

Strengthening Haussmannian and Ski Resorts Hotels Wall Openings with Steel Beams and Steel Portal Frames

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Existing structures must be adapted to comply with current standards or for space efficiency requirements. This adaptation may include the need to create openings in existing walls. In load-bearing walls, the introduction of openings modifies locally the loading path, therefore the opening needs to be strengthened. Several strengthening techniques can be applied. In this paper, two strengthening practice solutions, based on the introduction of steel beams and steel portal frames currently applied in Haussmanian buildings and French Alps Ski resorts hotels, are described. Those practice solutions can be applied to openings in walls with different materials and thicknesses and for a high variety of loads, presenting acceptable results along time. The knowledge presented in this work is intended to give guidance to strengthening guidelines definition and at the same time to support and encourage the development of innovating strengthening techniques.

Keywords: Concrete wall, masonry wall, openings, strengthening, rehabilitation.

Along time, existing structures are subjected to functional modifications since they have to be adapted to comply with current living standards or space efficiency requirements. Such modification may include the addition of windows or doors, openings enlargement and new paths for ventilation and heating systems. All of which, requiring openings to be cut into existing structural walls, (Popescu, 2015). This operation can be easily achieved when the wall does not have a load-bearing function, as partition walls, nevertheless, when the walls are load-bearing, creating or enlarging openings in walls changes the load path within the wall and weaken the structure, adversely influencing its behavior, (Popescu *et al.* 2015), (Seddon, 1956). A new load path is established and the wall sections adjacent to the opening bear higher loads and the remaining lintel, if existing, is subjected to flexion. Since it is expected that the structural elements located in this new path have not been initially designed to withstand those news loads, an appropriate strengthening structure is required to restore the initial load-bearing wall strength, (Mohamed *et al.* 2013). A diversity of strengthening solutions can be applied, such as external composites, externally bonded steel, textile reinforced mortar, section thickness enlargement or by means of a lintel or a portal frame using concrete or steel members or a combination of those previous techniques, (Albert *et al.* 2001), (Engel, 2019), (Delatte, 2009). Nevertheless, currently there is a lack of normative guidelines related to opening strengthening. This paper is focused in the description of a wall opening strengthening technique currently applied in the Savoie and Haute Savoie departments in France and in the Haussmann buildings located in Paris

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Introduction

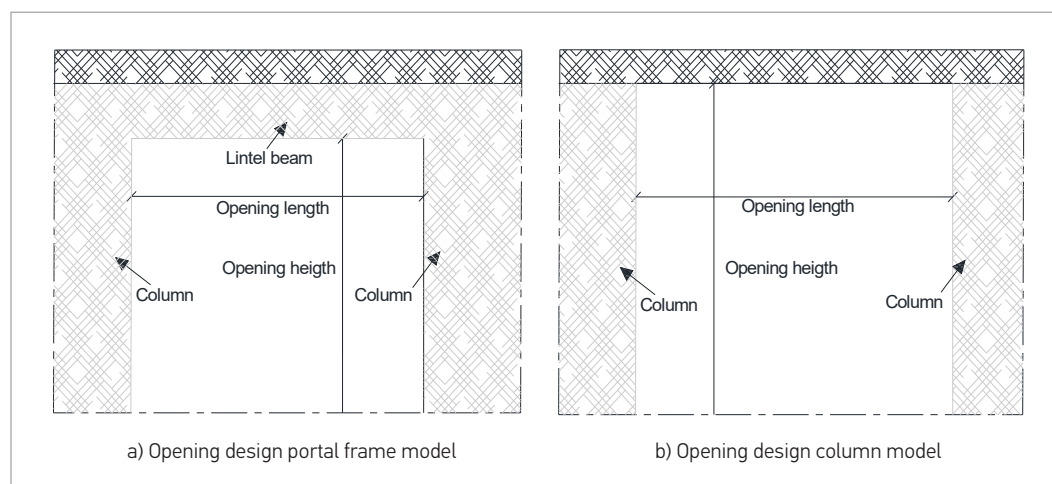


(Cardoso *et al.*, 2018, 2019). This technique is based in the introduction of steel beams and steel portal frames in the opening vicinity. The description is based on engineering design work carried by the author at STEBAT engineering design office based at Albertville, France, (Cardoso, 2018-a), 2018-b)). The result is an original and innovating technical note, which fills an existing gap between construction practices and research and development. The author strongly believes this work will give appropriate orientations in the development of normative strengthening guidelines, supporting the development of innovating strengthening techniques and practices involving sustainability concerns and allowing further knowledge in heritage rehabilitation and strengthening. The organization of the paper is the following: firstly, some backgrounds on wall openings strength and design is delivered, subsequently the strengthening technique is described by means of practices applications, and finally, some conclusions are indicated.

Wall openings strength and design

When loaded vertically, the strength of a wall depends on three main parameters. First, the boundary conditions defined by the number of restrained sides: two, three or four sides. The higher quantity of restrained sides reduces the wall's deformations, increase its ultimate strength and have a dominant influence on cracking patterns and failure modes. Second, the slenderness defining or not a buckling mode, (Saheb and Desayi, 1990). Third, the reinforcement ratio, increasing the ultimate strength, particularly if the reinforcement is placed on both sides of the wall, (Fragomeni and Mendis, 1997). A lot of research efforts have been done regarding axially loaded walls and to the authors' knowledge, the design of axially loaded walls is essentially based on column theory. Nevertheless when load-bearing walls contain openings, these are a source of weakness and can size-dependently reduce the structures' stiffness and load-bearing capacity, (Mohammed *et al.* 2013). Additionally, the design codes that have been reviewed (ACI 2008), (ACI 2011), (AS 2009), (CSA 2004), (ECS 2004), (ECS 2005) do not provide design equations to walls with openings. Only some guidelines are provided in the Australian and European standards (AS3600 2009, ECS 2004), stating that if, simultaneously, the wall is restrained on all sides and enclose an opening with an area less than 1/10 of the total wall area and the height of the opening is less than 1/3 of the wall height, then the effects of this opening on the axial strength can be neglected. A work from (Popescu, 2015) indicates that 25% and 50% reductions in the cross-sectional area of the concrete wall caused by the introduction of small openings and large openings reduces its load carrying capacity by nearly 36% and 50%, respectively. For the above-mentioned reasons, when designing concrete or masonry walls with openings, engineers tend to adopt a simplified method consisting in defining a simple design model constituted by a portal frame, Fig. 1-a), or isolated columns, Fig. 1-b). The ultimate load is governed by the column or lintel beam failure enclosing

Fig. 1
Opening design models



the opening. This method provides acceptable results in construction practices, but it is overly conservative. Furthermore, the design codes reviewed do not provide any strengthening design guidelines or even strengthening recommendations. In construction practices the load part resisted by the strengthening structure is evaluate following simple engineering judgment, experimental and numerical research is needed to quantify correctly the load resisted by the strengthening components and by the existing wall.

Introduction

Several practices techniques exist to strengthen openings in concrete or masonry walls, as textile reinforced mortar, bonded steel plates, externally bonded fiber reinforced polymers, thickness enlargement or concrete beams, (Todut *et al.*, 2015), (Triantafyllou and Papanicolaou, 2006), (Li and Lim, 2010). In this technical note, a technique based in the introduction of steel beams and steel portal frames is described. Two possibilities can be considered, in the first one, the steel structure is positioned laterally on both side of the existing wall and in the second possibility the structure axis is align with the wall longitudinal axis. For both solutions columns can be added at the beam ends, defining a steel portal frame which strengthens at the same time the existing adjacent walls.

Lateral steel beam strengthening

This technique consists in positioning U channel beams on both side of the existing wall as represented in Fig. 2. Fig. 2-a) is relative to a concrete wall and in Fig. 2-b) is relative to a masonry wall. On both cases the steel beams are located precisely bellow the existing floor, nevertheless, when a lintel is present, they can be applied at any level along the lintel height.



Fig. 2

Lateral steel beams strengthening

This solution can be applied for different materials and for different wall thicknesses, the concrete wall in Fig. 2-a) is 18 cm thick and the masonry wall in Fig. 2-b) is 50 cm thick. In Fig. 2-a) the strengthening beam is loaded with the upper floor and with the lintel existing along the opening, the bearing load is transmitted to the adjacent wall through steel columns defining a portal frame. For the masonry wall, Fig. 2-b), the load is transmitted directly to the adjacent walls. The steel beams on both sides of the masonry wall are connected together with LNP channels profiles beam, Fig. 3-a), and the connection between the steel beams and the masonry wall is materialized through adhesive anchor threaded rods, Fig. 3-b).

Fig. 4 represents a construction drawing relative to an opening strengthening performed in a concrete wall located in a ski resort hotel located in Savoie department in France. The opening is 3.00 meters long and the concrete wall is 18 cm thick. Before the opening is sawed, two U channel beams constituted with UNP240 profiles with a full length of 360 cm, drilled before, are positioned against the concrete wall, 19 Hilti concrete wedge anchors HSA M12, 115 mm long, are bored into the wall

The strengthening openings technique

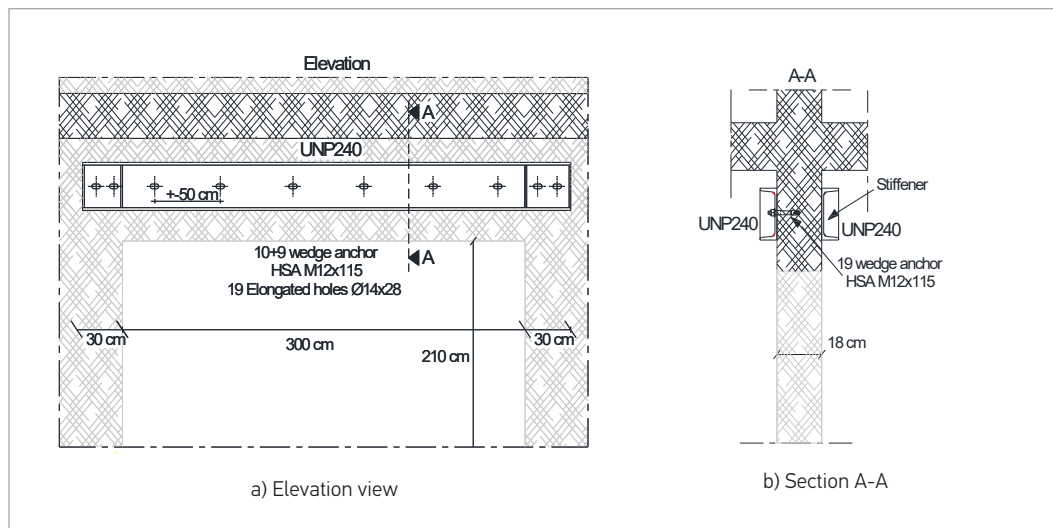
Fig. 3

Connections



Fig. 4

Concrete wall opening strengthening



through the profiles elongated holes, Fig. 4-b). The distance between connectors is approximately 50 cm. At beam ends and in each wall face, two wedge anchors are bored into the wall. Four 6 mm thick steel plate web stiffeners are welded along each bearing length, one on each side of the web, to avoid premature flange buckling and web crushing. The design load, corresponding to one floor, is constituted with a distributed dead load equal to $60 \text{ kN/m} \times 1.35$ and a distributed live load equal to $18 \text{ kN/m} \times 1.5$. The design bending moment is equal to $M_{sd} = 108 \times 3.3^2/8 = 147 \text{ kN/m} < M_{rd} = 84 \text{ kN/m} \times 2$ corresponding to the resistant bending moment of two UPN 240.

Fig. 5 is relative to a construction solution similar to the previous one, but now applied to a masonry wall. This solution was applied in a Haussmann building located in Paris. The opening length is 340 centimeters long. Two UNP 300 profiles are positioned against in each side of the wall and just below the upper floor and then the existing wall is sawed along the total height. LNP metallic profiles are welded transversally to the longitudinal profiles to avoid torsion effects in each profile, Fig. 5-a).

At the bearings and since for masonry wall the bearing stress is limited to $700\text{-}2000 \text{ kN/m}^2$, HEB profiles are introduced along the thickness wall to spread the beams vertical reaction along the wall masonry, Fig. 5-b), avoiding the high stresses around the beam ends HAS M16 anchor threaded rods. The design load, corresponding to three floors, is constituted with a distributed dead load equal to $72 \text{ kN/m} \times 1.35$ and a distributed live load equal to $30 \text{ kN/m} \times 1.5$. The design bending moment is equal to $M_{sd} = 142 \times 3.7^2/8 = 243 \text{ kN/m} < M_{rd} = 148 \text{ kN/m} \times 2$ corresponding to the resistant bending moment of two UPN 300.

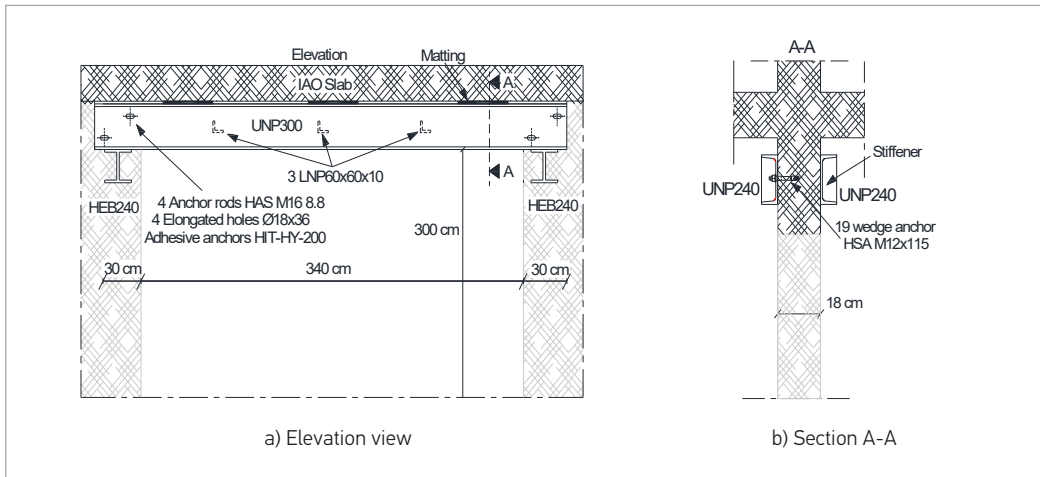


Fig. 5
Masonry wall opening strengthening

Using the same technique, a 100 cm long strengthen opening located in the Haute-Savoie department, is represented in Fig. 6-a). In that case, and as represented in Fig. 6-b), beyond the two U channel beams, two columns constituted with UNP 120 profiles are positioned against the wall to support the U channel beam ends, defining a portal frame. The U channel beams are linked together through 6 adhesive anchor threaded rods HAS M16 8.8 from Hilti , Fig. 6-b).

Each U channel column is 50 cm high, Fig. 7-a) and is fixed through 3 chemical anchor rods HAS M16 8.8 from Hilti, Fig. 7-b).

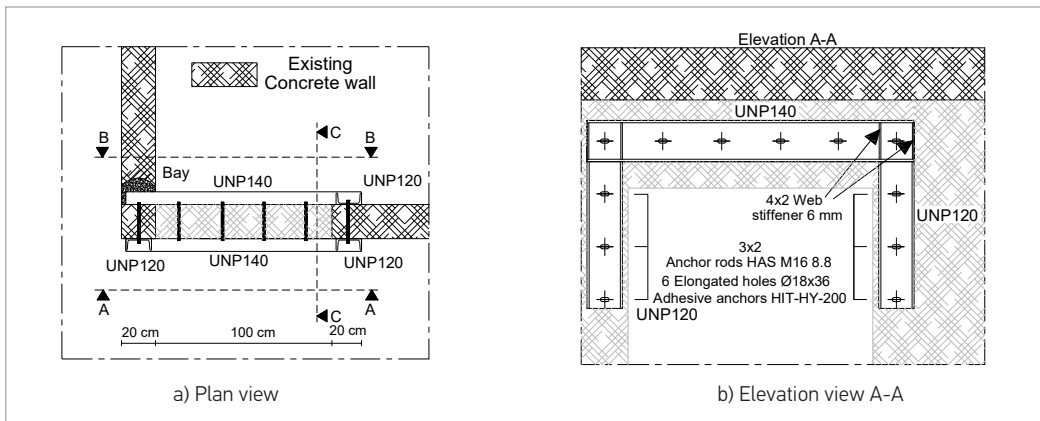


Fig. 6
Portal frame opening strengthening - I

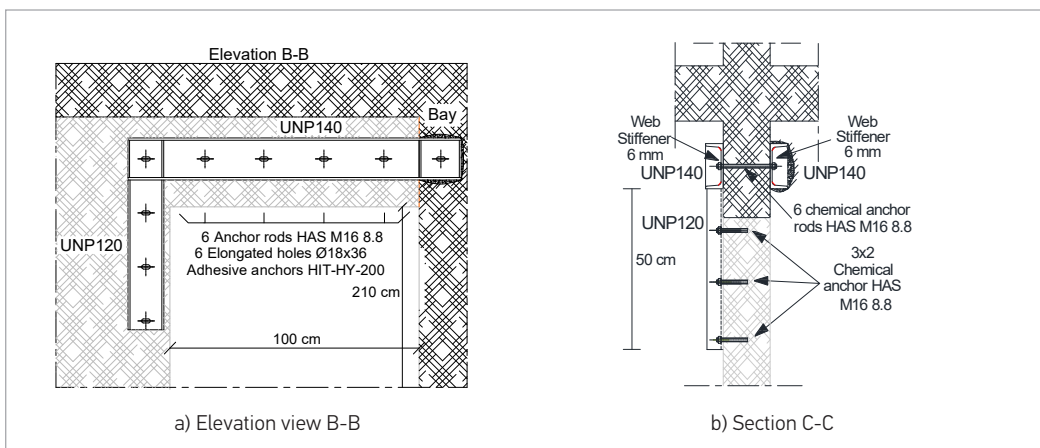


Fig. 7
Portal frame opening strengthening - II

Fig. 8
Opening
strengthening



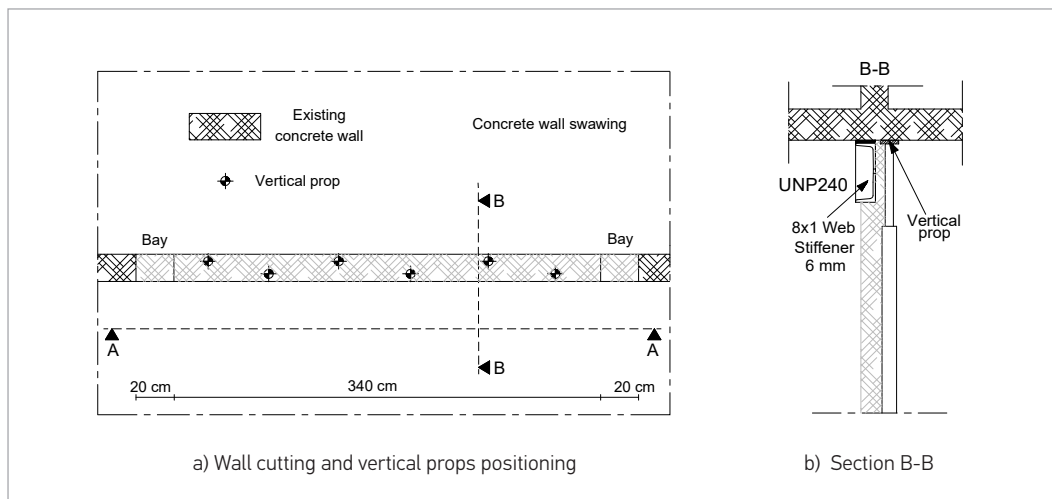
This solution allows to diffuse the beam reaction along the wall height, avoiding high stresses around the beam ends chemical anchor rods HAS M16.

Align steel beam strengthening

In this technique the opening is strengthened with a beam whose axis is aligned with the existing wall axis. In Fig. 8, two bolted steel channels running side by side along the opening and supported by bays created in the adjacent walls are represented.

Fig. 9 represents the design drawing relative to a concrete wall opening strengthening corresponding to the association of two apartments located in Paris. The concrete wall is 15 cm thick, the opening is 3.40 meter long. To achieve the strengthening a specific methodology is applied. First, the opening is created cutting the wall with 1 meter long width and positioning at the same time vertical props, Fig. 9-a). This operation is repeated until the entire opening is created. At the end the entire upper structure is held up by vertical props positioned along two rows located on both sides of the wall axis, as represented in Fig. 9-b). Secondly, all the props located along one row are removed and the first UNP channel is positioned. This operation is then repeated for the second props row and the second UNP channel is positioned.

Fig. 9
Align beam
strengthening



As represented in Fig. 10-a), the two U channels are 3.80 meters long and are bolted together using 8 M12 8.8 bolts. Web stiffeners 6 mm thick are introduced in the bearing length, as represented in Fig. 10-b). The bearing length is 20 cm long and consists in bays created in the existing wall.

The solution presented in Fig. 11 is similar to the previous one, but complementary, vertical steel U channels are connected to the opening lateral sides, Fig. 11-a), defining a steel portal frame. The columns and beams define a stiffer structure, when compared to the previous one, and at the same time they strengthen the wall opening lateral sides. The two U channels beams are bolted

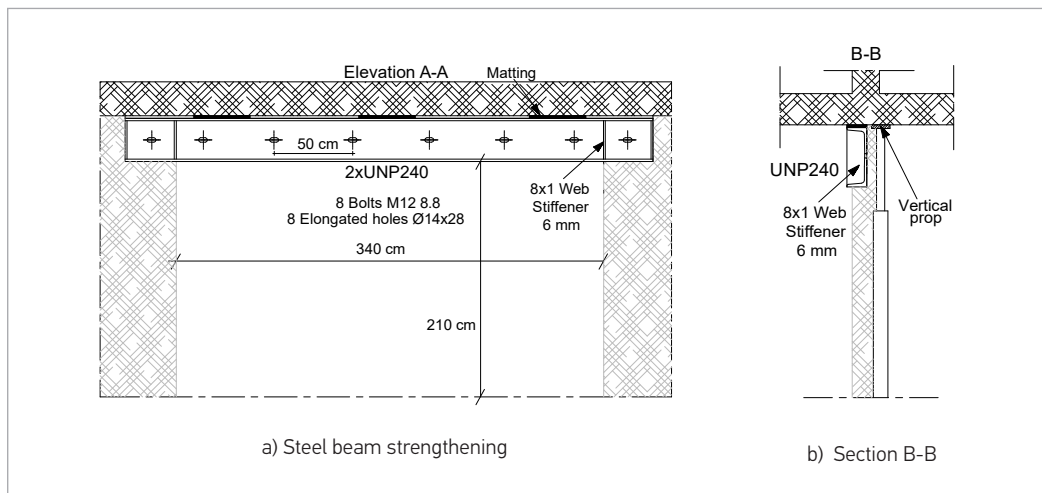


Fig. 10

Elevation view

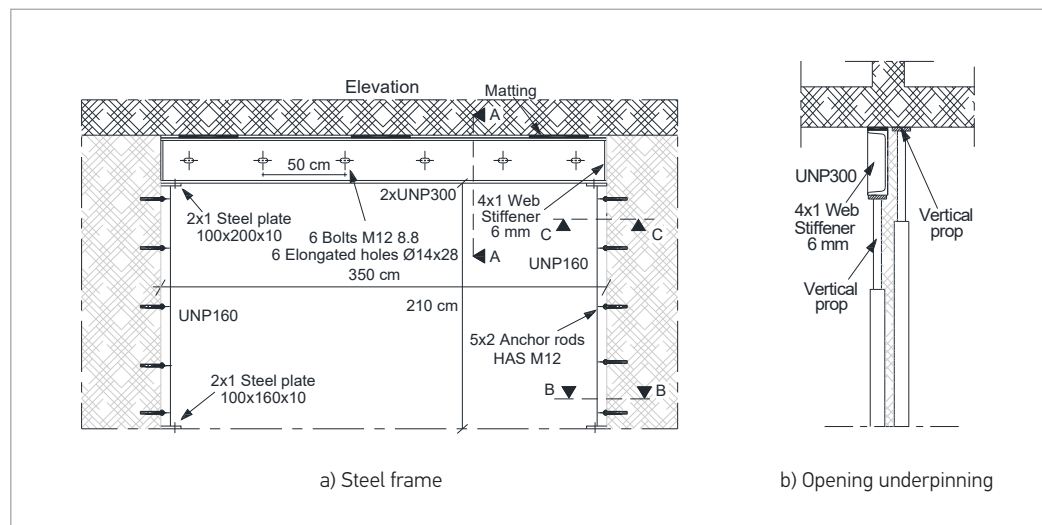


Fig. 11

Steel frame opening strengthening

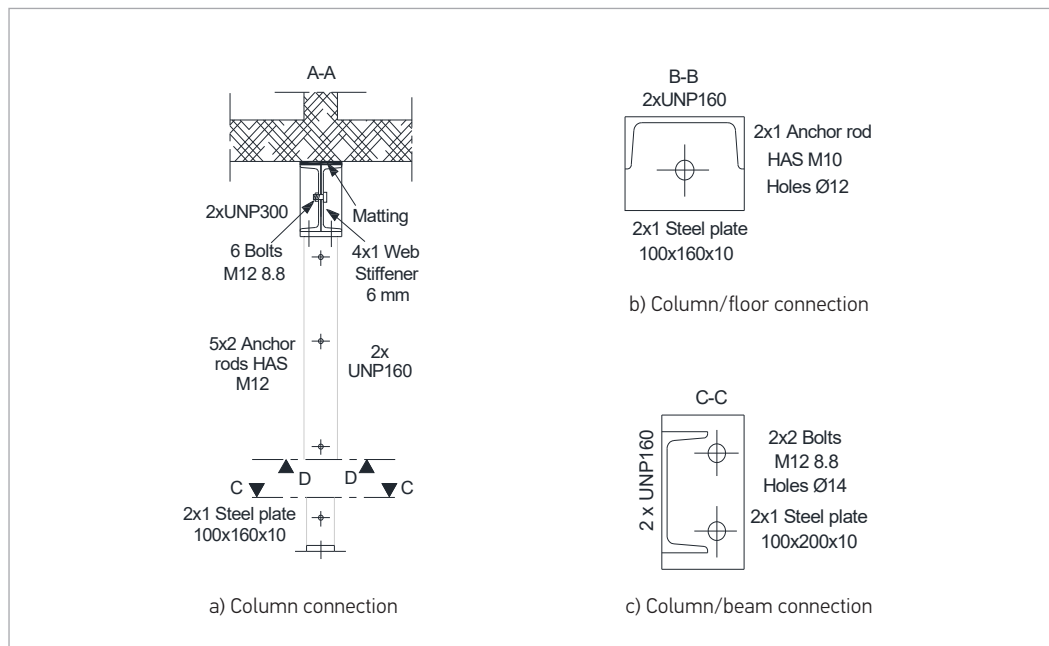
together through 6 bolts M12 8.8 inserted in 6 elongated holes. Web stiffeners 6 mm thick are located at the U channel beam ends as represented in Fig. 11-b). The constructive methodology is also similar to the previous one, but during the positioning of each U channel and before the introduction of the columns it is necessary to underpin the beam with vertical props, as represented in Fig. 11-b).

The connection between the U channel and the opening lateral side is materialized through 5 adhesive anchor threaded rods HAS M12, Fig. 11-a) and Fig. 12-a). The connection between the U channel columns and the floor is realized with a steel plate 10 mm thick and one Hilti adhesive anchor rod HAS M10, Fig. 12-b) and the connection between each column and the beam is materialized with a steel plate 10 mm thick and two bolts M12 8.8, Fig. 12-c).

The technique described as been used for opening lengths varying from 1.00 to 3.50 meters. Grade 235 steel is used with a yielding strength of 235MPa and with an elastic modulus of 200GPa. This practice construction technique has shown good results along time, being currently a traditional opening strengthening technique.

Fig. 12

Connection detailing



Conclusions

The current normative documents as Eurocode, beyond others, do not provide any guidelines regarding wall opening strengthening techniques or even the design of openings created in existing walls. In this paper a current practical strengthening technique currently applied in Paris Haussmann buildings and in Savoie and Haute-Savoie departments Ski resort hotels that uses steel profiles to strengthen vertically loaded walls with openings is presented and described and construction design drawings are delivered. This engineering practice presents acceptable results, preserving the carrying capacity of the walls and compensating the wall stiffness reduction being recommended to strengthen walls with openings.

Currently, in design practice, a simplified method which consists in dividing the wall with openings into isolated columns connected by a beam is adopted, resulting in a slight overdesign for the structural elements, thus providing excessive safety. Nevertheless, the degree to which the upgrade system and the existing structural elements share the loads need to be quantify, thus experimental and numerical research should be realized in order to validate accurate and safe design procedures regarding this strengthening technique and to support the development of normative strengthening guidelines.

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