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Load-carrying capacity of GFRP bars under combined axial force–transverse force loading

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ABSTRACT

In several applications, glass fiber reinforced plastic (GFRP) bars are loaded with a transverse force while they simultaneously carry an axial force. Short-term tests of combined axial and transverse loading on assemblies consisting of one GFRP bar and two steel sleeves are described in this paper. The results show that the axial force capacity of the GFRP bar is affected only if the transverse force exceeds a certain threshold. A qualitative fracture criterion for combined axial force–transverse force loading is suggested. Further combined axial force–transverse force loading tests have been conducted on a specimen with a severe, forced 4° bending misalignment. These misaligned GFRP bars sustained more than 80% of the tensile resistance of the corresponding straight bars (without misalignment).

1. Introduction

In the tunneling and mining industry, glass fiber reinforced plastic GFRP bars are used more frequently than steel for temporary rock anchors because they are more easily cut, which avoids damage to the tunnel drilling machine. GFRP bars are also used more frequently in the building industry because they are more resistant to corrosion, weigh less and have a lower heat conductivity than steel. In some of these applications, the application of an axial force to the GFRP bar is accompanied by a transverse force. Such transverse forces may appear with dislocation movements when rock bolts are used. The combined axial force–transverse force loading has not been investigated extensively.

An experimental investigation of the pultruded GFRP elements of a cellular cross section is described in [1]. These GFRP elements have been built in a load carrying a “thermal insulation section” system for cantilevered balconies. Fig 1 shows the main elements of another type of thermal insulation section for overhanging balconies, including the ceiling slab, the insulation section and the balcony slab. The GFRP elements of [1] carried both compressive and transverse forces. However, the GFRP, as one component of the system, was not critical at the ultimate limit state. Therefore, no conclusions about the fracture behavior of the GFRP could be drawn from this study.

However, there have been investigations of single GFRP elements. The investigation described in [2] describes the failure behavior of slender, pultruded GFRP laminates under axial compressive forces. Bending moments and transverse forces occur within these slender GFRP laminates because of the lateral deformations (buckling), and this interlaminar shear leads to failure.

Short elements have also been extensively investigated. The transverse force behavior of GFRP and steel bars used as dowels in pavement joints with full scale static and cyclic tests is described in [3,4]. However, contrary to the present study, no axial force was applied to the GFRP bar because the pavement joints are designed as dilatation joints. One criterion of that study was the “joint effectiveness”, which describes the stiffness as a function of the relative vertical movements between adjacent pavement slabs. Another criterion was the magnitude of the stress between the dowel and the concrete.

This paper describes a mechanical component of a thermal insulation section (Fig. 1), which was developed in a collaborative operation between the Hitek Construction AG Company, Gstaad, Switzerland and Empa. The patent rights for the load-transferring GFRP elements are now in the possession of ERICO LENTON Concrete Reinforcement Products. The shear forces and bending moments are transferred exclusively through the GFRP bars and GFRP blocks, which cross vacuum insulation panels horizontally and are anchored in the adjacent concrete slabs. A detailed description of the entire investigation program can be found in [5]. This paper focuses on the tests of the upper GFRP element, as shown Fig. 1. Combined axial force–transverse force loading tests have also been conducted with a specimen with a forced 4° bending misalignment. Misalignment may occur because of inaccuracies during mounting in the field or may have to be considered in the

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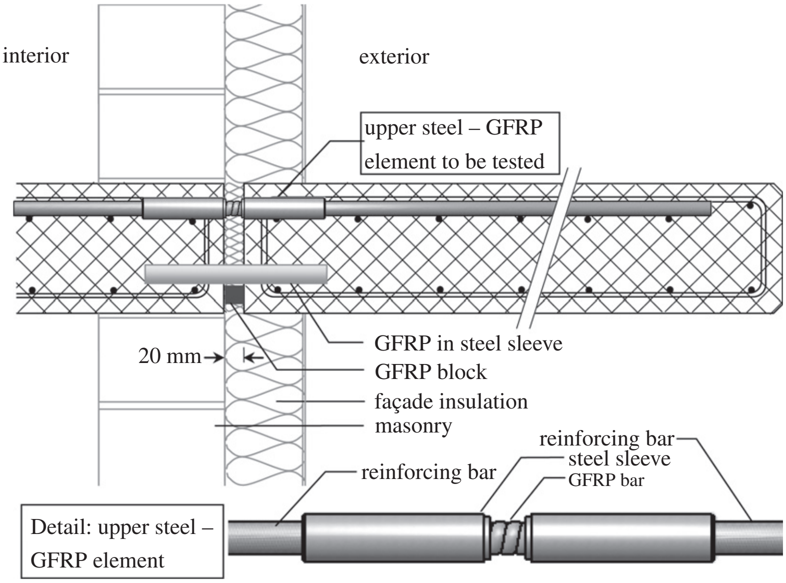

Fig. 1. Load-transferring insulation section with horizontal steel–GFRP elements.

design of structures which should resist to damage scenarios leading to permanent deformations. The magnitude of the present forced misalignment may be considered as a severe case.

A test set-up was designed to produce similar mechanical constraints for the upper GFRP element.

2. Test specimen

The test specimen is shown in Fig. 2. The specimen consisted of a threaded GFRP bar with unidirectional E-glass fibers embedded in an epoxy resin matrix (glass fiber volume content, $\Phi_V = 65\,\%$). The GFRP bar is screwed 100 mm into two threaded steel sleeves that serve as anchorages. The void between the bar and the sleeve is injected with epoxy resin. The GFRP bar has a free length of 25 mm between the two sleeves. The axial force is introduced through a threaded connection at both ends of the specimen.

3. Tests without forced misalignment

3.1. Loading system

The loading system (Fig. 3) allows both sleeves to remain parallel to each other while translational movements between both sleeves remain possible. Both axial and transverse forces may be applied to the GFRP.

The forces are produced by hydraulic jacks and measured by load cells.

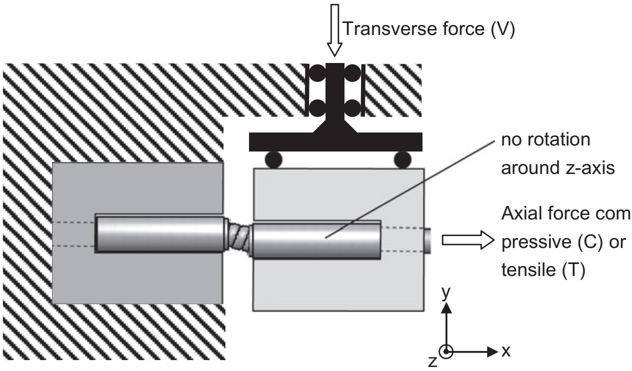

Fig. 3. Schematic loading system for the steel–GFRP element.

3.2. Experimental program and test results

Pure transverse force, axial force and combined axial–transverse force tests were conducted. The transverse and ultimate axial forces are listed in Table 1.

The transverse force was increased until failure at a rate of 120 N/s for the pure transverse force tests (Nos. 1 and 2 in Table 1). The transverse forces in tests 1 and 2 reached $V = 22.3$ and 20.9 kN, respectively.

The force was increased at a rate of 650 N/s for the pure tensile force tests (Nos. 3–6). The ultimate forces ranged from 235 to

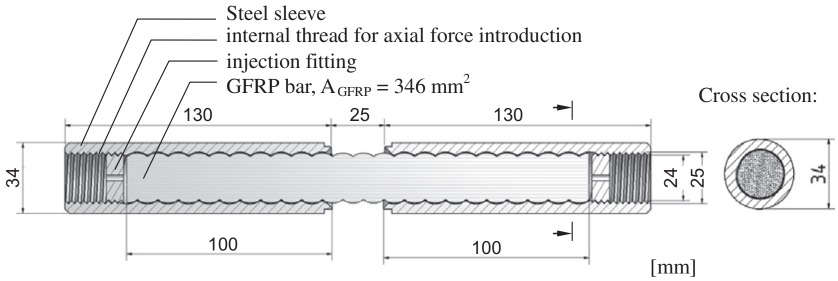

Fig. 2. Longitudinal section and cross section of the steel–GFRP element.