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Dissipative capacity on FRP spatial pultruded structure

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ABSTRACT

The dissipation capacity of a generic structure depends on its many characteristics – like material, shape of the cross-sections, structural scheme, regularity and typology of structures – and it is accomplished by means of the behavior factor q through a very strategic reduction of seismic action. This is the reason why this research shows an overview on the evaluation of the q factor, preparatory to an analysis related to a spatial frame structure of built-up members made of FRPs (Fiber Reinforced Polymers) pultruded profiles, FRP gusset plates and steel bolts. The factor q proposed starts directly from experimental data, in detail the outcomes due to the dynamic identification on site carried out. Subsequently, a finite element model under the hypothesis of kinematic equivalence for the measurement of q was calibrated. The adopted structure investigated is a spatial frame with concentric diagonal bracings for which its dissipation capacity by means of the strength hierarchy criteria was assigned. To exalt the overall behavior of the all-GFRP structure a case of rigid connection is assumed with a comparison with semi-rigid conditions. The analysis was carried out also on the variability of the q factor, considering some typological variants of the basic structure.

1. Introduction

Frames made by FRP pultruded elements are a building technology that, due to their physical and mechanical characteristics, can be applied for civil engineering structural application in seismic areas. This potential is at the moment penalized by the limited knowledge of the fundamental seismic and ductility parameters, whose knowledge is needed for more conscious use of this kind of structure.

In fact, the use of FRP pultruded profiles frames was widely investigated under the point of view of statics as shown by technical recommendations [1–3] and by the work of Bank [4], but there is still scarce information about the dynamic characterization. In particular, some of the main available researches address the dynamic identification of elements [5–7] through vibration methods. More generally, Boscato et al. [8] used field test results to develop a successful FE modeling methodology to analyze the dynamic behavior of a FRP sheet pile. Besides, the modal analysis was applied by Russo [9] to assess the damage and non-homogeneous effects on dynamic parameters of pultruded FRP profiles.

Concerning the studies on pultruded FRP structures, Minghini et al. [10] investigated the vibration frequencies and mode shapes of pultruded FRP plane and space frames with semi-rigid joints. In the same field, an applied dynamic identification to discern the response of a pultruded GFRP frame with different rotational stiffness of bolted joints is shown in [11]. About the evaluation of all-GFRP structures already built, the researches on dynamic response address mainly bridges [12,13]. In this field the dynamic response of PFRP pedestrian bridges have been treated [14,15].

The early information about the FRP structure investigated in this paper, based on the experimental response in free vibration field, is available in research works already published [16–18].

The aim of the research is, in fact, to give some numerical and experimental information on the evaluation of the behavior factor q and the main dynamic parameters of all-PFRP frames. This study takes advantage of the availability of one of the biggest PFRP frames in Italy [18] by giving an early evaluation of the q factor starting from the experimental assessment of the basic parameters of on-site seismic engineering such as frequency and mode shape.

The well known tested structure [18] was built in order to temporarily protect the church of Santa Maria Paganica in L'Aquila that was badly damaged during the 2009 earthquake. By applying the output-only technique with the sole input of earthquake-induced vibration, the main mode shapes were determined, together with their frequency and the damping ratio. The experimental dynamic parameters obtained were then used to calibrate a finite element model by using the model updating that also allows to simulate the displacement degrees correspondent to the simply supported structure.

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The calibrated model, affected by the above assumptions, was then used to evaluate the dissipative capacity of the entire structure.

Considering the long vibration period of all-PFRP frames, the equivalence of maximum displacement criteria [19–21] was chosen and used to calculate the q factor.

Following Eurocode 8, the structural types are defined according to the behavior of their primary resisting structure under seismic actions [21]. Indeed the structure here analyzed can be defined as a frame with concentric bracings, and the dissipative elements are mainly the diagonals one. This is the reason why, in order to dissipate the energy and to reach the strength limit set by the constitutive law of the material, the diagonal bracing members were attributed potential collapse mechanisms. The obtained results show that, even if the material behave as an elastic–brittle one, the investigated all pultruded FRP frame has a certain kind of progressive reduction of displacements that seems to be dissipative. This procedure was carried out considering knowingly every joint of the frames in two different ways. The first way assumes that the joints are rigid in order to enhance the effects of concentric bracings and then comparing the outcomes with the similar one obtained in presence of concentric bracings combined with moment resisting frames; the second way takes into account an appropriate moment–curvature law for the beam-columns connections [22] – particularly two different laws – in order to investigate the different dissipation capacity of the structure at varying the rotational stiffness.

2. Description of the pultruded FRP structure

This structure allows to test two types of frames, the lower one named structure 1 with concentric *V*-bracings and the higher one named structure 2 with active tension diagonal bracings. The pictures in Fig. 1 shows structures 1 (low) and 2 (high) made by pultruded profiles and steel bolts which are the object of this study; Fig. 1a represents the whole view while Fig. 1b and c shows the two structures in detail.

Fig. 2 shows the plan of the structures inside the church of Santa Maria Paganica and the frame they are made of, detailed in Figs. 3 and 4, indicated with the letters from a to q. For frames from g to m of structure 1, the appendix of an additional structure see asterisks of Fig. 2 covers the perimeter masonry walls, see Fig. 5.

With reference to Fig. 2, structure 1 (Fig. 1b) stretches for 607 m^2 above the nave and reaches a maximum height of 22.5 m. Structure 2 (Fig. 1b) shelters the apse zone being 266 m^2 and 29.4 m high.

For structure 1, the concentric *V* bracings lie in *XZ* plane while in the *YZ* plane only the bays of the ends are braced, see Fig. 3a and b. In the structure 2 the concentric bracings lie both in *XZ* and *YZ* planes, see Fig. 4a and b.

Figs. 3 and 4 show the details of the frames with reinforced concrete (RC) foundation blocks linked to one another. Each structural member is denoted by an abbreviation that indicates the number of assembled profiles (e.g. 4Cs is for four channel profiles, 2L is for two angle profiles) and their cross-section dimensions in millimeters. The connections between the GFRP frames and the RC foundation blocks simply laid on the pavement are shown in Fig. 6. The foundation block is made of two concrete castings. In the first casting, the built-up members are embedded in RC foundation blocks while in the second casting the members are linked with the steel reinforcement of RC foundation blocks by steel bars crossing the GFRP built-up members. Fig. 6 details the RC foundation blocks adopted for both structures 1 and 2.

The simply supported structure was designed against the typical seismic actions, of the site of L'Aquila, taking into account the high vulnerability to local buckling phenomena [23–26]. In the investigation the all-GFRP structure is assumed as independent from the surrounding masonry walls.

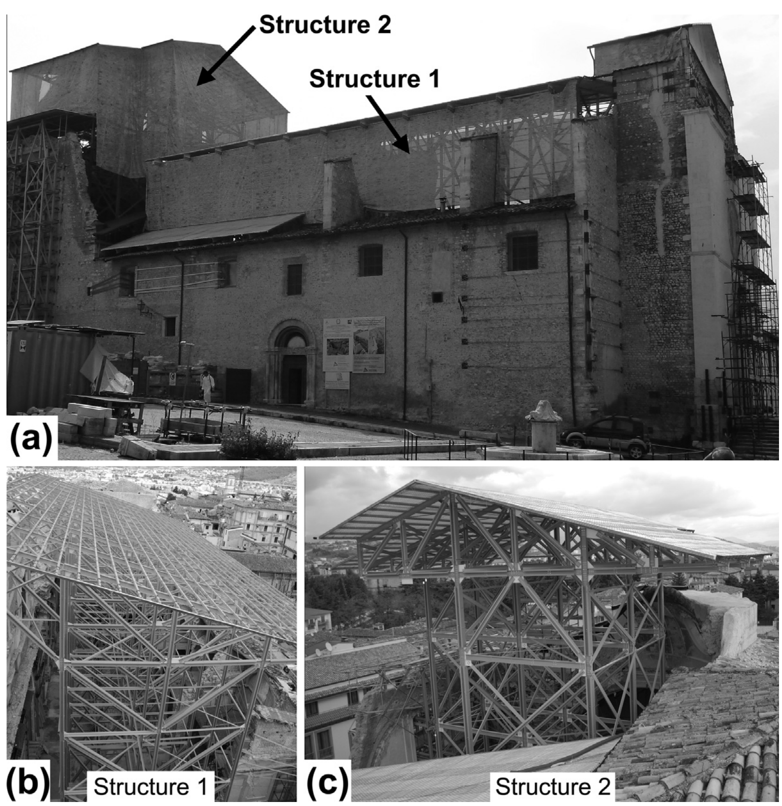

Fig. 1. External view of the church and pultruded FRPs structure (a); detail of PFRPs structures 1 "low" (b) and 2 "high" (c).