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Dottorato di Ricerca in Ingegneria delle Strutture e del Recupero Edilizio e Urbano
XIV Ciclo N.S. (2013-2015)

INNOVATIVE GFRP SECTIONS SHAPE AND PROPORTIONAS IN CIVIL ENGINEERING STRUCTURES

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Abstract

Although traditional materials (steel, concrete, timber and masonry) still dominate the building industry, new materials are constantly being explored by engineers and scientists. For instance, the use of the so-called FRPs (Fibre-Reinforced Polymers) is gradually spreading worldwide [1-4].

The main idea of FRPs is the combination, on a macroscopic scale, of two different long continuous fibres and a polymeric resin. More specifically, high strength fibres (glass, carbon, aramid or ultra-thin steel wires) provide strength and stiffness while the resin (polyester, vinylester or epoxy) protects the fibres and guarantees the stress transfer between them. As a result, enhanced final properties are obtained with respect to those exhibited by the individual constituents.

Among several type of fibers, Glass Fibre Reinforced Polymers (GFRP) are widely used due to their relatively low cost, although glass fibres exhibit much lower elastic modulus and ultimate strength than carbon fibres. In addition, some additional issues emerge with regard to durability in alkaline environments and long-term response under sustained stresses. FRP pultruded beams take advantage of their principal features [5-6].

Since the late 1990s, among the FRPs elements, those frequently used in civil engineering are the pultruded ones.

They are obtained by the pultrusion process that make possible to produce such profiles with both closed or open cross sections; the only limitation is that the same cross section is required over the length.

Pultruded profiles reinforced with glass fibers (GFRP) present many advantages, including very high stiffness and strength to weight ratios, magnetic transparency, corrosion resistance, and an effective manufacturing process.

For these features they can be qualified as non-corrosive, high mechanical strength and lightweight materials.

In the last few years, they have been used in several different civil structures, acquiring a relevant role as primary bearing structural elements for applications such as cables, stands, truss members, footbridges, boardwalks, high voltage electricity poles, small buildings and emergency-oriented solutions [7-9].

Examples of relevant structures consisting of FRP profiles include a number of bridges and footbridges, where both open and closed shapes are usually used. Examples are I-, L-, H- and tubular profiles.

The first applications of FRP were recorded in China at the beginning of 80's. Nowadays in this Country it can be counted numerous bridges made from fiber reinforced composite materials, among them the most important are the Miyun Bridge in Beijing and the Xiangyong Bridge recently built in Chengdu.

The same is happened in the U.S.A. where the most important bridge realized are the Tom's Creek Bridge (1996), the Clear Creek Bridge (1996), the Laurel lick Bridge (1997), the Wickwire Run Bridge (1997), the Bentley Creek Bridge (2000) and the Deer Creek (2001).

In particular, in the bridge over Deer Creek in Maryland State, USA, the deck on a steel trough-truss bridge was replaced by FRP composite deck. The weight of the new deck was about 40% less than a conventional concrete deck, resulting in increased live load capacity for the bridge.

Advanced applications of FRP composite tubes can be found also in North America, where hybrid configurations of FRP/lightweight concrete have been proposed for arch members. Furthermore, composite piles have also been proposed for marine installations.

In Europe the first application of structures in fiber reinforced material was realized by means an innovative systems through in the United Kingdom and called ACCS (Advanced Composite Construction System). The ACCS developed by Maunsells Structural Plastic Ltd is an example of connection method, in which plank units (multi-cellular box sections) are assembled by sliding a toggle section into the groove of each panel. The most important structures are some bridges in Scotland, in Galles and England, in particular the Aberfeldy Bridge (1992), the Bonds Mill Lift Bridge (1992), the Bromley South Bridge (1992) and the Parson's Bridge (1995).

The Aberfeldy Bridge was the first suspension bridge realized completely of composite materials: the deck and the columns are realized with the ACCS systems while the rods are made by Aramid fiber (Kevlar).

It is impossible not remember the pedestrian Fiberline Bridge in Kolding, Denmark, open on 18 June, 1997 as the first composite bridge in Scandinavia. The Fiberline pedestrian and cyclist bridge was the first of its kind to cross a railway line. The busy railway line restricted installation work to only a few hours during nights. The short installation time has illustrated the clear advantages of composites.

Another important application is the composite pedestrian bridge Ooypoort that was officially opened in Nijmegen, the Netherlands. The bridge structure consists purely of glass fiber-reinforced polyester. With its span of 56m it is among the longest single-span composite bridges in the world.

Meaningful is the 38 m span Lleida Footbridge in Spain, consisting of a double-tied arch crossing an existing roadway and a high-speed railway line. The arches and the tied longitudinal bridge deck girders were made of a rectangular hollow FRP cross-section obtained from two U-profiles joined together with two bonded flat plates to form the rectangular tubular section.

Other relevant applications of composite material in the Civil Engineering regarded some experimental building.

The first buildings made from FRP profiles were single-storey gable frames used in the electronics industry for Electromagnetic Interference (EMI) test laboratories.

Two important examples are the Compaq Computer Corporation and the Apple Computer building in California. In both cases the choice was motivated by the need to avoid possible interference between the internal and external electromagnetic fields.

One of the most famous, full-composite structures was the five-storey GFRP Eyecatcher Building erected in Basel, Switzerland in 1998 for the Swiss Building Fair. It is also the tallest FRP structure constructed until now.

In all these structures, pultruded profiles were not used in their original shape but were joined together to form more complex cross-sections, not available on the market.

In fact, in order to make pultruded members more appealing to the construction industry, most manufacturers produce profiles that imitate standard structural steel members (e.g. I-, H-, C-, and angle profiles), but in the field of composite research, the belief that these "steel-like" profiles do not represent the optimum geometry for composite sections is gradually gaining currency. Considering that standard engineering guidelines developed for conventional materials are not applicable to FRP shapes, several technical documents dealing with the design equations and methods, material properties, and safety factors for pultruded elements have been developed or under development.

Starting from the EuroComp Design Code and Handbook [11], published in 1996, that provided, for the first time, an independent, practical guidance on structural design of polymer composites.

Following in 2002, the EN 13706 standard [12] defined two different classes of materials, associated with minimum values of material properties and although provides many specifications for pultruded profiles, no design guidance was provided in this document.

In 2007, the Italian National Research Council (CNR) published the first Italian design guide (DT 205/2007) for the design and construction of structures made of FRP pultruded elements [13] which is not a binding regulations and is still rather incomplete.

In 2011, the Construction Institute of the American Society of Civil Engineers (ASCE) published the Manuals of Practice (MOP) #102 for the design of FRP composite connections [14]. This manual covers major issues related to the analysis and design of composite joints and frame connections manufactured from fibre-reinforced polymer composites in general and pultruded composites in particular. Currently, a joint effort between the Pultrusion Industry Council (PIC) and the ASCE Structure Institute for developing American Standards for PFRP structures is underway and will be published in the near future.

Finally, the Technical Committee 250 of CEN (Comité Européen de Normalization), responsible for the structural Eurocodes, appointed a specific Working Group (WG4: Fibre Reinforced Polymer Structures) to draw up a scientific and technical report on the design and verification of full composite structures. The report, recently published, represents the first step toward a Structural Eurocode on this subject and his main goal is to stimulate the debate about the topic of full composite structures.

The actual state of knowledge allowed WG4 to give answers to many questions relating to the design and verification of FRP structures.

In all these documents, the pultruded elements could be considered as linear elastic, homogeneous, and transversely isotropic in the case of aligned fibers, with the plane of isotropy being normal to the longitudinal axis (i.e. the axis of pultrusion) [15].

It is has been assessed that the mechanical behavior, especially in the case of open profiles, is highly affected by warping strains [16-17]. Moreover, the low values of the shear moduli (more or less the same as those of polymeric resin), coupled with their time dependency, can provoke non-negligible increases in lateral deflections, thus affecting both the local and global buckling loads. In particular, a long slender beam under bending about the strong axis may buckle through combined twisting and lateral bending of the cross section, a phenomenon known as flexural–torsional buckling.

As a consequence, FRP members exhibit complex behavior related to the multi-interaction between shear deformability, warping, non-uniform torsional rigidity and creep.

Furthermore the low elastic moduli make often design for serviceability and stability the governing limit states and they inhibit taking greater advantage of the high strength of FRP.

In order to ensure the structural reliability of load bearing pultruded composite members, the shape and fibre architecture of PFRP profiles must be optimized and designed properly.

Because the industrial process is optimized for mass pultrusion of a limited number of shapes, it is difficult to produce complex shapes with standard cost targets.

As a consequence, these unconventional cross-sections represent a critical point relative to the mechanical response in terms of buckling, deformability and adhesive layer resistance of such elements.

The first objective of the present thesis was to develop an innovative mechanical model in order to study the behavior of pultruded elements with complex (not conventional) cross section shapes able to take into account for the shear deformability, the warping effects and the possible discontinuities at the web/flange connections.

The above introduced model was translate into a finite element code which results, in terms of possible new cross section shapes and their mechanical response are reported in Part I of the present document.

The best technique to join together two GFRP profiles is without doubts the adhesion.

This choice is motivated by the fact that bonding technology permits to reduce the cost and the weight of structures as well as to limit high stress concentrations, typical of bolted joints, due to the presence of several holes.

Furthermore, under this point of view, the bonding technique represent an excellent instrument in order to obtain complex shape in FRP material.

Although the bonding technique is nowdays a custom, relative to the bonding of pultruded plates and/or to the bonding of pultruded lamina to concrete, mansonry and steel substrates [18-24], there is a lack of knowledge with respect to bonding together two pultruded profiles to form more complex shapes. This lack of confidence has inspired the second object of present research, focused on the possibility of achieving a GFRP profile with a complex cross-sectional shape, not available on the market with a cost lower then the pultrusion process, by bonding an appropriate number of simple pultruded plates with a common epoxy glue.

Substantially, the idea is to identify a design strategy based on modularity.

For example, a generic I-profile may be obtained by bonding three rectangular panels (the top/bottom flanges and the web panel), rather than via a unique pultrusion application.

In order to achieve this second purpose a comprehensive experimental campaign was developed followed by a wide numerical analysis.

The results are reported in the Part II of the present document.

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