Design Guide for FRP Composite Connections

ASCE Manuals and Reports on Engineering Practice No. 102

Ayman S. Mosallam, Ph.D., P.E.

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By Ayman S. Mosallam, Ph.D., P.E.

Sponsored by
the Structural Composites and Plastics Committee of
the Construction Institute of
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PREFACE

In recent years, the construction industry has realized the potential of using fiber-reinforced polymer (FRP) composites in construction applications. As with any emerging technology, the construction industry and civil engineering community struggled with the design and application of these systems. Frequently, engineers experienced tremendous difficulties when they attempted to utilize FRP materials in a manner similar to practice with conventional materials such as steel, concrete, and wood. One obstacle was a lack of design standards and authoritative codes for the use of FRP materials in construction applications. Despite the fact that there was a great deal of research and applications information available from the aerospace industry, which spanned more than a half-century, civil engineers are still searching for ways to convince themselves as to the reliability, applicability, and structural efficiency of FRP materials. The Construction Institute's Structural Composites and Plastics Committee (SCAP) of the American Society of Civil Engineers (ASCE) recognized the need for developing reliable design specifications for FRP composites and has been working with the composite industry and the civil engineering community to achieve this goal.

One FRP composite product that is getting attention from the construction industry is pultruded FRP (PFRP) composites. PFRP composites have been available for the past 40 years or so, and they are popular in specific industries for their noncorrosiveness, electromagnetic transparency, and high strength-to-weight characteristics. For this reason, they have been used mainly by structural engineers—with some exceptions—as secondary, nonstructural applications. SCAP has been taking the lead in providing reliable information on PFRP composite materials. In the late 1980s, two pioneering publications were developed by SCAP, namely, the *Structural Plastic Design Manual* in 1984, and the *Structural Plastics Selection Manual* in 1985. In 1995, ASCE jointly with the Pultrusion Industry Council (PIC) of the Society of the Plastics Industry (SPI) launched a multiphase project with a long-range goal of developing accepted standards for structural design, fabrication, and erection of PFRP composite structural systems. The first phase of the project was completed in 1996 with a prestandard document that was co-developed by the author. Currently, the second phase of the PFRP standard development project is underway and is expected to be available to the public in the near future. As a continuing effort by ASCE-SCAP, this publication is aimed at providing analytical and design information on critical aspects that are essential in designing PFRP composite structures, that is, PFRP plate joints and frame shear and moment connections.

This technical design manual, comprising nine chapters, covers major issues related to the analysis and design of composite joints and frame connections that are lacking in other national and international standards, design manuals, and technical publications. In this manual, the term "joint" refers to plate shear joints such as single- and double-lap joints that are commonly used in aerospace applications, and some civil engineering structural elements such as gusset plates for PFRP trusses and bracing members. The term "connection" in this manual refers to civil engineering-type construction framing joints between structural members such as beams, girders, columns, bases and foundations, and truss members. Examples of these typical connection details are presented and discussed in Chapters 7 and 8 of this manual.

Topics covered herein are: (1) design philosophy and design considerations for structural composite members and connections; (2) basic information and research and development work on the mechanics of fasteners and bolted composite joints; (3) analysis and design methods for bolted composite joints; (4) basic physical and mechanical information on structural adhesives and bonded composite joints; (5) analysis and design methods for bonded composite joints; (6) structural performance combined (bolted/bonded) joints; (7) basic information and research and development related to PFRP framing connections; (8) analysis and design methods for PFRP framing connections; and (9) numerical analysis review of available finite element codes suitable for modeling and designing composite frame structures. Throughout this manual, step-by-step practical numerical design examples and connection details are presented to make this manual unique, more effective for designers, and suitable as an undergraduate and graduate textbook. In addition, and in order to facilitate the analysis and design procedures, FORTRAN computer codes were developed to analyze both single- and multi-bolted pultruded composite joints as well as adhesively bonded joints. The bolted joints program is based on experimental studies conducted on a large number of typical off-the-shelf pultruded composite joint specimens. User instructions are provided, in addition to several graphs generated from these programs to assist design engineers, at the Construction Institute Web site, http://www.constructioninst.org. A second computer code for analyzing adhesively bonded composite joints is available at the same site, along with user instructions. This program is based on a simplified approach developed by NASA. The Web site provides information on using these FORTRAN programs and finite element animation for selected FE models described in Chapter 9.

This manual is intended for structural engineers (civil, aerospace, mechanical, naval, etc.) designing with FRP composites in general and pultruded composites in particular. It is also a useful source of information for composite manufacturers, especially pultruders, FRP fabricators, contractors, code and national standards developers, buildings officials, and academics and researchers as well as undergraduate and graduate students and others who have interest in composite frame connections.

I gratefully acknowledge the support of the ASCE Construction Institute led by Dr. Marvin Oey, the SCAP committee chaired by Dr. Albert Doris, and the contributions of all members of SCAP. Special thanks to Professor Hota GangaRao, West Virginia University, for his valuable technical contributions and for his careful technical review of the manuscript, and to Professor Robert Yuan, Lamar University, for his assistance in providing the Phase I ASCE/SCAP Connections Report. Thanks also go to the two technical review panels of this manual.

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Finally, I would like to state that I have endeavored to bring all of my experience, knowledge, and wisdom into the pages of this design manual. It is my hope and desire that practicing engineers will use this tool to develop safe and innovative systems. It is also my wish that the next generation of engineers will use this manual as a roadmap to avoid the errors of the past. In that regard, best practices save lives and ASCE continues to lead the way.

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