FRP-QUAKE – Seismic Behaviour and Ductility of Structures Built with Glass Fibre Reinforced Polymers

Summary

This project addresses the seismic behaviour or pultruded glass fibre reinforced polymer (GFRP) structures and the development of innovative constructive solutions that promote their energy dissipation capacity, through the integration of innovative connection and bracing systems. The lack of specific regulation and the typical brittle failure of GFRP materials (in contrast with current design practice aiming at exploiting material ductility) have hampered their widespread use, especially in seismic areas, where there are well-founded concerns and uncertainty about their seismic response.

At the same time, GFRPs are currently used as energy dissipators in automotive, naval and aerospace industries, where progressive/ductile failure modes have been exploited. This type of behaviour, which may be beneficial under seismic action, was never studied in civil engineering applications.

Therefore, to enable a widespread use of GFRP structures in construction, with the consequent socio-economic benefits, it is of the utmost importance to study their seismic behaviour, to develop material-adapted connection and bracing systems with improved ductility and to develop/adapt seismic design rules.

In order to develop GFRP structural solutions with adequate seismic behaviour, this project aims at (i) quantifying the energy dissipation capacity at the material, component, connection and structural levels; (ii) developing beam-to-column connection and bracing systems with improved ductility, enhancing the inelastic energy dissipation capacity of GFRP structures, and (iii) proposing seismic analysis and design rules.

A comprehensive experimental study will be developed including (i) mechanical characterization tests on the GFRP material, with particular focus on its fracture; (ii) dynamic and quasi-static (cyclic) tests in GFRP beams and columns; (iii) static and dynamic tests on beam-to-column connections (conventional and improved); and (iv) static (in a reaction wall) and dynamic (in a shaking table) tests in 2D and 3D frames, combining different types of connection and bracing systems and assessing the influence of non-structural elements. The novel connection systems to be developed include (i) composite connections, combining bolting and bonding (with ductile adhesives, cf. Figure 1), and (ii) connections with stainless steel components (cf. Figure 2). The new bracing systems to develop comprise (iii) GFRP materials, promoting bearing failure at connections, and (iv) stainless steel cables and plates.

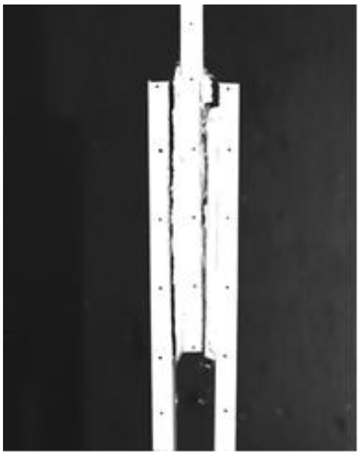

Figure 1. Polyurethane adhesive double-lap test.

Figure 2. Beam-to-column connection test.

Large-scale monotonic and cyclic tests were performed on 2D GFRP frame structures (cf. Figure 3), featuring different connection systems, bracings and in-fill walls. For the first time, a real-scale 3D GFRP frame structure, comprising 2 storeys and one bay in each direction, was tested on a shaking table (cf. Figure 4). The structural system tested showed great resilience to earthquake loads, being able to sustain the ground accelerations caused by the maximum design response curve for the Portuguese territory.

Figure 3. 2D frame sway tests.

Project Reference

PTDC/ECM-EST/6465/2014

Leading Institution

IST-ID – Associação do Instituto Superior Técnico para a Investigação e Desenvolvimento (Portugal)

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CERIS

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Project Website

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Figure 4. 3D frame shaking table tests.

The numerical study includes the development of finite element (FE) models to simulate: (i) the GFRP material characterisation tests (cf. Figure 5); (ii) connection tests, modelling the GFRP material and the contacts at the various interfaces (Figures 6 and 7 show FE models of double-lap and a beam-to-column connection specimen, respectively; and (iii) the frame tests, considering the constitutive laws of the materials and connections defined previously. This numerical study required the development of a new damage propagation model which allows the simulation of complex 3D geometries, such as connections. Simpler linear elastic models were also be developed, similar to those used in engineering practice. The comparison between simpler and more complex models allowed drawing recommendations for the seismic analysis and design of GFRP structures, following Eurocode 8 criteria.

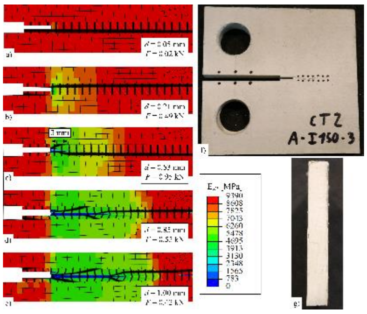

Figure 5. Damage on a 3D model of a compact tension specimen.

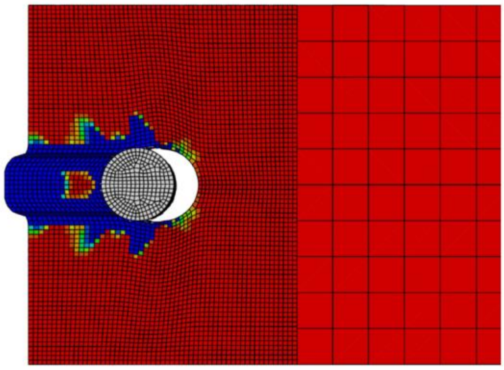

Figure 6. Damage on a bolted double-lap specimen.

The following results were retrieved from this project: (i) in-depth understanding about the static and dynamic responses of GFRP structures at different levels (material, component, connection and structure), including the fracture behaviour, damping and ability to dissipate inelastic energy; (ii) GFRP structures with adequate seismic performance, comprising innovative ductile connection and bracing systems, and (iii) a manual for the seismic analysis and design of GFRP structures (following Eurocode 8), enabling their widespread (and safe) use in seismic areas, making use of their advantages over traditional materials and promoting the competitiveness of the national industry.

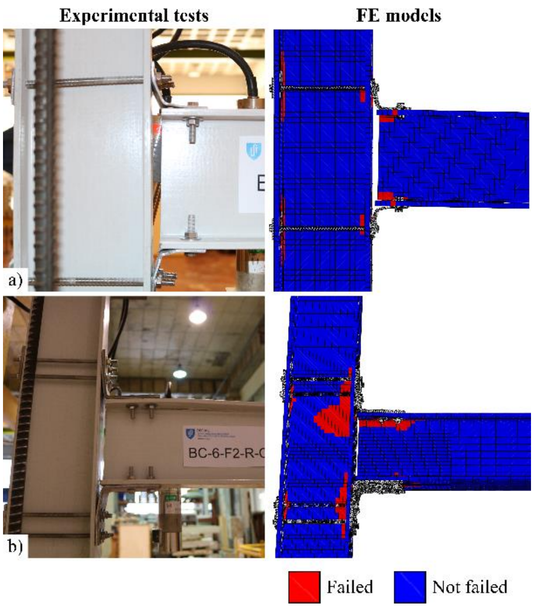

Figure 7. Damage on a beam-to-column connection double-lap specimens.