



(12) **EUROPEAN PATENT APPLICATION**

(43) Date of publication:
05.07.2023 Bulletin 2023/27

(51) International Patent Classification (IPC):
E04C 2/06 (2006.01) E04C 2/288 (2006.01)
E04C 2/38 (2006.01) E04C 2/04 (2006.01)

(21) Application number: **22165414.8**

(52) Cooperative Patent Classification (CPC):
E04C 2/06; E04C 2/288; E04C 2/384;
E04C 2002/048

(22) Date of filing: **30.03.2022**

(84) Designated Contracting States:
AL AT BE BG CH CY CZ DE DK EE ES FI FR GB
GR HR HU IE IS IT LI LT LU LV MC MK MT NL NO
PL PT RO RS SE SI SK SM TR
Designated Extension States:
BA ME
Designated Validation States:
KH MA MD TN

(72) Inventors:
• **TSIKALOUDAKI, Aikaterini**
54655 Thessaloniki (GR)
• **NIKOLAIDIS, Themistoklis**
54351 Thessaloniki (GR)
• **KATAKALOS, Konstantinos**
55236 Panorama Thessalonikis (GR)
• **THEODOSIOU, Theodoros**
54622 Thessaloniki (GR)
• **ILIADIS, Theodoros**
57001 Neo Rissio Thessalonikis (GR)

(30) Priority: **30.12.2021 GR 20210100921**

(71) Applicants:
• **Aristotle University of Thessaloniki - Elke**
54636 Thessaloniki (GR)
• **Iliadis, Theodoros**
57001 Neo Rissio Thessalonikis (GR)

(74) Representative: **Petsis, Christos**
Attorney at Law
Kyparissias 4-6
54249 Thessaloniki (GR)

(54) **PREFABRICATED COMPOSITE STRUCTURAL WALL SYSTEM AND METHOD OF ASSEMBLY AND MANUFACTURING THEREOF**

(57) Prefabricated structural wall system for the construction of a building and its assembly, particularly low-rise, comprising a set of wall elements (1), a structural building framework made of a plurality of main structural members consisting of mutually cooperating columns (3) and beams (2), which are provided with connection means (17) between them for mutually connecting said main structural members, and a series of hollow steel sections (6) arranged vertically respective said beams (2) within said wall elements (1), wherein said main structural members (2, 3) are made of steel. It is remarkable in that said wall elements (1) comprise at least two composite wythes (5) parallel layers made of a heavy material consisting of reinforced concrete or a concrete-like material, and a thermal insulation layer (13) embedded in-between both said wythes (5), resp. layers, wherein said wythes (5) are each reinforced with a steel bar mesh (4), which are interconnected with said hollow steel sections (6) by means of sheer connectors (7), and which (5) are positioned on either side of said hollow steel sections (6), wherein said wall elements (1) are formulated by a composite combination of precast wythes (5) and hollow steel sections (6) in the form of a composite sandwich-panel and said beam (2). The invention also relates to an assembly method thereof.

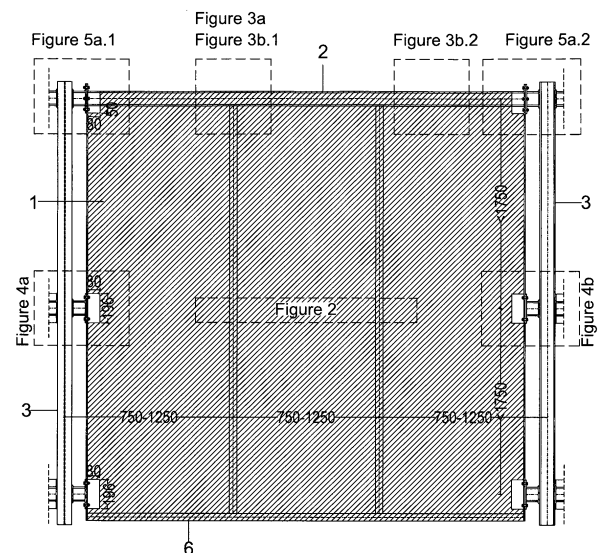


Figure 1

Description

Technical field of the invention

[0001] The present invention relates to a prefabricated structural wall system for the construction and assembly of low-rise buildings and optimal use of material for load bearing elements.

Background of the invention

[0002] Prefabricated buildings consist of factory-made components or units that are transported and assembled on-site to form a complete structure. This building system offers many advantages, such as a significant reduction in cost and time, an improved quality and accuracy in manufacture, the speed of installation on-site, an easy dismantle and reuse of its components. In addition, it also offers a reduction in the environmental degradation, an increase of productivity gains, a decrease of labour requirements and an improvement of the working conditions.

[0003] There are many prefabricated building types on the construction market, which are categorized with regard to the main material of their structure, namely wood, reinforced concrete and steel.

[0004] In low rise buildings having up to 2-3 storeys above ground, the most widespread prefabrication type is the steel framework due to the easiness and speediness of its site installation, as well as the adaptability of its design. However, in most prefabricated steel constructions, the wall elements are made of lightweight panels, which are designed primarily to sustain gravity and wind loads with limited or no seismic consideration, and neither participation in the structural performance of the building. This leads to the need of bigger and/or more steel structural elements, which increase the total steel weight of the building, and thus also the cost and the environmental impact thereof.

[0005] Besides, the use of light weight elements for configuring the building envelope decreases the thermal mass of such building types, creating a negative impact on the control of interior temperature and increased possibility of overheating, thermal discomfort and cooling energy needs during the warm period of the year.

[0006] Over the last 30 years, many buildings have been constructed using a combination of precast concrete and structural steelwork. The high interest in mixed construction is motivated by its efficient employment with modular construction techniques enabling a faster erection and completion of many different types of buildings compared to conventional constructional methods. Steel and concrete modules are easily manufactured in the factory under a quality and low-cost environment. They are transported afterwards and assembled on-site using suitable connections to assure structural continuity.

[0007] Nowadays, steel frames infilled with prefabricated load-bearing walls are widely used in steel and

composite structures. The relevant research is mainly focused on the development of the precast load-bearing walls and the assessment of their performance.

[0008] Concerning the precast concrete walls, two main types are discerned: monolithic elements and sandwich panels, both employing concrete for their construction.

[0009] The monolithic concrete elements are made in the factory and they are joined together in situ either through especially designed connectors [1-3] or with cast-in-place concrete [4-6]. A drawback of this system is that it results in heavy and thick elements, which burden their handling and slow the installation process.

[0010] The sandwich panels consist of two, or three, concrete wythes that embed a layer of thermal insulation. In currently available solutions, the wythes are made of concrete reinforced with steel bars in a mesh, carbon or glass textiles or fibres made of steel, glass or polypropylene [7]. The connection between the concrete wythes is realized with concrete connectors, metallic connectors or fibre reinforced polymer connectors [7] crossing through the insulation layer. More specifically, the concrete wythes can be connected with continuous ribs or discrete zones of concrete, solid concrete zones, e.g. on the top and bottom edge of the panels or around all edges of the panel [8]. The metallic connectors may have the form of diagonal bars, truss, a tube, a plate or a pin. The fibre reinforced polymer connectors are made either by non metallic fibres (FRP), glass, carbon or basalt fibre reinforced polymer and may have the form of a discrete pin, plate, X shaped, rigid truss, mesh, etc. The thermal insulation material is usually in the form of plates.

Prior art

[0011] CN107724596A discloses a partially prefabricated sandwich wall element composing of prefabricated thermal insulation plates, a thermal insulation core layer, a steel wire mesh, diagonal plug wires and prefabricated outer surface layers. The surface layers are not load bearing and they are connected through diagonal steel elements and a steel wire mesh. The drawback of this system is that it is not fully load-bearing and its thermal mass is limited.

[0012] CN 111705996A discloses a prefabricated wall element, which consists of a frame assembly made by C-, U- and I-shaped steel elements, a filler material within the voids of the framework and panels fixed on the steel framework. The panels are not reinforced and the main load-bearing element is the steel framework. Given that the panels do not have a load bearing role, they do not interact with each other and with the steel framework: this solution cannot be regarded as a composite one and has a limited contribution to the whole structural performance of the building, especially as regards seismic loads.

[0013] CN 209277334U concerns a prefabricated composite wall element with integrated thermal insulation comprising autoclaved aerated concrete boards,

light steel elements in the form of keels (c-channel) and a thermal insulation core layer. The aerated concrete boards are connected with the steel elements through drilling and self-tapping bolts. The specific system is not considered as a load-bearing element, as the concrete boards are not reinforced and they cannot carry horizontal, off-plane forces.

[0014] WO 2012174434A presents a wall element comprising a wooden frame assembly made by horizontal and vertical members, coupled together with fasteners, such as nails, screws, foam insulation disposed in the voids between the frame members and sheathing, such as plywood or press wood boards, opposite the frame assembly. The wall element is not formed as a combination of concrete and steel elements and has a structural performance that is different from the aimed development.

Aim of the invention

[0015] Although several prefabricated concrete sandwich panels exist in the market, they are not load bearing and they do not have the capacity to contribute to the structural performance of the building. The present invention aims at overcoming this technical problem. Accordingly, the concrete wythes are reinforced with a steel bar mesh and they are interconnected with an array set of hollow steel elements by means of simple sheer connectors. This particular configuration of the composite wall elements, along with their connection to the main structural elements, generate a wall system that is part of the building's bearing organization.

[0016] Within this context, the use of reinforced concrete or other heavy materials is not usual in the construction of sandwich panel elements. In that case, this adversely results in a reduced thermal mass. However, thermal mass is important for the regulation of indoor thermal conditions and is regarded as one of the measures to optimize building energy performance and thermal comfort in Mediterranean regions.

[0017] A practical means to increase the thermal mass of lightweight buildings is to add elements made of heavier materials on the building enclosure, which have the capacity to store heat and dissipate it when the conditions are favorable, e.g. when the indoor temperatures lowers.

[0018] Such elements can be made of precast reinforced concrete, which has an adequate thermal capacity.

[0019] The combination of precast concrete and structural steel elements in building prefabrication offers structures with enhanced structural and thermal performance.

[0020] The present invention thus aims at overcoming the technical problem of reduced low thermal mass, thanks to the use of a heavy material, particularly reinforced concrete, the construction of the concrete wythe, as well as through an appropriate selection of its width, which provides the optimal thermal capacity to the element.

Summary of the invention

[0021] There is thus proposed according to the invention a system comprising a composite wall system, respectively a composite wall element and its connections with the main structural steel members of the building, consisting of a set of columns and beams. This composite wall element remarkably consists of two reinforced concrete wythes respectively positioned on either side of vertical hollow steel beams. The connections between this wall element and the structural building framework are realized with a set of connecting means consisting of distinct bolted joints.

[0022] The present invention thus relates to a composite structural wall element as such, as well as to a system composed of such prefabricated elements and its connections.

[0023] According to the invention, an innovative prefabricated structural wall system is thus provided, which includes prefabricated composite wall modules outstandingly constructed as a combination of precast concrete wythes and steel elements in the form of a sandwich panel, steel structural frame members and their connections through distinct bolted joints.

[0024] The prefabricated wall system according to the invention is thus featured by an advanced structural and thermal performance, contributing to the optimal use of the proposed material for load bearing elements, beyond the easy and fast assembly on site.

[0025] The performance of the prefabricated wall system according to the invention has been verified through analytical studies and measurements in certified laboratories. More specifically, the structural performance was tested through experimental investigation under compression and diagonal tension, ultimate strength at limit state failure under out of plane loading conditions and in plane cyclic pseudo dynamic loading. The tests showed the capacity of the new prefabricated wall element to act as a load bearing one. This is mainly attributed to the cooperation of the reinforced concrete wythes with the steel elements, achieved through the use of the sheer connectors.

[0026] The thermal performance was tested with regard to the determination of the U-value, the thermal bridging effect and the thermal capacity. The U-value was found lower than the one of conventional wall materials of the same width, due to the integrated thermal insulation panel. The thermal capacity was also higher than most of the prefabricated sandwich panels, which is attributed to the increased thermal mass of the concrete wythe.

[0027] The present invention thus provides a system comprising two concrete wythes/layers each being reinforced with a steel bar mesh and vertical steel hollow elements in between, which are connected with the steel bar mesh of the concrete wythes/layer. It is considered as a composite prefabricated wall element, given that the two concrete wythes/layers act together as a single unit to resist applied loads till failure. The shear transfer be-

tween the two wythes is provided by the connection between the vertical hollow steel elements and the steel bar meshes of the two concrete panels through the use of a simple connector.

[0028] The present invention relates to a composite, load-bearing prefabricated wall system, which increases the building's structural performance by carrying axial, lateral and dynamic forces thanks to the integration of reinforced concrete and steel elements and their cooperation with simple steel connectors.

[0029] When compared with other load-bearing elements made as sandwich panels with precast concrete, the proposed invention offers, together with the main frame system, optimal response against seismic loads.

[0030] The proposed shear connection between the concrete wythes differentiates from the existing types of sandwich load-bearing walls, in that in all previous wall configurations reported in the prior art, the connection between the concrete wythes was realised by metallic connectors with the form of diagonal bars, truss, tubes, plates or pins. The use of vertical steel hollow sections, that are normally distributed along the wall length and are interconnected with the concrete wythes' steel mesh, is thus not only a differing but also a remarkable technique, which increases the structural performance of the module and transforms it to a load bearing one as regards both axial and lateral forces.

[0031] Beyond the increased structural capacity, also the thermal mass of the prefabricated wall element is improved as well thanks to the use of the optimum width of reinforced concrete for the concrete wythes.

[0032] The present invention also relates to a method for realising the latter system as a manufacturing method and assembly for connecting.

[0033] Besides, it provides an easier and faster construction in the factory, devoid of specialized components or complicated procedures, thus contributing to minimized cost for its fabrication and assembly, both in the factory and on site.

[0034] At the same time, the thermal insulation is easily embedded into the panel, advancing the energy efficiency and the sustainability of the building element, given that its thermal performance is higher than the one calculated for other traditional building façade elements, which usually lack any thermal insulation.

[0035] Additionally, the concrete wythes provide the necessary thermal mass. The increased thermal mass is a result of the use of an optimum width of the concrete panel and the thermal capacity of reinforced concrete which is used as the construction material.

[0036] The configuration of the proposed element provides constructions with increased structural and thermal performance with a minimized wall width. Along with the reduced volume of the steel structural members due to the load-bearing role of the wall elements that enables them to carry axial and lateral forces, the building envelope occupies a lesser percentage of the built area, allowing for more free indoor space. The contribution of

the building element to the structural performance of the building leads to lighter steel components of the main steel framework of the building. This is because the wall element carries part of the loads, as a result thereof the main steel framework of the building can be realized with steel elements with decreased dimensions. The use of steel components with decreased dimensions leads to reductions on the cost of construction, transportation and assembly on site, as well as the environmental impact through the whole life cycle.

[0037] The geometry length-height of the wall element is not standard, and it can be easily adjusted to the building's architectural morphology. Although the standardization of the construction is usually wanted in industrialized construction, the ability of the new wall system to be constructed in various dimensions -lengths and heights- provides flexibility and adaptability in most architectural morphologies and designs of residential buildings. This capability of the new proposed prefabricated wall system is further supported by the described configuration of the connections of the wall element with the other building components.

[0038] Consequently, the total design of the building element guarantees the structure's robustness under axial and lateral forces, including seismic hazard, reduced weight of the structural steel members, decreased cost, enhanced hygrothermal, energy and environmental performance, increased adaptability in the architectural design, as well as fast and easy construction in the factory and on site.

Brief description of drawings

[0039]

Figure 1 is a plan view of the prefabricated wall system according to the invention that includes the positions for the detailed views of figures 3a, 3b, 4a, 4b, 5a and 5b showing an outline of said wall system and providing references to the following figures.

Figure 2 shows a horizontal cross section of the composite wall element according to the invention.

Figure 3 is a detailed representation of the wall to beam connection further showing the upper edge of said wall element according to the invention.

Figure 3a shows the view plan of the wall to beam connection.

Figure 3b represents the vertical cross section of the wall to beam connection in two positions: along the rectangular hollow steel section referred to as RHS as shown in Figure 3b.1 and next to the RHS as shown Figure 3b.2.

Figure 4 shows a horizontal cross section of the wall to column connection when the column's web is perpendicular to the wall element's longitudinal axis (a) and when the column's web is parallel to the wall element's longitudinal axis b.

Figure 5 is a detailed representation of the column

to beam connection according to the invention, wherein

Figure 5a shows the top in Figure 5a.1 and side in Figure 5a.2 plan view of the column to beam connection when the column's web is perpendicular to the wall element's longitudinal axis, whereas, Figure 5b shows the top in Figure 5b.1 and side in Figure 5b.2 plan view of the column to beam connection when the column's web is parallel to the wall element's longitudinal axis.

Legend

[0040]

1. Composite wall element
2. HEA100 beam
3. HEA100 column
4. Steel bar mesh
5. Concrete
6. Rectangular, resp. Square Hollow steel sections, (RHS, resp. SHS)
7. Steel bar shear connector
8. Void
9. Steel plate (120 x 120 x 8)
10. Steel plate (150 x 196 x 8)
11. Short HEA unit
12. M12 bolts
13. Thermal insulation

Detailed description

[0041] Fig. 1 shows a prefabricated structural wall system comprising a first component consisting of a composite wall element 1, a second component consisting of a steel beam 2, which is integrated within the said wall element 1, a third component consisting of a pair of steel columns 3 as well as their connections, as shown in Figures 3, 4 and 5.

[0042] Said composite wall element 1 integrating said steel beam 2 is constructed in a factory and transferred to site. Similarly, the steel columns 3 are prepared in the factory, where they are cut in the desired length and then the connectors are fit to the pre-estimated positions, before they get transferred and positioned on site. Afterwards, the wall element 1 is mounted with the columns 3 through the connections that have been realized in both components e.g. by means of bolts.

[0043] The composite wall element 1 comprises a 5th component consisting of two 50 mm thin concrete wythes/layers 5, each reinforced with a 4th component consisting of a steel bar mesh 4 as shown in Fig. 2. The steel bar mesh 4 consists of horizontal and transverse steel bars, having 6 mm in diameter and of B500A quality with a nominal yield strength of 500 MPa, spaced at 150 mm and 155 mm respectively. The concrete mesh reinforcement 4 is mounted at about 20 mm of each external surface of the panel. The concrete mix is made from or-

dinary Portland cement, medium coarse sand and coarse aggregate with a maximum size of 10 mm.

[0044] A space for insulation plates 13 is formed between the two concrete wythes 5 through the integration of parallel steel hollow sections 6 either rectangular of 30 mm x 50 mm constituting a rectangular hollow section referred to as RHS 50X30X3/S235H or square shaped of 50 mm x 50 mm forming a square hollow section designated as SHS 50X50X3/S235H with a 235 MPa nominal yield strength. The voids between the vertical hollow steel sections 6 are filled with thermal insulation material in the form of insulation plates 13.

[0045] The two concrete wythes 5 are attached with full contact to the said RHSs sections 6 and the insulating material. The RHSs 6 are connected to the steel bar mesh 4 of the concrete panels through U shaped steel bars 7, with 8 mm in diameter and of B500C quality, equally spaced along the RHS 6 at a distance of about 400 mm. The two parallel members of the U-shaped steel bars 7 are 95 mm long, while the middle member is 110 mm long. The inextricable connection of the U-shaped steel bars 7 with the steel bar mesh 4 and the RHSs 6 is achieved through welding.

[0046] The distance between the RHSs 6 is not standard and it ranges from 700 mm to 1250 mm. The number of RHSs within the wall element 1 is defined by the total width of the building element, which is specified by the distance between the main steel structural members of the building as derived by the structural design and relevant calculations, as well as the presence of openings wherein RHSs are positioned around them.

[0047] The edges of the wall element 1 are specially formulated in order to allow for the safe transfer of loads and the inextricable connection with the building's structural members, i.e. the beam 2 on the upper part, the columns 3 on the lateral sides of the wall element 1, and the slab on the lower part of the wall element 1.

[0048] The configuration of the wall element's edges and its connection with the abovementioned structural members of the building's frame are presented henceforth in detail.

[0049] Figure 3 shows the upper horizontal edge of the wall element 1 and wall to beam connection. The upper horizontal edge of the wall element 1 integrates a HEA100 beam 2. The HEA beam 2 is incorporated on the wall element 1 during its construction in the factory.

[0050] The HEA100 beam 2 is connected to the said RHSs sections 6 of the wall element 1 through welding. It is also connected to the steel bar mesh 4 of the concrete wythes through U-shaped shear steel bars 7, which are welded to the lower flange of the HEA100 beam 2. The shear steel bars 7, with 8 mm in diameter and of B500C quality, are equally spaced along the HEA100 beam 2 at a distance of about 400 mm. The middle member of the U-shaped shear steel bar 7, which is welded on the HEA100 beam 2, is 95 mm long and the two parallel members are 110 mm long.

[0051] The steel bar mesh 4 of each concrete wythe 5

covers the height of the beam 2 and it is welded on its upper and lower flanges. It is then covered by concrete as shown in Figure 3b. Special voids 8 are foreseen at the two upper corners of both the concrete wythes 5, in order to allow for safe bolting between the steel beam 2 and the steel column 3 on site. The voids 8 are 80 mm long and 50 mm high. After bolting, the voids are infilled with strong cement mortar (EMACO).

[0052] Figure 4 shows lateral edges of the wall element 1 and the wall to column 3 connection.

[0053] The vertical edges of the building element are configured with thin steel plates 10. The thin steel plates 10 are 8 mm thick and 150 mm wide, covering the width and the whole height of the building element. Their nominal yield strength is equal to 235 MPa.

[0054] They are connected to the steel bar mesh 4 of the concrete wythes 5 through U shaped steel bars 7, 8 mm in diameter and of B500C quality, equally spaced along the steel plate 10 at a distance of about 400 mm. The two parallel members of the U-shaped steel bars 7 are 95 mm long, while the middle member is 110 mm long. The inextricable connection of the U-shaped steel bars 7 with the steel bar mesh 4 and the steel plates 10 is achieved through welding.

[0055] The wall element 1 is connected to the main steel HEA columns 3 of the building frame through bolting. The bolting is realized at three positions along the height of the element: one at the top, which corresponds to the connection between the column 3 and the beam 2 that is integrated on the wall, one at the bottom and one at the middle height of the element, under the condition that the distance between these positions does not exceed 1,75 m. In order to allow for easy bolting, voids 8 are foreseen on the specific locations at the edges of the concrete wythes 5, which are created with the help of spacers. The length as horizontal dimension and the height as vertical dimension of the voids 8 are equal to 80 mm and 196 mm respectively. After bolting is realised on site, the voids 8 are infilled with strong cement mortar (EMACO).

[0056] The HEA columns 3 are connected with the wall elements 1 with the help of additional short HEA100 11, configured and cut in 80 mm long, that are welded perpendicular to the column 3.

[0057] More specifically, if the HEA column's web is perpendicular to the longitudinal axis of the wall element 1, a steel plate 9, sized 120 mm × 120 mm × 8 mm, is welded on the edges of the upper and the lower flange and then the short HEA unit is welded on the steel plate 9.

[0058] If the HEA column's web is parallel to the longitudinal axis of the wall element 1, a steel plate 9, with dimensions 120 mm × 120 mm × 8 mm is welded on the flange of the HEA column 3 and then the short HEA unit is welded on the steel plate.

[0059] For both cases, on the other edge of the short HEA100 unit, another steel plate 10 is welded, with dimensions 150 mm × 196 mm × 8 mm. The connection between the column configuration 3 and the wall element

1 is made by bolting the two plates 9, 10 together, i.e. the one 9 that is attached to the column 3 and the one 10 integrated at the edge of the wall element 1, by means of 2 × 2 M12 bolts 12 of grade 8.8 according to EN1993-1-8.

[0060] The connections between the column 3, the plates 9, 10 and said short HEA100 units 11 are made in the factory, while bolting is made on site.

[0061] Figure 5 shows the beam to column connection.

[0062] The HEA beam 2 is connected to the HEA column 3 through bolting on site. Within this context, the HEA columns 3 are equipped with said short HEA100 units 11, 80 mm long, that are welded perpendicular to the column 3, by means of a steel plate 9, sized 120 mm × 120 mm × 8 mm. At the other edge of the short HEA100 unit, another steel plate 10 with dimensions 150 mm × 196 mm × 8 mm, is welded. The connection between the column configuration 3 and the wall element 1 is made by bolting the two plates 9, 10 together, i.e. the one 9 that is attached to the column 3 and the one 10 integrated at the edge of the wall element 1, by means of 3 × 2 M12 bolts 12 of grade 8.8 according to EN1993-1-8.

[0063] For allowing easy and safe bolting, voids are foreseen on the concrete wythes at the two upper corners of the wall element 1. After bolting, the voids are infilled with strong cement mortar (EMACO).

[0064] As to the lower horizontal edge of the building element, the base of the wall element 1 is configured with the help of a horizontal steel hollow section 6 of 30 mm × 50 mm, either RHS 50X30X3/S235H or SHS 50X50X3/S235H with a 235 MPa nominal yield strength.

[0065] The vertical RHSs of the wall element 1 are welded on the horizontal one. The connection of the horizontal steel hollow section 6 with the concrete wythes 5 is supported through U-shaped steel shear bars 7 about 8 mm thick, which are welded along the horizontal RHS at equal spaces of about 400 mm. The free members of the U-shaped shear connectors are welded on the steel bar mesh 4 of the concrete wythes 5.

[0066] A method of realizing the assembly is based on the following construction method as set out hereafter. The structural study defines the position of the main structural members of the building's frame, the length of the wall elements 1 and the position of the RHSs within the wall element 1.

[0067] The composite wall element 1 integrating the steel beam 2 and the columns 3 of the structural framework are constructed in the factory and then transferred to site. Afterwards, the wall elements 1 and the columns 3 are connected through bolting in the predetermined positions.

[0068] More specifically, as regards the manufacturing of the wall element 1 integrating the steel beam 2, a mould is formed with the desired dimensions. The steel bar mesh 4 of the concrete wythes, the RHSs, the steel plates and the HEA beam 2 are cut to the desired dimensions.

[0069] The steel bar mesh 4 of the concrete plate is positioned horizontally and it is elevated from the working

surface over a certain distance, e.g. by 25 mm by means of spacers. The position in which the steel rectangular hollow elements (RHS) will be put, is determined. The RHSs are connected with the steel bar mesh 4 through U-shaped steel bars 7 spaced at a distance of 400 mm along the steel element. For this reason, one of the two free members of the U-shaped steel bar 7 is mounted on the steel bar mesh 4 before the concrete is poured. The other free member is getting connected with the second concrete plate, while the middle part of the U-shaped steel bar 7 is in contact with the RHS 6. The U-shaped steel bars 7 are positioned alternately on both free sides of the RHS 6.

[0070] The configuration of the element's edges follows, with respect to the structural design, the vertical edges integrate steel plates, the upper horizontal a HEA beam 2 and the lower horizontal a RHS.

[0071] The concrete is poured after the preparation of the concrete wythes reinforcement, the positioning of the connectors with the RHS and the configuration of the perimeter edges.

[0072] After the concrete is dried, the plates of the thermal insulation material 13 are positioned above the wythe 5. The steel bar mesh 4 of the second concrete wythe 5 is positioned at a distance of 25 mm above the thermal insulation layer and it is mounted with the U-shaped steel bar connectors already attached on the RHS.

[0073] The second layer of concrete is poured. Once cured, the panels are stripped, tilted vertically and lifted out of the formwork, and stored until to be used.

[0074] As regards the preparation of the steel columns 3 of the building's framework, they are cut to the desired dimensions and the configuration of the connections with the wall 1 and the beam element 2 is made. More specifically, the connections are prepared in the factory at three positions along the column 3: at the higher, at the middle and at the lower part of the wall 1. In each position specified by the structural study, the steel plate 9 having a size of e.g. 120 mm x 120 mm x 8 mm is welded on the steel column 3, either on the edges of the upper and the lower flange or the flange, depending on the structural plans and then the short HEA unit 11 is welded on it. Another steel plate 10, having a size of e.g. 150 mm x 196 mm x 8 mm is welded on the other side of the short HEA unit 11, forming the element that will be directly connected with the wall element 1.

[0075] The columns 3 are then transferred on site and are positioned on the building's foundation. On site, the foundations and the concrete slab are constructed. The columns 3 are positioned on the desired locations and afterwards the wall elements 1 are put in place and bolted. The voids 8 that are created between the columns 3 and the wall elements 1 are infilled with thermal insulation material. The upper slab or roof is constructed using conventional techniques.

[0076] The walls are further insulated with thermal insulation materials that are glued on their external side. The finishing of both sides of the wall is made with syn-

thetic plaster.

References

5 **[0077]**

10

15

20

25

30

35

40

45

50

55

1. Hetao Hou, Xuexue Yan, Bing Qu, Zhihao Du, Yuxi Lu, Cyclic tests of steel tee energy absorbers for precast exterior wall panels in steel building frames, *Engineering Structures*, Volume 242, 2021, 112561, ISSN 0141-0296, <https://doi.org/10.1016/j.engstruct.2021.112561>.
2. D. Dan, C. Todut, V. Stoian, M. Fofiu, Theoretical and experimental study of precast reinforced concrete walls with different openings under seismic loads, *Engineering Structures*, Volume 240, 2021, 112397, ISSN 0141-0296, <https://doi.org/10.1016/j.engstruct.2021.112397>.
3. Ramin Vaghei, Farzad Hejazi, Ali Akbar Firoozi, Analytical model for precast wall equipped with U-shaped steel channel connection, *Structures*, Volume 32, 2021, Pages 406-432, ISSN 2352-0124, <https://doi.org/10.1016/j.istruc.2021.02.054>.
4. Hetao Hou, Haideng Ye, Bing Qu, Tianxiang Ma, Xiang Liu, Lei Chen, Shuhui Zhang, Precast segmental reinforced concrete walls under eccentric compressive loading: An experimental study, *Engineering Structures*, Volume 113, 2016, Pages 79-88.
5. Shubham Singhal, Ajay Chourasia, Yogesh Kajale, Dirgha Singh, Behaviour of precast reinforced concrete structural wall systems subjected to in-plane lateral loading, *Engineering Structures*, Volume 241, 2021, 112474, ISSN 0141-0296, <https://doi.org/10.1016/j.engstruct.2021.112474>.
6. Qing Jiang, Jie Shen, Xun Chong, Ming Chen, Hanqin Wang, Yulong Feng, Junqi Huang, Experimental and numerical studies on the seismic performance of superimposed reinforced concrete shear walls with insulation, *Engineering Structures*, Volume 240, 2021, 112372, ISSN 0141-0296, <https://doi.org/10.1016/j.engstruct.2021.112372>.
7. Richard O'Hegarty, Oliver Kinnane, Review of precast concrete sandwich panels and their innovations, *Construction and Building Materials*, Volume 233, 2020, 117145, ISSN 0950-0618, <https://doi.org/10.1016/j.conbuildmat.2019.117145>.
8. H. Gleich, New Carbon Fiber Reinforcement Advances Sandwich Wall Panels, *Structure Magazine* (April). (2007) 61-63.

Claims

1. Prefabricated structural wall system for a building, particularly of the low-rise type, comprising a set of wall elements (1), a structural building framework made of a plurality of main structural members consisting of mutually cooperating columns (3) and

beams (2), which are provided with connection means (17) between them for mutually connecting said main structural members, and a series of hollow steel sections (6) arranged vertically respective said beams (2) within said wall elements (1),

wherein said main structural members (2, 3) are made of steel, **characterised in that** said wall elements (1) comprise at least two composite wythes (5) made of a heavy material, particularly reinforced concrete or a concrete-like material in parallel, and a thermal insulation layer (13) embedded in-between both said wythes (5), wherein said wythes (5) are each reinforced with a steel bar mesh (4), which are interconnected with said hollow steel sections (6) by means of sheer connectors (7), wherein said wythes (5) are positioned on either side of said hollow steel sections (6), wherein said wall elements (1) are formulated by a composite combination of precast wythes (5) and hollow steel sections (6) in the form of a composite sandwich-panel and said beam (2).

2. Prefabricated wall system according to claim 1, **characterised in that** said precast wythes (5) are made of reinforced concrete having a thermal capacity providing an increased thermal mass in combination with said sandwich panel having a minimized width, wherein two said concrete wythes layers (5) act together as a single unit to resist loads applied thereto, thereby carrying axial, lateral and dynamic forces through the incorporation of said reinforced concrete (5) and hollow steel sections (6) and their cooperation with said connectors (7), providing an increase of the building's structural performance, wherein said wall system is thus load bearing.
3. Prefabricated structural wall system according to claim 1 or 2, **characterised in that** said bar mesh (4) consists of horizontal and transverse bars made of steel as well.
4. Prefabricated structural wall system according to any one of the claims 1 to 3, **characterised in that** said sheer connectors (7) establish a connecting cooperation between said reinforced wythes (5) and said hollow steel sections (6), particularly wherein a shear transfer between both wythes (5) of said sandwich-panel is established by means of said sheer connectors (7), through the connection between the hollow steel sections (6) and the steel bar meshes (4) of the two sandwich-panels.
5. Prefabricated structural wall system according to any one of the claims 1 to 4, **characterised in that** the hollow steel sections (6) are connected to said

wythes (5) through said connectors (7) consisting of U shaped steel bars having two opposite free members.

6. Prefabricated structural wall system according to claims 1 to 5, **characterised in that** said connectors (7) are equally spaced along said hollow steel sections (6) at a certain mutual distance, wherein said U-shaped steel bars (7) are inextricably connected with the steel bar mesh (4) and the steel hollow sections (6) by a welding connection.
7. Prefabricated structural wall system according to one of the claims 5 or 6, **characterised in that** said free members of said connectors (7) are welded on the steel bar mesh (4) of said wythes (5), wherein said interconnection between said steel hollow sections (6) arranged vertically along the wall length and the wythes' steel mesh (4) generate an increase of the structural performance of the wall elements (1), thereby transforming it to a load-bearing unit regarding both axial and lateral forces.
8. Prefabricated structural wall system according to any one of the claims 1 to 7, **characterised in that** said wall elements (1) are connected to the columns (3) of the structural building framework through joint means, particularly distinct or individual and bolted, enabling a fast and safe connection between them (1, 3); and **in that** said connection means (17) are made of the same material as said main structural members (2, 3), of steel.
9. Prefabricated structural wall system according to any one of the claims 1 to 8, **characterised in that** the distance between the vertical hollow steel sections (6) is not standard, ranging from 700 mm to 1250 mm, wherein the number of vertical hollow steel sections (6) within the wall element (1) is defined by the total width of the building element, which is specified by the distance between the main steel structural members of the building as derived from the structural design and specifically adapted calculations, as well as the presence of openings wherein the vertical hollow steel sections (6) are positioned around them, wherein a structural evaluation defines the position of the main structural members of the building's frame, the length of the wall elements (1) and the position of the hollow steel sections (6) within the wall element (1).
10. Method for assembling the prefabricated wall system as defined in any one of the preceding claims 1 to 9, **characterised in that** the reinforced wythes (5) are brought to cooperate with said hollow steel sections (6) under the connecting action of said sheer connectors (7), yielding that said prefabricated wall element (1) acts as a load bearing unit.

11. Method according to the preceding claim 10, **characterised in that** said wythe (5) is made from a heavy material as reinforced concrete, whereas thermal insulation layer (13) is embedded in the sandwich-panel in a void created between its two wythes (5) in parallel, and **in that** its width is adjusted to a minimum width so as to provide an optimal thermal capacity to the wall element (1), resp. to increase thermal mass.

12. Method according to claim 11, **characterised in that** said composite, load-bearing prefabricated wall system carries axial, lateral and dynamic forces by incorporating reinforced concrete (5) and steel elements (6) and by their cooperating with steel connectors (7), thereby increasing the building's structural performance, and **in that** calculations are made for the structural capacity of the building that indicate the exact positions of the main structural members (2) and wherein said wall element (1) is positioned between them.

13. Method according to any one of the claims 10 to 12, **characterised in that** said system is realized by the following construction method steps:

the structural position of the main structural members, esp. columns (3) of the building's frame is established from a preliminary structural analysis, as well as the length of the wall elements (1) and the position of the steel hollow sections (6) within the wall element (1); **in that** the composite wall element (1) integrating the steel beam (2), as well as the columns (3) of the structural framework are constructed in the factory and then transferred to site; after which the wall elements (1) and the columns (3) are connected through bolting in the predetermined positions as established.

14. Method according to one of the claims 11 to 13, for manufacturing the wall element (1) integrating the steel beam (2), **characterised in that** a mould is formed with desired dimensions; the steel bar mesh (4) of the concrete wythes (5), the steel hollow sections (6), the steel plates (10) and the beam (2) are cut to the desired dimensions;

the steel bar mesh (4) of the concrete plate is positioned horizontally and it is elevated from the working surface over a certain distance by means of spacers; the position, in which the hollow steel section (6) will be put, is determined; said sections (6) are connected with the steel bar mesh (4) through U-shaped steel bars (7) spaced at a distance along said hollow steel section (6); one of the two free members of the U-

shaped steel bar (7) is mounted on the steel bar mesh (4) before the concrete is poured; the other free member is connected with the second concrete plate, while the middle part of the U-shaped steel bar (7) is in contact with the steel hollow section (6) the U-shaped steel bars (7) are positioned alternately on both free sides or ends of said steel hollow section (6); then the wall element's (1) edges are configured, the vertical edges integrate steel plates, the upper horizontal a HEA beam (2) and the lower horizontal a hollow steel section (6);

the concrete is poured after the preparation of the concrete wythes reinforcement, the positioning of the connectors with the RHS section and the configuration of the perimeter edges; after the concrete is dried, the plates (13) of the thermal insulation material are positioned above the wythe (5); the steel bar mesh (4) of the second concrete wythe (5) is positioned at a distance above the thermal insulation layer (13) and it is mounted with the U-shaped steel bar connectors (7) already attached on the hollow steel section (6);

the second layer of concrete is poured; once cured, the panels are stripped, tilted vertically and lifted out of the formwork, and stored until to be used;

the steel columns (3) of the building's framework are cut to the desired dimensions and the configuration of the connections with the wall (1) and the beam (2) is made.

15. Method according to claim 12 or 14, **characterised in that** the connections are prepared in the factory at three positions along the column (3): at the higher, at the middle and at the lower part of the wall (1); in each specified predetermined structural position, the steel plate (9) is welded on the steel column (3), either on the edges of its upper and the lower flange or along the flange, and then the short HEA unit (11) is welded on it; another steel plate (10), is welded on the other side of the short HEA unit (11), forming the element to be directly connected with the wall element (1);

the columns (3) are then transferred on site and are positioned on the building's foundation; on site, the foundations and the concrete slab are constructed; the columns (3) are positioned on the desired locations and afterwards the wall elements (1) are put in place and bolted; the voids (8) created between the columns (3) and the wall elements (1) are infilled with thermal insulation material; the upper slab or roof is added; the walls are further insulated with thermal insulation materials that are glued on their external side; and the finishing of both sides of the wall is made.

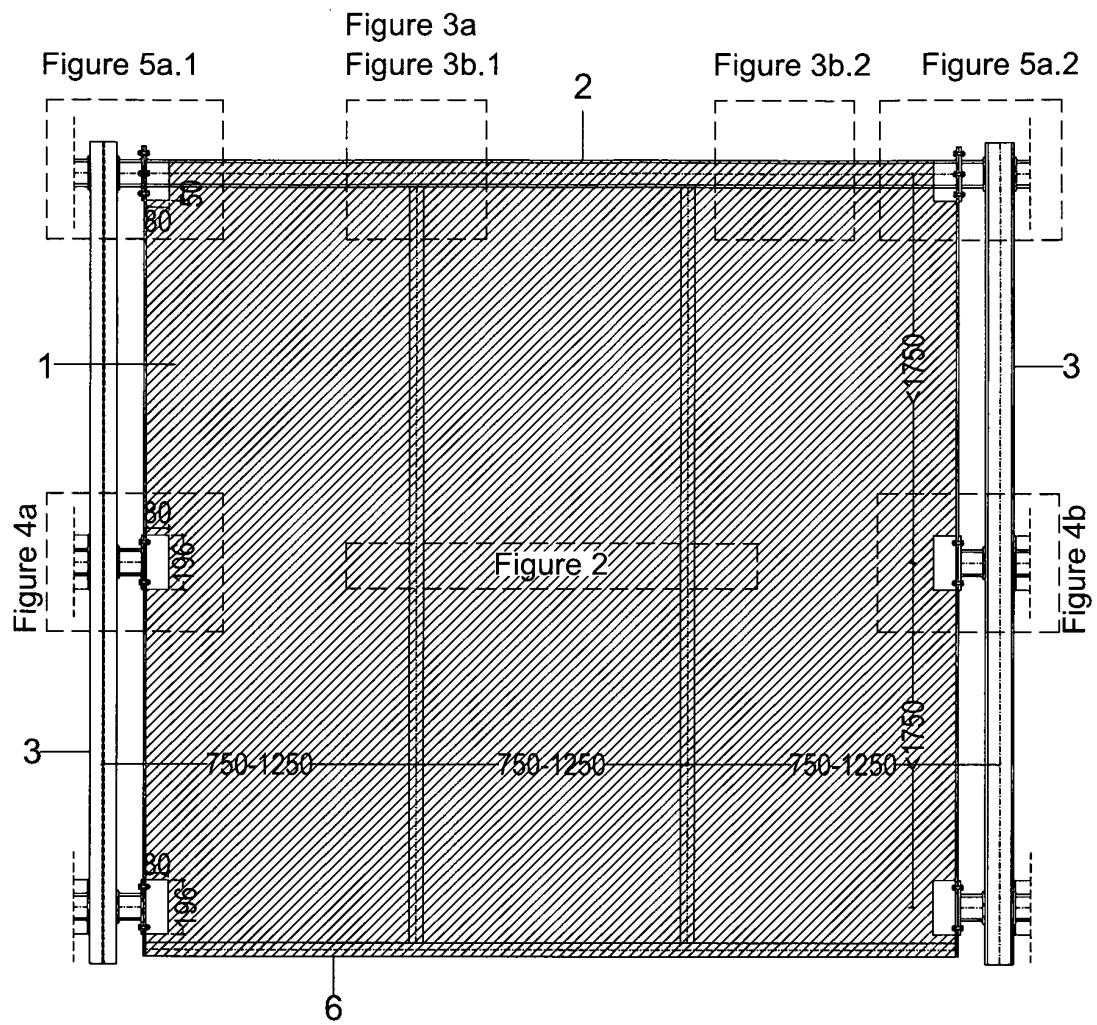


Figure 1

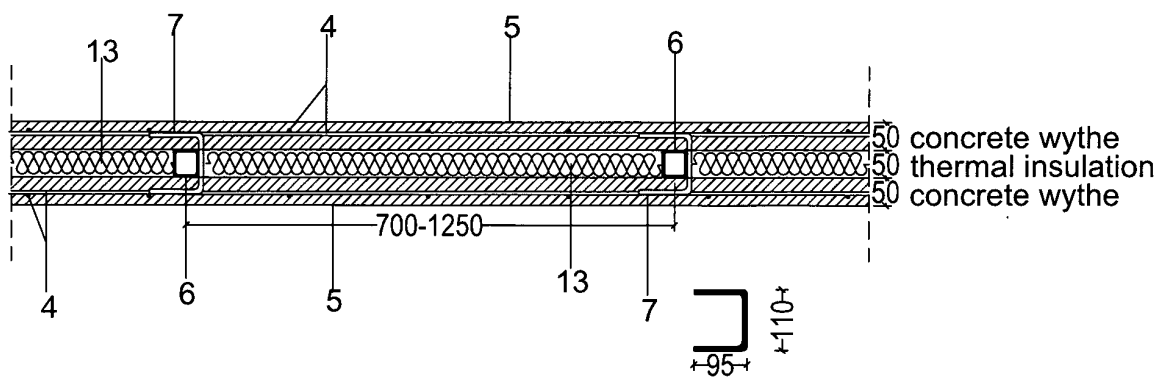


Figure 2

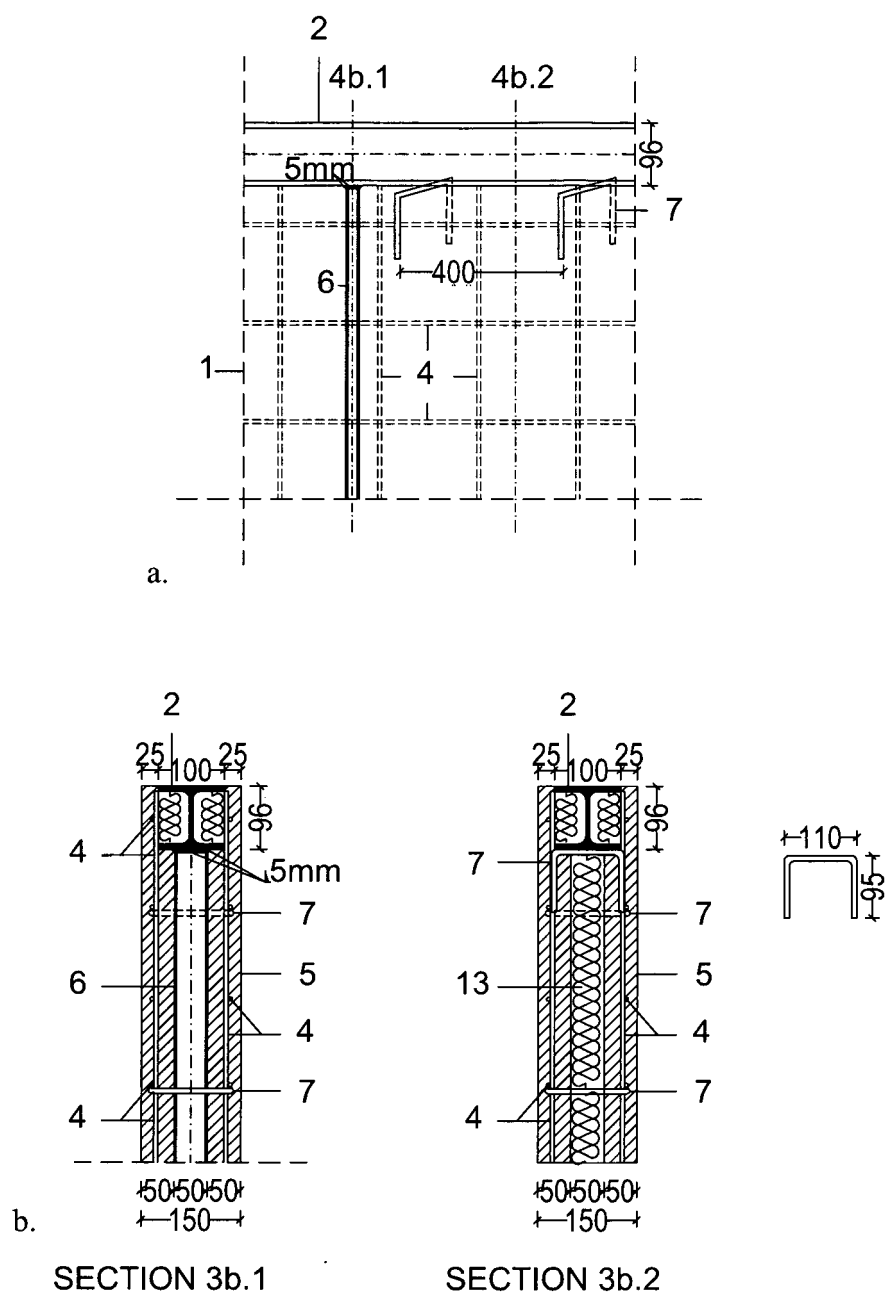
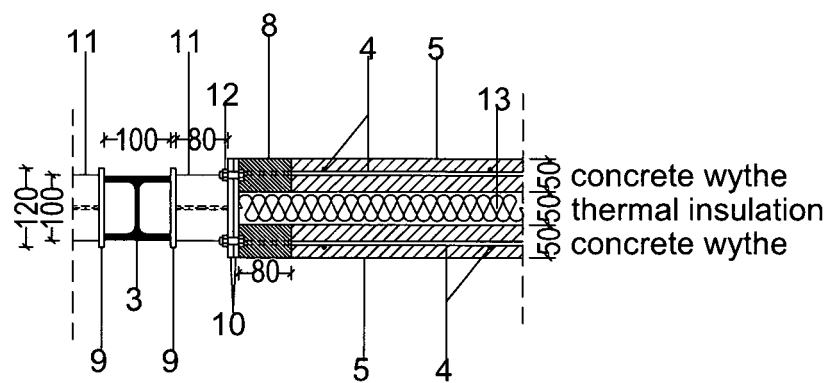
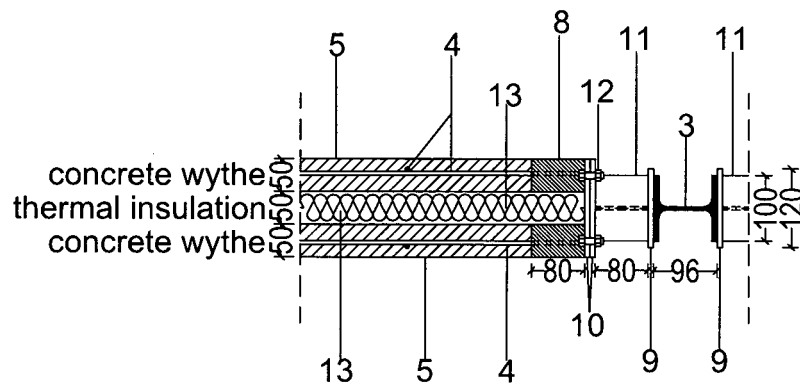


Figure 3



SECTION 4a



SECTION 4b

Figure 4

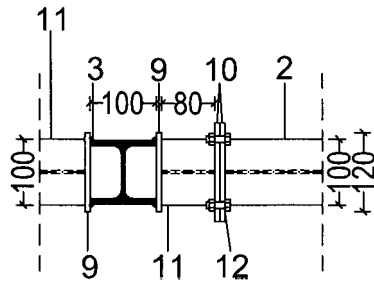


Figure 5a.1

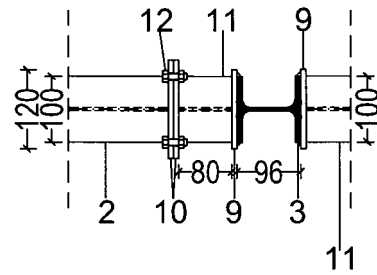


Figure 5b.1

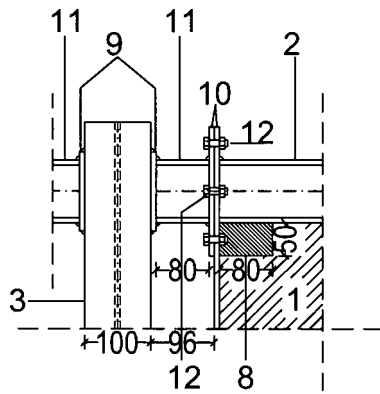


Figure 5a.2

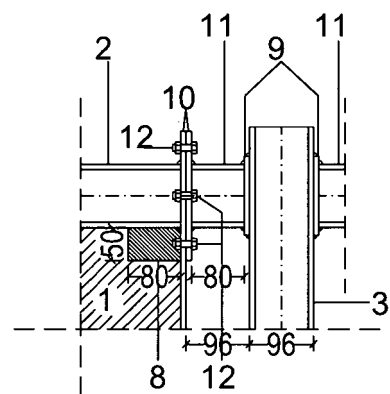


Figure 5b.2

Figure 5



EUROPEAN SEARCH REPORT

Application Number

EP 22 16 5414

5

10

15

20

25

30

35

40

45

50

55

1

EPO FORM 1503 03.82 (P04C01)

DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
Y	EP 0 691 441 A1 (GRAULICH PETER W P [US]) 10 January 1996 (1996-01-10)	1-4, 8-13	INV. E04C2/06
A	* page 2, lines 25-36 * * figures * -----	5-7, 14, 15	E04C2/288 E04C2/38 E04C2/04
Y	EP 0 285 465 B1 (SARET [FR]) 24 April 1991 (1991-04-24)	1-4, 8-13	
A	* column 2, lines 4-33 * * column 5, line 24 - column 11, line 42 * * figures * * See in particular figures 11 and 13 * -----	5-7, 14, 15	
A	US 4 454 702 A (BONILLA-LUGO JUAN [US] ET AL) 19 June 1984 (1984-06-19) * column 2, line 68 - column 4, line 52 * * figures * -----	1-15	
The present search report has been drawn up for all claims			TECHNICAL FIELDS SEARCHED (IPC) E04C
Place of search Munich		Date of completion of the search 18 August 2022	Examiner Durrenberger, Xavier
CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document		T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document	

**ANNEX TO THE EUROPEAN SEARCH REPORT
ON EUROPEAN PATENT APPLICATION NO.**

EP 22 16 5414

5 This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report.
The members are as contained in the European Patent Office EDP file on
The European Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

18-08-2022

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
EP 0691441	A1	10-01-1996	NONE
EP 0285465	B1	24-04-1991	AT 62965 T 15-05-1991
		EP 0285465 A1	05-10-1988
		ES 2022645 B3	01-12-1991
		FR 2620153 A1	10-03-1989
US 4454702	A	19-06-1984	NONE

REFERENCES CITED IN THE DESCRIPTION

This list of references cited by the applicant is for the reader's convenience only. It does not form part of the European patent document. Even though great care has been taken in compiling the references, errors or omissions cannot be excluded and the EPO disclaims all liability in this regard.

Patent documents cited in the description

- CN 107724596 A [0011]
- CN 111705996 A [0012]
- CN 209277334 U [0013]
- WO 2012174434 A [0014]

Non-patent literature cited in the description

- **HETAO HOU ; XUOXUE YAN ; BING QU ; ZHIHAO DU ; YUXI LU.** Cyclic tests of steel tee energy absorbers for precast exterior wall panels in steel building frames. *Engineering Structures*, 2021, vol. 242, 112561 [0077]
- **D. DAN ; C. TODUT ; V. STOIAN ; M. FOFIU.** Theoretical and experimental study of precast reinforced concrete walls with different openings under seismic loads. *Engineering Structures*, 2021, vol. 240, 112397 [0077]
- **RAMIN VAGHEI ; FARZAD HEJAZI ; ALI AKBAR FIROOZI.** Analytical model for precast wall equipped with U-shaped steel channel connection. *Structures*, 2021, vol. 32, ISSN 2352-0124, 406-432 [0077]
- **HETAO HOU ; HAIDENG YE ; BING QU ; TIANXIANG MA ; XIANG LIU ; LEI CHEN ; SHUHUI ZHANG.** Precast segmental reinforced concrete walls under eccentric compressive loading: An experimental study. *Engineering Structures*, 2016, vol. 113, 79-88 [0077]
- **SHUBHAM SINGHAL ; AJAY CHOURASIA ; YOGESH KAJALE ; DIRGHA SINGH.** Behaviour of precast reinforced concrete structural wall systems subjected to in-plane lateral loading. *Engineering Structures*, 2021, vol. 241, ISSN 0141-0296, 112474 [0077]
- **QING JIANG ; JIE SHEN ; XUN CHONG ; MING CHEN ; HANQIN WANG ; YULONG FENG ; JUNQI HUANG.** Experimental and numerical studies on the seismic performance of superimposed reinforced concrete shear walls with insulation. *Engineering Structures*, 2021, vol. 240, 112372 [0077]
- **RICHARD O'HEGARTY ; OLIVER KINNANE.** Review of precast concrete sandwich panels and their innovations. *Construction and Building Materials*, 2020, vol. 233, 117145 [0077]
- **H. GLEICH.** New Carbon Fiber Reinforcement Advances Sandwich Wall Panels. *Structure Magazine*, April 2007, 61-63 [0077]