

First Evaluation on Structural Behavior of All FRP Bolted Built-up Columns

A. Adilardi and S. Russo

Abstract—The proposed study analyze the structural performances of built-up columns made by open FRP (fiber reinforced polymer) profiles. These open profiles are connected to each other and each column has two typologies of connection: the first guarantees the junction between the two channel-web and the second one assures the connection between the built-up-web and the external flanges. Specifically, the research verify the influence of the anisotropy of the material and the shear deformability as well as the interaction between local and global buckling on the overall bearing capacity of the assembled column. The analyzed case regards a built-up column made by four FRP channels made by pultrusion process and connected along the column with steel bolts. The study proposes both a numerical and experimental analysis. The comparison between these, aims to better fit particularly the influence of shear and to determine the local mechanisms of diffusion and the load's distribution through the bolted connection and the four FRP channels.

Index Terms—Local buckling, pultruded material, built-up column, steel-FRP interaction, shear effect.

I. INTRODUCTION

The proposed study analyzes the structural performances of built-up columns made by open pultruded FRP (fiber reinforced polymer) profiles between them connected through steel bolts. The research focused also on the interaction between local and global buckling with some deepening on the relation between FRP and steel material in the connections.

The research is in a current and previous frame related to the definition of the static and dynamic performance of the pultruded FRP elements already present in the technical recommendations [1], dedicated books and in literature [2], [3]. Also the topic related to the pultruded FRP connection has been very well studied, especially in presence of the beam-column connection [4].

Given that, these studies have supported also several applications by now widely used, as reinforcement, [5], emergency structures, [6], [7] or permanent ones, [8], [9], due, first of all, to the benefits related to the high value of strengths with low density and very high level of durability that characterize the pultruded FRP material. This material is used also for housing, pedestrian and vehicular bridges [10], [11], with first reference to the dissipative capacity – even if in presence of its elastic-brittle behavior [12], [13] – as well as in relation to the damage evaluation [14] and about the

techniques disposable to understand the mechanical characteristics.

By the way, the proposed research take something as a starting point from the first works on the same item and analyzes now the shear and local effects on the buckling with first comparison with same built-up columns made by steel, at least from the structural design point of view.

The two typologies of all pultruded FRP built-up columns are characterized by a different dimensions of C shape FRP elements and this study following other works dedicated to the same topic on a first global approach [15], [16]. The study gives particularly care to the distribution of load through the four pultruded FRP channels.

II. MECHANICAL MODEL AND TESTS RESULTS

Each column has two typologies of connection, the first named B1, guarantees the junction between the two channel-web, the second one, named B2, assures the connection between the built-up-web and the external flanges (Fig. 1).

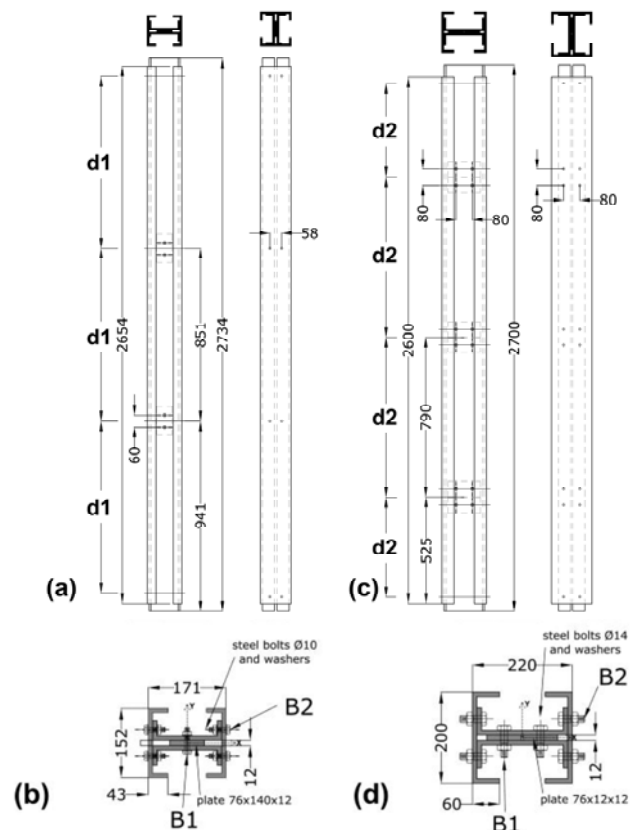


Fig. 1. Built-up columns, type BC1 detail (a-b) and type BC2 detail (c-d); measures in mm.

The dimensions of the columns and the related

Manuscript received April 15, 2014; revised June 18, 2014.

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cross-sections are reported in Fig. 1, while the mechanical features of the FRP pultruded material, also employed in the FE analysis, are indicated in Table I.

TABLE I: MECHANICAL CHARACTERISTICS OF PULTRUDED FRP MATERIAL
MEAN VALUES

Mechanical properties	Symbol	Value
Longitudinal tensile strength	σ_Z	350 MPa
Transversal tensile strength	$\sigma_X = \sigma_Y$	70 MPa
Longitudinal elastic modulus	$E_Z = E_L$	23 GPa
Transversal elastic modulus	$E_X = E_Y = E_T$	8.5 GPa
Shear modulus	$G_{XY} = G_T$	3.4 GPa
Shear modulus	$G_{ZX} = G_{ZY} = G_{LT}$	3 GPa
Poisson's ratio	$\nu_{ZX} = \nu_{ZY} = \nu_{LT}$	0.23
Poisson's ratio	$\nu_{XY} = \nu_T$	0.09
Density	γ	1750 kg/m ³
Fibres percentage	V_f	40%

III. DISTRIBUTION OF LOAD BETWEEN CHANNELS THROUGH BOLTS

From a general point of view, a first hypothesis about the progressive model of distribution of the load through the four pultruded FRP channels is proposed in Fig. 2.

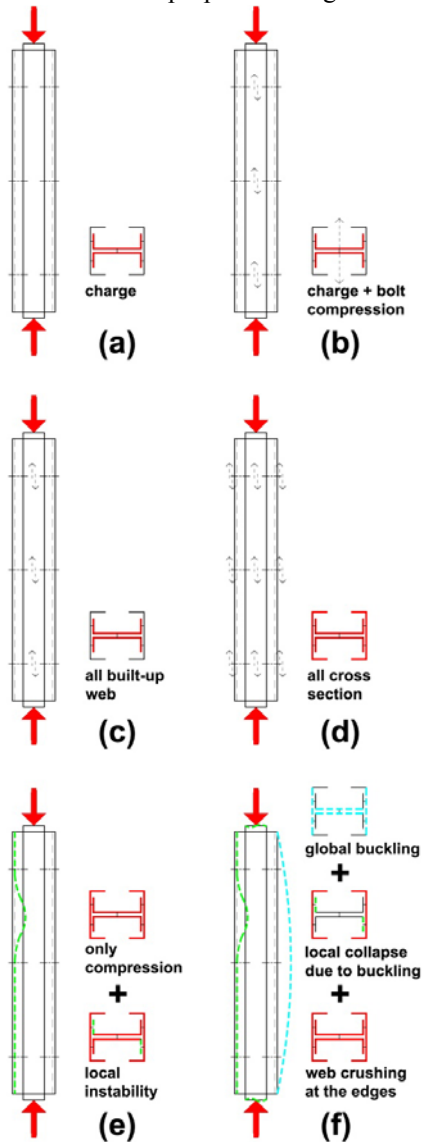


Fig. 2. Progressive model of the built-up column.

The described progressive charge of each built-up column gives prominence to the interaction between the two types of buckling, local and global [4]. Indeed in Fig. 3 are showed for example some cases of the different buckling interaction in presence of opens pultruded FRP shapes. The crisis of the two columns BC1 and BC2 are indicated in Fig. 4.

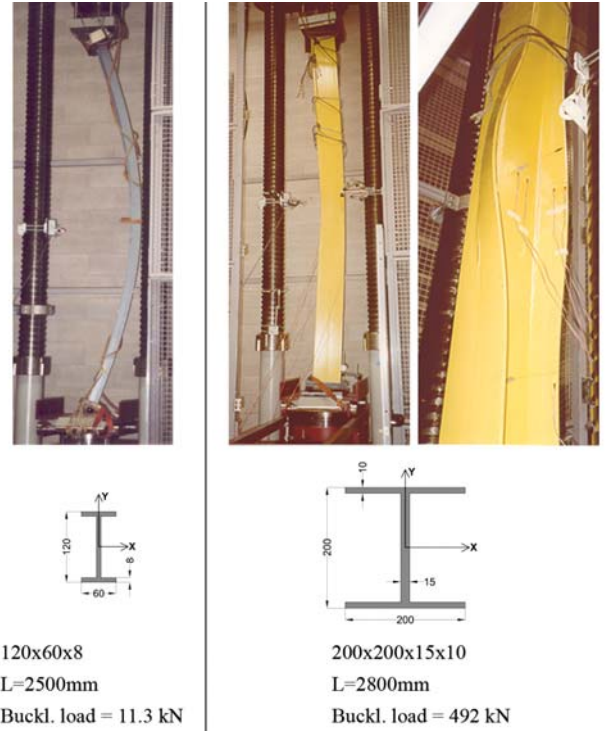


Fig. 3. Interaction between global and local buckling [4].

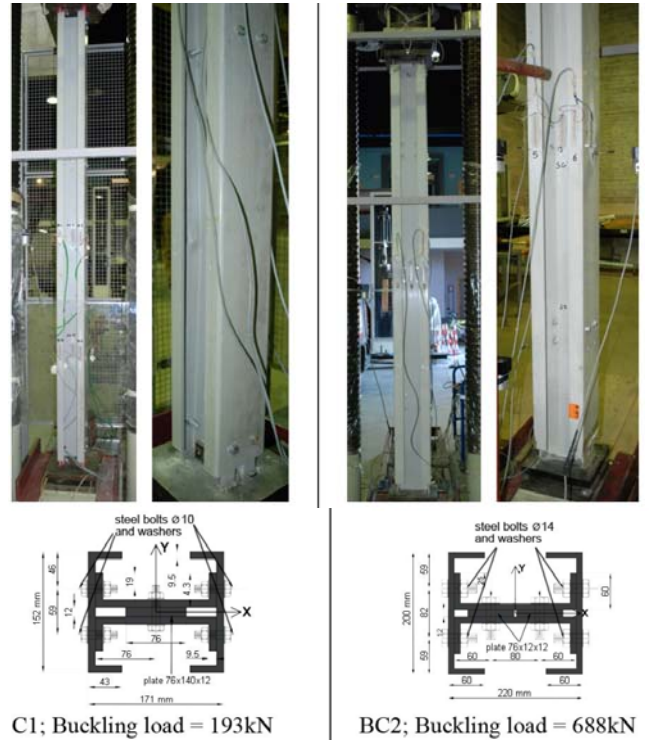


Fig. 4. Set up and collapse phases of built-up column BC1 and BC2

If we consider the equilibrium in the direction of the applied load, a simplified model could be proposed in agreement with the shortened of the built-up-web that onset the load transfer to the external flange. As showed in Fig. 5, the total load N_{tot} could be divided into N_1 and N_2 respectively applied to the 'built-up-web'

and to the external flanges.

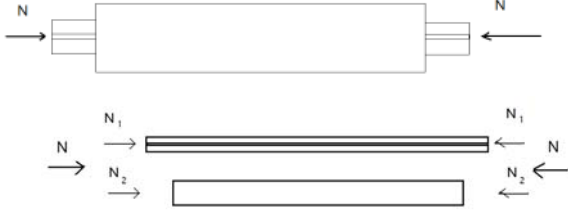


Fig. 5. Simplified model.

These following equations could be then proposed in function of the two areas involved that are the A_1 related to the built-up web and the A_2 as a sum of the two flanges:

$$N_1 + N_2 = N_{tot} \quad (1)$$

$$2 \cdot N_1 \cdot A_1 + 2 \cdot N_2 \cdot A_2 = N_{tot} \quad (2)$$

Starting from the assumptions indicate in (1) and (2) the following relations will be obtained:

$$N_1 = N_{tot} \cdot \frac{N \cdot A_1}{(2 \cdot A_1 + 2 \cdot A_2)} \quad (3)$$

$$N_2 = N_{tot} \cdot \frac{N \cdot A_2}{(2 \cdot A_1 + 2 \cdot A_2)} \quad (4)$$

TABLE II: VALUES OF BEARING CAPACITY IN BOLT CONNECTION

Column	$V_{sd} - (kN)$	$V_{md} - (kN)$
<i>BC0</i>		
Nmax exp	24.16	27.54
Nmode I	28.75	27.54
Nnon linear	26.63	27.54
<i>BC1</i>		
Nmax exp	/	27.54
Nmode I	37.50	27.54
Nnon linear	37.38	27.54
<i>BC2</i>		
Nmax exp	42.42	42.85
Nmode I	46.40	42.85
Nnon linear	46.30	42.85
Channel C152	$N_{cr} (kN) = 11.00$	/
Channel C200	$N_{cr} (kN) = 17.00$	/

IV. CONCLUSION

The model showed in Fig. 2 and in coherence with the one showed in Fig. 5 means that the rule of external connections is to transfer the load while the rule of the internal connection (along the length of each built up column) is to reduce the length related to the second order effects. Given that, in presence of the local bearing capacity in each bolted connection, we obtain [1]:

$$V_{sd} = \frac{N_2}{n_{bolt}} < V_{md} \cdot \gamma_{frp} \cdot D \cdot t \quad (5)$$

where V_{sd} coincide with the calculated strength due to bearing capacity, N_2 is the applied load to the flanges (Fig. 5), n_{bolt} is the number of bolts, V_{dm} is the declared strength from the producers assumed equal to 240 MPa. Then γ_{frp} is the coefficient of the material assumed equal to 1.3 [1]-[3], D and

t are respectively the diameter of the hole and the thickness of the pultruded FRP channel. About the intermediate connections between flanges and the built-up-web, the value of load in the bolt - that potentially is related to the local bearing capacity - will be compared with the critical load of a singular channel calculated through the Engesser approach [17], as following:

$$N < N_{cr} \quad (6)$$

where N_{cr} represents therefore the critical load and N is equal to $N_{2/2}$. Table II summarizes the calculated values of bearing capacities through the previously equations.

Based on the results showed in Table II, (5) is always satisfied for the column type *BC0* and *BC2*, while in presence of the column *BC1* the calculated value of bearing capacity exceeds the available strength. Besides, in presence of singular channel the N_{cr} value is lower than the value in fact applied at each bolt.

ACKNOWLEDGMENT

For this research have been used scientific equipment acquired by the University IUAV of Venice within the project Iuav_lab, IUAV laboratories of innovation for architecture, the project is co-financed by the Veneto Region as part of the POR-CRO, the ERDF, 2007-2013, 1.1.1.

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