compared with the experimental results, showing correlation. This proves the use of SAP2000 can make engineers works easier as the analysis software has a high accuracy.

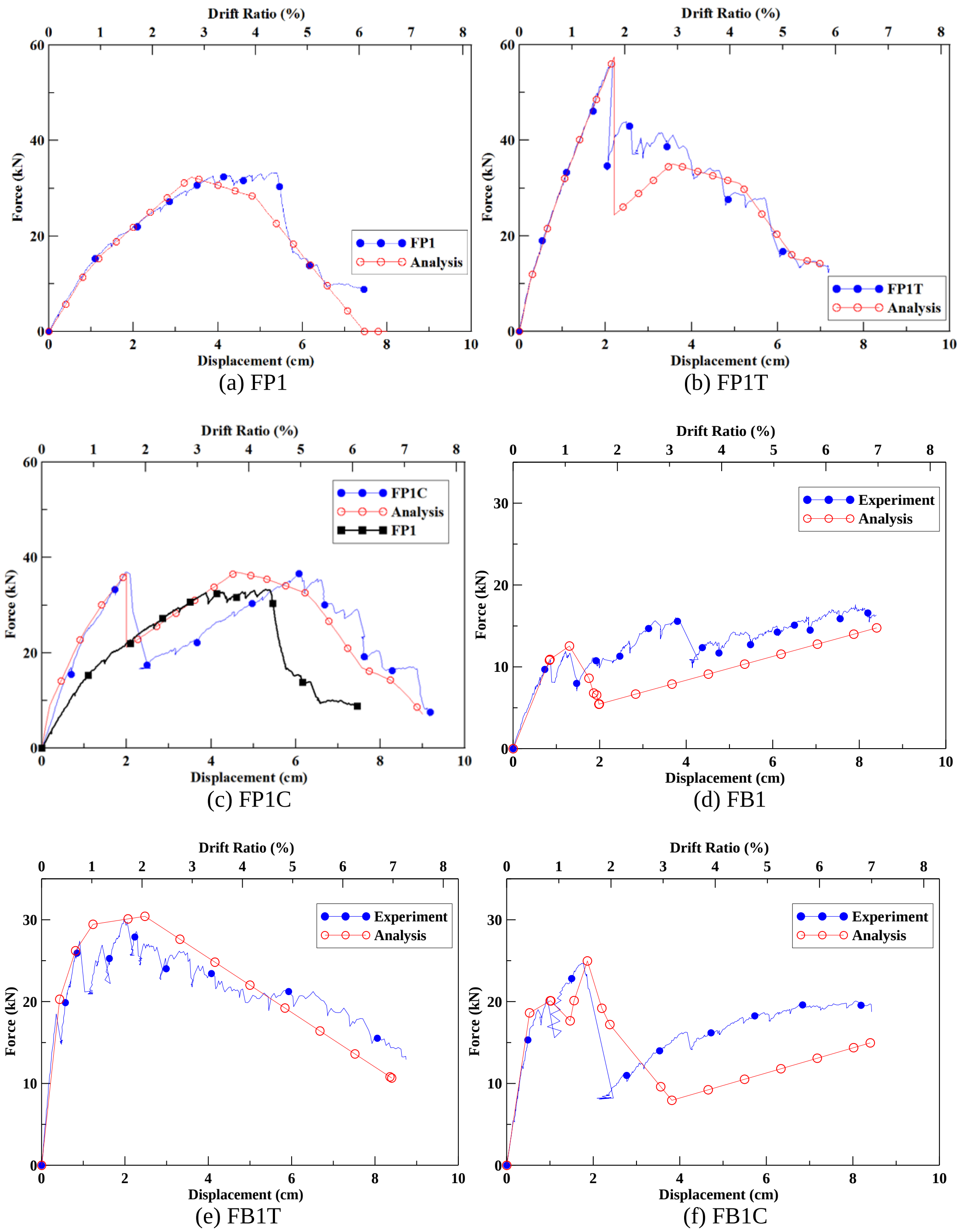


Figure 3. Comparison of the experimental and numerical results of the force-displacement relationships of GFRP frames

Acknowledgements

The authors are grateful for the financial support of the Ministry of Science and Technology of Taiwan, under contract No. NSC-100-2622-E-027-027-CC3.

References

Ascione, F., Feo, L., Maceri, F., On the Pin-Bearing Failure Load of GFRP Bolted Laminates: An Experimental Analysis on the Influence of Bolt Diameter, *Composites Part B: Engineering*, 41(6), 482-490, 2010.

Al-kharat, M., Rogers, C. A., Inelastic Performance of Cold-Formed Steel Strap Braced Walls, *Journal of Constructional Steel Research*, 63(4), 460-474, 2007.

Bao, W., Shao, Y. S., Xing, L. T., Measuring Method of Rotation Used in Research on Steel Frame Semi-Rigid Beam-to-Column Connection, *Advanced Materials Research*, 243, 1439-1442, 2011.

Davalos, J. F., Salim, H. A., Qiao, P., Lopez-anido, R., Analysis and Design of Pultruded FRP Shapes under Bending, *Composites Part B: Engineering*, 27(3), 295-305, 1996.