

SLEEVE CONNECTION ASSEMBLY AND METHOD FOR MODULAR BUILDING CONSTRUCTION

5 FIELD OF THE INVENTION

The present invention relates to a sleeve connection assembly and a method for modular building construction.

10 BACKGROUND

Any mention and/or discussion of prior art throughout the specification should not be considered, in any way, as an admission that this prior art is well known or forms part of common general knowledge in the field.

15 Prefabricated Prefinished Volumetric Construction (PPVC) refers to a construction method in which free-standing volumetric modules (complete with finishes for walls, floors and ceilings) are constructed and assembled in an accredited fabrication facility, in accordance with any accredited fabrication method, and then installed in a building under building works [<https://www.bca.gov.sg/BuildableDesign/ppvc.html>].

20 Generally, the attractiveness of PPVC as a construction method lies in cost- and time-saving compared to conventional construction methods. Also, PPVC allows for much of the work to be done off-site in a controlled manufacturing environment, which is generally desirable to raise construction productivity and quality. The off-site manufactured modules are then installed at the building site, which includes the lateral and horizontal interconnection of the modules. One of the challenges faced in PPVC construction relates to providing interconnection methods and connector assemblies for the modules that can provide or enhance the required structural integrity of the constructed building, while being as time-, labour- and cost-efficient as possible. This is particularly relevant to the application of PPVC for multi-storey buildings.

30 Embodiments of the present invention seek to address at least one of the above challenges.

SUMMARY

35 According to one aspect of an example of the present invention, there is provided a sleeve connection assembly for modular building construction, wherein the assembly comprises: a first module; a second module; and a sleeve having a hollow core, the sleeve being attached to and extending from the first module, wherein the sleeve is configured to plug into the second module, wherein a grouted sleeve connection connecting the first module to the second module is formed when grout is applied to fill a void between the sleeve and the second module, wherein the sleeve is configured to engage cured grout in the void to restrict movement of the first module relative to the second module, and no fastener is required to further connect the first module to the second module to assemble the sleeve connection assembly, wherein the first module comprises a column, the sleeve extends from a planar surface at one end of the column, and area of the planar surface is wider than cross-section of the sleeve.

40 According to another aspect of an example of the present invention, there is provided a method for modular building construction, the method comprising: assembling a sleeve connection assembly by: plugging into a second module, a sleeve with a hollow core that is attached to and extending from a first module, the first module comprising a column; and applying grout to fill a void between the sleeve and the second module to form a grouted sleeve connection connecting the first module to the second module, wherein the sleeve is configured to engage cured grout in the void to restrict movement of the first module relative to the second module, and no fastener is required to further connect the first module to the second module to assemble the sleeve connection assembly, wherein the sleeve extends from a planar surface at one end of the column of the first module, and area of the planar surface is wider than cross-section of the sleeve.

Other optional features are defined in the dependent claims in claim section of the present disclosure.

5 **BRIEF DESCRIPTION OF THE DRAWINGS**

Embodiments of the invention will be better understood and readily apparent to one skilled in the art from the following written description, by way of example only and in conjunction with the drawings, in which:

- 10 Fig. 1 shows a perspective view of a steel/steel-composite chassis, which is a box-shaped module for modular building construction.
Fig. 2 shows a perspective view of eight box-shaped modules joined together to form a part of a multi-storey modular building.
- 15 Fig. 3 shows a plan view of different types of joints required at different locations in the assembly of a multi-storey modular building.
Fig. 4 shows a perspective view of a first type of sleeve configured as a steel hollow section, in particular a Square Hollow Section (SHS).
Fig. 5 shows a perspective view of a corner joint or module comprising a column with the sleeve of Fig. 4 extending therefrom and two extended ceiling beams.
- 20 Fig. 6a shows a perspective view of a corner joint or module with a column having two extended floor beams, where a sleeve of the corner joint of Fig. 5 is to be plugged into the column.
Fig. 6b shows a see-through view of a column where the sleeve of the corner joint of Fig. 5 is to be plugged into the column.
- 25 Fig. 7a shows a perspective view of two of the module of Fig. 5 placed adjacent to each other.
Fig. 7b shows a perspective view illustrating a spacer to be slotted over two sleeves of the two modules in Fig. 7a.
Fig. 7c shows a perspective view of two modules to be stacked on the two modules of Fig. 7a.
30 Fig. 7d shows a perspective view of an assembled joint with the two modules of Fig. 7a joined to the two modules of Fig. 7c.
Fig. 7e shows an exploded view of the assembled joint of Fig. 7d.
Fig. 8a shows a sectional view of the assembled joint of Fig. 7d revealing sleeves plugged into the two modules of Fig. 7c before grout is applied to form a grouted sleeve connection.
- 35 Fig. 8b illustrates a sectional view of the grouted joint of Fig. 7d.
Fig. 9 shows variations of a spacer to be used at different joints depending on numbers of modules to be connected at each joint.
Fig. 10 shows a perspective view of an end plate to be welded to a column.
Fig. 11 shows a perspective view of a column bottom end plate.
- 40 Fig. 12 shows variations in the design of sleeves.
Fig. 13 illustrates how conventional grouted sleeve connections are used to connect piles and offshore superstructures in offshore industry.
Fig. 14 shows a perspective view of a second type of sleeve configured as a steel hollow section, in particular a Square Hollow Section (SHS).
- 45 Fig. 15a shows a perspective view of a corner joint or module comprising a column with the sleeve of Fig. 4 extending therefrom and two extended ceiling beams.
Fig. 15b illustrates a perspective view of a shear key in a form of a raised platform, or step plate or structure.
Fig. 16a shows a perspective view of a corner joint or module with a column having two extended floor beams, where a sleeve of the corner joint of Fig. 15a is to be plugged into the column.
- 50 Fig. 16b shows a see-through view of a column where the sleeve of the corner joint of Fig. 15a is to be plugged into the column.
Fig. 17a shows a perspective view of two of the module of Fig. 15 placed adjacent to each other.
55 Fig. 17b shows a perspective view illustrating a spacer to be slotted over two sleeves of the two modules in Fig. 17a.
Fig. 17c shows a perspective view illustrating the spacer of Fig. 17b being slotted over the two sleeves.

Fig. 17d shows a perspective view illustrating the spacer of Fig. 17b slotted fully over the two sleeves.

Fig. 17e shows a perspective view of two modules to be stacked on the two modules of Fig. 7a.

5 Fig. 17f shows a perspective view of an assembled joint with the two modules of Fig. 7a joined to the two modules of Fig. 7c.

Fig. 17g shows an exploded view of the assembled joint of Fig. 17f.

Fig. 18a shows a sectional view of the assembled joint of Fig. 17f revealing sleeves plugged into the two modules of Fig. 17e before grout is applied to form a grouted sleeve connection.

10 Fig. 18b illustrates a sectional view of the grouted joint of Fig. 17f.

Fig. 18c illustrates a grouting method through a sectional view of the grouted joint of Fig. 18b.

Fig. 18d illustrates another grouting method through a sectional view of the grouted joint of Fig. 18b.

15 Fig. 19 shows a perspective view of a plate structure comprising a column end plate and a shear key.

Fig. 20 shows a perspective view of a sleeve structure.

Fig. 21 shows a side view of sleeves of Fig. 20 extending from a first module.

Fig. 22 shows a see-through side view of Fig. 21 with a reinforced concrete column.

Fig. 22a shows a sectional view E-E of Fig. 21.

20 Fig. 23 shows a see-through perspective view of a tube case that is embedded in a reinforced concrete column.

Fig. 24 shows a see-through perspective bottom view of the tube case of Fig. 23.

Fig. 25a shows an exploded view of a sleeve connection assembly according to an example of the present disclosure.

25 Fig. 25b shows a perspective bottom view of Fig. 25a.

These above-mentioned figures are not drawn to scale and are intended merely for illustrative purposes.

DETAILED DESCRIPTION

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Fig. 1 shows a perspective view of a steel/steel-composite chassis 100, which in an example of the present disclosure, is a module for modular building construction. This steel / steel-composite module 100 may be a boxed-shape module as shown in Fig. 1 or it may be any other suitable shape for modular building construction. An example in the case of a steel-composite module may be a steel-concrete composite. The following description and illustrations will focus on the connection of the major structural components according to some examples of the present disclosure, and hence, the internal finishes, walls, windows, and mechanical, electrical and plumbing (MEP) pertaining to the building being constructed, which are understood by a person skilled in the art, are not shown or described herein. As used herein in the present disclosure, the term 'module' refers to a building module, including one or more components or parts of building joint, which is used in modular building construction.

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45 Fig. 2 shows a perspective view of eight box-shaped modules, in particular, four top modules e.g. 100a and 100b and four bottom modules e.g. 100c and 100d. In the present example, each box-shaped module corresponds to the module 100 as shown in Fig. 1. Several of the module 100 are joined together to form part of a multi-storey modular building 102. This configuration with eight box-shaped modules is applicable for low-rise, mid-rise and high-rise modular buildings in various examples of the present disclosure. The layout of the modules may be varied to suit the architectural plan in various examples of the present disclosure. It is noted that the modules 100a-d are interchangeable as top or bottom modules, and each module can serve as a bottom module relative to an upper module and/or as an upper module relative to a lower module in a multi-storey building.

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55 Fig. 3 shows different types of joints J that typically occur at different locations A to E (i.e. JA, JB, JC, JD, and JE in Fig. 3) of a multi-storey modular building 300. Perspective views of the joints with their respective connecting beams are shown in Fig. 3.

As used herein in the present disclosure, the term 'joint' is not intended to refer to specific elements making up the interconnection, but is intended to generally refer to the arrangement at the interconnection region.

Depending on the locations and module layout, the joints of the multi-storey modular building 300 may have different configurations. The most complex joint in Fig. 3 is a JC joint, which directly connects eight modules at the same location. A less complex joint in Fig. 3 is a JB joint, which connects four modules at the same location. The JB joint would be one of the joints featured in examples of the present disclosure. A person skilled in the art will appreciate that other types, variation, or permutation of joints besides those shown in Fig. 3 can be readily implemented according to various examples of the present disclosure.

Fig. 4 to 6b illustrate parts of an example of a proposed sleeve connection assembly for modular building construction. Fig. 7a to 8b illustrate how the proposed sleeve connection assembly is assembled.

Fig. 4 shows an example of a type of sleeve 400 configured as a steel hollow section, which would form a part of the proposed sleeve connection assembly. Other than steel, the sleeve 400 may also be made of other materials such as another type of metal, metal alloys, composites, etc., that are suitable for use as a connecting element for structural components in building construction. The sleeve 400 may comprise of one or more holes 401 and 402 to allow for grout to flow in and out of the sleeve 400. A minimum of one hole should be present. The one or more holes 401 and 402 allows grout to reside outside the one or more holes 401 and 402 and to fill the space extending through the center of the sleeve 400 or to fill space inside the center of the sleeve 400. With the help of these holes 401 and 402, a strong grouted sleeve connection can be formed to hold the sleeve 400 in place and prevent joint movement in the sleeve connection assembly (or joint) that is formed. The grout used may be high-strength non-shrink grout. It should be appreciated that the number of holes 401 and 402 on the sleeve 400 can be varied and the shape of the holes 401 and 402 on the sleeve 400 can adopt various patterns such as slotted holes, holes of any shape (e.g. quadrilateral, elliptical, elongate holes, etc.).

In the example of Fig. 4, the sleeve 400 is a Square Hollow Section (SHS) with four major rectangular surfaces forming an outer surface area of the sleeve 400. Fig. 4 shows two circular holes disposed on each rectangular surface of the sleeve 400. It is appreciated that other than a Square Hollow Section (SHS), which has a square cross-section, the cross-section of the sleeve 400 may also be a Circular Hollow Section (CHS), a Rectangular Hollow Section (RHS), a H or I section and the like. In another example, the sleeves 400 may not be a hollow section with an elongate hollow core but more resemble solid beams or rods with through-holes. In this example, the hollow center of these through-holes in the sleeve 400 is regarded as forming the hollow core of the sleeves 400, which allows grout to flow through.

Fig. 12 shows examples of slotted holes and rectangular holes that can be adopted as the holes 401 and 402 in the sleeve 400 of Fig. 4. In a design A, one elongate slotted hole with rounded edges is disposed on each major surface of a RHS. In a design B, two identical slotted holes with rounded edges are disposed on each major surface of a RHS. In a design C, an elongate rectangular hole is disposed on each major surface of a RHS. The design of the holes are not limited to designs A to C. Other suitable designs may also be possible as long as each hole size and shape enables grout to flow through the sleeve.

Fig. 5 shows a corner joint 500 comprising a column 505, which in the present example is a steel column. The corner joint 500 comprises two extended beams 502 and 504 extending from a first end of the column 505. The beams 502 and 504 in the example of Fig. 5 are ceiling beams. The corner joint 500 is also referred herein as a first module. In Fig. 5, each of the beams 502 and 504, and column 505 is a Rectangular Hollow Section (RHS). In other examples, this RHS cross-section can be replaced by other cross-sections such as Square Hollow Section (SHS), channel, universal H or I section, etc. The column 505 is basically a structure that is columnar in shape or resembling a column suitable for use in building construction, and/or if necessary, having features for joining to other building structures such as the beams 502 and 504.

The sleeve 400 of Fig. 4 is to be attached to the corner joint 500 to form part of the proposed sleeve connection assembly. In the example of Fig. 5, a steel end plate 503 is first welded to a top end 501 of the column 505 of the first module 500. In another example, the steel end plate 503 may be attached to the column 505 through other means. The sleeve 400 is subsequently welded on to the end plate 503 so as to connect the sleeve 400 to the column 505 of the first module 500. In this manner, the sleeve 400 is attached to the first module 500 and extends from the first module 500.

In the example of Fig. 5, the first module 500 has the two extended beams 502 and 504. In other examples, depending on the building design, the first module 500 may not

require the two extended beams 502 and 504 or require less or more of such beams. Furthermore, notably, the sleeve 400 is extending from a planar surface at one end of the column 505. In Fig. 5, the planar surface refers to the surface of the end plate 503 attached to the end of the column 505 shown in Fig. 5. The area of such planar surface is wider than the cross-section of the sleeve 400. This enables space/void (e.g. voids 806 and 820 of Fig. 8b) to be provided between the sleeve 400 and a second module (e.g. 600 of Fig. 6a), which may comprise a column of similar width as the column 505 that has a hole wider than the cross-section of the sleeve 400 to receive the sleeve 400. This space is useful for holding grout, which cures to form a strong joint, coupling the first module 500 to the second module.

In other examples, the sleeve 400 may be attached to the first module 500 through other means besides welding. For instance, the sleeve 400 may be configured to be fastened to the first module 500 via screws, rivets, nuts and bolts, and the like. In the present example, the beams 502 and 504 of the corner joint 500 are extended in a direction orthogonal to direction of extension of the sleeve 400 from the corner joint 500. The beams 502 and 504 are also extended orthogonally with respect to each other from the column 505.

An example of the end plate 503 is a plate 1000 shown in Fig. 10. The plate 1000 has an access hole 1001 at its center that can be used to facilitate grouting. There is an advantage that during grouting, grout can flow through this access hole 1001 into the sleeve 400 or be injected through this access hole 1001 into the sleeve 400. Having said that, such access hole 1001 is an optional feature. If the access hole 1001 is present in the end plate 503, it is not visible in Fig. 5. The access hole 1001 may be covered by a plug in some examples of the present disclosure after grouting to prevent grout from leaking through the access hole 1001. The grouting process will be further described later. The plug may be made of rubber, concrete, or other suitable material.

The corner joint 500 with the sleeve 400 is just one half of the proposed sleeve connection assembly. The proposed sleeve connection assembly comprises a second half, which is the second module (e.g. 600 of Fig. 6a) described earlier. The second module will be further described later. The hollow sleeve 400 is configured to plug into the second module. Depending on the architectural plan, if the first module is to be used as a lower module, then the second module would be used as an upper module, and vice versa. In the proposed sleeve connection assembly, a grouted sleeve connection connecting the first module to the second module is formed when grout is applied to fill a void between the hollow sleeve 400 and the second module that the hollow sleeve 400 is plugged into. In addition to grout filling this void, the grouted sleeve connection may comprise of grout applied into the hollow core of the hollow sleeve 400 as well. In another example of the present disclosure, it may be configured such that only such void is filled with grout and the hollow core of the hollow sleeve 400 is not filled with grout. The sleeve 400 advantageously enables the grouted sleeve connection to be formed to join the first module to the second module. Furthermore, in the present example, the sleeve 400 has holes 401 and 402. Furthermore, the applied grout can also flow into these holes 401 and 402 to fill the hollow core of the sleeve 400. In this manner, the holes 401 and 402 of the sleeve 400 enable the sleeve 400 to engage cured grout in the void to restrict movement of the first module 500 relative to the second module and therefore, no fastener is required to further connect the first module 500 to the second module to assemble the proposed sleeve connection assembly. Other configurations of the hollow sleeve 400 are also possible as long as it engages the cured grout in the void to restrict movement of the first module relative to the second module.

As used herein in the present disclosure, the term 'fastener' includes any object for holding two separate objects or parts together such as but not limited to screw, nut and bolt, buckle, rivet, seal, clip, pin, clamp and the like that is suitable for connection in building construction.

Fig. 6a illustrates a corner joint 600, which is an example of the second module. Specifically, Fig. 6a shows the corner joint 600 comprising a column 605, which in the present example is a steel column. The column 605 is configured to allow the sleeve 400 to be plugged into the column 605. The corner joint 600 comprises two extended beams 602 and 604 extending from a first end of the steel column 605. The beams 602 and 604 in the example of Fig. 6a are floor beams to be joined to other structures such as other columns (not shown in Fig. 5). In Fig. 6a, each of the beams 602 and 604, and column 605 is a Rectangular Hollow Section (RHS). In other examples, this RHS cross-section can be replaced by other cross-sections such as Square Hollow Section (SHS), channel, universal H or I section, etc. In the present example, the beams 602 and 604 of the corner joint 600 are

extended in a direction orthogonal to a longitudinal axis 606 of the column 605. In the present example, once the first module 500 and the second module 600 are assembled together, the longitudinal axis 606 would correspond with the longitudinal axis of the sleeve 400 extending from the first module 500. The beams 602 and 604 are also extended orthogonally with respect to each other from the column 605.

Fig. 6b shows a see-through view of the column 605 of Fig. 6a, where the sleeve 400 of Fig. 5 is to be plugged into the column 605. The column 605 comprises of an end plate 603 welded to an end of the column 605 where the sleeve 400 of Fig. 5 is to be plugged into the end plate 603. A center of the end plate 603 has a hole or opening 601. The hole 601 is configured to match shape of the sleeve 400 to allow the sleeve 400 to be closely fitted through the hole 601 as the first module 500 of Fig. 5 is plugged into the second module, which in the present example is the corner joint 600 of Fig. 6a. In the present example, cross-sectional shape of the sleeve 400 is square and thus the shape of the hole 601 is square as well. This would enable the sleeve 400 to match the hole 601 of the end plate 603 that is welded to the column 605. In this manner, the sleeve 400 and the second module 600 are fitted such that the first module 500 and the second module 600 are prevented from rotating relative to each other about the longitudinal axis 606 in Fig. 6a, which corresponds with the longitudinal axis of the sleeve 400, and about an axis orthogonal to the longitudinal axis of the sleeve 400. When grouting is applied to form the grouted sleeve connection of the proposed sleeve connection assembly, the grout is applied to fill the void or space between the sleeve 400 and the column 605 that the sleeve 400 is plugged or inserted into.

An example of the end plate 603 is a plate 1100 shown in Fig. 11. The plate 1100 has an access hole 1101 at its center that is configured to match the shape of the sleeve 400 of Fig. 5 to allow the sleeve 400 to be closely fitted through the hole 601.

More than one of the module 500 of Fig. 5 and more than one of the corresponding module 600 of Fig. 6a may be used and, as required, modified slightly to create different types of joints, for instance, the joints as shown in Fig. 3.

Fig. 7a shows a perspective view of two of the module 500 of Fig. 5 placed or assembled adjacent to each other. The two modules in Fig. 7a are renumbered as 701 and 702 respectively. The sleeves extending from the modules 701 and 702 in a common direction are numbered as 707 and 708 respectively. The sleeves 707 and 708 are welded to end plates 711 and 712 respectively. Each of the end plates 711 and 712 is the same as the end plate 503 of Fig. 5. The end plates 711 and 712 may be each welded to respective columns 709 and 710 of the two modules 701 and 702 respectively. Ceiling beams 703 and 704 extend from the module 701. Ceiling beams 705 and 706 extend from the module 702. Specifically, the two modules 701 and 702 are assembled to contact and be adjacent to each other such that the two ceiling beams 701 and 706 extend in a direction away from each other and the two ceiling beams 705 and 704 extend in a same direction. In the present example, the two modules 701 and 702 arranged in the configuration shown in Fig. 7a are to be used as lower modules. They are arranged in such a configuration prior to joining to two corresponding upper modules (714 and 715) that will be described in Fig. 7c.

Notably, the two modules 701 and 702 each comprises of a column, for example, a structure that is columnar in shape or resembling a column suitable for use in building construction, and/or if necessary, having features for joining to other building structures such as the beams 703, 704, 705 and 706. In the example of Fig. 7a, the modules 701 and 702 each has two extended beams 703, 704, and 705, 706 respectively. In other examples, depending on the building design, the module 701 and 702 may not require the two extended beams 703, 704, and 705, 706 respectively or require less or more of such beams. Furthermore, notably, the sleeves 707 and 708 are each extending from a planar surface at one end of the columns 709 and 710 respectively. In Fig. 7a, the planar surface refers to the surface of the end plates 711 and 712 respectively at the end of the columns 709 and 710 respectively shown in Fig. 7a. The area of such planar surface is wider than the cross-section of the respective sleeves 707 and 708. This enables space/ void (e.g. voids 806 and 820 of Fig. 8b) to be provided between the sleeves 707 and 708, and a second module (e.g. 714 and 715 of Fig. 7c), which may comprise a column of similar width as the columns 709 and 710 that has a hole wider than the cross-section of the sleeves 707 and 708 respectively to receive the sleeves 707 and 708 respectively. This space is useful for holding grout, which cures to form a strong joint coupling the module 701 and 702 to each respective second module.

Fig. 7b shows a perspective view illustrating a spacer 713 to be slotted over the two sleeves 707 and 708 of the two modules 701 and 702 in Fig. 7a prior to the step of plugging or insertion of the sleeves 707 and 708 into the two corresponding upper modules. It should be appreciated that the spacer 713 is an optional feature but having it would provide certain advantages described below. The spacer 713 is configured to have two holes 724 for the sleeves 707 and 708 to slot through. The holes 724 are each configured to fit and enable each of the two sleeves 707 and 708 to slot through each hole 724. In this manner, the spacer 713 becomes a tie plate that restricts lateral movement of the two sleeves 707 and 708 with respect to each other, wherein the direction of the restricted lateral movement is orthogonal to the direction of extension of the two sleeves 707 and 708 from the two modules 701 and 702 respectively. As the spacer 713 is disposed in between the two modules 701 and 702 and the corresponding upper modules that the two modules 701 and 702 are to be plugged or inserted into, the spacer 713 has another function to prevent damage when the two modules 701 and 702 are plugged or inserted into the corresponding upper modules as it can take some impact. Furthermore, the spacer 713 can also act as a cover or seal to prevent grout from leaking when grout is applied to each of two sleeves 707 and 708 to form grouted sleeve connections.

Fig. 7c shows a perspective view of two of the module 600 of Fig. 6a placed or assembled adjacent to each other. The two modules in Fig. 7c are renumbered as 714 and 715 respectively. The columns of the modules 714 and 715 are numbered as 720 and 721 respectively. The columns 720 and 721 are to be joined to the sleeves 707 and 708 respectively. Floor beams 716 and 717 extend from the module 714. Floor beams 718 and 719 extend from the module 715. Specifically, the two modules 714 and 715 are assembled to contact and be adjacent to each other such that the two floor beams 716 and 718 extend in a direction away from each other and the two floor beams 717 and 719 extend in a same direction. In the present example, the two modules 714 and 715 arranged in the configuration shown in Fig. 7c are to be used as the corresponding upper modules to be joined to the two modules 701 and 702 in Fig. 7b. They are arranged in such a configuration prior to plugging or insertion of the sleeves 707 and 708 in Fig. 7b of the two modules 701 and 702 in Fig. 7b respectively.

Fig. 7d shows a perspective view of an assembled joint with the two modules 701 and 702 of Fig. 7a joined to the two modules 714 and 715 of Fig. 7c. This assembled joint is an example of the proposed sleeve connection assembly that is discussed in the present disclosure. This assembled joint can be used as the joint JB in Fig. 3.

Fig. 7e shows an exploded view of the assembled joint of Fig. 7d. In Fig. 7e, the two first modules 701 and 702 are grouped together, the two second modules 714 and 715 are grouped together, and the spacer 713 is to be placed between the first group modules 701 and 702 and the second group modules 714 and 715.

Fig. 8a shows a sectional view across A-A of the assembled joint of Fig. 7d. The sectional view reveals the sleeves 707 and 708 plugged into the two modules 714 and 715 respectively of Fig. 7c before grout is applied to form a grouted sleeve connection. A sectional view of the spacer 713, which is hidden in Fig. 7d is shown in Fig. 8a.

Fig. 8b shows two sectional views in a top drawing 801 and a bottom drawing 802 for comparison. The top drawing 801 is a sectional view of just the grouped modules 701 and 702 across A-A of the assembled joint of Fig. 7d before grout 803 is applied to form a grout sleeve connection. The bottom drawing 802 is a sectional view across A-A of the assembled joint of Fig. 7d after grout 803 is applied to form the grouted sleeve connection. There are several ways to apply grout. One way to grout the assembled joint is by letting the grout flow through the holes 804 and 805 of the end plates 711 and 712 of the first modules 701 and 702 respectively. Each of the end plates 711 and 712 is similar to the plate 1000 described with reference to Fig. 10. Each of the holes 804 and 805 is similar to the access hole 1001 described with reference to Fig. 10. The grout may be applied to firstly fill each hollow core 807 of the sleeves 707 and 708. The grout then flows through holes 809 of each of the sleeves 707 and 708 to fill voids 806 and 820 between the sleeves 707 and 708 and the columns 720 and 721 of the second modules 714 and 715 respectively. The grout 803 may be applied up to the height of the sleeves 707 and 708. If any of the columns 709, 710, 720, and 721 of the modules 701, 702, 714, and 715 are designed to be concrete filled tube composite columns, more grout can be applied to fill up inner hollow spaces of such columns. As illustrated by an arrow B in Fig. 8b showing a direction to apply grout 803, another possible way is to apply grout 803 is through an end of the columns 720 and 721 of the

second modules 714 and 715 that is opposite to the end connected to the first module 701 and 702. After the applied grout 803 has cured, the sleeves 707 and 708 engages the cured grout 803 in the voids 806 and 820 to restrict movement of the first group modules 701 and 702 relative to the the second group modules 714 and 715. In the present example, additionally, cured grout 803 in the hollow core 807 of each sleeve 707 and 708 contributes to such movement restriction of the first group modules 701 and 702 relative to the second group modules 714 and 715.

Fig. 9 shows several variations of a spacer to be used at different joints depending on number of modules to be connected at each joint. For instance, the spacer 713 described with reference to Fig. 7b may be used for joints JB, JD and JE shown in Fig. 3. A spacer 901 with just one hole to be slotted over one sleeve like the sleeve 400 of Fig. 5 is suitable to be used for joint JA in Fig. 3. A spacer 902 with four holes to be slotted over four sleeves like the sleeve 400 is suitable to be used for joint JC in Fig. 3.

Notably, after completion of the grouting process, no fastener is required to further connect the first group modules 701 and 702 of Fig. 7d to the second group modules 714 and 715 of Fig. 7d to assemble the proposed sleeve connection assembly. This is a key advantage of the features of the proposed sleeve connection assembly.

Fig. 14 to 16b illustrate parts of another example of a proposed sleeve connection assembly for modular building construction. Fig. 17a to 18b illustrate how this proposed sleeve connection assembly is assembled. The present example is very similar to the example described with reference to Fig. 4 to Fig. 8b.

Fig. 14 shows another type of sleeve 1400 according to an example of the present disclosure that replaces the sleeve 400 of Fig. 4. The sleeve 1400 can be a steel hollow section. The sleeve 1400 has a hollow core and a plurality of shear keys, namely, 1401, 1402, 1403, and 1404 evenly spaced apart on outer surfaces of the sleeve 1400. The shear keys 1401, 1402, 1403, and 1404 may be welded on around an outer perimeter of the sleeve 1400. Each shear key 1401, 1402, 1403, and 1404 is generally a corrugated surface formed on the outer surfaces of the sleeve 1400 and is designed to provide shear resistance. The shear keys 1401 to 1404 provide enhanced engagement between grout and the outer surface of the sleeve 1400. The shear keys 1401 to 1404 allow formation of compressive struts after grouting, which lead to further increase in shear resistance after the sleeve 1400 is grouted. Specifically, the shear keys 1401 to 1404 enable the hollow sleeve 1400 to engage cured grout in a void between the hollow sleeve 1400 and a second module such as 600 of Fig. 6a to restrict movement of a first module such as 500 of Fig. 5 relative to the second module. In another example, holes like the holes 401 and 402 described earlier with reference to the sleeve 400 of Fig. 4 can be provided in combination with the shear keys 1401 to 1404. These holes allow grout to flow into the hollow core and thus enhance grout engagement. The number, spacing and sizes of the shear keys 1401, 1402, 1403 and 1404 required may be varied depending on the building design requirements. As an example, the sleeve 1400 as shown in Fig. 14 has a Square Hollow Section (SHS). It is appreciated that other than a Square Hollow Section (SHS), the cross section of the sleeve 1400 may also be a Circular Hollow Section (CHS), Rectangular Hollow Section (RHS), H or I section, etc.

Fig. 15a shows a corner joint 1500 comprising a column 1505, which in the present example is a steel column. The corner joint 1500 comprises two extended beams 1502 and 1504 extending from a first end of the column 1505. The beams 1502 and 1504 in the example of Fig. 15a are ceiling beams. The corner joint 1500 is also referred herein as a first module. In Fig. 15a, each of the beams 1502 and 1504 is a Rectangular Hollow Section (RHS) and the column 1505 is a Square Hollow Section (SHS). In other examples, this SHS cross-section of the column 1505 can be replaced by other cross-sections such as Rectangular Hollow Section (RHS), channel, universal H or I section, etc. The column 1505 is basically a structure that is columnar in shape or resembling a column suitable for use in building construction, and/or if necessary, having features for joining to other building structures such as the beams 1502 and 1504.

The sleeve 1400 of Fig. 14 is to be attached to the corner joint 1500 to form part of the proposed sleeve connection assembly. In the example of Fig. 15a, a steel end plate 1503 is first welded to a top end 1501 of the column 1505 of the first module 1500. The sleeve 1400 is subsequently welded to the end plate 1503 so as to connect the sleeve 1400 to the column 1505 of the first module 1500. In this manner, the sleeve 1400 is attached to the first module 1500 and extends from the first module 1500. In other examples, the sleeve 400 may be attached to the first module 1500 through other means besides welding. For instance, the

sleeve 1400 may be configured to be fastened to the first module 1500 via screws, rivets, nuts and bolts, and the like. In the present example, the beams 1502 and 1504 of the corner joint 1500 are extended in a direction orthogonal to direction of extension of the sleeve 1400 from the corner joint 1500. The beams 1502 and 1504 are also extended orthogonally with respect to each other from the column 1505.

In the example of Fig. 15a, the corner joint 1500 has the two extended beams 1502 and 1504. In other examples, depending on the building design, the corner joint 1500 may not require the two extended beams 1502 and 1504 or require less or more of such beams. Furthermore, notably, the sleeve 1400 is extending from a planar surface at one end of the column 1505. In Fig. 15a, the planar surface refers to the surface of the end plate 1503 at the end of the column 1505 shown in Fig. 15a. The area of such planar surface is wider than the cross-section of the sleeve 1400. This enables space/void (e.g. voids 1806 and 1803 of Fig. 18b) to be provided between the sleeve 1400 and a second module (e.g. 1600 of Fig. 16a), which may comprise a column of similar width as the column 1505 that has a hole wider than the cross-section of the sleeves 1400 to receive the sleeve 1400. This space is useful for holding grout, which cures to form a strong joint coupling the corner joint 1500 to the second module.

An example of the end plate 1503 is the plate 1000 shown in Fig. 10. The end plate 1503 may have the access hole 1001 of Fig. 10 at its center that can be used to facilitate grouting. Grout can flow through this access hole 1001 into the sleeve 1400 or be injected through this access hole 1001 into the sleeve 1400. Such access hole 1001 is an optional feature. If the access hole 1001 is present in the end plate 1503, it is not visible in Fig. 15a. The access hole 1001 may be covered by a plug in some examples of the present disclosure after grouting to prevent grout from leaking through the access hole 1001. The grouting process will be further described later. The plug may be made of rubber, concrete, or other suitable material.

The corner joint 1500 of Fig. 15a with the sleeve 1400 is just one half of the proposed sleeve connection assembly of the present example. The proposed sleeve connection assembly of the present example comprises a second half, which is the second module (e.g. 1600 of Fig. 16a) described earlier. The second module will be further described later. The hollow sleeve 1400 is configured to plug into the second module 1600. Depending on the architectural plan, if the first module is to be used as a lower module, then the second module would be an upper module, and vice versa. In the proposed sleeve connection assembly, a grouted sleeve connection connecting the first module to the second module is formed when grout is applied to fill a void (e.g. voids 806 and 820 of Fig. 8b) between the hollow sleeve 1400 and the second module that the hollow sleeve 1400 is plugged into. Different from the example described with reference to Fig. 4 to 8b, the grouted sleeve connection of the present example does not require grout to be applied into the hollow core of the hollow sleeve 1400. In the present example, only the void (e.g. voids 806 and 820 of Fig. 8b) is filled with grout and the hollow core of the hollow sleeve 1400 is not filled with grout. The shear keys 1401 to 1404 of the sleeve 1400 enable the sleeve 1400 to engage the cured grout in the void (e.g. voids 806 and 820 of Fig. 8b) to restrict movement of the first module 1500 relative to the second module and therefore, no fastener is required to further connect the first module 500 to the second module to assemble the proposed sleeve connection assembly.

Fig. 15b shows an enlarged view of the connection of the sleeve 1400 with the column 1505. The purpose of Fig. 15b is to illustrate that there is a shear key 1506 present that is configured as a raised platform, step plate or structure mounted between the sleeve 1400 and the end plate 1503. The sleeve 1400, end plate 1503 and the shear key 1506 may be welded to each other or attached via fasteners. The shear key 1506 may be part of the sleeve 1400, part of the column 1505 or a separate individual part to be assembled. It should be noted that the shear keys described in the present disclosure may be configured differently from what is described in the present disclosure. For instance, instead of corrugated surfaces or a stepped platform, there could be protrusions, spikes and the like to engage the cured grout. However, all of them has the function of providing shear resistance when grout is applied to the sleeve (e.g. 400 of Fig. 4 or 1400 of Fig. 14).

With reference to a plate structure 2100 in Fig. 19 and the example described with reference to Fig. 15a and 15b, the end plate 1503 may be a lower plate portion 2103 as shown in Fig. 19. Stacked on top of the end plate 1503 is the shear key 1506. The shear key 1506 may be in a form of a step plate portion 2102 in Fig. 19 that is stacked on the lower

plate portion 2103. The step plate portion 2102 is integrated with the lower plate portion 2103 and they form a single body of the plate structure 2100. The step plate portion 2102 is smaller in dimensions compared to the lower plate portion 2103. The step plate portion 2102 is centrally located on the plate structure 2100. At the centers of the step plate portion 2102 and the lower plate portion 2103, there is a hole 2101 present going through both the step plate portion 2102 and the lower plate portion 2103. Like the access hole 1001 of Fig. 10, this hole 2101 can be used for grout injection during grouting. This hole 2101 can also be plugged to prevent grout leakage.

Fig. 16a illustrates a corner joint 1600, which is an example of the second module of the present example. Specifically, Fig. 16a shows the corner joint 1600 comprising a hollow column 1605, which in the present example is a steel hollow column. The column 1605 is a beam to be joined to the sleeve 1400. The corner joint 1600 comprises two extended beams 1602 and 1604 extending from a first end of the steel column 1605. The beams 1602 and 1604 in the example of Fig. 16a are floor beams to be joined to other parts of the building. In Fig. 16, each of the beams 1602 and 1604 is a Rectangular Hollow Section (RHS) and the column 1605 is a Square Hollow Section (SHS). In other examples, this SHS cross-section of the column 1605 can be replaced by other cross-sections such as Rectangular Hollow Section (RHS), channel, universal H or I section, etc. In the present example, the beams 1602 and 1604 of the corner joint 1600 are extended in a direction orthogonal to a longitudinal axis 1606 of the column 1605. In the present example, once the first module 1500 and the second module 1600 are assembled together, the longitudinal axis 1606 would correspond with the longitudinal axis of the sleeve 1400 extending from the first module 1500. The beams 1602 and 1604 are also extended orthogonally with respect to each other from the column 1605.

Fig. 16b shows a see-through view of the column 1605 of Fig. 16a, where the sleeve 1400 of Fig. 15 is to be plugged into the column 1605. The column 1605 comprises a plurality of shear keys, namely, 1607, 1608, 1609, and 1610 evenly spaced apart on inner surface of the column 1605. Each of these shear keys 1607, 1608, 1609, and 1610 is generally a corrugated surface formed on the inner surface of the sleeve 1400 and designed to provide shear resistance. These shear keys 1607 to 1610 work together with the shear keys 1401 to 1404 residing on the sleeve 1400 to engage grout that would be applied to the void between the sleeve 1400 and the inner surface of the column 1605. In this manner, good shear resistance is achieved to restrict movement of the first module 1500 of Fig. 15a relative to the second module 1600 of Fig. 16a.

More than one of the module 1500 of Fig. 15a and more than one of the corresponding module 1600 of Fig. 16a may be used and, as required, modified slightly to create different types of joints, for instance, the joints as shown in Fig. 3.

Fig. 17a shows a perspective view of two of the module 1500 of Fig. 15a placed or assembled adjacent to each other. The two modules in Fig. 17a are renumbered as 1701 and 1702 respectively. The sleeves extending from the modules 1701 and 1702 in a common direction are numbered as 1707 and 1708 respectively. The sleeves 1707 and 1708 are welded to end plates 1711 and 1712 respectively. Shear keys 1720 and 1730, each in the form of a raised platform or step plate, is placed between the sleeve 1707 and end plate 1711, and between the sleeve 1708 and the end plate 1712 respectively. Each of the end plates 1711 and 1712 is the same as the end plate 1503 of Fig. 15. The end plates 1711 and 1712 are each welded to respective columns 1709 and 1710 of the two modules 1701 and 1702 respectively. Ceiling beams 1703 and 1704 extend from the module 1701. Ceiling beams 1705 and 1706 extend from the module 1702. Specifically, the two modules 1701 and 1702 are assembled to contact and be adjacent to each other such that the two ceiling beams 1701 and 1706 extend in a direction away from each other and the two ceiling beams 1702 and 1704 extend in a same direction. In the present example, the two modules 1701 and 1702 arranged in the configuration shown in Fig. 17a are to be used as lower modules. They are arranged in such configuration prior to joining to two corresponding upper modules (1714 and 1715) that will be described in Fig. 17e.

Notably, the two modules 1701 and 1702 each comprises a column, for example, a structure that is columnar in shape or resembling a column suitable for use in building construction, and/or if necessary, having features for joining to other building structures such as the beams 1703, 1704, 1705 and 1706. In the example of Fig. 17a, the modules 1701 and 1702 each has two extended beams 1703, 1704, and 1705, 1706 respectively. In other examples, depending on the building design, the module 1701 and 1702 may not require the

two extended beams 1703, 1704, and 1705, 1706 respectively or require less or more of such beams. Furthermore, notably, the sleeves 1707 and 1708 are each extending from a planar surface at one end of the columns 1709 and 1710 respectively. In Fig. 17a, the planar surface refers to the surface of the end plates 1711 and 1712 respectively at the end of the columns 1709 and 1710 respectively shown in Fig. 17a. The area of such planar surface is wider than the cross-section of the respective sleeves 1707 and 1708. This enables space/void (e.g. voids 1806 and 1803 of Fig. 18a) to be provided between the sleeves 1707 and 1708, and a second module (e.g. 1714 and 1715 of Fig. 17e), which may comprise a column of similar width as the column 1709 and 1710 that has a hole wider than the cross-section of the sleeves 1707 and 1708 respectively to receive the sleeves 1707 and 1708 respectively. This space is useful for holding grout, which cures to form a strong joint coupling the modules 1701 and 1702 to each of their respective second modules.

Fig. 17b shows a perspective view illustrating a spacer 1713 to be slotted over the two sleeves 1707 and 1708 of the two modules 1701 and 1702 in Fig. 17a prior to the step of plugging or insertion of the sleeves 1707 and 1708 into the two corresponding upper modules. The spacer 1713 is the same as the spacer 713 of Fig. 7b with the same configuration and advantages, and it is an optional feature. The spacer 1713 is configured to have two holes 1724 for the sleeves 1707 and 1708 to slot through. The holes 1724 are each configured to fit and enable each of the two sleeves 1707 and 1708 to slot through each hole 1724. In this manner, the spacer 1713 becomes a tie plate to restrict lateral movement of the two sleeves 1707 and 1708 with respect to each other, wherein the direction of the restricted lateral movement is orthogonal to the direction of extension of the two sleeves 1707 and 1708 from the two modules 1701 and 1702 respectively. In this manner, the spacer 1713 provides shear resistance to prevent lateral movement of the first module 1500 relative to the second module 1600. As the spacer 1713 is disposed in between the two modules 1701 and 1702 and the corresponding upper modules to be plugged or inserted to the two modules 1701 and 1702, the spacer 1713 has another function to prevent damage when the two modules 1701 and 1702 are plugged or inserted into the corresponding upper modules as it can take some impact. Furthermore, the spacer 1713 can also act as a cover or seal to prevent grout from leaking when grout is applied to each of two sleeves 1707 and 1708 to form grouted sleeve connections. Like the spacer 713 of Fig. 7b, the different examples of spacers in Fig. 9 are also applicable to the spacer 1713.

Fig. 17c is a perspective view specifically illustrating that the holes 1724 of the spacer 1713 of Fig. 17b are sufficiently wide to enable the spacer 1713 to slot over shear keys 1401 to 1404 of the sleeves 1707 and 1708.

Fig. 17d is a perspective view specifically illustrating that the holes 1724 of the spacer 1713 of Fig. 17b are sufficiently wide to enable the spacer 1713 to slot over the shear keys 1720 and 1730 and rest on the end plates 1711 and 1712. Fig. 17d shows the spacer 1713 fully slotted and seated on the two modules 1701 and 1702.

Fig. 17e shows a perspective view of two of the module 1600 of Fig. 16a placed or assembled adjacent to each other. The two modules in Fig. 17e are renumbered as 1714 and 1715 respectively. The columns of the modules 1714 and 1715 are numbered as 1729 and 1721 respectively. The columns 1729 and 1721 are to be joined to the sleeves 1707 and 1708 respectively. Floor beams 1716 and 1717 extend from the module 1714. Floor beams 1718 and 1719 extend from the module 1715. Specifically, the two modules 1714 and 1715 are assembled to contact and be adjacent to each other such that the two floor beams 1716 and 1718 extend in a direction away from each other and the two floor beams 1717 and 1719 extend in a same direction. In the present example, the two modules 1714 and 1715 are arranged in the configuration shown in Fig. 17e are to be used as the corresponding upper modules to be joined to the two modules 1701 and 1702 in Fig. 17d. They are arranged in such configuration prior to plugging or insertion to the sleeves 1707 and 1708 in Fig. 17d of the two modules 1701 and 1702 in Fig. 17d respectively. In Fig. 17e, the shear keys 1607 to 1610 that are evenly spaced along the inner surface of the columns 1729 and 1721 respectively are visible.

Fig. 17f shows a perspective view of an assembled joint with the two modules 1701 and 1702 of Fig. 17a joined to the two modules 1714 and 1715 of Fig. 17e. This assembled joint is the proposed sleeve connection assembly of the present example that is discussed in the present disclosure. This assembled joint can be used as the joint JB in Fig. 3.

Fig. 17g shows an exploded view of the assembled joint of Fig. 17f. In Fig. 17g, the two first modules 1701 and 1702 are grouped together, the two second modules 1714 and

1715 are grouped together, and the spacer 1713 is to be placed between the grouped modules 1701 and 1702 and the grouped modules 1714 and 1715.

Fig. 18a shows a sectional view across C-C of the assembled joint of Fig. 17f. The sectional view reveals the sleeves 1707 and 1708 plugged into the two modules 1714 and 1715 respectively of Fig. 17e before grout is applied to form a grouted sleeve connection. A sectional view of the spacer 1713, which is hidden in Fig. 17f is shown in Fig. 18a.

Fig. 18b shows two sectional views in a top drawing 1801 and a bottom drawing 1802 for comparison. The top drawing 1801 is a sectional view of the grouped modules 1701 and 1702 across C-C of the assembled joint of Fig. 17f before grout 1807 is applied to form a grout sleeve connection. The bottom drawing 1802 is a sectional view across C-C of the assembled joint of Fig. 17f after grout 1807 is applied to form the grouted sleeve connection. There are several ways to apply grout. In Fig. 18b, the shear keys 1720 and 1730 and the end plates 1711 and 1712 are configured in the manner according to the plate structure 2100 of Fig. 19. Hence, the shear key 1720 and end plate 1711 has a common hole 1809 through their centers and the shear key 1730 and end plate 1712 has a common hole 1810 through their centers.

One way to grout the assembled joint shown in Fig. 18a is to make use of the holes 1809 and 1810 to inject grout 1807 to fill voids 1806 and 1803 between the sleeves 1707 and 1708 and the columns 1729 and 1721 of the second modules 1714 and 1715 respectively. It is noted that in the present example, hollow cores 1811 and 1812 of the sleeves 1707 and 1708 respectively are not filled with grout 1807. The grout 1807 may be applied to the voids 1806 and 1803 up to the height of the sleeves 1707 and 1708. If any of the columns 1709, 1710, 1729, and 1721 of the modules 1701, 1702, 1714, and 1715 are designed to be concrete filled tube composite columns, more grout can be applied to fill up inner hollow spaces of such columns. As illustrated by an arrow D in Fig. 18b showing a direction to apply grout 1807, another possible way is to apply grout 1807 through an end of the columns 1729 and 1721 of the second modules 1714 and 1715 that is opposite to the end connected to the first modules 1701 and 1702. After the applied grout 1807 has cured, the sleeves 1707 and 1708 engage the cured grout 1807 in the voids 1806 and 1803 to restrict movement of each first module 1701 and 1702 relative to the second module 1714 and 1715 respectively. In the present example, the shear keys 1720 and 1730, the shear keys 1607 to 1610 in the columns 1729 and 1721, and the shear keys 1401 to 1404 on each sleeve 1707 and 1708 engage the cured grout 1807 in the voids 1806 and 1803 to restrict movement of each first module 1701 and 1702 relative to the second module 1714 and 1715 respectively.

Fig. 18c and Fig. 18d show different ways of grouting the assembled joint of Fig. 18a. Reference numerals for similar parts are reused. Grout is indicated as 1807 in these drawings. Specifically, Fig. 18c shows the hollow cores 1811 and 1812 of the sleeves 1707 and 1708 are grouted respectively in addition to voids 1806 and 1803 between the sleeves 1707 and 1708 and the columns 1729 and 1721 of the second modules 1714 and 1715 respectively. This example uses more grout 1807 but provides a composite design for each sleeve 1707 and 1708 and enhances the confinement in the grout 1807, which further strengthens the axial force and bending moment resistance of the assembled joint. Specifically, Fig. 18d shows grouting in the voids 1806 and 1803 between the sleeves 1707 and 1708 and the columns 1729 and 1721 of the second modules 1714 and 1715 respectively but the hollow cores 1811 and 1812 of the sleeves 1707 and 1708 are not grouted. Caps 1814 (some form of cover) are added to cover the top of each sleeves 1707 and 1708 to seal off and prevent grout 1807 from flowing into the hollow cores 1811 and 1812 respectively. This example uses less grout (reducing cost incurred for grout) compared to the example of Fig. 18c.

Notably, after completion of the grouting process, no fastener is required to further connect the first modules 1701 and 1702 of Fig. 17d to the second modules 1714 and 1715 of Fig. 17e to assemble the proposed sleeve connection assembly of the present example. This is a key advantage of the features of this example of the proposed sleeve connection assembly.

Fig. 20 shows a perspective view of a sleeved structure 2200 of yet another example of sleeve connection assembly proposed in the present disclosure. The sleeved structure 2200 may be used for a reinforcement concrete column. In the sleeve structure 2200, there comprises two sleeves 2201 and 2202 attached to and extending from an end plate 2203. In another example, there could be more of such sleeve 2201 and 2202 attached to and extending from the end plate 2203. The two sleeves 2201 and 2202 may be welded to the

end plate 2203. The sleeves 2201 and 2202 may each be provided with a plurality of holes 2010 to allow for grout to flow in and out of the sleeves 2201 and 2202. In the present example, the sleeves 2201 and 2202 are Square Hollow Sections (SHS) with an elongate hollow core like the sleeve 400 of Fig. 4. Specifically, each of the sleeves 2201 and 2202 has four sides and each side comprises 3 holes of the plurality of holes 2010. In total, the number of the plurality of holes 2010 is 12 holes for each sleeve 2201 and 2202. In another example, the sleeves 2201 and 2202 may not be hollow sections with an elongate hollow core but more resemble solid beams or rods with through-holes. In this example, the hollow center of these through-holes in the sleeves 2201 and 2202 is regarded as forming the hollow core of the sleeves 2201 and 2202, which allows grout to flow through. In further examples, the sleeves 2201 and 2202 may also be Rectangular Hollow Sections (RHS) and the like, and the number of holes could be more or less. These holes 2010 provide the same shear resistance advantage as the holes 401 and 402 of the sleeve 400 of Fig. 4. The holes 2010 allow grout to reside outside the holes 2010 and to fill the space extending into the hollow core of the sleeves 2201, 2202. The holes 2010 help to form a strong grouted sleeve connection to hold the sleeves 2201 and 2202 in place to prevent joint movement in the sleeve connection assembly (or joint) that is formed. The end plate 2203 is attached to a reinforcement element 2204 comprising two inverted U-shaped beams arranged with elongate limbs extending in a common direction from a bridge portion. The elongate limbs are extending in a direction away from the two sleeves 2201 and 2202. Specifically, the end plate 2203 is attached to the bridge portion of the U-shaped beams. The end plate 2203 may be welded to the reinforcement element 2204.

Fig. 21 shows a side view of the sleeves 2201 and 2202 of Fig. 20. In Fig. 21, the U-shaped beams attached to the end plate 2203 are casted in a reinforced concrete column 2301. The end plate 2203 and the reinforced concrete column 2301 are part of a first module and the sleeves 2201 and 2202 are extending from the first module.

Fig. 22 shows a side view of Fig. 21 looking from the direction of an arrow 2110 drawn in Fig. 21. The walls of the reinforced concrete column 2301 are deliberately made transparent to reveal the reinforcement element 2204 of Fig. 20 and reinforcement beams 2205 present inside the reinforced concrete column 2301.

Fig. 22a shows a sectional view E-E of Fig. 21. In the sectional view, the reinforcement element 2204 of Fig. 20 is shown along with the reinforcement beams 2205 present in the reinforced concrete column 2301. The hollow core of each sleeve 2201 and 2202 is illustrated in Fig. 22a and one side of each sleeve 2201 having 3 holes is shown.

Notably, the sleeves 2201 and 2202 are each extending from a planar surface of the end plate 2203 located at one end of the reinforced concrete column 2301. The area of such planar surface is wider than the cross-section of the respective sleeves 2201 and 2202. This enables space/void to be provided between the sleeves 2201 and 2202, and a second module (e.g. 2503 of Fig. 23), which may comprise holes (e.g. 2402 and 2404 of Fig. 24) wider than cross-section of the sleeves 2201 and 2202 and such holes will receive the sleeves 2201 and 2202 respectively. This space is useful for holding grout, which cures to form a strong joint coupling the reinforced concrete column 2301 to the second module. An example of this space/void will be discussed in Fig. 23.

Fig. 23 shows a see-through perspective view of a tube case 2502 that is embedded in a reinforced concrete column 2503. The reinforced concrete column 2503 constitutes of a second module to be joined to the first module described with reference to Fig. 21. The tube case 2502 is configured to receive the sleeves 2201 and 2202 of Fig. 21, which extend from the first module. The tube case 2502 may be made of steel or other suitable material. The tube case 2502 may be provided with an inlet 2501 for grouting purposes. Grout may be injected through the inlet 2501 to fill a void between the sleeves 2201 and 2202 and the inner surface of the tube case 2502. A grouted sleeve connection is formed in this manner. Grout would enter the holes 2010 of the sleeves 2201 and 2202, and enter the space extending through the center of the sleeves 2201 and 2202. The grouted sleeve connection that is

formed provides shear resistance to restrict movement of the first module relative to the second module.

Fig. 24 shows a see-through perspective bottom view of the tube case 2502. An end plate 2601 with two holes 2402 and 2404 may be attached at a bottom of the tube case 2502. The shape of the holes 2402 and 2404 of the end plate 2601 should correspond or match the shape of the sleeves 2201 and 2202 to ensure smooth installation of the first module to the second module and to provide a close fit. Such a close fit contributes to movement restriction of the first module relative to the second module. Therefore, it can be said that the end plate 2601 of the tube case 2502 assists to activate dowel action and that leads to higher structural resistance.

Fig. 25a shows an exploded view of the sleeve connection assembly of the present example. The first module formed as described with reference to Fig. 21 is shown in Fig. 25a and is denoted by a reference numeral 2703 in Fig. 25a. The second module formed as described with reference to Fig. 23 is shown in Fig. 25a and is denoted by a reference numeral 2701 in Fig. 25a.

An optional spacer 2702 similar to the spacer 713 in Fig. 7b and the spacer 1713 in Fig. 17b is shown in Fig. 25a. The spacer 2702 would be disposed in between the first module 2703 and the second module 2701. Like the spacers 713 and 1713, the spacer 2702 will be slotted over the sleeves 2201 and 2202 that are attached to and extending from the first module 2703. In the present example, the spacer 2702 acts as a tie plate. It comprises two holes 2704 for receiving the two sleeves 2201 and 2202 respectively.

Fig. 25b shows a perspective bottom view of Fig. 25a, revealing the end plate 2601 and its holes 2402 and 2404 for the sleeves 2201 and 2202 to plug into.

Fig. 13 shows a grouted sleeve connection that is conventionally used in the offshore industry. However, this type of technology has not been used in onshore structures. Furthermore, the configuration of the steel sections in the offshore industry has been limited to Circular Hollow Sections (CHSs), which are less preferred in modular building construction such as Prefabricated Prefinished Volumetric Construction. One difference between examples of the present disclosure and conventional grouted sleeve connection is that the sleeve of the conventional grouted sleeve connection used for connecting two building structures is not configured to engage cured grout to restrict movement of the two building structures relative to each other. However, the sleeve or sleeves of examples of the present disclosure is or are configured to engage cured grout to restrict such movement, for example through holes (e.g. 401 and 402 of Fig. 4, and 2010 of Fig. 20) or shear keys (e.g. the shear keys 1720 and 1730 of Fig. 17, the shear keys 1607 to 1610 of Fig. 16, and the shear keys 1401 to 1404 of Fig. 14).

Due to the inability of the conventional grouted sleeve connection to strongly engage the cured grout, axial tensile and compression forces are not well transmitted through the conventional grouted sleeve connection. However, as examples of the grouted sleeve connection of the present disclosure has the ability to better engage the cured grout, the axial compression force is transmitted by directing bearing action between the first module and the second module while the axial tensile force is resisted by engaging the cured grout.

Advantages of the examples of the present disclosure over conventional grouted sleeve connection in the offshore industry may include the following:

- a) easy to install with adjustable tolerances;
- b) possess great moment and axial resistance close to member capacity; and
- c) high-fatigue resistance;
- d) increased productivity in modular building construction when used to join individual steel / steel-composite modules together to form multi-storey buildings.

More on benefits/advantages of the proposed sleeve connection assembly of the present disclosure are as follows:

- All installation works for connecting the modules together are performed on the outside of the modules. This will help to speed up the progress of internal finishes work of a modular unit. This will also prevent damages to the internal finishes of the modular unit during the installation works. Furthermore, since less openings are required on the modules, this helps to reduce water penetration into the module and increase the airtightness of the module.

- As no fasteners are required in the sleeve connection assembly (e.g. weldless, boltless, holeless, etc.), the sleeve connection assembly is unique and increases productivity.
- 5 • A grouted sleeve connection joint is provided and it is characterized by better durability and fire resistance.
- The proposed sleeve connection assembly may comprise of moment connections with high axial tensile resistance. This will therefore provide vertical continuity and prevent vertical separation of columns between top and bottom modules under an action of lateral load.
- 10 • The proposed sleeve connection assembly is a more economical design that uses less construction material. There are also more usable spaces due to smaller structural components.
- The proposed sleeve connection assembly enables a plug-in type of module stacking which increases the construction speed of module stacking as compared to bolted connections or multiple rebar splice type of module joining technique. The proposed sleeve connection assembly also allows for larger tolerance level in on-site adjustment while stacking the modules.
- 15 • The proposed sleeve connection assembly may also be modified to be used in regular buildings to act as column or wall splice connections.
- 20 • The proposed sleeve connection assembly is a versatile design that can be adopted in many construction systems (e.g. concrete, steel and composite systems).

Examples of the present disclosure may have the following features.

A sleeve connection assembly for modular building construction, wherein the assembly comprises: a first module (e.g. 500 of Fig. 5, 701 and 702 of Fig. 7a, 1500 of Fig. 15a, 1701 and 1702 of Fig. 17a, 2703 of Fig. 25a, etc.); a second module (e.g. 600 of Fig. 6a, 714 and 715 of Fig. 7c, 1600 of Fig. 16a, 1714 and 1715 of Fig. 17e, 2503 of Figs. 23 and 24, etc); and a sleeve (e.g. 400 of Fig. 4, 708 of Fig. 7a, 1400 of Fig. 14, 1707 and 1708 of Fig. 17a, 2201 and 2202 of Figs. 20, 21, 22, 22a, 25a and 25b, etc.) having a hollow core (e.g. 807 of Fig. 8b; 1811 and 1812 of Fig. 18b, etc.), the sleeve being attached to and extending from the first module, wherein the sleeve is configured to plug into the second module, wherein a grouted sleeve connection connecting the first module to the second module is formed when grout (e.g. 1807 in Fig. 18b, 18c and 18d) is applied to fill a void (e.g. voids 806 and 820 of Fig. 8b, voids 1803 and 1806 of Fig. 18b, etc.) between the sleeve and the second module, wherein the sleeve is configured to engage cured grout in the void to restrict movement of the first module relative to the second module, and no fastener is required to further connect the first module to the second module to assemble the sleeve connection assembly, wherein the first module comprises a column, the sleeve extends from a planar surface at one end of the column, and area of the planar surface is wider than cross-section of the sleeve.

The sleeve and the second module may be fitted in a manner to prevent the first module and the second module from rotating relative to each other about an axis orthogonal to a longitudinal axis (e.g. 606 of Fig. 6a) of the sleeve. In another example, the sleeve and the second module may be fitted in a manner to prevent the first module and the second module from rotating relative to each other about a longitudinal axis (e.g. 606 of Fig. 6a) of the sleeve and about an axis orthogonal to the longitudinal axis of the sleeve.

The sleeve may be configured to slot into one opening (e.g. 2402 and 2404 of Fig. 24) of the second module so as to plug into the second module and the opening is configured to match shape of the sleeve to provide a close fit.

The second module may be a tube structure (e.g. 2502 of Fig. 23) comprising the opening, wherein the opening is configured to receive the sleeve.

The tube structure may comprise an inlet (e.g. 2501 of Fig. 23) for grout to flow therethrough to fill a hollow core of the tube structure, wherein the hollow core of the tube structure comprises the sleeve projecting through the opening.

The sleeve may have one or more holes (e.g. 401 and 402 of Fig. 4, 809 of Fig. 8b, 2010 of Fig. 20, etc.) to allow grout to flow therein to enable the sleeve to engage the cured grout in the void to restrict movement of the first module relative to the second module.

The sleeve may comprise one or more shear key (e.g. 1401, 1402, 1403, and 1404 of Fig. 14,) to enable the sleeve to engage the cured grout in the void to restrict movement of the first module relative to the second module.

5 The first module or second module may comprise one or more beam (e.g. 502 and 504 of Fig. 5, 703, 704 705 and 706 of Fig. 7b, 716, 717, 718 and 719 of Fig. 7c, 1703, 1704, 1705, and 1706 of Fig. 17a, 1716, 1719, 1717, and 1718 of Fig. 17e, etc.) extending from the first module or second module respectively in a direction orthogonal to direction of extension of the sleeve from the first module.

10 More than one of the beam extending from the first module or second module respectively may be arranged to extend orthogonally with respect to one another.

The first module may comprise a column (e.g. 505 of Fig. 5, 709 and 710 of Fig. 7a, 1505 of Fig. 15a, 1709 and 1710 of Fig. 17b, 2301 of Figs. 21, 22 and 22a, etc.) on which the sleeve is attached and a plate (e.g. 1000 of Fig. 10 and 1100 of Fig. 11) is fixed to the column with an access hole (e.g. 1001 of Fig. 10 and 1101 of Fig. 11) forming an inlet for grout to flow therethrough to fill the hollow core of the sleeve.

15 The assembly may comprise a spacer (e.g. 713 of Fig. 7b, 1713 of Fig. 17b, and 902 of Fig. 9, and 2702 of Fig. 25a) disposed between the first module and the second module.

There may be at least two of the sleeves (e.g. 707 and 708 of Fig. 7a; 1707 and 1708 of Fig. 17a; 2201 and 2202 of Figs. 20, 21, 22, 22a, 25a and 25b, etc.) and the at least two sleeves may be attached to one or more of the first module and extending in a same direction from the one or more first module, wherein the at least two sleeves may be configured to engage one or more of the second module, and the spacer may be configured to engage the at least two sleeves to restrict lateral movement of the at least two sleeves with respect to one another, wherein direction of the restricted lateral movement is orthogonal to the direction of extension of the at least two sleeves from the one or more first module.

25 The spacer may be a tie plate comprising holes (e.g. 724 of Fig. 7b, 1724 of Fig. 17b and 2704 of Fig. 25a), wherein each hole receives each of the at least two sleeves respectively.

There may be more than one of the first module and each of the at least two sleeves extends from each first module.

30 There may be more than one of the second module and each of the at least two sleeves is configured to plug into each second module.

The second module may comprise one or more shear key (e.g. 1607 to 1610 of Fig. 17e) to enable the second module to engage the cured grout in the void to restrict movement of the first module relative to the second module.

35 The hollow core of the sleeve may be applied with grout.

The hollow core of the sleeve may be covered to prevent grout flowing into the hollow core.

A method for modular building construction, the method comprising: assembling a sleeve connection assembly by: plugging into a second module (e.g. 100 of Fig. 1, 600 of Fig. 6a, 714 and 715 of Fig. 7c, 1600 of Fig. 16a, 1714 and 1715 of Fig. 17e, 2503 of Figs. 23 and 24, etc.), a sleeve (e.g. 400 of Fig. 4, 708 of Fig. 7a, 1400 of Fig. 14, 1707 and 1708 of Fig. 17a, 2201 and 2202 of Figs. 20, 21, 22, 22a, 25a and 25b, etc.) with a hollow core (e.g. 807 of Fig. 8b; 1811 and 1812 of Fig. 18b, etc.) that is attached to and extending from a first module (e.g. 100 of Fig. 1, 500 of Fig. 5, 701 and 702 of Fig. 7a, 1500 of Fig. 15a, 1701 and 1702 of Fig. 17a, 2703 of Fig. 25a, etc.); and applying grout to fill a void (e.g. voids 806 and 820 of Fig. 8b, voids 1803 and 1806 of Fig. 18b, etc.) between the sleeve and the second module to form a grouted sleeve connection connecting the first module to the second module, wherein the sleeve is configured to engage cured grout (e.g. 1807 in Fig. 18b, 18c and 18d) in the void to restrict movement of the first module relative to the second module, and no fastener is required to further connect the first module to the second module to assemble the sleeve connection assembly, wherein the first module comprises a column, the sleeve extends from a planar surface at one end of the column of the first module, and area of the planar surface is wider than cross-section of the sleeve.

When there is more than one of the first module, there may be at least two of the sleeves (e.g. 707 and 708 of Fig. 7a; 1707 and 1708 of Fig. 17a; 2201 and 2202 of Figs. 20, 21, 22, 22a, 25a and 25b, etc.), the at least two sleeves may be attached to the more than one first modules and may be extending in a same direction from the more than one first modules, and each of the at least two sleeves may extend from each first module. In this case, the method may comprise: placing each first module in contact with each other to form a single module comprising the at least two sleeves (some examples of the at least two sleeves are illustrated in Fig. 7a and Fig. 17a) before the step of plugging the at least two sleeves into one or more of the second module (some examples are illustrated in Fig. 7e and Fig. 17g).

10 The method may further comprises disposing a spacer (e.g. 713 of Fig. 7b, 1713 of Fig. 17b, and 902 of Fig. 9) between the first module and the second module, wherein the spacer is configured to engage the at least two sleeves to restrict lateral movement of the at least two sleeves with respect to one another, wherein direction of the restricted lateral movement is orthogonal to the direction of extension of the at least two sleeves from the one or more first module.

15 With regard to the sleeve connection assembly described in examples of the present disclosure, in one example, the first module (e.g. 500 of Fig. 5, 701 and 702 of Fig. 7a, 1500 of Fig. 15a, 1701 and 1702 of Fig. 17a, 2703 of Fig. 25a, etc.) may be a column configured to attach to the sleeve (e.g. 400 of Fig. 4, 708 of Fig. 7a, 1400 of Fig. 14, 1707 and 1708 of Fig. 17a, 2201 and 2202 of Figs. 20, 21, 22, 22a, 25a and 25b, etc.). The cross-section of such column may be non-hollow such as a H sectional column or I sectional column. During assembling of the sleeve connection assembly, such non-hollow H or I sectional column may be welded in a manner such that the non-hollow H or I sectional column is welded via an intermediate plate to an element having a hollow section. Hence, the intermediate plate is positioned between the non-hollow H or I sectional column and the element having the hollow section. The intermediate plate may be welded to the non-hollow H or I sectional column and the element at a position approximately three-quarters of the total height of the final structure comprising the non-hollow H or I sectional column welded on with the element. In this way, the final structure will have a portion comprising the non-hollow H or I sectional column and a portion comprising the element with a cross-section that is hollow for receiving the sleeve. In another example, the sleeve may be welded to the element after the element receives the sleeve. In yet another example, the sleeve may be welded to the intermediate plate that is welded to the non-hollow H or I sectional column and the element is not present. In a further example, the sleeve may be welded directly to the non-hollow H or I sectional column and both the intermediate plate and the element are not present.

35 The terms "tube structure", "tube case", "tube column", "tube composite column" etc. used in the present disclosure may have cross-section with shapes such as circle, square, rectangle, triangle, H-shape, semi-circular and the like.

40 In the specification and claims, unless the context clearly indicates otherwise, the term "comprising" has the non-exclusive meaning of the word, in the sense of "including at least" rather than the exclusive meaning in the sense of "consisting only of". The same applies with corresponding grammatical changes to other forms of the word such as "comprise", "comprises" and so on.

45 While the invention has been described in the present disclosure in connection with a number of embodiments and implementations, the invention is not so limited but covers various obvious modifications and equivalent arrangements, which fall within the purview of the appended claims. Although features of the invention are expressed in certain combinations among the claims, it is contemplated that these features can be arranged in any combination and order.

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CLAIMS

1. A sleeve connection assembly for modular building construction, wherein the assembly comprises:
 - 5 a first module;
 - a second module; and
 - a sleeve having a hollow core, the sleeve being attached to and extending from the first module, wherein the sleeve is configured to plug into the second module,
 - 10 wherein a grouted sleeve connection connecting the first module to the second module is formed when grout is applied to fill a void between the sleeve and the second module,
 - wherein the sleeve is configured to engage cured grout in the void to restrict movement of the first module relative to the second module,
 - 15 and no fastener is required to further connect the first module to the second module to assemble the sleeve connection assembly,
 - wherein the first module comprises a column, the sleeve extends from a planar surface at one end of the column, and area of the planar surface is wider than cross-section of the sleeve.
- 20 2. The sleeve connection assembly of claim 1, wherein the sleeve and the second module are fitted in a manner to prevent the first module and the second module from rotating relative to each other about a longitudinal axis of the sleeve and about an axis orthogonal to longitudinal axis of the sleeve.
- 25 3. The sleeve connection assembly of claim 1 or 2, wherein the sleeve is configured to slot into one opening of the second module so as to plug into the second module and the opening is configured to match shape of the sleeve to provide a close fit.
- 30 4. The sleeve connection assembly of claim 3, wherein the second module is a tube structure comprising the opening, wherein the opening is configured to receive the sleeve.
- 35 5. The sleeve connection assembly of claim 4, wherein the tube structure comprises an inlet for grout to flow therethrough to fill a hollow core of the tube structure, wherein the hollow core of the tube structure comprises the sleeve projecting through the opening.
- 40 6. The sleeve connection assembly of any one of claims 1 to 5, wherein the sleeve has one or more holes to allow grout to flow therein to enable the sleeve to engage the cured grout in the void to restrict movement of the first module relative to the second module.
- 45 7. The sleeve connection assembly of any one of claims 1 to 6, wherein the sleeve comprises one or more shear key to enable the sleeve to engage the cured grout in the void to restrict movement of the first module relative to the second module.
- 50 8. The sleeve connection assembly of any one of claims 1 to 7, wherein the first module or second module comprises one or more beam extending from the first module or second module respectively in a direction orthogonal to direction of extension of the sleeve from the first module.
- 55 9. The sleeve connection assembly of claim 8, wherein more than one of the beam extending from the first module or second module respectively are arranged to extend orthogonally with respect to one another.
- 60 10. The sleeve connection assembly of any one of claims 1 to 9, wherein the first module comprises a column on which the sleeve is attached and a plate fixed to the column with an access hole forming an inlet for grout to flow therethrough to fill the hollow core of the sleeve.

11. The sleeve connection assembly of any one of claims 1 to 10, wherein the assembly comprises a spacer disposed between the first module and the second module.
- 5 12. The sleeve connection assembly of claim 11, wherein there is at least two of the sleeve and the at least two sleeves are attached to one or more of the first module and extending in a same direction from the one or more first module, wherein the at least two sleeves are configured to engage one or more of the second module, and
10 the spacer is configured to engage the at least two sleeves to restrict lateral movement of the at least two sleeves with respect to one another, wherein direction of the restricted lateral movement is orthogonal to the direction of extension of the at least two sleeves from the one or more first module.
13. The sleeve connection assembly of claim 12, wherein the spacer is a tie plate comprising holes, wherein each hole receives each of the at least two sleeves respectively.
14. The sleeve connection assembly of claim 12 or 13, wherein there is more than one of the first module and each of the at least two sleeves extends from each first module.
- 20 15. The sleeve connection assembly of any one of claims 12 to 14, wherein there is more than one of the second module and each of the at least two sleeves is configured to plug into each second module.
- 25 16. The sleeve connection assembly of any one of claims 1 to 15, wherein the second module comprises one or more shear key to enable the second module to engage the cured grout in the void to restrict movement of the first module relative to the second module.
- 30 17. The sleeve connection assembly of any one of claims 1 to 16, wherein the hollow core of the sleeve is to be applied with grout.
- 35 18. The sleeve connection assembly of any one of claims 1 to 17, wherein the hollow core of the sleeve is covered to prevent grout flowing into the hollow core.
- 40 19. A method for modular building construction, the method comprising:
assembling a sleeve connection assembly by:
plugging into a second module, a sleeve with a hollow core that is attached to and extending from a first module; and
applying grout to fill a void between the sleeve and the second module to form a grouted sleeve connection connecting the first module to the second module, wherein the sleeve is configured to engage cured grout in the void to restrict movement of the first module relative to the second module,
45 and no fastener is required to further connect the first module to the second module to assemble the sleeve connection assembly,
wherein the first module comprises a column, the sleeve extends from a planar surface at one end of the column of the first module, and area of the planar surface is wider than cross-section of the sleeve.
- 50 20. The method of claim 19, wherein there is more than one of the first module, there is at least two of the sleeve, the at least two sleeves are attached to the more than one first modules and extending in a same direction from the more than one first modules, and each of the at least two sleeves extends from each first module, wherein the method comprises:
55 placing each first module in contact with each other to form a single module comprising the at least two sleeves before the step of plugging the at least two sleeves to one or more of the second module.
21. The method of claim 20, wherein the method comprises:

5 disposing a spacer between the first module and the second module, wherein the spacer is configured to engage the at least two sleeves to restrict lateral movement of the at least two sleeves with respect to one another, wherein direction of the restricted lateral movement is orthogonal to the direction of extension of the at least two sleeves from the one or more first module.