(12) CERTIFIED INNOVATION PATENT (11) Application No. **AU 2013101345 B4**
(19) AUSTRALIAN PATENT OFFICE

(54) Title
Methods, systems and components for multi-storey building construction

(51) International Patent Classification(s)
B66C 1/66 (2006.01) ***E04B 1/35*** (2006.01)
E02D 35/00 (2006.01) ***E04B 2/00*** (2006.01)

(21) Application No: **2013101345** (22) Date of Filing: **2013.10.11**

(30) Priority Data

(31) Number	(32) Date	(33) Country
2012904567	**2012.10.18**	**AU**

(45) Publication Date: **2013.11.14**
(45) Publication Journal Date: **2013.11.14**
(45) Granted Journal Date: **2013.11.14**
(45) Certified Journal Date: **2014.06.26**

(71) Applicant(s)
Merhis Pty Ltd

(72) Inventor(s)
Merhi, Mark;Merhi, Khalil

(74) Agent / Attorney
Shelston IP, L 21 60 Margaret St, Sydney, NSW, 2000

(56) Related Art
JP 2000-177980
US 3863418
JP H07-76932

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ABSTRACT

A method of installing a wall section in a multi-storey building (1), including the steps of providing a plurality of pre-fabricated structural panels (25), each including a lifting formation (43) whereby the panel can be lifted. A rail formation (63) is releaseably attached to a support structure (3) of the building in a substantially horizontal orientation generally above an intended location for the wall section. A crane carriage assembly (70) incorporating a panel engagement mechanism in the form of a wire rope (74) and lifting hook (75) is releaseably attached to the rail formation by means of a rail traversing mechanism whereby the carriage assembly is adapted securely to traverse the rail. The lifting hook on the carriage assembly is releaseably engaged with the lifting formation on the panel whereby the panel is suspended from the rail formation, and the carriage assembly is moved along the rail so as to position the suspended panel adjacent the intended location for the wall section. The panel is then lifted into position, secured in the wall section, and released from the carriage assembly. These steps are repeated to position successive panels in contiguous side-by-side relationship, thereby to form the wall section of the building.

Figure 16

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"Methods, Systems and Components for Multi-Storey Building Construction"

Field of the Invention

[0001] The present invention relates generally to building construction, and more specifically to methods, systems and components for multi-storey building construction.

[0002] The invention has been developed primarily for use in connection with multi-level residential apartment buildings, retail shopping complexes, hotels, and the like and will be described predominantly in this context. It should be appreciated, however, that the invention is not limited to this particular field of use, being potentially applicable to a broad range of other building types including high-rise office blocks, schools, hospitals, security complexes and other forms of commercial and industrial complex such as factories, hangers and warehouses, as well as bridges, towers, tunnels, elevated walkways, airport infrastructure and other civil engineering developments. It should also be understood that although the invention is particularly well adapted for multi-level constructions, it may also be applied to single level structures.

Background of the Invention

[0003] The following description of the prior art is intended to place the invention in an appropriate technical context and enable the advantages of it to be more fully appreciated. However, any references to prior art should not be construed as an express or implied admission that such art is widely known or forms part of common general knowledge in the relevant field.

[0004] In contemporary civil engineering, a number of techniques are currently used to construct multi-level buildings for use as apartment complexes, hotels, commercial office blocks and the like. These techniques typically involve constructing the building floor by floor, following excavation for foundations and preparation of appropriate structural footings. Construction of the building is usually based around vertical support structure adapted to transfer structural loads to the foundations. These support structures are typically formed from steel columns, beams or trusses, or from reinforced concrete. In recent times, it has become increasingly popular to utilize a structural core formed from reinforced concrete cast level by level *in situ*, in a generally tubular form

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which is in essence cantilevered vertically from the ground. Concrete floors and external walls are then effectively suspended from the structural tubular core. In some cases, depending upon the design, the walls or parts of them may also form integral elements of the primary vertical support structure.

[0005] Regardless of the specific form and composition of the vertical support structure, it is conventional to form the floors defining each level of the building from reinforced concrete, which is cast *in situ*. The fabrication process for these concrete floors involves initial fabrication and installation of complex customised formwork and associated support props, systematic placement of reinforcing bars, and subsequent pumping of concrete into each section of formwork. The concrete must then be screeded, levelled and allowed to cure until self-supporting. The formwork and temporary support props must then be removed, following which subsequent floor levels are progressively constructed in succession, until the main building structure has been completed. In some buildings, internal and/or external wall sections are also formed from reinforced concrete cast *in situ*, floor by floor, in a similar manner.

[0006] Although this construction technique has proven to be relatively effective and reliable, it suffers from a number of significant and inherent disadvantages. Firstly, a large number of separate trades are required on site, to implement a highly labour-intensive process involving lifting of formwork and temporary support structures into position on site, erecting the formwork, placing the steel reinforcement, pumping and pouring the concrete, screeding and levelling the wet mix, and subsequently dismantling and removing the formwork once the concrete has set. Further trades are also required to provide access for building services through the concrete floor slabs or sections as required. Furthermore, in multi-story developments, sophisticated and expensive high-pressure concrete pumping equipment is required in order to deliver the wet concrete mix at the necessary elevations. All of these trades and equipment must be carefully coordinated in sequence on site along a critical planning path, as part of a complex project management exercise.

[0007] As well as the labour intensity, labour cost and planning complexity, the overall process is inherently slow. This is partly because of the relatively large number of separate and distinct trades involved. More significantly, the concrete in most cases must be allowed to set and harden adequately in each section before the associated

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formwork and temporary support props can be removed, and before work on the next floor level can be commenced. This often necessitates delays of up to several weeks between floors, because many of the central process steps are on the same critical path, which becomes rate-limiting for the entire project. In the context of a medium to high-rise developments, the cumulative delays inherent in this process can amount to many months, at an economic cost of many millions of dollars for a single construction project.

[0008] It is an object of the present invention in one or more of its various aspects, to overcome or substantially ameliorate one or more of the deficiencies of the prior art, or at least to provide a useful alternative.

Summary of the Invention

[0009] Accordingly, in a first aspect, the invention provides a method of forming a building, comprising the steps of:

erecting a series of vertically oriented support columns in spaced apart relationship to define a generally vertical support structure;

connecting a series of horizontally oriented support beams to the support columns in spaced apart relationship to define a generally horizontal support structure for afloor;

providing a plurality of pre-fabricated structural panels; and

positioning the structural panels in substantially contiguous side-by-side relationship on the horizontal support structure to form a structural floor.

[0010] It should be understand that the terms “building”, “buildings” and the like as used herein are intended to be construed broadly, as encompassing virtually any form of building or civil engineering structure, regardless of the intended purpose and whether single or multi-level in configuration.

[0011] Preferably, the pre-fabricated structural panels are formed from a reinforced autoclaved aerated concrete (AAC) material.

[0012] Preferably, the method includes the further step of filling respective clearance spaces defined between adjacent edges of respective pairs of the adjoining structural

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panels with a compatible cementitious material, thereby to form a substantially continuous upper surface on the structural floor.

[0013] Preferably, the building is multi-storey and the vertical support structure extends for at least one level above the ground. In some embodiments, the vertical support structure extends for multiple levels above ground but may additionally or alternatively extend for multiple levels below ground.

[0014] In some preferred embodiments, the support columns are formed at least predominantly from steel, in sections that are bolted, welded or otherwise fastened together either on site or as pre-fabricated structural sub-assemblies. The structural AAC panels preferably include internal longitudinally extending steel reinforcing elements.

[0015] In some embodiments, the structural panels are generally rectangular in configuration. However, it should be understood that a wide variety of other shapes and configurations of panels may be used, preferably tessellating configurations. Preferably, the horizontal support beams are disposed in generally parallel relationship, at orientations and spacing intervals complementary with the orientation, size and strength of the structural panels to be supported.

[0016] In some embodiments, the panels are formed with complementary or partially complementary edge profiles, optionally including corresponding interlocking, abutting or interlinking edge formations. In one embodiment, the adjoining edge profiles define complementary tongue and groove configurations.

[0017] In one embodiment, the edge profiles are adapted to define an upwardly opening or upwardly diverging generally V-shaped or U-shaped channel extending longitudinally between each pair of adjoining structural panels disposed in abutting side-by-side relationship. In some embodiments, the channel may be defined by upwardly converging sidewalls.

[0018] In this embodiment, the method preferably includes the further steps of placing an elongate reinforcing bar longitudinally in the channel and subsequently filling the channel with the cementitious material, thereby to form a substantially continuous upper

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surface extending between the adjoining structural panels, while reinforcing the intermediate joints.

[0019] In some embodiments, the method includes the further step of fastening the structural panels to the underlying support beams in situ. The fastening step may involve one or more fastening techniques including gluing, screwing, bolting, nailing or securing with brackets or other mechanical anchoring or locating formations.

[0020] In one embodiment, a plurality of structural panels formed from autoclaved aerated concrete (AAC) are oriented vertically and positioned side-by-side, in contiguous edge to edge relationship, to form one or more wall sections extending between or adjacent the structural columns.

[0021] Optionally, a sealing layer, primer, skim coat, render, textured surface layer, or combinations thereof may be applied over the entire exposed surface of the floor or wall, to provide a relatively uniform appearance as well as to provide particular aesthetic or performance characteristics that may be required, such as additional sealing or waterproofing, additional fire retardant properties, suitability for painting, sound installation or dispersion, surface grip, colour, texture or the like. Other suitable surface finishes, depending upon the intended application, include polymer-modified stucco or plaster, natural or manufactured stone, internal or external cladding including “Gyprock”, timber panelling or fibre-cement sheeting, as appropriate.

[0022] In preferred embodiments, the method includes the step of forming the structural panels so as to include at least one lifting hole extending from a front or upper face to a rear or lower face of the panel. The lifting hole is preferably adapted releasably to receive a lifting eye, to facilitate crane lifting of the panel to the appropriate floor level in the building structure. As an alternative to lifting holes extending through the panels, lifting formations may be secured around the panels or to one or more faces of the panels, either as temporary or permanent fixtures.

[0023] In one embodiment, each panel includes a single centrally located lifting hole. In other embodiments, each panel includes a pair of spaced apart lifting holes, ideally disposed generally symmetrically about a centreline or centre of gravity of the panel. In

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some embodiments, three, four or more lifting holes may be provided, not all of which need necessarily be utilised in all lifting situations.

[0024] In a variation of this aspect of the invention, prefabricated structural panels are additionally or alternatively positioned in substantially contiguous side-by-side relationship, preferably in a vertical orientation, on the horizontal support structure, to form a wall for the building. This method of wall construction may optionally be utilised in conjunction with more conventional floor construction techniques, and vice versa, if desired.

[0025] In a further aspect, the invention provides a building structure, formed substantially in accordance with the method previously defined, the structure including:-

a series of vertically oriented support columns disposed in spaced apart relationship to define a generally vertical support structure;

a series of horizontally oriented support beams connected to the support columns in spaced apart relationship to define a generally horizontal support structure for a floor; and

a plurality of pre-fabricated structural panels positioned in contiguous side-by-side relationship on the horizontal support structure to form a structural floor.

[0026] In a variation of this aspect, the prefabricated structural panels are additionally or alternatively positioned in contiguous side-by-side relationship on the support structure to form a wall.

[0027] Again, the structural panels are preferably formed from autoclaved aerated concrete (AAC). The respective clearance spaces defined between adjacent edges of the adjoining structural panels are preferably filled with a compatible cementitious material, thereby to form a substantially continuous upper surface on the structural floor.

[0028] Preferably, the building is multi-storey, and the vertical support structure is formed substantially from steel, extending for at least one level above the ground and in some embodiments for multiple levels above and/or below ground level.

[0029] In a further aspect, the invention provides a method of installing a section of floor or wall in a multi-storey building structure, the building structure including a series of

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vertically oriented support columns disposed in spaced apart relationship to define a generally vertical support structure, and a series of horizontally oriented support beams connected to the support columns in spaced apart relationship to define a generally horizontal support structure for an elevated floor, the method including the steps of:-

providing a plurality of pre-fabricated structural panels;

providing at least one lifting hole extending from a first face to a second face of each of the structural panels;

releasably securing a lifting attachment incorporating a pair of lifting formations to each of the structural panels such that one of the lifting formations is accessible from the first face and the other lifting formation is accessible from the second face, and such that the lifting formations are interconnected directly by a load-bearing connecting element extending through the respective lifting hole;

releasably interconnecting a plurality of the structural panels together as a series using a plurality of intermediate linking elements, whereby the lifting formation on the second face of each panel in the series is joined to the lifting formation on the first face of the next panel in the series by means of a respective linking element;

connecting the first structural panel in the series to a crane hook by means of the lifting formation on the first face of the first panel;

hoisting the first panel by means of the crane hook and thereby hoisting the subsequent interconnected panels in the series to a height corresponding generally to the required level for the floor or wall whereby all of the structural panels in the series are elevated substantially simultaneously to the required level in a single lifting operation;

releasing the lifting formations and the linking elements from the panels in the series;

positioning the panels in contiguous side-by-side relationship on the support structure to define a corresponding section of the elevated floor or wall; and

repeating the process steps as required, to complete the floor or wall.

[0030] Preferably, once again, the prefabricated structural panel is formed from steel-reinforced, autoclaved aerated concrete (AAC).

[0031] In one embodiment, each of the lifting formations includes a generally circular lifting eye, and each lifting attachment preferably includes a shank portion adapted upon installation to extend through the lifting hole in the panel, to connect the associated lifting eyes.

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[0032] In one preferred embodiment, the lifting formation includes an eye-bolt having a head with an integral lifting eye and a complementary eye-nut incorporating an integral lifting eye, configured such that the shank of the eye-bolt is adapted in use to extend through the lifting hole in the panel for releasable engagement with the eye-nut on the opposite side of the panel.

[0033] In some embodiments, the lifting attachment preferably also includes a base plate with a mounting hole adapted to accommodate the shank of the eye-bolt, the base plate being adapted to be positioned between either the eye-bolt or the eye-nut and an outer face of the associated panel, to distribute load and reduce stress concentrations in the structural panel around the lifting hole. In some embodiments, the base plate may be formed integrally with the eye-bolt and/or the eye-nut.

[0034] In one embodiment, each linking element includes a predetermined length of chain with a hook at each end, the hooks being adapted in use for releasable engagement with the respective mutually opposing lifting eyes on adjacent panels. In other embodiments, the linking elements may take alternative forms, such as lengths of wire cable or rope, or bars, rods or the like formed from steel or other suitable structural or load-bearing materials.

[0035] Depending upon the size and weight of the panels, multiple lifting holes and associated lifting attachments and linking elements may be used. In such cases, the lifting holes will typically be distributed uniformly around the centreline or centre of gravity of the panels, and will be positioned to facilitate stable simultaneous lifting of all of the panels in the series.

[0036] In preferred embodiments, the series may comprise any number of panels, from two, up to five, six or potentially more. The upper limit will be governed by the weight of each panel and the load rating of the particular crane being deployed to hoist the panels, as well as the load ratings of the lifting attachments and linking elements. Typically, if lighter panels are used, a larger number can be linked or ganged in each series and hoisted together in a single lifting operation.

[0037] In a related aspect, the invention provides a prefabricated structural building panel incorporating at least one lifting hole extending from a first face to a second face of

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the panel, adapted for use in conjunction with a plurality of complementary building panels to form a wall or floor in a building structure, in the method as previously defined.

[0038] In a further aspect, the invention provides a method of installing a wall section in a multi-storey building, the building including a series of vertically oriented support columns disposed in spaced apart relationship to define a generally vertical support structure, the method including the steps of:-

providing a plurality of pre-fabricated structural panels, each panel incorporating a lifting formation including at least one lifting hole extending from a front face to a rear face of the panel;

releasably attaching a rail formation to the support structure in a substantially horizontal orientation generally above an intended location for the wall section;

providing a crane carriage assembly incorporating a panel engagement mechanism and a rail traversing mechanism;

releasably attaching the crane carriage assembly to the rail formation by means of the rail traversing mechanism whereby the carriage assembly is adapted securely to traverse the rail;

releasably connecting the panel engagement mechanism on the carriage assembly with the lifting formation on the panel by means of a selectively disengageable lifting frame, the lifting frame including lifting arms adapted in use to extend downwardly from an upper bridge section along opposite faces of the panel to a lifting element extending through the associated lifting hole, whereby the panel is suspended from the rail formation;

moving the carriage assembly along the rail so as to position the suspended panel adjacent the intended location for the wall section;

positioning and securing the panel in the wall section;

releasing the panel engagement mechanism;

repeating the foregoing steps with successive panels positioned in contiguous side-by-side relationship to form the wall section of the building.

[0039] In one preferred embodiment, once again the structural panels are formed from steel-reinforced autoclaved aerated concrete (AAC).

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[0040] Preferably, the rail formation is attached by a series of spaced apart removable connecting brackets, each in use extending from a respective support column to a corresponding position on the rail formation.

[0041] In one embodiment, the lifting formation includes at least one lifting hole extending from a front face to a rear face of each of the structural panels. Preferably, the

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lifting formation also includes an eye-bolt having a head with an integral lifting eye, configured such that the shank of the eye-bolt is adapted to extend through the lifting hole for releasable engagement with a complementary nut and optionally a base plate on the opposite side of the panel.

[0042] In one preferred embodiment, the panel engagement mechanism on the carriage assembly includes a wire rope, cable or chain terminating in a hook formation adapted for releasable engagement with the lifting eye on the panel.

[0043] In one embodiment, the rail formation takes the form of an I-beam comprising horizontally oriented upper and lower flanges and a vertically oriented interconnecting web. The carriage assembly preferably includes a rail traversing mechanism including guide wheels adapted for rolling engagement with the lower flange of the I-beam. The support brackets are preferably connected to the upper flange of the I-beam.

[0044] In one preferred embodiment, the carriage assembly is motorised, incorporating a first drive mechanism adapted to drive the carriage on the rail, optionally by remote control. Preferably, the carriage assembly includes a second drive mechanism adapted in use to progressively raise and lower the suspended panel via the engagement mechanism, again optionally by remote control. Preferably, the second drive mechanism is connected with a winch, adapted to control the wire rope connected to the panel and hence to regulate the height of the panel.

[0045] In some embodiments, the second drive mechanism permits the panels to be raised or lowered by a distance corresponding to at least two floor levels, thereby permitting the same rail formation to facilitate the erection of wall sections on multiple levels of the building structure.

[0046] In some embodiments, the method also includes the steps of:-

releasably interconnecting a plurality of the panels together as a series using a plurality of intermediate linking elements,

connecting the first panel in the series to the carriage assembly by means of the engagement mechanism on the carriage and the lifting formation on the first panel;

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lifting the first panel by means of a drive mechanism in the carriage and thereby hoisting the subsequent interconnected panels in the series to a required height for the lowermost panel;

positioning, securing and releasing the lowermost panel; and

positioning, securing and releasing the subsequent panels in the series successively using the drive mechanism to form a corresponding wall section or sub-section in the building.

[0047] In yet another aspect, the invention provides a crane carriage assembly as defined, adapted for use on a supporting rail formation connected to a building support structure, to facilitate positioning of prefabricated structural wall or floor panels, substantially in the manner previously described.

[0048] In yet a further aspect, the invention provides a pre-packaged kit of complementary component parts including prefabricated support columns, prefabricated support beams and prefabricated structural panels substantially as defined above, and adapted upon assembly in a predefined configuration, in accordance with instructions associated with the kit, to form a building structure.

[0049] In one embodiment of this aspect, the assembly process for the kit utilises one or more of the methods or systems for building construction substantially as previously defined. In one embodiment, the component parts are selected or designed, and optimally arranged, for compact "flat-packing" and efficient bulk transportation. This form of the invention, being highly cost-effective and readily transportable, is particularly well adapted, inter-alia, for low-cost housing and other building infrastructure, in remote locations or developing countries.

[0050] In yet a further aspect, the invention consists in a prefabricated structural panel adapted to be supported in contiguous side-by-side relationship with a plurality of like panels to form a structural floor or wall between supporting frame elements in a building, each panel including at least one pre-formed lifting hole extending through the panel from one face to an opposing face, the lifting hole thereby providing a lifting formation to enable secure crane lifting of the panel and to enable inter-linking of multiple panels in series by means of the respective lifting holes to enable simultaneous lifting.

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[0051] Preferably, the panels are formed substantially from AAC and the lifting holes are formed before the panels are autoclaved. Optionally be panels include supplementary reinforcement within the in the AAC matrix in the vicinity of the lifting hole. The lifting hole may also be lined in some embodiments, for example by means of a tubular metal sleeve, for supplementary reinforcement.

Brief Description of the Drawings

[0052] Preferred embodiments of the invention will now be described, by way of example only, with reference to the accompanying drawings, in which:

[0053] Figure 1 is a diagrammatic perspective view showing a multi-storey building structure formed in accordance with the present invention;

[0054] Figure 2 is a plan view of the building structure from the perspective of arrow “A” in Figure 1;

[0055] Figure 3 is an elevation view of the building structure from the perspective of arrow "B" in Figure 1;

[0056] Figure 4 is an elevation view of a further building structure formed in accordance with the invention, showing below-ground basement levels and above-ground upper levels;

[0057] Figure 5 is a plan view showing an upper level framing and floor panelling arrangement of the building structure shown in Figure 4;

[0058] Figure 6 is an enlarged cross sectional side elevation view showing the flooring system of the building structure of Figures 4 and 5, in more detail;

[0059] Figure 6A is a further enlarged cross-sectional detail taken from Figure 6;

[0060] Figure 7 is a perspective view showing a section of flooring formed from contiguous AAC structural panels on a steel beam horizontal floor supporting structure, in accordance with the invention;

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[0061] Figure 8 is a cross-sectional view taken along line A-A of Figure 7, showing a reinforcing bar supported in a channel defined between a pair of adjoining structural panels;

[0062] Figure 9 is a side elevation view in the direction of line B-B of Figure 7, showing the reinforcing bar and surrounding grouting material in the channel defined between the adjoining structural panels;

[0063] Figure 10 is a perspective view showing a structural panel formed from reinforced AAC, with a pair of spaced apart lifting attachments in accordance with the invention;

[0064] Figure 11 is an enlarged perspective view showing one of the lifting attachments of Figure 10, in more detail;

[0065] Figure 12 is a perspective view of an alternative form of structural panel formed with a lifting hole, fitted with a lifting attachment, and connected to a crane hook in accordance with the invention;

[0066] Figure 13 is a perspective view showing two structural panels of the type shown in Figure 12, interconnected as a series by linking chains for simultaneous lifting in a single operation, in accordance with the invention;

[0067] Figure 14 is a perspective view similar Figure 13, showing a series of three of the structural panels interconnected for simultaneous lifting by crane in a single lifting operation;

[0068] Figure 15 is a diagrammatic perspective view of a vertically oriented structural frame for a multi-storey building, incorporating temporary rail formations to facilitate positioning of structural wall panels, in accordance with one aspect of the invention;

[0069] Figure 15A is an enlarged perspective view showing region "A" of Figure 15 in more detail;

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[0070] Figure 15B is an enlarged perspective view showing region "B" of Figure 15 in more detail;

[0071] Figure 15C is an enlarged perspective view showing region "C" of Figure 15 in more detail;

[0072] Figure 16 is an enlarged perspective view showing one of the rail formations and associated panel lifting elements from figure 15 in more detail, with the carriage assembly represented diagrammatically;

[0073] Figure 17 is a further enlarged perspective view, showing the carriage assembly from Figures 15 and 16 in more detail;

[0074] Figure 18 is a perspective view similar to figure 17, showing the lifting crane and carriage assembly used in conjunction with a dedicated lifting frame;

[0075] Figures 18A to 18C are a series of enlarged perspective views showing various alternative embodiments of the dedicated lifting frame illustrated in figure 17, adapted for use respectively with complementary structural panels having different configurations of lifting holes; and

[0076] Figure 19 is a perspective view showing one level of a support structure according to a further embodiment of the invention, incorporating diagonal bracing elements and a modular support structure for a lift core.

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Preferred Embodiments of the Invention

[0077] The invention in one aspect provides a multi-storey building structure 1 and an associated method of construction. Referring initially to Figures 1 to 3, the structure 1 includes a series of vertically oriented support columns 2 disposed in spaced apart relationship to define a generally vertical support structure 3. In this embodiment, the support columns 2 are formed from structural steel I-beams, connected end-to-end as required by means of complementary steel connection brackets 4 and associated bolts. However, it should be appreciated that other structural materials, column configurations and interconnection methods may additionally or alternatively be used.

[0078] A series of horizontally oriented floor support beams 5 are connected to the vertical support columns 2 in generally parallel spaced apart relationship, to define a horizontal support structure 6 for an elevated floor. The floor support beams 5 are preferably also formed from structural steel I-beams, bolted or welded to the respective vertical support columns 2, but again in other embodiments, alternative materials and connection methods may be used.

[0079] The flooring itself is formed from a plurality of prefabricated structural panels 10, formed from a suitable lightweight autoclaved aerated concrete (AAC) formulation in a generally rectangular configuration. The AAC panels are pre-formed with internal steel reinforcing rods and hence can be used in structural applications. This material confers a number of important and unique characteristics and advantages, including reduced weight, adequate strength, good acoustic and thermal installation, fire resistance, durability (subject to appropriate finishing), ease of installation, and workability in situ. AAC is also resistant to water, rot, mould, mildew, insect infestation, and freeze/thaw degradation.

[0080] The panels 10 are positioned in contiguous side-by-side relationship and anchored to the underlying horizontal support beams 5 to form an elevated structural floor 12. Anchoring of the panels 10 to the floor support beams 5 may be achieved using a variety of techniques including bolting, screwing, gluing, bracketing, locating pins, lugs, or the like. In one preferred method, the panels are simply set into a layer of thin-bed mortar applied to the support beams. In some embodiments, because the panels are

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located laterally by perimeter beams, no internal anchoring or fixing to the floor support structure is required.

[0081] The panel dimensions can vary significantly according to the intended application. Typically the panels will be 600 mm wide, although the panel width may vary from under 200 mm to over 1000 mm according to different applications and requirements. The panels are preferably around 200 mm thick, although thickness may vary from less than 100 mm to more than 300 mm, according to load constraints and performance requirements. The panels are preferably formed in lengths of 6 m, although length may range from less than 1 metre to 10 metres or more, as required. The panel density is typically around 800 kg/m3, but again the density may vary from less than 500 kg/m3 to more than 1,000 kg/m3, depending upon strength, porosity, durability, workability and other performance requirements. Compressive strength is preferably in the range of 2.0 to 8.0 Mpa, and ultimate tensile strength preferably in the range of 0.2 to 0.8 Mpa.

[0082] A typical base formulation for a suitable AAC material includes quartz sand, lime, cement and water. Aluminium powder is also added, typically in the proportion of 0.05% to 0.08% by volume, as required according to the density specified for the finished product. During the production process, the aluminium powder reacts with calcium hydroxide and water to form hydrogen, which foams to substantially increase the volume of the mixture. The hydrogen eventually disperses, to be replaced by air. While the material is solid but still soft, it is removed from a cast or mould (with reinforcing rods embedded as required), and placed in an autoclave chamber, typically for 12 hours at a temperature of around 190°C and a pressure of 8 to 12 bar. Under these conditions, the quartz sand reacts with calcium hydroxide to form calcium silica hydrate, which confers the requisite strength and other mechanical properties. After autoclaving, the product is ready for use. Depending upon the final density and strength requirements, up to 80% of the volume of an AAC block or panel can comprise air, and the weight per unit volume can be as little as 20% of that for conventional concrete.

[0083] It should be appreciated that a wide variety of formulations and process modifications may be utilised, subject to specified performance parameters being satisfied. Special purpose additives or substitute ingredients may be used in the formulations for specific applications or performance characteristics, including fire

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retardants, sealants, surfactants, aerators, density modifiers, insulators, adhesives, fillers and the like. Suitable AAC products can be sourced from a number of specialist suppliers. The detailed manufacturing processes involved in order to achieve specific material characteristics and performance parameters are well understood by those skilled in the art, and so will not be described in further detail.

[0084] Another building structure 1 is shown in Figures 4 to 6, wherein similar features are denoted by corresponding reference numerals. In this case, the structure includes several below-ground basement levels 15 and a plurality of above-ground upper levels 16. A foundation structure 17 including a peripheral basement shoring system is also shown. In this embodiment, the basement levels 15 incorporate floor levels composed substantially from composite slabs, comprising wet-poured reinforced concrete over metal decking, formed in situ in accordance with conventional constructions techniques. The upper levels 16 incorporate lightweight structural flooring formed from AAC panels in accordance with the present invention.

[0085] Figures 5 and 6 show the upper level framing and flooring system from the structure of Figure 4, in more detail. Referring particularly to Figures 6 and 6A, it will be seen that the structural panels 10 rest on the horizontal steel beams 5. The panel edges adjacent the wall are located and supported by a steel perimeter beam 20, which in turn is connected to the vertical support columns 2. An internal wall structure 22 is formed from lightweight steel framing members 23 and an internal cladding material (not shown). The external walls are formed from vertically oriented generally rectangular structural AAC wall panels 25, similar in configuration to the flooring panels and again disposed in contiguous side-by-side relationship, but typically thinner and lighter than the flooring panels.

[0086] The structural flooring panels 10 and the preferred method of interconnection are shown in more detail in Figures 7 to 9. The panels are generally rectangular in configuration with complementary edge profiles, which may optionally include interlocking, overlapping or abutting elements such as tongue-and-groove formations adapted for inter-engagement when adjoining panels are disposed in contiguous side-by-side relationship.

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[0087] In the specific arrangement shown, as best seen in Figure 9, the abutting edge profiles are adapted in combination to define an upwardly depending generally V-shaped or U-shaped channel 30, extending longitudinally between each pair of adjoining panels. In order to finish each inter-panel joint, it is preferred that a reinforcing bar 32 is initially positioned to extend longitudinally through the associated channel 30. These reinforcing bars 32, or alternatively reinforcing cables, are initially supported by ring beams 35 (see Figure 8), or other suitable support structures, optionally including stands adapted for installation within the channels 30.

[0088] With the reinforcing bars supported in position, preferably with at least one bar in each channel, the channels are filled with a compatible cementitious grouting material 36, which bonds to the aerated concrete material from which the panels are formed. The grouting material thereby forms a substantially continuous upper surface 37 extending between the adjoining structural panels, while securing the panels to one another and reinforcing the intermediate joints. Suitable joint filling materials include a variety of non-shrink grouts, mortar and concrete. The finished joint is best seen in Figure 9. In one variation of this embodiment (not shown), the side walls of the U-shaped channels 30 converge upwardly to a marginal degree. This has the effect of mechanically keying the grouting material in place once it has set, thereby to provide additional integrity, stability and durability to the respective inter-panel joints.

[0089] In the building structures of Figures 1 and 4, a similar technique using AAC panels disposed in contiguous side-by-side relationship is used to form the main wall sections 38. As best seen in Figure 6, the wall panels 25 are primarily supported on horizontal flanges 39 extending outwardly from the perimeter beams 20, and are retained in place by suitable bolts, brackets, adhesives, lugs and/or other fastening means.

[0090] In some embodiments and implementations of the invention, various components of the building system may be compactly pre-packaged as discrete bundles of componentry in matched quantities and efficiently delivered to site as a kit, optionally with detailed assembly instructions in accordance with a pre-defined building plan. This form of the invention may be particularly advantageous for construction in isolated or remote locations, or in developing countries, where supplementary materials, resources or expertise on site may be limited.

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[0091] In a further variation on this theme, another implementation involves the construction of discrete building modules off-site, for example in a dedicated production facility. Such modules may comprise, for example, a series of vertical support columns, horizontal support beams and structural panels, partially or fully pre-assembled for delivery to site in a modular format. The modules in this context may comprise sections of floor or wall, entire rooms, a multiple of interconnected rooms, discrete sections of a structural core, or potentially even an entire level of a building structure, subject to size, weight, transportation and other logistical constraints. In this way, construction on site may be oriented primarily toward the interconnection and integration of a series of prefabricated structural modules, in accordance with a pre-defined building plan.

[0092] Because of the possibility of partial pre-fabrication, modular construction and/or final assembly at different locations, it should be understood that unless the context clearly dictates otherwise, the various method steps described may be carried out in different sequences, at different times and at different locations. Such variations wherever feasible should be understood to fall within the scope of the invention as described.

[0093] In a further aspect, the invention provides a method and system for efficiently lifting and positioning the structural panels on site, as described below. Referring initially to Figures 10 to 12, each panel includes at least one lifting hole 40, extending from the upper face to the lower face of the panel. In the embodiment shown in Figure 10, two such lifting holes are provided and these holes are disposed symmetrically about the centreline and centre of gravity of the panel, for well-balanced, stable lifting with the panels in a generally horizontal orientation.

[0094] Each lifting hole 40 is adapted releaseably to receive a lifting formation 43, to facilitate secure crane lifting of the panel to the appropriate level and position in the building structure.

[0095] In one embodiment, as best seen in Figure 11, the lifting formation 43 comprises a threaded eye-bolt 44 formed with a head incorporating a lifting eye 46, and a complementary eye-nut 47 which optionally incorporates a second lifting eye 46, permitting the panel to be lifted from either side. A base plate 50 is also optionally provided as part of the lifting formation, to minimise stress concentrations around the

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lifting hole, particularly during lifting operations. Base plates 50 may be provided on both sides of the panel, if required, and may optionally be permanently attached. Importantly, the bolt shank extends right through the panel, for optimal safety and security during lifting operations.

[0096] If required, additional steel mesh or other suitable reinforcing materials may be incorporated into the panel in the vicinity of the lifting hole during the panel fabrication process, for enhanced structural integrity. Other lifting formations are also envisaged, such as external clamping mechanisms or brackets anchored to one or more faces of the panel, whereby through-holes and through-bolts are not necessarily required.

[0097] As well as allowing the individual panels to be securely lifted, as shown in Figures 10 and 12, the method and system of the invention in a further aspect allows multiple panels to be at interlinked and lifted simultaneously, as described more fully below.

[0098] With reference to Figures 13 and 14, each lifting attachment 43 in this case incorporates a pair of lifting eyes 46. One lifting eye is incorporated into the head of the eye-bolt as previously described and is accessible from the upper face of the panel, while the other lifting eye is incorporated into the eye-nut and is accessible from the lower face of the panel. In this way, the lifting eyes are interconnected directly by a load-bearing connecting element, in this case the shank of the lifting bolt, extending through the respective lifting hole.

[0099] This arrangement allows a number of the panels to be releaseably connected as a series 52, using a plurality of intermediate linking elements 53 (see Figures 13 and 14). Each linking element includes a predetermined length of chain 54 with a hook 55 at each end, the hooks being adapted for releasable engagement with the mutually opposing lifting eyes 46 on adjacent panels. In other embodiments, the linking elements may take alternative forms, such as lengths of wire cable or rope, solid bars, rods or the like formed from steel or other suitable load bearing materials.

[0100] In the arrangement shown, each panel is connected to the next panel in the series by a pair of linking elements 53 disposed uniformly about the centreline of the respective panels. In other arrangements, different numbers and configurations of

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linking elements may be used. In some cases, only a single linking element is used between each pair of interlinked panels, whereas with heavier panels, three, four or more linking elements may be used, as required. Also in other arrangements, the panels in each series may be interconnected in different orientations, including horizontally edge-to-edge, and vertically end-to-end.

[0101] Once the predetermined number of panels has been interconnected to form a series 52, the first panel in the series is connected to a crane hook 58 by means of the lifting eye or eyes on the upper face of the first panel.

[0102] The process then involves the step of lifting the first panel via the crane hook and thereby hoisting the subsequent interconnected panels in the series to a height on the support structure corresponding generally the floor level where the panels are required. In this way, all of the panels in the series are elevated substantially simultaneously, in a single crane lifting operation. It should also be appreciated that multiple series of panels may be lifted simultaneously in a single operation.

[0103] Once each series of panels has been manipulated into position at the required floor level, the linking chains 54 are released from the lifting eyes 46 and the eye-bolts and nuts are removed from the panels. The panels are then manually positioned in contiguous side-by-side relationship on the horizontal support structure, to form the basis for a corresponding section of the elevated floor.

[0104] The process is then repeated as often as required with successive series or inter-linked groups of structural panels, and the joints finished as required, until the entire floor for that level has been completed. The next series of panels is then lifted to the height of the next level and so on, until the entire flooring system for the multi-level building structure has been completed.

[0105] It will be appreciated that advantageously, this method allows multiple panels (typically three, four, five or six at a time depending upon panel size and weight) to be elevated in each lifting operation of the crane, which greatly reduces the overall construction time. The time savings become greater with increasing height, due to the corresponding increase in the time required for the crane hook to be raised and lowered from ground level in each lifting operation.

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[0106] In yet another aspect, the invention provides a method and system for installing a wall section in the building structure, again preferably utilizing structural panels formed from steel-reinforced AAC or other suitable materials. This system and method will typically be deployed once the wall panels 25 have been lifted to the appropriate floor level in series or groups using the panel linking method previously described. However, it may also be adapted to lift the wall panels directly from the ground, if required.

[0107] Referring to Figures 15 to 17, a rail formation 63, which in this embodiment takes the form of an I-beam having an upper flange 64 and a lower flange 65, is initially secured to the building frame or support structure in a generally horizontal orientation above the intended location for the wall section to be constructed. This is done by means of a series of spaced apart removable connecting brackets 66. In the embodiment shown, each of the connecting brackets 65 extends from a respective vertical support column 2 to a corresponding position on the upper flange of 64 of the I-beam rail.

[0108] Each of the panels is fitted with a lifting formation 43, preferably in the form of an eye-bolt 44 extending through a pre-formed lifting hole, in the manner previously described in relation to the AAC floor panels. In this case, however, the lifting hole is ideally positioned toward the upper end of the panel, so as to facilitate lifting of the panel in the vertical orientation in which it will be positioned in the building structure.

[0109] As best seen in figure 17, a remote controlled electrically operable lifting crane carriage assembly 70 is then attached to the lower flange 65 of the guide rail, whereby the carriage is adapted to securely traverse the rail on guide wheels 72. The carriage 70 includes a panel engagement mechanism, preferably in the form of a wire rope 74 terminating in a hook 75 adapted for releasable engagement with the lifting eye 46 on the wall panel.

[0110] The crane carriage 70 incorporates a first drive motor 80 adapted to drive the carriage on the rail via wheels 72 in response to remote control inputs from the operator. A second drive motor 82 is connected to a winch mechanism 83, adapted progressively to raise or lower the suspended panel via the wire rope 74 connected to the panel, again by remote control.

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[0111] In this way, as best seen in Figures 15 to 17, the carriage supporting a wall panel is able to traverse the rail to a position directly above the intended location for the panel, and then lower the panel into position in the wall section under construction using the motorised winch mechanism 83, by remote control.

[0112] With the panels secured in position by operators on the corresponding floor of building structure, the lifting hook is then released, and the process repeated with successive panels, whereby the panels are progressively positioned in contiguous side-by-side relationship to form a wall section of the building structure. Advantageously, because the operators can be safely positioned within the building structure behind guard rails while securing the outer wall panels, the extent of external scaffolding during the wall construction process can be substantially reduced.

[0113] It will be appreciated that multiple crane carriages may operate simultaneously on a single rail, if required. Also, internal rails 63 and crane carriages may optionally be utilised, to facilitate positioning of internal wall and/or floor panels within the envelope of the building structure if required.

[0114] In some embodiments the winch mechanism 83 incorporates sufficient cable to permit the panels to be raised or lowered by a distance corresponding to at least two floor levels, thereby permitting the same rail formation to facilitate the erection of wall sections on multiple levels of the building structure. This is indicated in the arrangement of Figure 15, in which each guide rail effectively services three floor levels below it. Advantageously, this minimises the number of rails required.

[0115] In some embodiments, longer wall panels may be used, such that a single vertically oriented panel may span two or more floor levels. For example, a single 12 metre panel can be used to span four floor levels of a multi-storey building structure. In such cases, due to the additional panel weight, multiple lifting holes may be provided for improved load distribution within the panel during the lifting operation. This panel configuration and installation method not only greatly reduces time required to place the wall panels in position, it also substantially reduces (potentially by several multiples) the number of inter-panel joints required. This produces a cleaner overall aesthetic result, and also minimises the extent of costly labour input at the panel joints, associated with

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finishing processes, sealing and the like. It should also be appreciated that this method and apparatus may be used for elevating the floor panels to the required levels.

[0116] In the embodiment illustrated, the rails 63 are intended to be removed once the walls have been constructed. In other embodiments, however, the rails may be formed integrally with the framing structure and/or as permanent features of the building. In that case, the rails may be architecturally integrated into the overall building aesthetics, and/or may be adapted for other functional purposes such as supports external window cleaning or maintenance equipment once the building has been completed.

[0117] In a further variation, multiple wall panels may be interlinked or interconnected using a series of intermediate linking elements such as chains or wire ropes, in essentially the same manner as previously described in relation to the floor panels, whereby multiple panels in the series can be efficiently positioned in rapid succession, by means of the crane carriage assembly system.

[0118] Figure 18 shows a crane carriage 70 in the same configuration as shown in Figure 17. In this case, however, the wire rope 74 is connected to the structural wall panel 25 by means of a dedicated lifting frame 85. The lifting frame is substantially symmetrical, including a pair of lifting arms 86 adapted in use to extend downwardly from an upper bridge section 87 along opposite faces of the panel to the associated lifting hole 40. The length of the bridge section 87 corresponds approximately to the thickness of the panel. A lifting lug 88 extends upwardly from the bridge section 87 and includes a lifting hole 89 adapted for engagement by a corresponding fitting such as a crane hook securely mounted to the end of the wire rope.

[0119] A lifting bolt 90 is inserted so as, in use, to extend through corresponding aligned holes 91 in the respective lifting arms 86, and also through the aligned lifting hole 40 in the panel. The bolt is adapted for engagement with a corresponding nut 92, which in this case is welded to the respective lifting arm. It will be appreciated that the symmetrical configuration of the lifting frame permits safe and secure lifting of the panel, in a stable vertical orientation, with minimal risk of damage to the panel by the lifting apparatus. Once the panel has been securely lifted into position on the required level of the building structure, the lifting frame is removed and lowered to ground level for reuse on subsequent panels.

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[0120] Figures 18A to 18C, in which similar features are denoted by corresponding reference numerals, show a series of alternative configurations of the lifting frame 85. These frames have different configurations of lifting arms 86 (including horizontally and vertically oriented arms) and associated lifting holes 91, to accommodate panels with various different configurations of lifting holes.

[0121] Another embodiment of the invention is shown in Figure 19, wherein again similar features are denoted by corresponding reference numerals. This figure shows one level of a steel framing and support structure 3, which would typically comprise multiple levels of similar layout. As in the previous embodiments described, the structure includes a series of vertically oriented support columns 2 interconnected as a matrix with horizontally oriented floor support beams 5. In this case, in selected locations, the support structure also includes a diagonal bracing members 95 to provide enhanced structural integrity and lateral stability.

[0122] Additionally, it will be seen that the support structure of this embodiment includes a structural elevator core 97, also formed predominantly from steel. The lift core is preferably formed from a plurality of structural steel core modules 98 stacked and secured one above the other, with the height of each module corresponding to the height of the respective level in the structure. The lift core modules 98 also include diagonal bracing members 95, for enhanced strength and stability. Importantly, these core modules can be fabricated off-site if desired, and installed very rapidly on-site exactly when required in the project management schedule.

[0123] Once the modular lift core 97 is secured in place, it forms an integral part of the steel support structure. The outer walls can then be completed with structural panels 10 of the type previously described, or by other suitable materials, including non-structural materials. Further cladding layers may also be provided if needed, for example to provide appropriate levels of acoustic insulation, fire rating performance, and the like. Advantageously, this avoids the need for costly, time-consuming and labour-intensive formwork and wet pouring of concrete on-site, as is usually required for structural elevator cores in conventional high-rise building construction.

[0124] It will be appreciated that the invention in its various aspects and preferred embodiments provides a number of advantages. By avoiding the need to construct each

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floor level from concrete formed and poured in situ, there is a significant reduction in the number of individual workmen and different trades required on-site, which reduces cost and planning complexity while substantially improving safety.

[0125] As an indication of the significance of this advantage, a typical medium-rise building project using conventional techniques would usually require around 80 to 100 workers on site at any given time during construction of the primary structural framing and flooring, with all of the cost, scheduling complexity and safety risks that this inherently entails. By contrast, a comparable building project optimised and constructed in accordance with preferred aspects of the present invention may typically only require 8 to 10 workers spanning significantly fewer trades on site at any given time, during the corresponding construction phase.

[0126] By avoiding the inherent delays involved in waiting for the wet concrete on each level to adequately set before the next level can be formed, further substantial production efficiencies and reductions in overall construction time can be achieved.

[0127] Moreover, by eliminating the need for conventional propping to be erected, left in place while wet concrete sets, and subsequently removed, an entire layer of cost, complexity and delay is removed from the construction process Risks of injury associated with the propping processes and related equipment are also substantially eliminated.

[0128] By allowing multiple prefabricated structural flooring panels to be linked in series and crane-lifted simultaneously, yet further improvements in project planning, efficiency and construction time are achievable. By providing a dedicated method and system for rapid positioning of structural wall panels, yet further efficiency gains are obtainable.

[0129] A further benefit of the invention in its preferred aspects is the significant reduction in weight achievable through the use of AAC structural panels, which produce flooring or walling that is substantially lighter than an equivalent area of conventional reinforced concrete. This in turn allows the use of lighter steel framing and/or alternative supporting structures, which contributes to further cost savings, in terms of both material utilisation and construction time.

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[0130] Substantially lighter steel and AAC concrete building structures are also inherently more resistant to earthquake damage, which represents an additional cost saving dimension and a further safety feature.

[0131] The lightweight nature of the building structure also readily lends itself to the construction of additional levels or other extensions on top of existing building structures. Such structures may otherwise need to be completely demolished in order to create additional height or additional storeys using conventional techniques, as a result of the associated additional weight. Construction of additions and extensions based on the methods and systems described herein, using an existing building and other structure as a foundation or base, should be understood to fall within the scope of the invention.

[0132] By enabling a significant proportion of the primary structural elements of the building to be prefabricated under controlled manufacturing conditions in dedicated factories off-site, an improved quality product with tighter tolerances, more accurate dimensional control and superior finishes can be achieved. Furthermore, because more of the manufacturing processes can take place in a more readily controlled production environment at ground level off-site, the risks of workplace injury can be substantially reduced, along with the associated on-costs such as downtime and workers compensation.

[0133] As an added dimension, the invention in its preferred forms offers a more environmentally friendly solution to building construction by requiring less material, less energy, less time, fewer crane lifts and fewer people on site, thereby creating a substantially lower carbon footprint as compared with conventional building construction techniques.

[0134] A related advantage stems from the requirement for relatively fewer deliveries of construction materials to building sites, and reduced levels of waste materials requiring removal, leading in turn to reduced traffic congestion and road blockages caused by delivery trucks, concrete mixers, cranes and the like. As an extension of this benefit, concentration of the prefabrication processes in dedicated factories allows for improved utilisation of public transport infrastructure by workers, again helping to minimise traffic congestion and associated environmental impacts.

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[0135] In these and other respects, the invention represents a practical and commercially significant improvement over the prior art.

[0136] Although the invention has been described with reference to specific examples, it will be appreciated by those skilled in the art that the invention may be embodied in many other forms. It should also be understood that the various aspects and embodiments of the invention as described can be implemented either independently, or in conjunction with all viable permutations and combinations of other aspects and embodiments. All such permutations and combinations should be regarded as having been herein disclosed.

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Claims

1. A method of installing a wall section in a multi-storey building, the building including a series of vertically oriented support columns disposed in spaced apart relationship to define a generally vertical support structure, and the method including the steps of:-

providing a plurality of pre-fabricated structural panels, each panel incorporating a lifting formation including at least one lifting hole extending from a front face to a rear face of the panel;

releasably attaching a rail formation to the support structure in a substantially horizontal orientation generally above an intended location for the wall section;

providing a crane carriage assembly incorporating a panel engagement mechanism and a rail traversing mechanism;

releasably attaching the crane carriage assembly to the rail formation by means of the rail traversing mechanism whereby the carriage assembly is adapted securely to traverse the rail;

releasably connecting the panel engagement mechanism on the carriage assembly with the lifting formation on the panel by means of a selectively disengageable lifting frame, the lifting frame including lifting arms adapted in use to extend downwardly from an upper bridge section along opposite faces of the panel to a lifting element extending through the associated lifting hole, whereby the panel is suspended from the rail formation;

moving the carriage assembly along the rail so as to position the suspended panel adjacent the intended location for the wall section;

positioning and securing the panel in the wall section;

releasing the panel engagement mechanism;

repeating the foregoing steps with successive panels positioned in contiguous side-by-side relationship to form the wall section of the building.

2. A method according to claim 1, wherein the rail formation is attached by a series of spaced apart connecting brackets, each in use extending from a respective support column to a corresponding position on the rail formation.

3. A method according to claim 1 or claim 2, wherein the panels are sized so as to span at least two floor levels of the building in a vertical orientation, whereby the wall

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section of the building formed by a single row of panels positioned in contiguous side-by-side relationship spans multiple levels.

4. A method according to any one of the preceding claims, including the further steps of:-

releasably interconnecting a plurality of the panels together as a series using a plurality of intermediate linking elements,

connecting the first panel in the series to the carriage assembly by means of the engagement mechanism on the carriage and the lifting formation on the first panel;

lifting the first panel by means of a drive mechanism in the carriage and thereby hoisting the subsequent interconnected panels in the series to a required height for the lowermost panel;

positioning, securing and releasing the lowermost panel; and

positioning, securing and releasing the subsequent panels in the series successively using the drive mechanism to form a corresponding wall section or sub-section in the building.

5. A crane carriage assembly adapted for use on a supporting rail formation to facilitate positioning of prefabricated structural wall or floor panels for a building in accordance with the method as defined in any one of claims 1 to 4, the carriage assembly including a panel engagement mechanism adapted releaseably to engage a selected wall or floor panel and thereby suspend the panel from the carriage assembly, and a rail traversing mechanism permitting the carriage assembly to move along the rail formation so as to position the suspended panel adjacent an intended location for a section of wall or floor to be constructed, the carriage assembly further including a first drive mechanism adapted to move the carriage on the rail formation, a second drive mechanism adapted in use to progressively raise or lower the suspended panel via the engagement mechanism, and a remote control mechanism permitting control of the first and second drive mechanisms by a remote operator.

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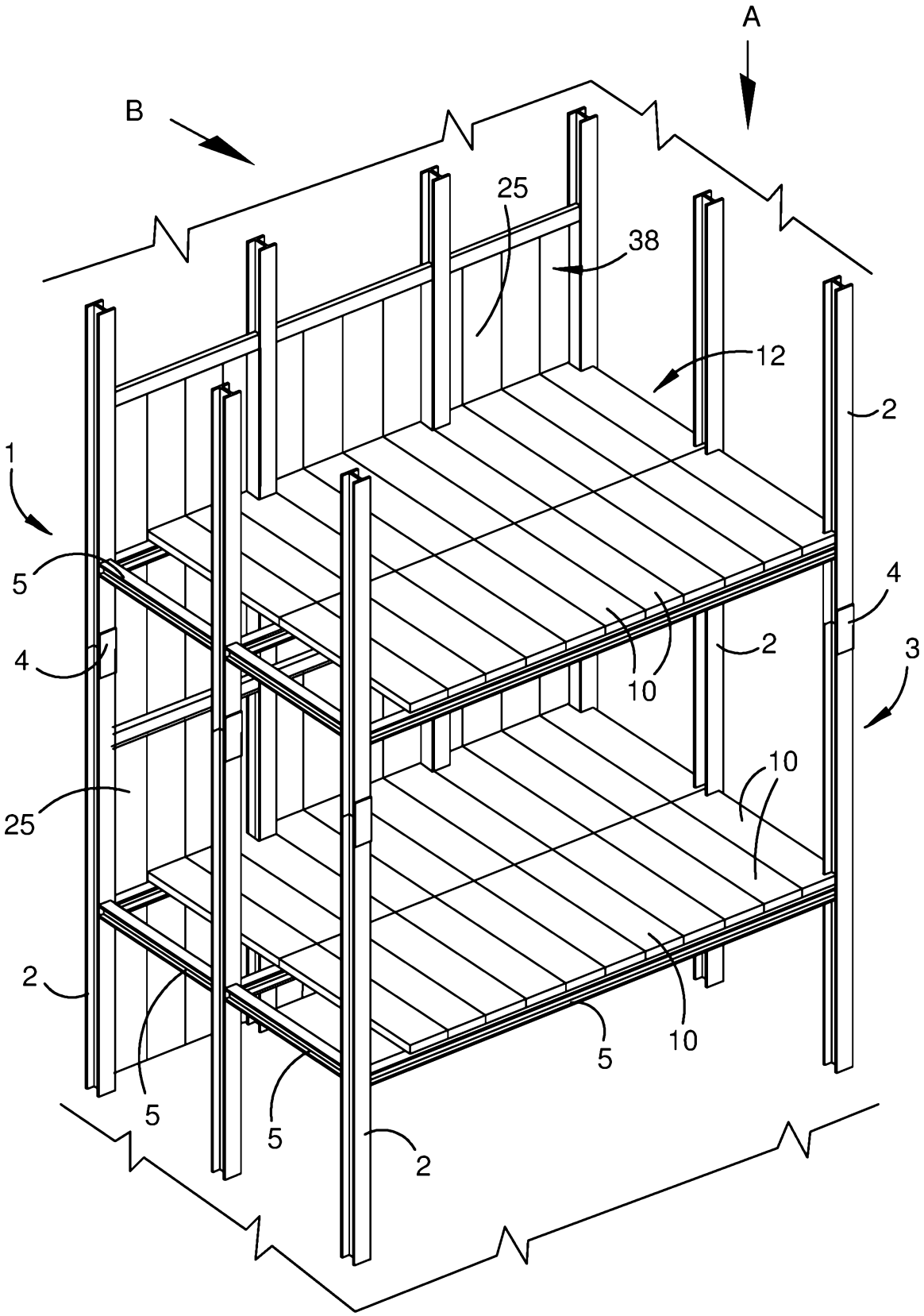


FIGURE 1

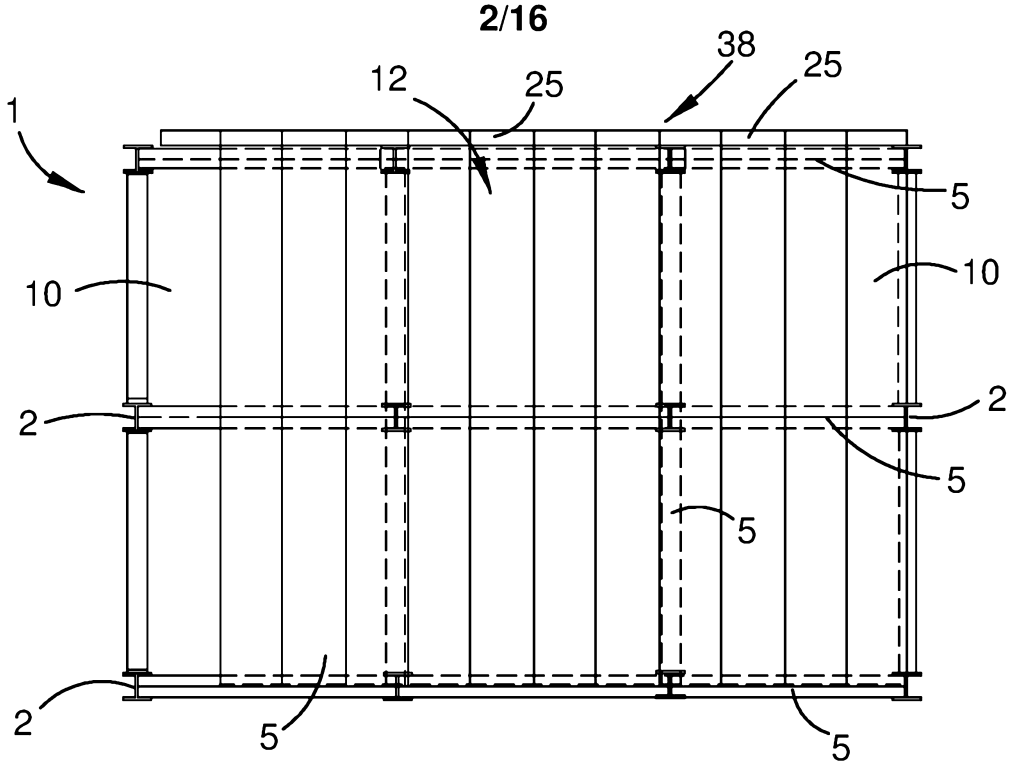


FIGURE 2

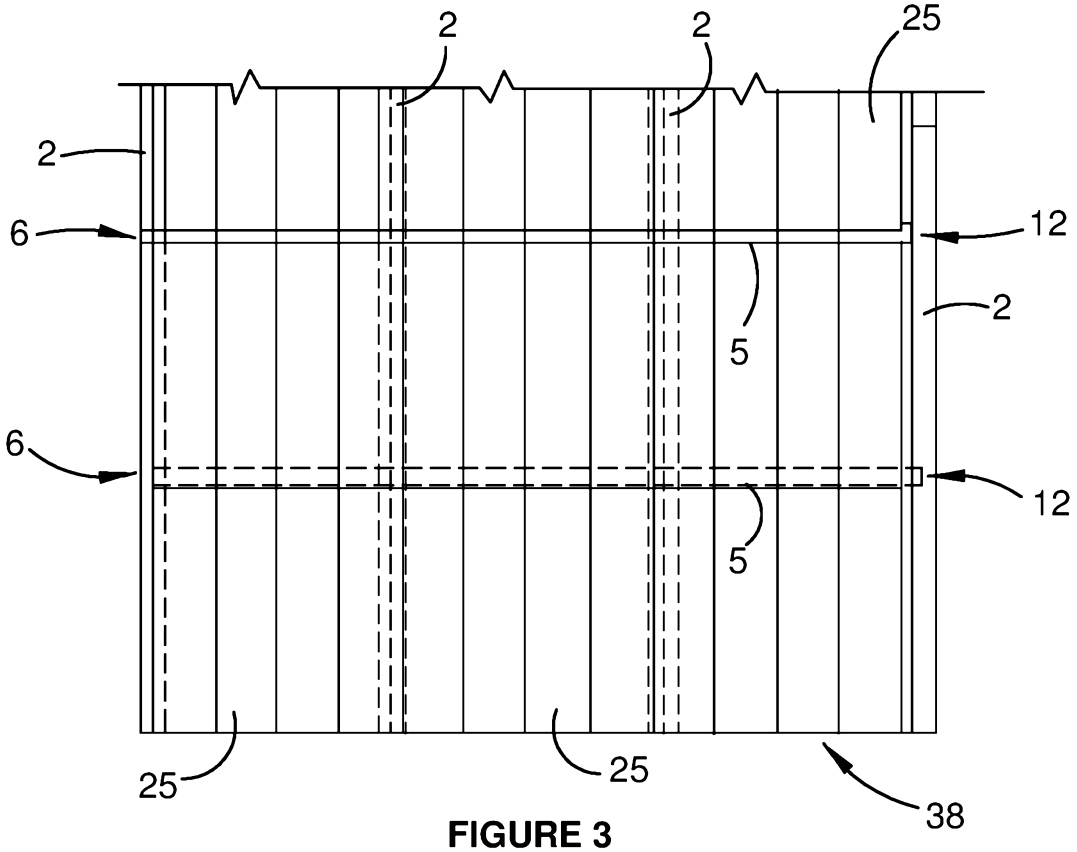


FIGURE 3

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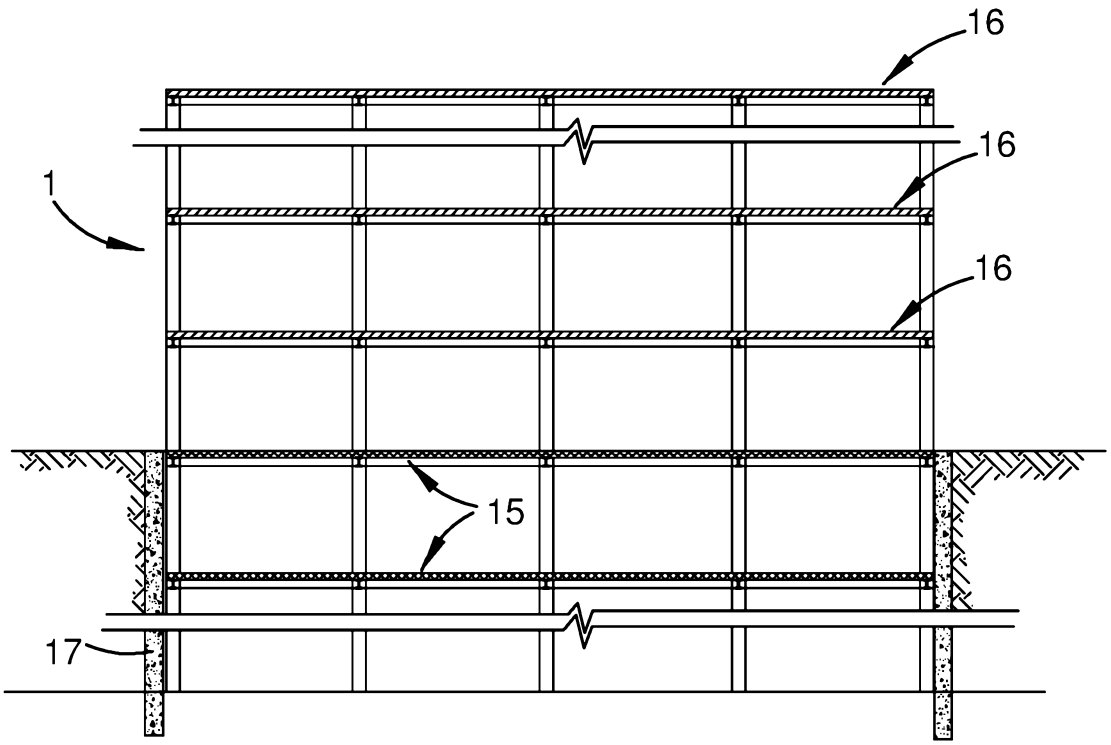


FIGURE 4

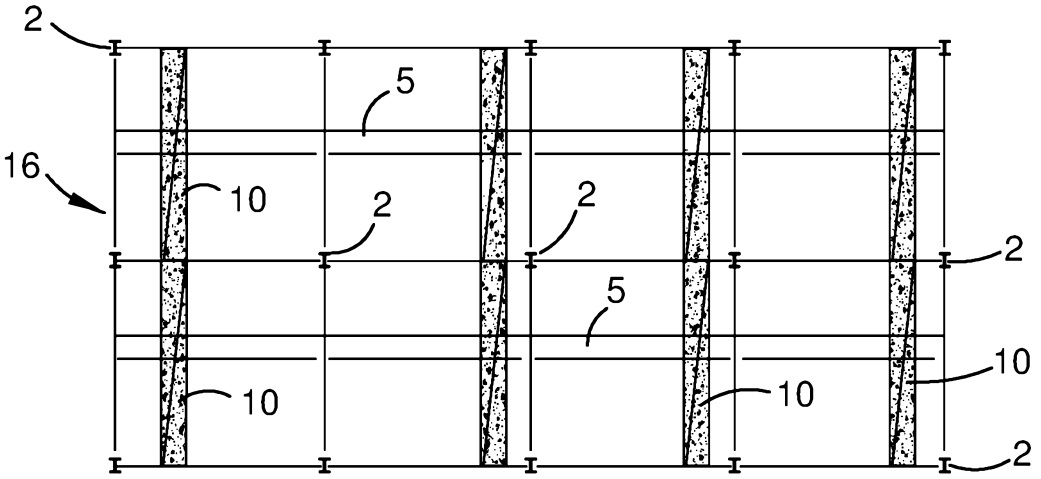


FIGURE 5

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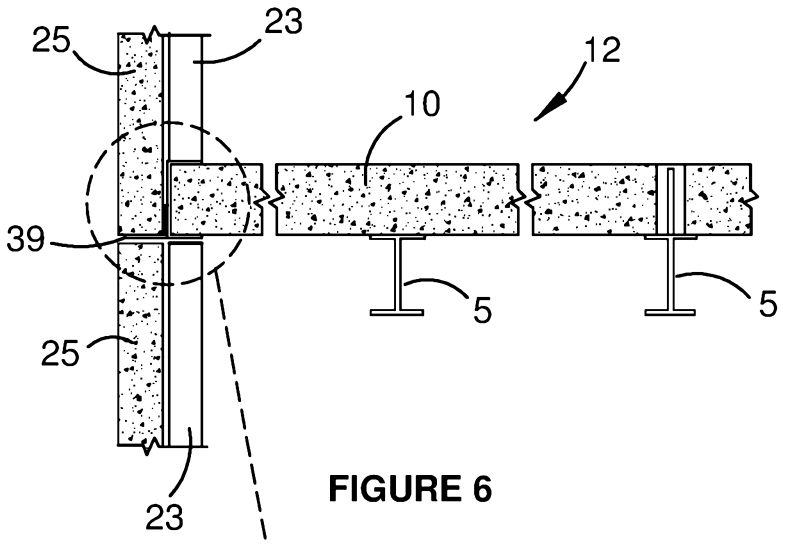


FIGURE 6

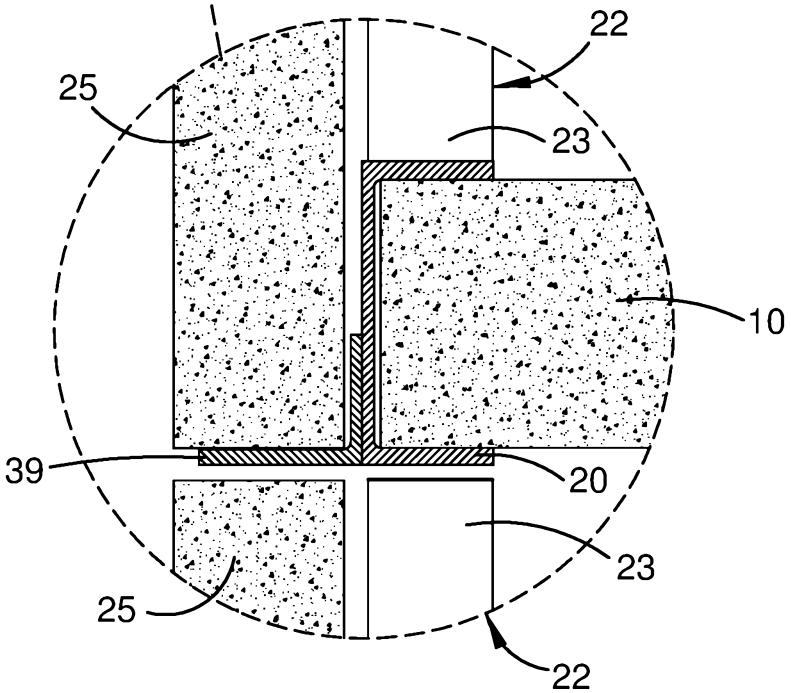


FIGURE 6A

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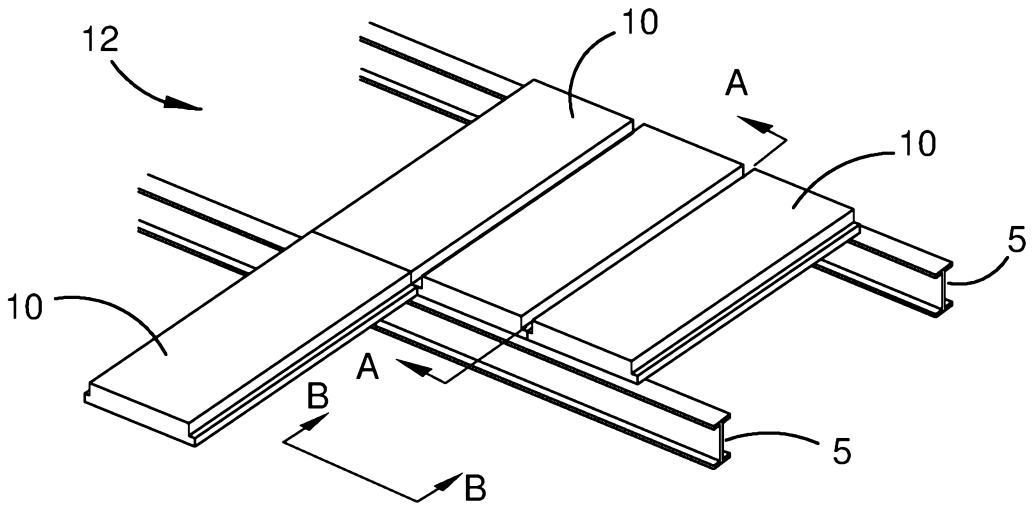


FIGURE 7

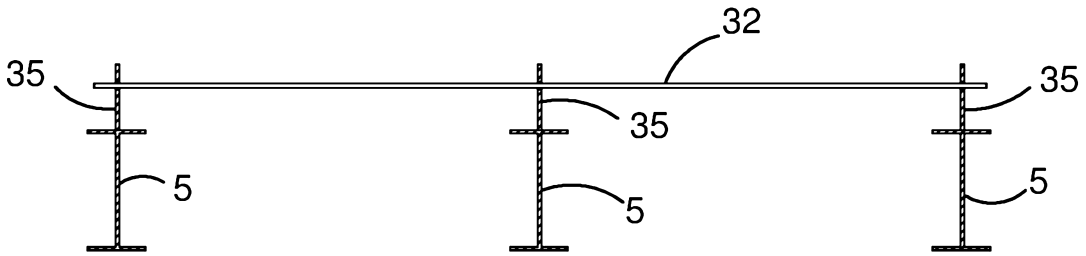


FIGURE 8

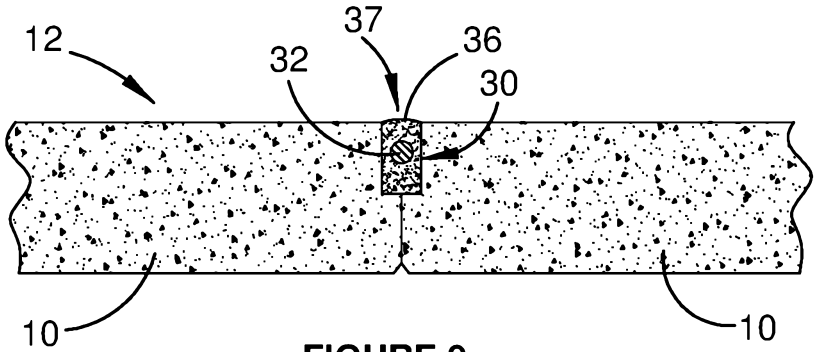


FIGURE 9

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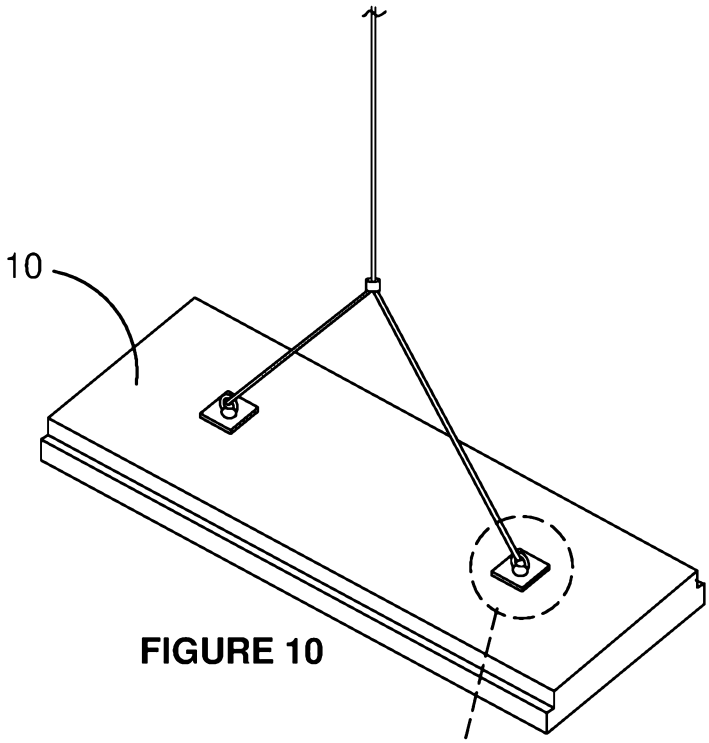


FIGURE 10

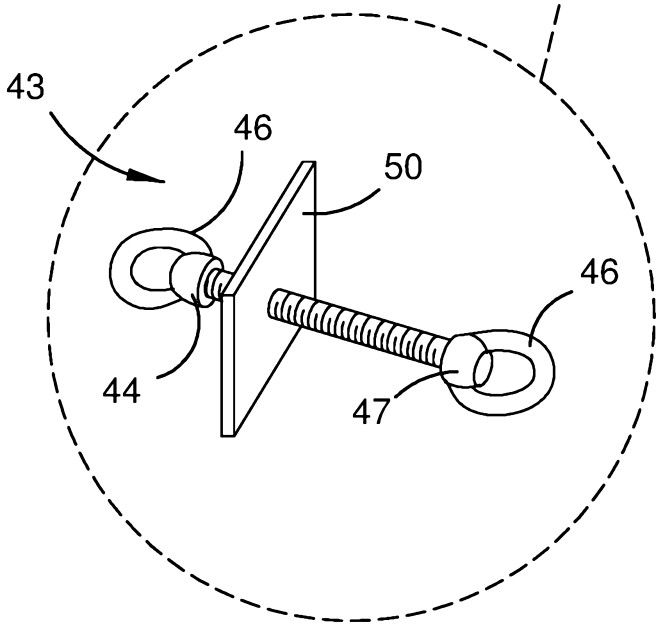


FIGURE 11

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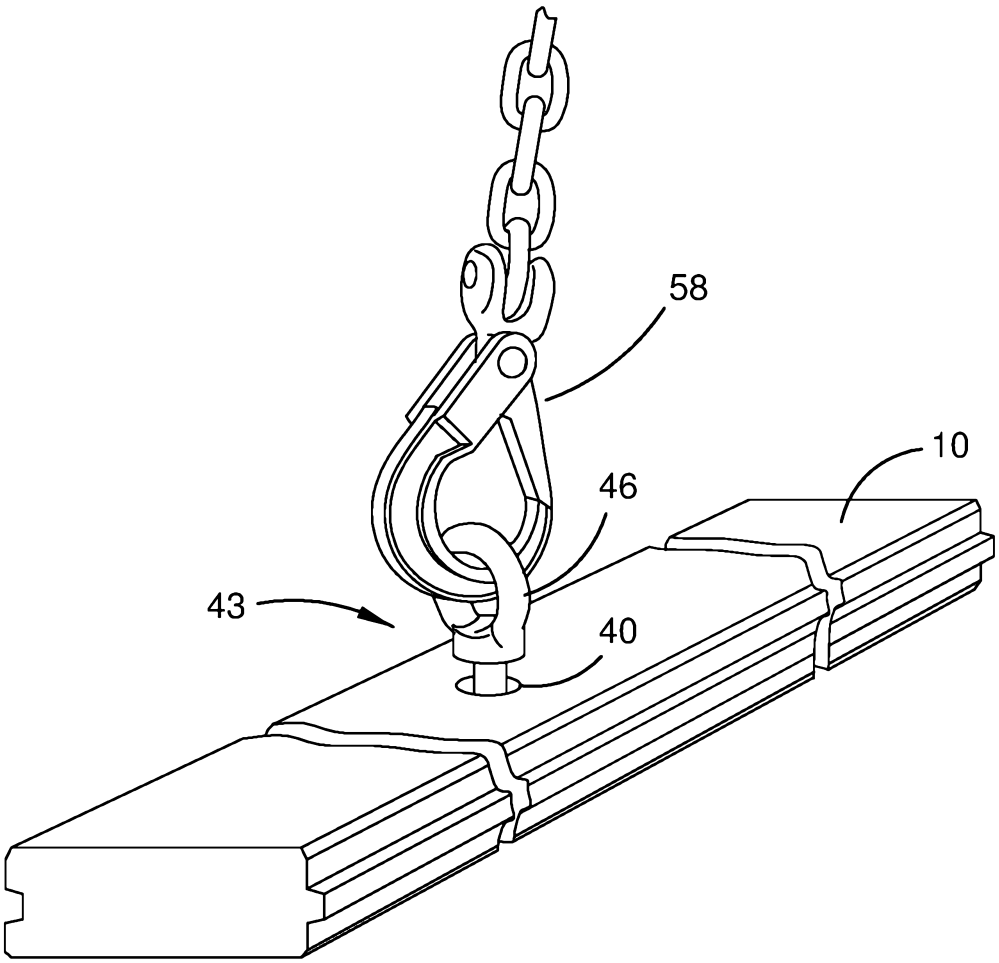


FIGURE 12

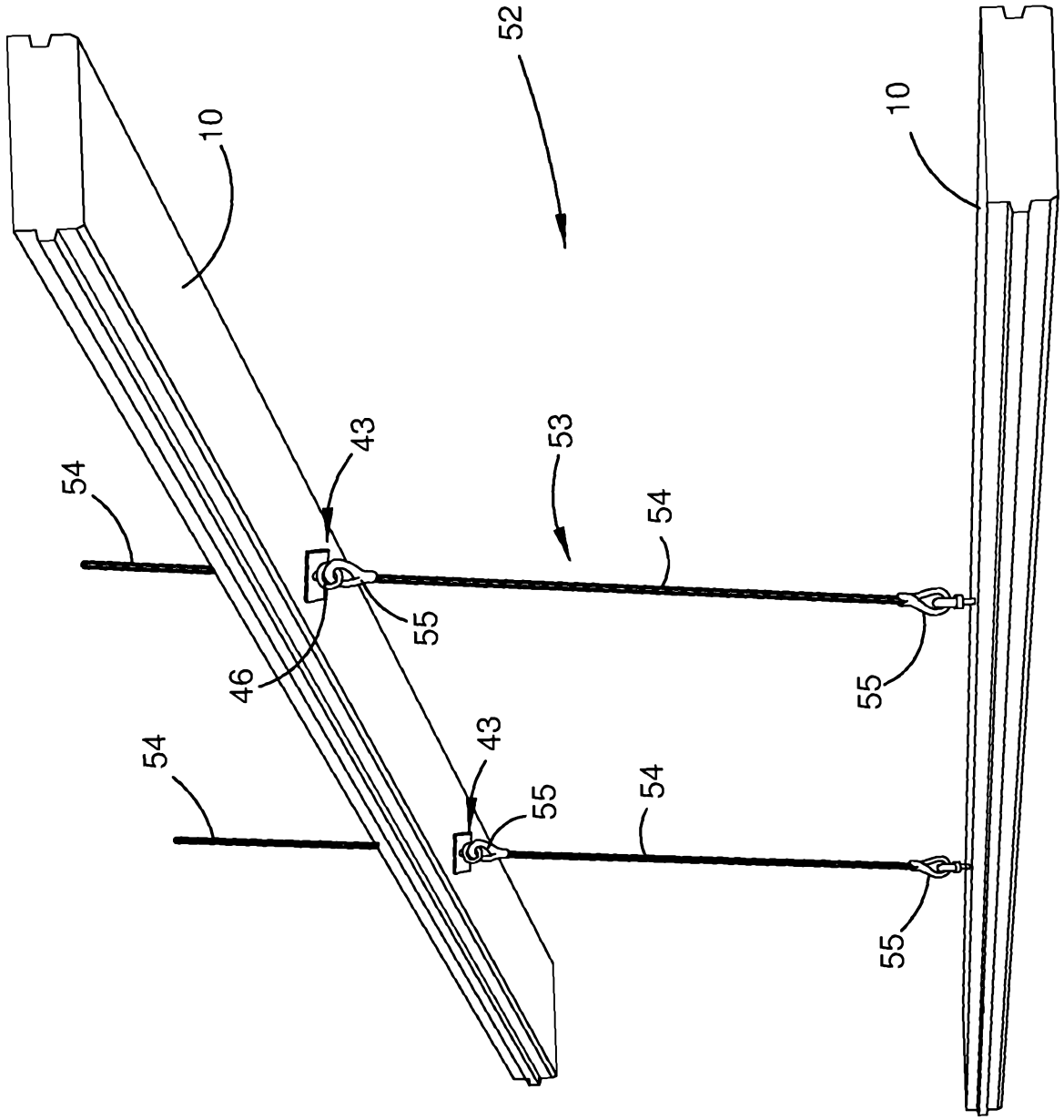


FIGURE 13

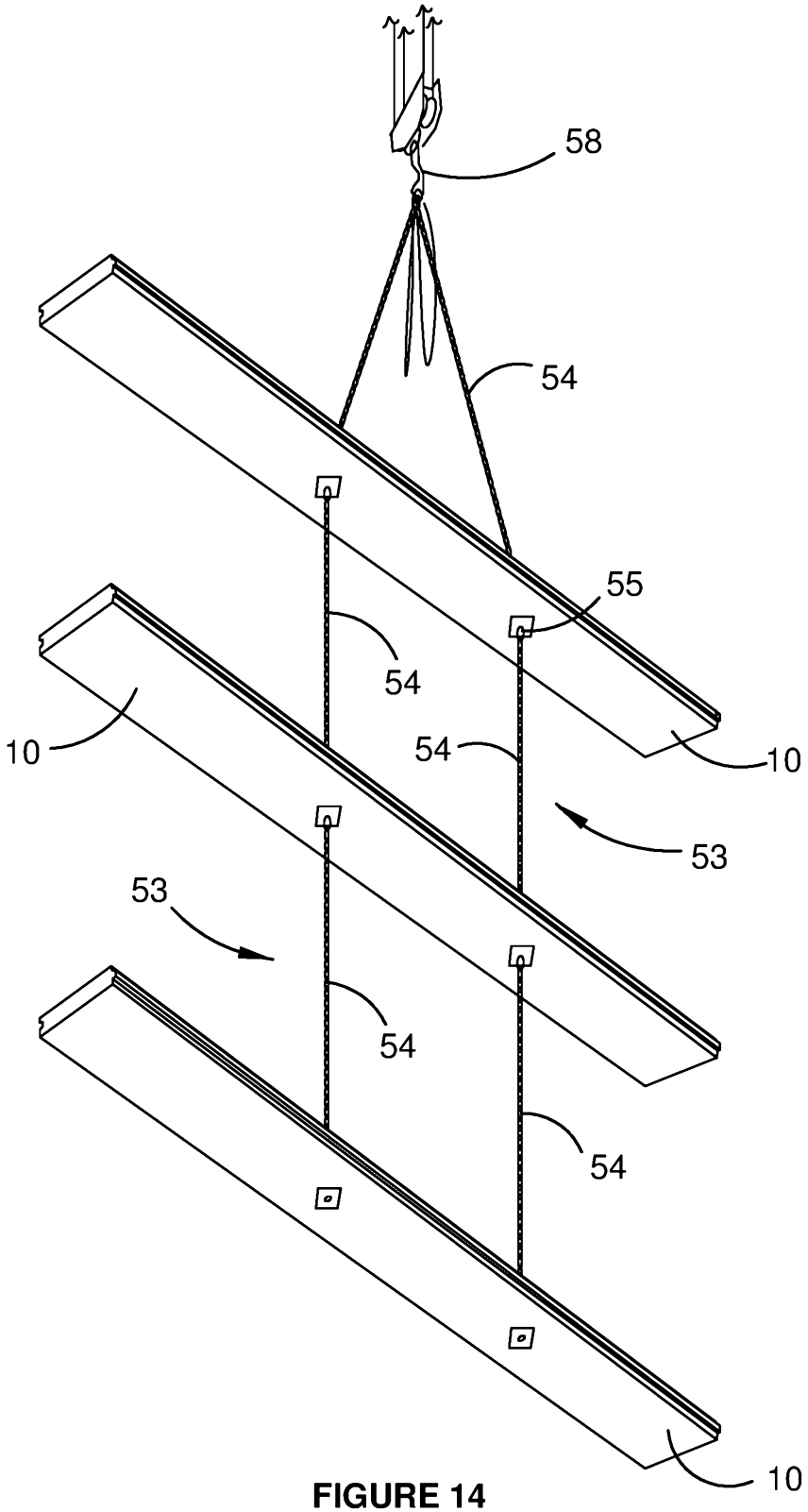


FIGURE 14

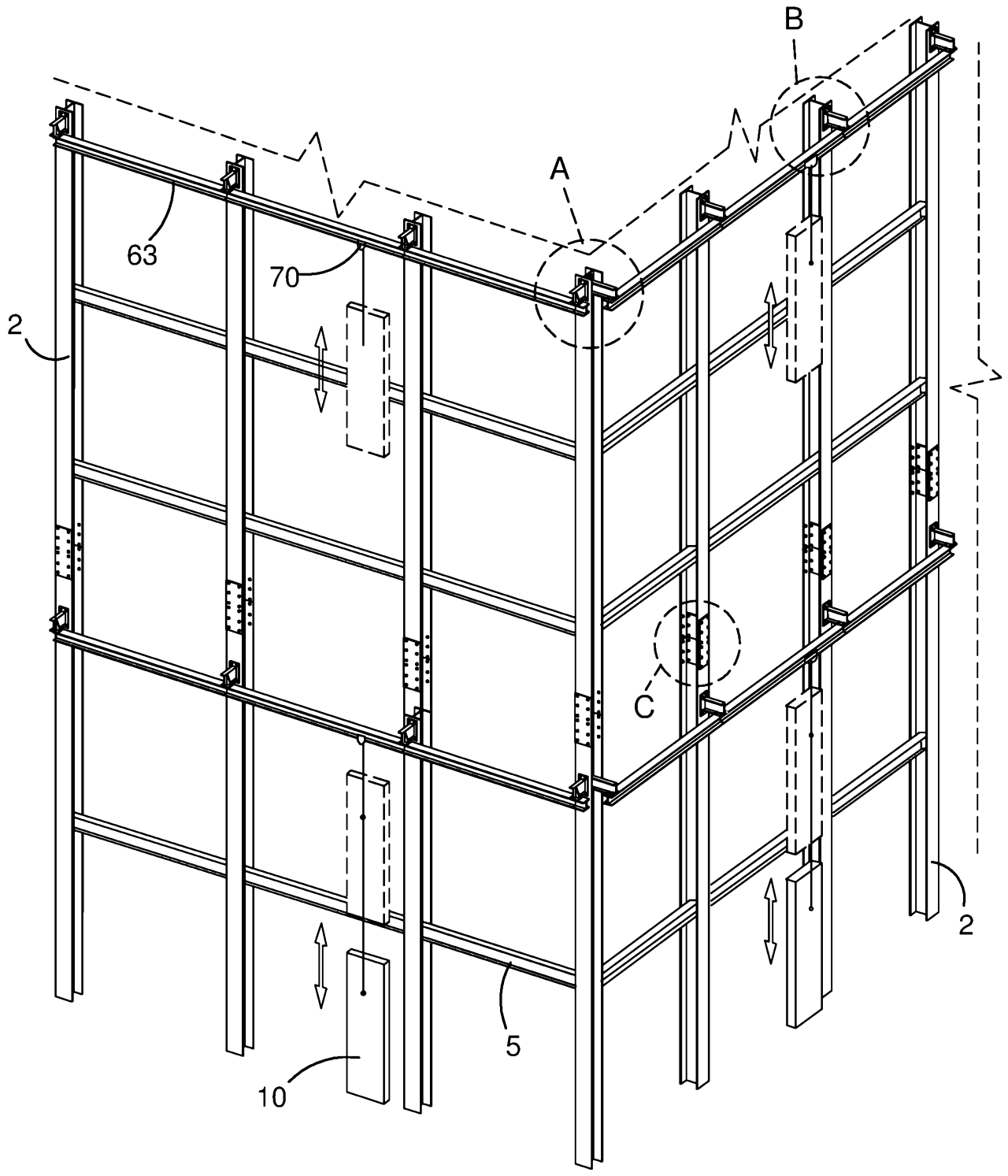


FIGURE 15

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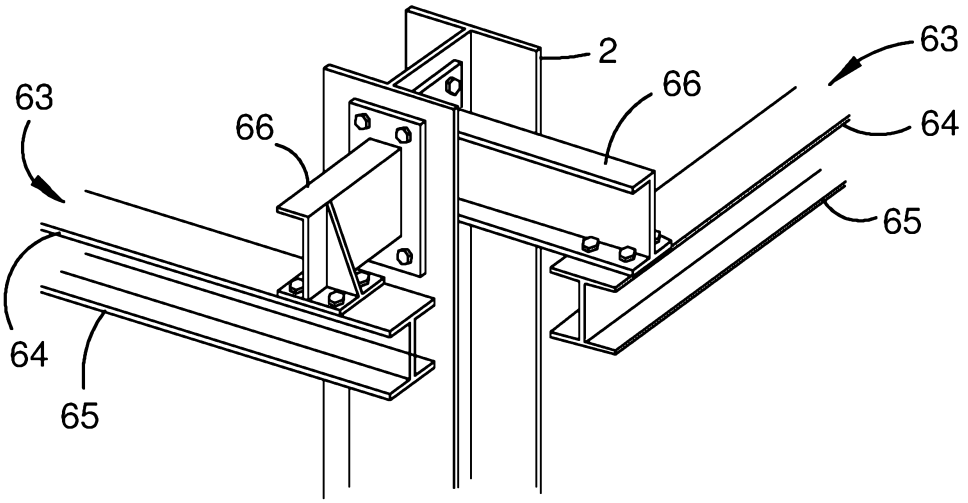


FIGURE 15A

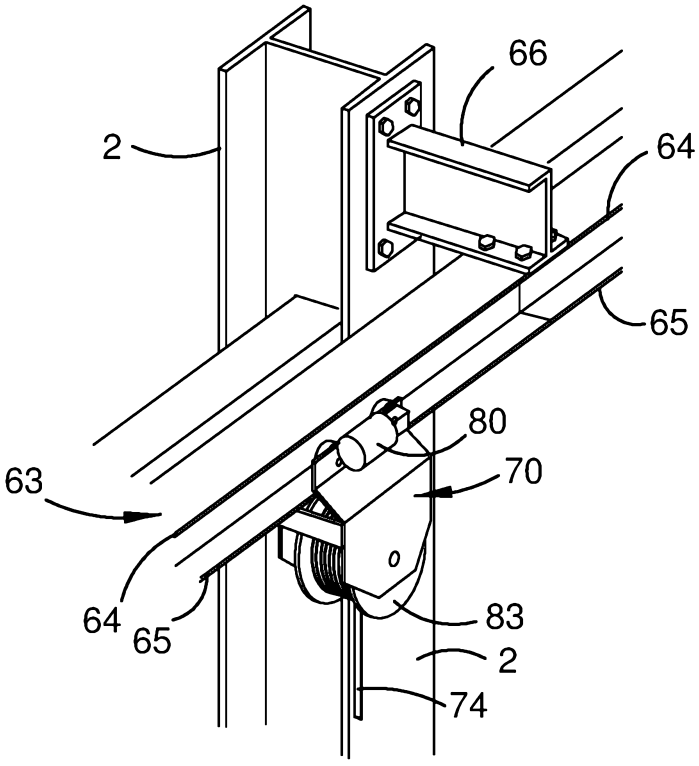


FIGURE 15B

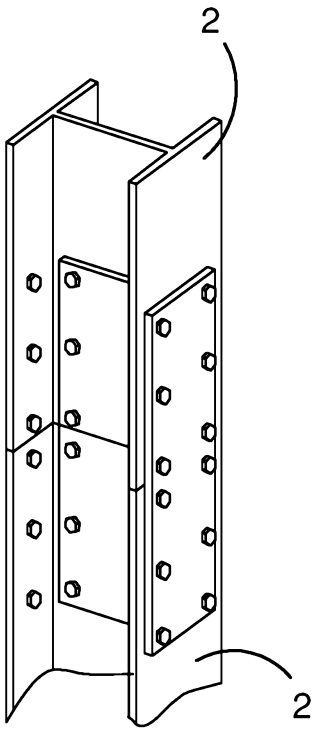


FIGURE 15C

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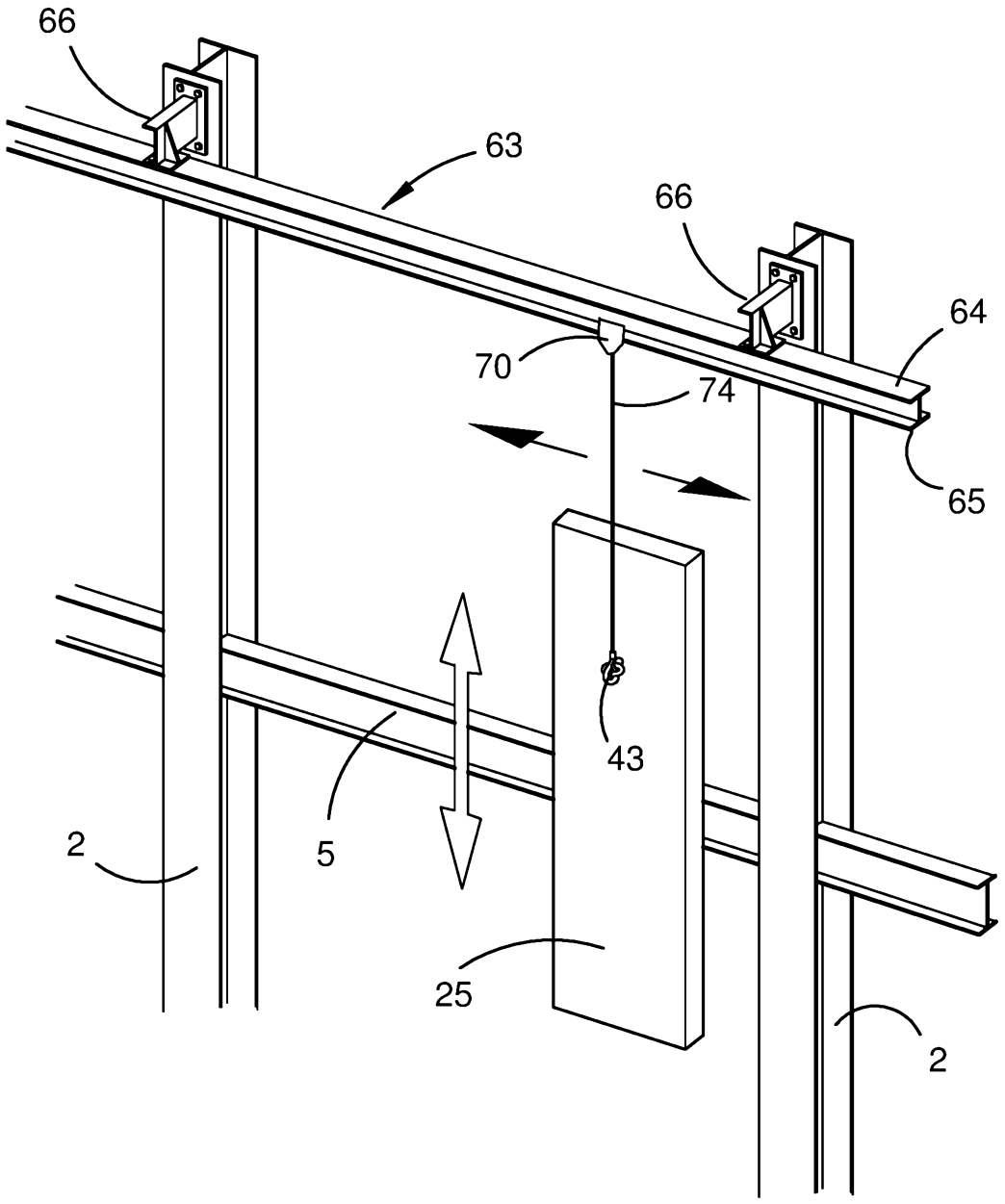


FIGURE 16

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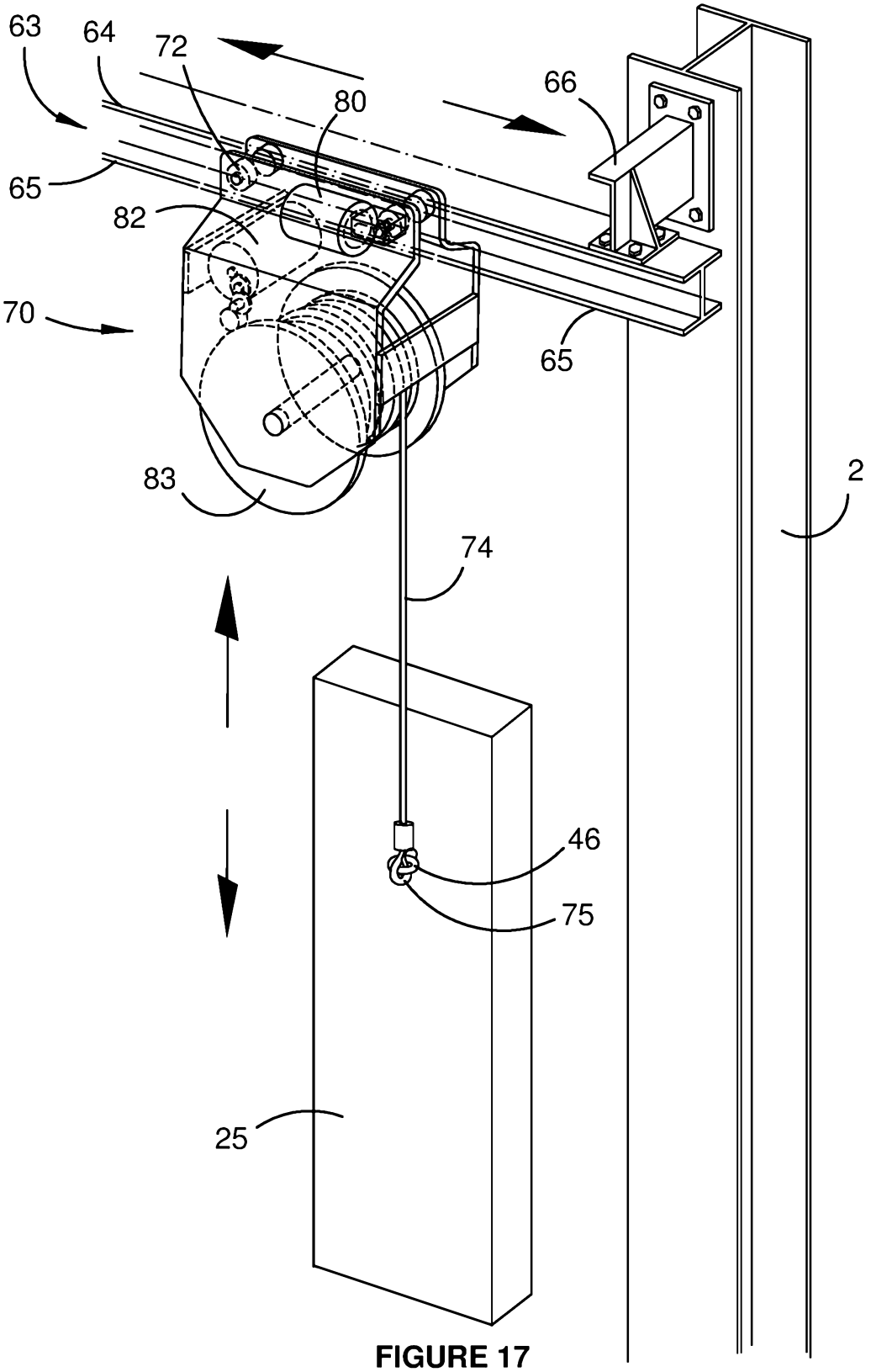


FIGURE 17

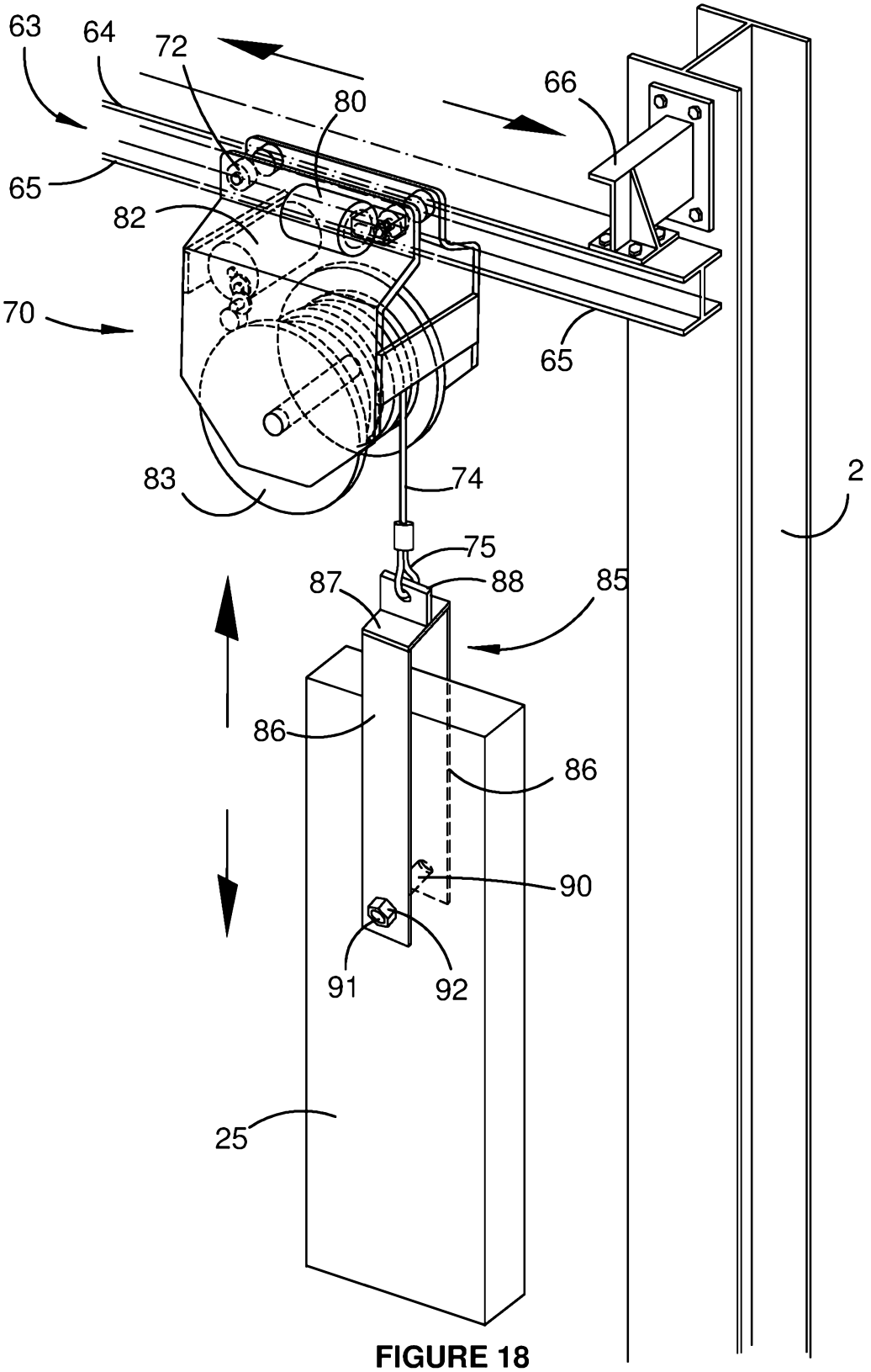


FIGURE 18

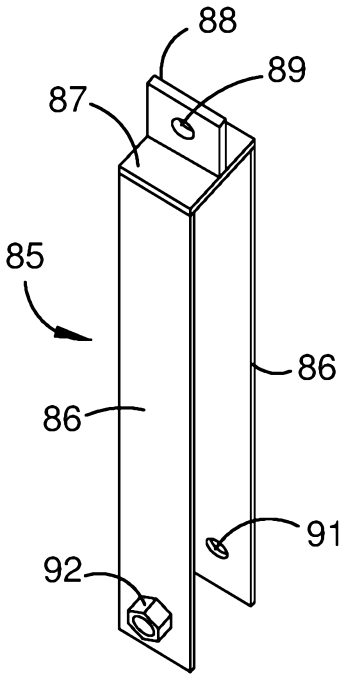


FIGURE 18A

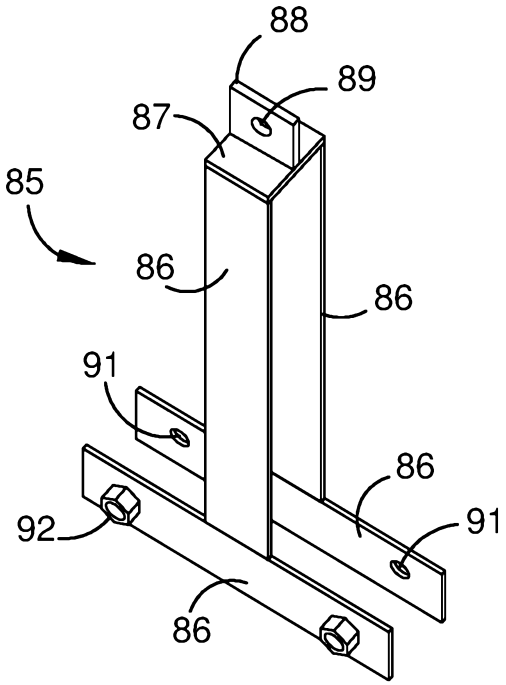


FIGURE 18B

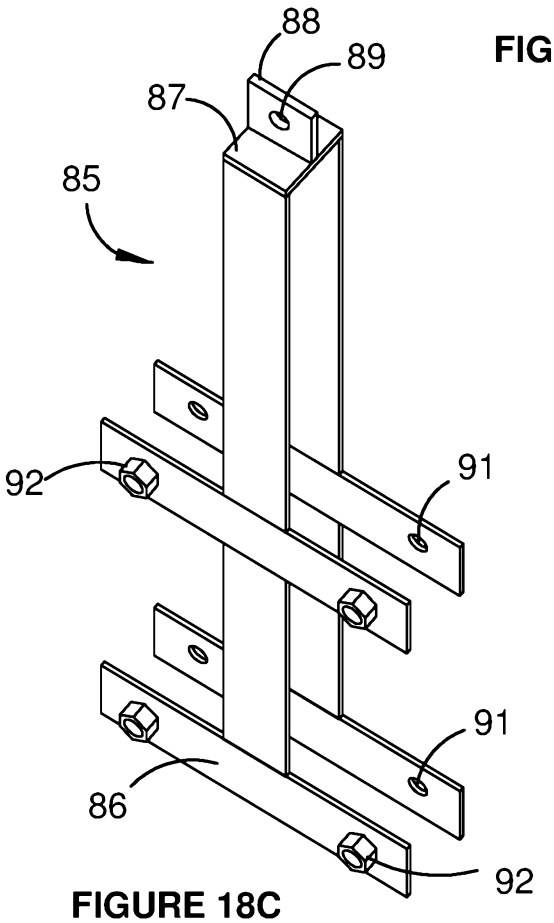


FIGURE 18C

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FIGURE 19