

PREFABRICATED MODULE INTERCONNECTION FOR MODULAR BUILDING**Field of the Invention:**

The invention relates to construction from prefabricated modules, such as Modular Integrated Construction (MIC)/Prefabricated Prefinished Volumetric Construction (PPVC) and, more particularly, to interconnection between prefabricated modules used to construct multi-storey buildings.

Background:

Traditional construction of multi-storey buildings such as high-rise apartment buildings and office buildings is a time-consuming and expensive process. Due to weather conditions, construction may be delayed or damaged or may be impractical during certain seasons. Interior finishing and electrical/plumbing connections may be made in less-than-ideal environments with extensive re-working required when defects are discovered.

In order to accelerate building construction and improve quality control, various modular construction techniques are being adopted. Modular Integrated Construction (MIC) and Prefabricated Prefinished Volumetric Construction (PPVC) involve the creation of modules in a controlled factory environment, followed by assembly onsite into a multi-storey building. Typically, the prefabricated modules represent a unit of a building, such as a flat, apartment, office, or a portion thereof, optionally formed complete with plumbing fixtures, electrical wiring, built-in cabinets, etc. The prefabricated modules may include up to four vertical walls and a ceiling and floor; alternatively, they may have fewer than four walls and only a ceiling or floor with the third and/or fourth wall and either ceiling or floor being provided by an adjacent module. FIG. 1 (prior art) depicts the construction of a multi-storey building 10 in which prefabricated modules are lifted into place by a crane and joined together in a unitary structure.

Several techniques exist to join prefabricated modules together. Typically, mechanical solutions are employed, for example, a pin from one module being inserted into a mating recess or socket or horizontal and vertical plates bolted to the modules and interconnected with each other. These are commonly used for steel-based modules. Newer connection techniques have also been proposed. For example, WO 2017/058117 uses a module-joining technique involving a retainer, fastener, and link plate. WO 2018/101891 depicts interlocking plates for steel-framed PPVC modules. SG 10201703972W describes a technique for making composite

structural walls in PPVC construction in which channels formed in a pair of wall channels receive a linking rod.

While these techniques are acceptable for many environments, locations that are subject to extreme conditions such as high winds (typhoons, hurricanes) or earthquakes may require greater strength in the joints between adjacent prefabricated modules. Further, many prior art joining techniques are directed to steel-framed based modules rather than concrete-based modules. Thus, there is a need in the art for high-strength connections in modular construction to accommodate the needs of buildings subject to potentially harsh environments.

10 Summary

The present invention provides an attachment between concrete-based prefabricated modules that are positioned adjacent to one another in a single storey of a multi-storey modular building. In the multi-storey building, there is a first concrete-based prefabricated module wherein at least a portion of the module is load bearing. The first prefabricated module includes at least two concrete-based vertical walls and at least one horizontal structure selected from a ceiling or a floor that is at least partially attached to the at least two vertical walls. A plurality of first reinforcing attachment members is connected to at least a first vertical wall of the first concrete-based prefabricated module vertical walls, each reinforcing attachment member having periodic projections extending from the first vertical wall.

A second concrete-based prefabricated module is positioned in the same storey with the first concrete-based prefabricated module. As with the first concrete-based prefabricated module, at least a portion of the second module is load bearing. The second prefabricated module includes at least two concrete-based vertical walls and at least one horizontal structure selected from a ceiling or a floor that is at least partially attached to the at least two vertical walls. A plurality of second reinforcing attachment members is connected to at least a second vertical wall of the second concrete-based prefabricated module vertical walls. Each reinforcing attachment member has periodic projections extending from the second vertical wall.

The first concrete-based prefabricated module and the second concrete-based prefabricated module are positioned adjacent to one another within a single storey of the multi-storey modular building such that the first attachment member periodic projections face the second attachment member periodic projections. A tie assembly engages the first and second attachment member periodic projections. In-situ cast concrete embeds the first and second

attachment members and fills a space between the first concrete-based prefabricated module first vertical wall and the second concrete-based prefabricated module second vertical wall.

Brief Description of the Drawings:

- 5 FIG. 1 (prior art) schematically depicts a multi-storey building constructed from plural prefabricated modules.
- FIG. 2 schematically depicts two adjacent prefabricated modules.
- FIG. 3 schematically depicts a prefabricated module with a plurality of reinforcing attachment members embedded in a module vertical wall.
- 10 FIG. 4 schematically depicts a girder for use as a reinforcing attachment member.
- FIG. 5 is a top view of a girder embedded in a module vertical wall.
- FIG. 6 is a horizontal view of two girders positioned in facing adjacent vertical walls of two prefabricated modules.
- FIGS. 7A and 7B respectively depict side and top views of forces in two girders positioned in
- 15 facing adjacent vertical walls of two prefabricated modules.
- FIGS. 8A and 8B depict a further embodiment of a reinforcing attachment member.
- FIG. 9 depicts a further embodiment of a reinforcing attachment member.
- FIG. 10 depicts a further embodiment of a reinforcing attachment member.
- FIGS. 11A and 11B respectively depict top and side views of a composite wall using the
- 20 reinforcing attachment member of FIG. 10.
- FIG. 12 depicts a module wall with a plurality of reinforcing attachment members of FIG. 10.
- FIG. 13 depicts forces in a composite wall using the reinforcing attachment member of FIG. 10.
- FIGS. 14A and 14B depict a further embodiment of a reinforcing attachment member.
- 25 FIGS. 15A, 15B and 15C depict a further embodiment of a reinforcing attachment member.
- FIGS. 16A and 16B depict a tying system for holding together two adjacent module walls.
- FIGS. 17A and 17B depict a further embodiment of a tying system for holding together two adjacent module walls.
- FIG. 18 is a prior art embodiment of joining walls.
- 30 FIG. 19 shows a tie bar assembly (left) and a cross-section of a slotted hollow section assembly (right) used to join modules in a further embodiment of the present disclosure.
- FIG. 20 shows the slotted hollow section assembly and tie bar assembly of FIGS. 19A and 19B assembled together to connect two modules.

Detailed Description

Turning to the drawings in detail, FIG. 2 depicts a first, concrete-based prefabricated module 100 and a second, concrete-based prefabricated module 200 positioned adjacent to each other. Module 100 includes a first vertical wall 110 and a second vertical wall 120 along with a floor 130 attached to first vertical wall 110 and second vertical wall 120. Similarly, module 200 includes a first vertical wall 210 and a second vertical wall 220, the second vertical wall being positioned adjacent to the first vertical wall 110. The second module includes a second floor 230 attached to the second module vertical walls 210 and 220.

Alternatively, one of the walls may instead be comprised of one or more support columns instead of a planar wall as shown in the FIGS. However, as the term is used in the specification and claims, “wall” includes a planar wall, or support columns, or a portion of a wall. In short, any supporting member that is attached to a floor or ceiling along with an additional wall member may form a module according to the present invention.

Each of the prefabricated modules include load-bearing elements so that the modules may be used to build a multi-storey building such as building depicted in FIG. 1. The load-bearing elements may be one of the vertical walls or support columns. In the load-bearing walls and columns, reinforcing steel bars (“rebar”) are positioned in horizontal and vertical directions for strengthening the structure. When the prefabricated modules are used to form housing units, various features may be incorporated such as windows, plumbing, electrical wiring, built-in units such as kitchen cabinets, flooring, HVAC, etc. Advantageously, by constructing various finishings in a factory setting, factory testing may be performed to ensure proper functioning of all components prior to assembly at the building site. Alternatively, the prefabricated modules may be shells that are finished following assembly into a multi-storey building. The level of finishing of the modules does not impact the attachments of the present invention.

In forming the multi-storey building 10, it is necessary to join pre-cast load-bearing walls 110 and 220 to form a composite load-bearing wall that has enhanced structural capacity compared to the sum of the individual precast walls. To this end, reinforcing attachment members are embedded in an exterior surface of the respective walls.

FIG. 3 depicts a plurality of reinforcing attachment members 300 connected to at least a first vertical wall of the first concrete-based prefabricated module 100. As best seen in FIG. 4, each reinforcing attachment member 300 includes a base portion 310 embedded in the first vertical wall and periodic projections 320 extending away from the base portion. In the embodiment of FIG. 4, the reinforcing attachment member is selected to be a girder although, as seen below, a wide variety of reinforcing attachment member configurations may be used

in the present invention. The particular attachment member 300 is a lattice girder that includes two base rails 310 and a pair of triangular truss-configured projections extending towards a third rail 330 that periodically repeat along the length of the girder. In one embodiment, the base rails 310 of the girder are embedded in the pre-cast concrete walls with the truss-shaped projections 320 extending away from the embedded base.

To connect walls 110 and 220 of FIG. 2, both walls 110 and 220 include the reinforcing attachments 300. The modules are positioned adjacent to one another such that the projections 320 do not overlap in the horizontal plane (the “long” direction of the wall) as seen in the top view of FIG. 5. An approximately 10 mm gap may be maintained between the adjacent reinforcing attachments/girders. In the vertical plane, (the “short” direction of the wall) as seen in the side view of FIG. 6, respective projections/truss members 320, 320’ from each of the attachments 300 overlap, creating a strengthening structure to be described in further detail below. When prefabricated modules 100 and 200 are positioned with the attachment members 300 as shown in FIGS. 5 and 6, concrete is cast in-situ, element 400, such that the two pre-cast walls, attachment members 300 and in-situ cast concrete forms a single composite wall with a total thickness equal to the sum of the two precast walls and the cast in-situ core.

Turning to FIG. 7, the distribution of forces is shown in the formed composite wall comprising the two vertical precast walls 110 and 220, attachment members 300, and in-situ cast concrete 400. When a load is applied to the wall, stresses will be generated tending to separate walls 110, 220, and in-situ cast concrete 400. In the absence of attachments 300, there is substantial stress borne by the bond between the in-situ cast concrete 400 and the walls 110 and 220. In high-loading environments, such as during a typhoon or hurricane, the bond is insufficient to withstand these forces. Therefore, the composite wall will fail, not attaining the normal capacity of a comparable-thickness monolithic reinforced concrete wall.

In contrast, the overlapping projections 320 of the attachment members 300 are able to transfer tensile and shear forces across the three composite wall components, walls 110, 220, and in-situ concrete 400. In the side view of FIG. 7A, attachment members 300 and 300’ respectively project from walls 110 and 220, with projections 320 and 320’ overlapping in the vertical plane but not the horizontal plane. Due to splitting stresses from an applied load, tensile forces are formed in the truss-shaped diagonal projections 320 and 320’. In the region 360 of FIG. 7A, the projections 320 and 320’ overlap. A concrete strut is formed in region 360 from the in-situ concrete 400, the strut acting between an apex of projection 320 and an apex of projection 320’. A compressive force is formed in the concrete strut which is transmitted to the apex of the triangular-shaped projection 320 and the apex of the triangular-shaped

projection 320'; this results in the tensile stresses in the respective diagonal members of the attachments 300 and 320'. Because the diagonal members cross the interphase region at an angle, interphase shear is resisted as well. This overall combination of forces holds the opposite walls 110 and 220 together, creating a stronger composite wall.

As discussed above, the particular configuration of the reinforcing attachment members 300 in FIGS. 4-7 represents only one of many possible configurations for a reinforcing attachment member. Alternative configurations are depicted in FIGS. 8-14. FIGS. 8A and 8B depict top and side views of a planar truss girder 500 used as a reinforcing attachment member. The planar truss girder includes a single set of triangular projections 520 attached to a base member 510. FIG. 9 depicts a sinusoidal-shaped girder 600 in which the repeating projections are sinusoidal curves 620 from a base 610. In both FIGS. 8 and 9, there are overlapping regions from opposing girders projecting from facing walls. As a result, the force distribution is substantially similar to that depicted in FIGS. 7A and 7B.

A further embodiment of reinforcing attachment members is depicted in FIG. 10. FIG. 10 depicts an attachment member 700 including an array of projecting shear studs 720 attached to a base member 710. In one aspect, the base member may be embedded in a vertical concrete wall 110, with projections 720 extending outward from the wall as shown in FIG. 12. FIG. 11A depicts a top view while FIG. 11B depicts a side view of the projecting shear studs 720 depicting the overlapping and non-overlapping configurations in respective planes. FIG. 13 depicts the distribution of forces during loading of the composite wall formed by the vertical walls 110, 220, and in-situ concrete 400. The letter T indicates the tension in the shear studs 720 while the letter C indicates the compressive forces in the in-situ concrete 400. The letter c' indicates a balancing compressive force in the concrete. The forces are similar to the concrete strut action depicted in FIGS. 7A and 7B; thus, the composite wall does not shear apart.

In an alternative embodiment, a C-channel plate may be used as the reinforcing attachment member. FIGS. 14A and 14B respectively depict top and side views of C-channel plates 800 embedded in concrete walls 110 and 220. In the C-channel, one side of the "C" acts as base member 810 while the other side of the C 820 acts as the projecting member. FIG. 14C depicts the tension and compression forces in the C-channel and the concrete enveloped by the C-channel.

In another aspect as shown in FIG. 15A and FIG. 15B, a plate 900 having perforations 950 may be used as the reinforcing attachment member. The perforations 950 create the effect of an alternating periodic structure that overlaps a mating alternating periodic structure in facing

walls 110 and 220. FIG. 15C depicts the structural action of the perforated plate 900 depicting the regions of tension and compression.

Depending upon the required strength of the composite wall, additional mechanisms may be employed to increase the strength. In one aspect, in-situ casting of the concrete may tend to force adjacent module vertical walls apart. Therefore, it may be advantageous to include a tying system between adjacent module vertical walls. Examples of tying systems are depicted in FIGS. 16A, 16B, 17A, and 17B. Turning to top view of FIG. 16A, metallic C-channels 1100 and 1110 are cast in adjacent module vertical walls 110 and 220. Prior to casting the concrete 400, tying members 1120 are inserted into the C-channels 1100 and 1110 with heads 1125 received in the channel such that the heads cannot be pulled out by forces tending to separate walls 110 and 220 (e.g., during casting of the concrete). For resisting pull-out, C-channels with lips may be used. The tying members 1120 may be metal bolts with enlarged heads 1125 or any other linking rod that can be received in the C-channels.

An alternative tying system is depicted in FIGS. 17A and 17B. FIG. 17A depicts a set of C-channels 1100 cast in module vertical wall 110. A set of tying members 2000 is cast in adjacent module wall 220. When the module 100 is positioned adjacent to module 200, the tying members are slid into C-channels 1100 to link the first and second modules. The tying member may be a shear stud/rod with an enlarged head 2010. In the embodiments of both FIGS. 16 and 17, tension in the tying member prevents the separation of the composite wall; that is, wall 110 does not separate from wall 220 due to the action of the tying members and the C-channels.

Alternative Connection of Module Walls (FIGS. 19-20)

Description of Slotted hollow section assembly

A slotted hollow section assembly, including perforated steel plate 2500, as seen in FIG. 19B, is placed at intervals along the length of a module wall (as seen in FIG. 20). FIG. 19A depicts a tie bar 2400 for linking together periodic steel reinforcements 2410 embedded in respective concrete module walls 2620 and 2630 as seen in FIG. 20. These assemblies perform the following functions:

1. When concrete or cement grout is poured into a gap between walls, hydrostatic pressure tends to force walls 2620 and 2630 apart. The assemblies tie the walls together and withstand the hydrostatic pressure until the concrete or grout hardens.

2. After the concrete or grout hardens, the assemblies act as normal confinement links and ties in reinforced concrete construction and prevent buckling of reinforcing steel bars and splitting of the concrete section under compression.

5 FIG. 18 depicts a prior art connection system for concrete walls in which U-shaped ties are inserted into re-bar loops in adjacent concrete walls.

Turning to FIG. 20, the use of the tie bar assembly and perforated steel plate of FIGS. 19A and 19B are demonstrated in connecting module walls. A steel hollow section 2510 may be cast into each wall as shown in FIG. 20, labelled as wall A 2630 and opposite wall B 2620 to be connected. The steel hollow sections 2510 are anchored to the respective walls. A slot 2512 is cut on one side of the steel hollow section 2510. The hollow steel sections 2510 are positioned such that the slots 2512 face one another. After the module walls 2620 and 2630 are erected in place, there is only a small gap 2700 between the opposite facing steel hollow sections 2510. A steel plate with perforations 2500 is inserted into the slots 2512 of the steel hollow sections 2510. The steel plate 2500 is configured to fit into the slot 2512 formed by the hollow steel sections 2510. Perforations 2502 are pre-drilled in the steel plate 2500 such that when it is lowered down progressively into the steel hollow sections 2510, steel rods 2800 can be inserted into the perforations 2502. The length of steel rods 2800 is designed such that it is slightly, say 2mm, shorter than the clear width of the steel hollow section. Once the steel rods 2800 are slotted into the steel plate 2500 and lowered into the steel hollow section 2510, the steel rods 2800 follow the steel plate 2500 to be lowered into the final position. In its final state, pairs of steel rods 2800 will be positioned at fixed vertical intervals along the height of wall A and wall B. The vertical intervals may be selected to be any range of values according to requirements of code of practice or structural design requirements, for example, the necessary strength of the joints. The spacing may be closer for jurisdictions that require extra strength due to seismic activity, hurricane or typhoon zones.

For each pair of steel rods 2800, one is lodged in the steel hollow section 2510 of wall A and the other in the steel hollow section 2510 of wall B. When concrete or grout fills the void between wall A and B, hydrostatic pressure pushes the steel hollow sections 2510 away from one another. The steel rods 2800, being restrained by both the steel plate and the hollow sections themselves, will push against the steel hollow section wall in the vicinity of the opposing slots 2512. This action prevents movement of the steel hollow sections 2510, and hence the respective wall A or B which anchors the steel hollow section. Therefore, a structural

tie action is effected by the hollow section assembly. After concrete or grout hardens, the structural tie action remains. Any forces that tend to split the concrete or grout filler will be resisted by the slotted hollow section assembly.

5 *Description of Steel Bar Tie Assembly*

The steel bar tie assembly is another technique to prevent separation of walls A and B when concrete or grout filler is pumped in to a gap between the walls. Although several techniques are depicted in FIG. 20 for joining the walls, each assembly may be used independent of the other assemblies or together depending on the required strength of the joint between the walls/modules. The steel bar tie assembly is provided along the length of the wall.

In each of walls A and B, open loop steel bars 2900 may be embedded such that a portion of the loop extends out of the concrete wall as seen in FIG. 20.

For the module wall connections according to the present embodiment, two walls from adjacent modules, wall A and wall B, are placed side by side. Open loops are cast into the walls A and B. The walls are placed such that open loops are side by side, see FIG. 20.

A tie assembly 2400 consists of a straight metal bar 2410 and a number of “L” shaped joining metal bar segments 2420, as seen in FIG. 19A. The “L” shaped metal bar segments 2420 are joined to the straight bar 2410, for example, by welding or mechanical fasteners. The dimensions and diameters of the straight bar 2410 and “L” shaped metal joining bars are chosen according to structural design requirements and the size of the loops 2900. Further, the L-shaped joining metal bars may take on other shapes as long as there is a portion of the shape that can engage a loop 2900.

At a precast yard, the tie assembly may be temporarily fixed to the open loop reinforcement with wires or other attachments, and be in position in loops 2900 when either wall A or B is cast. After the module is delivered to a construction site and placed in position, the temporary attachment will be removed (e.g., an attachment wire will be cut), such that the tie assembly is free to be moved within the open loop reinforcement and free to rotate, pivoting about the vertical steel bar 2410.

From the above description, the steel loop reinforcement 2900 of walls A and B are side by side. In the example set forth above, the tie bar 2400 is pre-assembled within the loop. The clear vertical spacing of each adjacent loop reinforcement 2900 may be slightly larger than the overall height of the “L” shaped joining bar segments. Therefore, the tie assembly 2400 may pivot about the straight bar (inside the loop of wall A) to rotate the vertical leg of the “L” shaped bar segments 2420 into a corresponding reinforcing loop 2900 of wall B, and lower the

tie assembly to engage the corresponding open loop. The resulting position of the tie assembly will have the straight bar positioned within the wall A open loops, and the vertical leg of “L” shaped joining bar segments within wall B open loops. Therefore, a structural tie action ~~similar to a U-shaped bar~~ is achieved with the arrangement. After concrete or grout is cast into the void

5 space, a structural tie action continues inside the concrete or grout.

In an alternative embodiment, the tie assembly 2400 may be used to connect a pair of periodically-projecting reinforcing steel bars 3000 that extend through each of walls A and B as described in the above embodiments. As seen in FIG. 20, steel bars 3000 are partially embedded in each wall and partly project outward from each respective wall, forming a closed

10 loop with the surface of each wall. As with the loop reinforcement described above, a tie assembly 2400 may be positioned with a closed-loop section of a periodically-projecting reinforcing steel bar 3000. Temporary attachments may be provided, such as a wire, to tie the tie assembly 2400 to steel bar 3000. As in the previous embodiment, the attachment is severed and the bar is free to pivot, inserting L-shaped joining portion 2420 into the mating

15 periodically-projecting reinforcing steel bar 3000 to engage the facing steel bar 3000, tying together the respective walls A and B in which the reinforcing steel bars 3000 are embedded. The tie resists the hydrostatic pressure from the concrete or grout poured into the space to fill the gap between walls A and B.

20 It should be apparent to those skilled in the art that many modifications besides those already described are possible without departing from the inventive concepts herein. The inventive subject matter, therefore, is not to be restricted except in the spirit of the disclosure. Moreover, in interpreting the disclosure, all terms should be interpreted in the broadest possible manner consistent with the context. In particular, the terms “includes”, “including”, “comprises”

25 and “comprising” should be interpreted as referring to elements, components, or steps in a non-exclusive manner, indicating that the referenced elements, components, or steps may be present, or utilized, or combined with other elements, components, or steps that are not expressly referenced.

CLAIMS

1. A multi-storey modular building comprising a plurality of concrete-based prefabricated modules, the building comprising:

5 a first concrete-based prefabricated module wherein at least a portion of the module is load-bearing, the first prefabricated module including at least two concrete-based vertical walls and at least one horizontal structure selected from a ceiling or a floor that is at least partially attached to the at least two vertical walls;

10 a plurality of first reinforcing attachment members connected to at least a first vertical wall of the first concrete-based prefabricated module vertical walls, each reinforcing attachment member comprising a shaped bar having periodic projections in which at least a portion of the shaped bar is embedded in the first vertical wall and at least a portion of the periodic projections extends outside the first vertical wall forming a closed loop between the projections and the wall;

15 a second concrete-based prefabricated module wherein at least a portion of the module is load bearing, the second prefabricated module including at least two concrete-based vertical walls and at least one horizontal structure selected from a ceiling or a floor that is at least partially attached to the at least two vertical walls;

20 a plurality of second reinforcing attachment members connected to at least a second vertical wall of the second concrete-based prefabricated module vertical walls, each reinforcing attachment member comprising a shaped bar having periodic projections in which at least a portion of the shaped bar is embedded in the first vertical wall and at least a portion of the periodic projections extends outside the first vertical wall forming a closed loop between the projections and the wall;

25 the first concrete-based prefabricated module and the second concrete-based prefabricated module being positioned adjacent to one another within a single storey of the multi-storey modular building such that the first attachment member periodic projections face the second attachment member periodic projections;

30 a tie bar assembly comprising plural joining bars engaging the first and second attachment members;

 in-situ cast concrete embedding the first and second attachment members and filling a space between the first concrete-based prefabricated module first vertical wall and the second concrete-based prefabricated module second vertical wall.