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Connection systems between composite sandwich floor panels and load-bearing walls for building rehabilitation

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ABSTRACT

The use of advanced composites for building rehabilitation presents several advantages when compared with traditional construction materials. When degraded building floors need to be replaced, composite sandwich panels are a potentially interesting solution, namely for buildings with load-bearing rubble masonry walls. In this paper, connection systems between composite sandwich floors and load-bearing walls are proposed, and their behaviour under vertical loading is investigated. The systems comprise steel angles anchored to the walls, serving as main supports of the sandwich panels, which are then adhesively bonded and/or bolted to the angles. These connection systems are experimentally assessed using sandwich panels made of glass-fibre reinforced polymer (GFRP) face sheets and cores of either polyurethane (PUR) foam or balsa wood, by means of flexural tests on cantilevers, which are also simulated using non-linear finite element models. The structural response of the connection systems is determined, including the rotational stiffness conferred to the floors, the strength and the failure modes. Moment–rotation relationships are obtained for the connection systems and sandwich panel types considered, which provide a wide range of rotational stiffness values, from 60 to 10,856 kNm/rad per unit width (m). These are then used to analytically estimate the short-term mid-span deflections of floors with semi-rigid connections and spans ranging between 2 m and 5 m. It is shown that some of the proposed connections allow significant floor stiffness increases compared with simply supported conditions, with reductions in total mid-span deflection of up to 65% being achieved for a span of 4 m. The results obtained for the proposed connections highlight (i) their potential benefits for fulfilling serviceability limit states and (ii) the importance of considering an adequate structural model when designing sandwich floor panels.

1. Introduction

Building rehabilitation often requires the structural strengthening or the replacement of structural elements. In old buildings made of masonry walls wooden floors are among the structural elements that more frequently need to be replaced, as they often suffer from excessive deformations and/or are not able to comply with current structural performance requirements [1]. Traditional rehabilitation solutions involve the construction of new timber floors or the adoption of different floor systems made of either reinforced concrete (RC), steel or composite (steel–concrete or timber–concrete) elements. However, wooden floors have limited durability, whereas RC, steel and composite solutions substantially increase the structural mass, generally making it necessary to strengthen the building walls, especially in seismic regions [2].

Lightweight systems have high potential for building rehabilitation, as the additional dead load transmitted to the existing structure is limited. This is particularly relevant in the case of building floors, which typically represent a very significant portion of the total structural mass of buildings [2,3]. The use of sandwich construction, characterised by two relatively thin and stiff faces and a relatively thick and lightweight core, may be an interesting solution for building floor rehabilitation. Currently there are several types of sandwich panels commercially available for civil engineering applications, which typically comprise steel facings and high density polymeric cores [4,5]. However, such solutions are still considerably heavier than typical timber floors, and are used mostly in new construction.

Fibre-reinforced polymer (FRP) composites, and particularly FRP sandwich panels, may be a viable alternative lightweight solution for the rehabilitation of building floors [6,7], presenting advantages over panels with steel facings due to their lightness, higher durability and limited maintenance [8]. In fact, composite

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sandwich panels are being increasingly used in civil engineering structural applications and have already been successfully applied in roof structures [9,10], bridge decks [11] and building façades [12]. Their potential use in building floors has also been suggested by several authors [6,13,14].

In the development of a sandwich floor panel several structural behaviour aspects must be considered, including the connections between the floor elements and their vertical supports. In old buildings, such supports are frequently load-bearing rubble masonry walls. This paper addresses this subject, with the objective of: (i) proposing connection systems for composite sandwich floor panels for use in building rehabilitation, (ii) experimentally and numerically assessing their structural behaviour and performance under vertical loading, and (iii) providing an analytical method to calculate the deflections of sandwich panels supported using the proposed connection systems. It is worth mentioning that while the investigated connection systems are also expected to transfer horizontal loads, their behaviour under such actions is beyond the scope of the current study.

The different connection systems proposed in this paper comprise anchoring steel angles to the masonry walls, which in turn support the sandwich floor panels via adhesively bonded, bolted, and mixed (adhesive and bolted) connections. Sandwich panels made of (i) glass-fibre reinforced polymer (GFRP) faces and (ii) cores made of polyurethane (PUR) foam and balsa wood are considered. These connections are experimentally tested under vertical loads in a cantilever configuration, loaded at the panels' free edge, and connected to a closed steel frame to simulate a rigid load-bearing wall. The tests are simulated using finite element (FE) models, in order to understand in further depth the stress distributions within the connection components, and to obtain the moment–rotation (M–θ) relationships that characterise each connection system. Finally, an analytical method is suggested to calculate the maximum deflections of sandwich panels when supported using the proposed connection systems.

2. Description of the connection systems

The primary function of floor-to-wall connection systems is to guarantee the transfer of vertical and horizontal (seismic and wind) loads between the floors and the load-bearing walls. In addition, it is also useful to guarantee some rotation restriction at these connections, as this reduces the floor's flexibility, i.e. the maximum deflections along the span. This can be a significant advantage given that maximum allowable deformability criteria are usually the limiting factor in the design of FRP composite sandwich floor panels [6].

In the rehabilitation of old timber floors one of the typical connection solutions comprises embedding the new joists in the load-bearing walls and/or using steel angles to anchor them to the walls (Fig. 1). These steel angles provide additional support length and in-plane stiffness to the floors [15,16], while also contributing to improve the out-of-plane behaviour of the exterior masonry walls [17]. The connection systems proposed in this paper, illustrated in Fig. 2, are based on that practice, with the steel angles acting as the main supporting element. The option of embedding the panels inside the walls was discarded, due to the continuous nature of this connection (as opposed to the discrete embedding of timber joists) – its implementation would significantly affect the walls' structural integrity and would be very labour intensive. Therefore, to increase the rotation stiffness of the connection, a second steel angle connected to the top face of the sandwich panels is considered in addition to the bottom steel angle where the floor panels are supported. These steel angles can be covered/embedded by the footer (top angle) or the moulding/suspended ceiling (bottom angle). Three different methods were used to join the panels and the steel angles: (i) adhesive bonding (Fig. 2a and b), (ii) bolting (Fig. 2c and d), and (iii) a combination thereof (Fig. 2e).

Fig. 1. Connection between a new timber floor and timber-framed masonry walls using steel angles.

3. Experimental investigation

3.1. Test setup and materials

A large sandwich panel of 3560 mm length × 1250 mm width × 134 mm thickness was manufactured by vacuum infusion. After curing, the sandwich panel was cut into specimens with a length of 850 mm and width of 250 mm. The panels[1] comprised 7 mm thick GFRP face sheets (nominal dimensions) enclosing a 120 mm thick core, made of either (i) rigid PUR foam, or (ii) balsa wood. Table 1 presents a summary of the most relevant properties of the constituent materials used in the sandwich panels (obtained from material characterisation tests).

One of the extremities of the test panels was supported in a single cantilever configuration and a point load was applied at the free edge, as illustrated in Fig. 3. The angles that supported the sandwich panels were connected to a closed steel frame comprised of HEB 300 profiles. These had a bending stiffness equivalent to a rigid rubble masonry load-bearing wall with a thickness of 1 m and a Young's modulus of 2 GPa (approximately 50,000 kN/m^2). The angles consisted of L-150 × 12 profiles of S275 JR grade steel, with a leg width of 150 mm and wall thickness of 12 mm. These were cut to a width of 300 mm, and bolt holes were drilled according to the specifications presented in Fig. 3. M10 bolts were machined and threaded to the required length from smooth S275 JR grade steel bars and used to connect the sandwich panels to the steel angles. An epoxy adhesive supplied by Sika AG (Sikadur 31 EF) was used for the adhesively bonded connections, all presenting a thickness of 2 mm (guaranteed using appropriate spacers).

Regarding the test instrumentation, vertical displacements were measured at the bottom face of the panels at the load application point (D1) and at a cross-section distanced 135 mm (approximately the same as the panel thickness) from the edge of the support (D2), using TML CDP-100 displacement transducers, with a stroke of 100 mm and precision of 0.01 mm. Displacement

[1] For the adopted aspect ratio, the specimens behave more closely to beams (or one-way slabs) rather than bidirectional panels. However, the current study envisages the use of floor panels similar to those described in [18], and consequently the term "panel" is used to keep consistency with the topic.