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Influence of initial geometric imperfections in the lateral buckling problem of thin walled pultruded GFRP I-profiles

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ABSTRACT

This paper aims at investigating the influence of some typical manufacturing geometric imperfections on the pre-buckling behavior of transversally loaded GFRP I-beam. One dimensional mechanical approach is proposed by modelling each panel of the cross section as a Timoshenko rectangular beam. In addition to the usual displacement and rotational degrees of freedom used in conventional beam models, few extra degrees of freedom are introduced in order to account for sectional distortions.

The model is based on the common assumptions of linear elasticity with small strains and moderate rotations.

Two kinds of manufacturing imperfection are taken into account: minor axis out-of-straightness and web/flange planes non-orthogonality the latter representing a particular feature of the present model.

Numerical analyses, developed via finite elements, show that such kind of imperfections can significantly influence the pre-buckling behavior making deformability requirements a fundamental design rule.

1. Introduction

In the field of civil engineering, innovative materials applications, especially those involving the use of composite materials, are attracting great attention. Their first applications date back to the mid-80s and since then the FRPs have steadily evolved in terms of performance, types of products, areas of application and normative references [1–4], acquiring a leading role as structural elements.

Due to their well-known properties of high strength, rigidity and lightness as well as corrosion resistance, they are particularly suitable as reinforcement for concrete and steel members in the form of uni- and two-directional laminates and fabrics. In the last decade many interventions of such kind have been realized [5–11].

Besides the aforementioned laminates and fabrics, FRP pultruded profiles are manufactured by so-called automated process of pultrusion that is able to produce profiles with constant and complex cross sections having similar shapes as steel sections.

These profiles are characterized by excellent mechanical and chemical performances, and thanks to the use of glass fibers and efficient manufacturing, they are also economically attractive. Consequently, the cases of new structures realized by using FRP profiles have been increased in the last years, mainly for what concerns the construction of bridges and footbridges [12–14].

Their structural behavior differs from that of steel ones. Hence the need exists to investigate some peculiar aspects of the mechanical behavior of the above mentioned structures in order to develop a specific set of design rules.

From a mechanical point of view, FRP pultruded profiles can be considered as linear elastic, homogeneous and transversely isotropic, with the plane of isotropy being normal to the longitudinal axis (i.e. the axis of pultrusion). It is generally asserted that their mechanical behavior is highly affected by warping strains due to their small thickness. In addition, low shear moduli, more or less the same as that of the polymeric resin, can provoke a non-negligible increase in lateral deflections, thus affecting both the local and global buckling loads. Consequently, the design of FRP members is usually driven by deformability and stability requirements which are generally more relevant than the strength limits.

In particular, with reference to such topics, the lateral buckling behavior of FRP beams has been widely investigated in literature from a theoretical, numerical, and experimental point of view, especially for what concerns the particular case of thin-walled I-beam [15–22]. Bauld and Tzeng's paper [23], extended the Vlasov's thin-walled beam theory to symmetric fiber reinforced laminates. Fourteen years later Kabir and Shelbourne [24] studied the lateral buckling of I-section composites beams based on the Ritz method.

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In the same years Turvey and Brooks [25] conducted a series of lateral buckling tests on GRP I-section cantilever beams.

In 2001, Lee and Kim [26] proposed a mechanical model, based on the lamination theory, to predict lateral buckling load of a thin walled I-section subjected to axial load. The same authors extended their previous work analyzing other types of loading [27] a year later.

More recently, Nguyen et al. [28] studied the change in lateral torsional buckling resistance of a PFRP I-beam at different spans by varying load height, end displacement boundary condition and initial geometric imperfections. The analyses were conducted referring to a simply supported beam having a vertical point load at mid-span by using geometric non-linear solver in Abaqus. In the same year Ascione et al. investigated the local and global buckling of GFRP I-beams by using the mechanical approaches presented in [29–31].

More recent experimental studies by Mosallam et al. [32] and Feo et al. [33] showed that, the condition of a rigid connection should be replaced by a more appropriate assumption due to the presence of a higher local resin concentration in the connection region between the flange and web. Furthermore, taking into account that pultrusion guarantees very high strength and stiffness along the longitudinal direction of the beam, a deeper investigation of this topic is required.

Within this framework, the author in [34], based on the experimental results presented by Mosallam et al. in [32], modelled the stiffness of the web/flange junction by a bilinear law, developing an innovative 1-D beam model capable of accounting for the web/flange rotations as explained in the next section.

The aim of the present paper is to analyze the influence of manufacturing imperfections on the equilibrium problem of transversally loaded GFRP I-beams from a numerical point of view by using the same mechanical model. The analysis is carried out by assuming the hypotheses of small deformations and moderate rotations. In fact, a linear analysis, is not adequate to analyze the pre-buckling behavior of imperfect GFRP I-beams as this paper demonstrates.

Various types of geometric imperfections (typical manufacturing ones), boundary conditions and cross-section shapes (I shape with narrow and wide flanges) are considered in the analyses.

As it is well known, FRP pultruded profiles possess sufficient geometric imperfections in the form of out of straightness, twist, angularity, etc. that could reduce their buckling resistance drastically. For this reason the presence of these imperfections have to be included in the mechanical model.

Specifically, two kinds of expected manufacturing imperfections are taken into account: minor axis out-of-straightness and web/flange planes non-orthogonality, the latter being a particular feature of the present model.

The reliability of the mechanical model utilized has been assured by comparisons with other numerical and experimental results available in literature and regarding the lateral buckling behavior of I-section beams.

2. Notations

The main relevant symbols utilized are listed below.

$\{\Omega, \mathbf{i}, \mathbf{j}, \mathbf{k}\}$	global reference system
L	beam axis length
B	flange width
H	web depth
b_f	flanges thickness
b_w	web thickness
Σ	generic cross-section
$\Sigma^{(i)}$	intersection between Σ and the i-th sub-component
$\Sigma_{(1)}$, $\Sigma_{(2)}$	ends of the beam
$\mathbf{O}$	intersection between the $\mathbf{k}$ axis and Σ
$\mathbf{P}$	generic point of the beam
x, y, z	cartesian components of $\mathbf{P}$
$\mathbf{x}$	position vector of the generic point $\mathbf{P}$: ($\mathbf{x} = x\mathbf{i} + y\mathbf{j} + z\mathbf{k}$)
$\mathbf{u}$	displacement field
$\mathbf{H}$	displacement gradient
ε	symmetric part of $\mathbf{H}$
$\mathbf{E}$	Green strain tensor
$\mathbf{S}$	Cauchy stress tensor
δL_{int}	internal virtual work
δL_{ext}	external virtual work
δL_{con}	virtual work due to the deformability of the web/flange junction
$\mathbf{b}$	external force per unit volume
$\mathbf{p}$	external force per unit surface acting on the boundary of the beam
E	longitudinal Young modulus along the beam axis

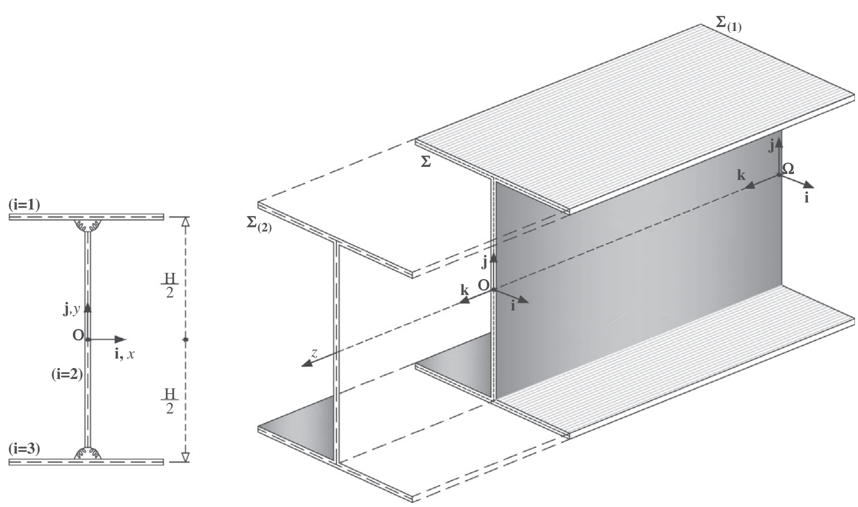

Fig. 1. Beam configuration.