PREFABRICATED PREFINISHED VOLUMETRIC CONSTRUCTION (PPVC) MODULES AND METHODS OF MANUFACTURE THEREOF

Technical Field

The present invention relates to a prefabricated prefinished volumetric construction (PPVC) module; and to a method of manufacturing the same.

Background

High-rise buildings are typically built-up level by level and this can be time-consuming especially if it is a high-rise building. In addition, the fit-out and finishes of the building services, for example electrical and plumbing systems, can only be performed after construction of the building frame. This may further delay the time whereby the tenants can begin occupying the premises.

Prefabricated Volumetric Construction (PPVC) is a recently developed method of construction in which the fully fitted building, or a part thereof, is fabricated off-site and later brought on-site to be assembled with adjacent modules at its final location. A problem with PPVC is having a method of connecting sections of the building together in a secure manner that is also cost effective. Previously, this has been achieved in a manner that requires fasteners to extend through neighbouring walls to effectively pin them together. The result may not be aesthetically pleasing.

Another problem with PPVC is with the alignment and assembly of the various sections of the building. In assembling the various sections, it is critical that they are aligned so as to ensure structural stability and proper alignment of finishes. It is also important to ensure adequate coupling between the various sections and provide structural continuity in both vertical and horizontal directions.

In particular, industrialization of the construction process based on PPVC modules requires efficient and robust connections ensuring the modular building structure performs similarly to conventional (non-modular) construction. The load bearing elements of buildings formed from PPVC modules are formed by the assembly of the two concrete shells forming the sides of the module boxes in a single element that needs to perform similarly to a monolithic reinforced concrete wall of similar width.

One previously-known method of connecting adjoining PPVC modules uses horizontal guides on opposed wall panels, which overlap to provide a channel to receive a linking rod. The linking rod secures the wall panels together by coupling the guides while the grout is dispensed and cured. However, it has been found that a construction of this type does not have sufficient ability to resist tension and shear, such that it lacks the requisite safety characteristics of high-rise construction.

It would be desirable to address one or more of the above difficulties, or at least to provide a useful alternative.

Summary

The present invention provides a wall panel for a prefabricated prefinished volumetric construction (PPVC) module, comprising:

a concrete shell having a plurality of elongate recesses formed in an outer surface thereof and extending along a length of the concrete shell; and

at least one undulating cable located at each elongate recess, the at least one undulating cable being partially embedded in the concrete shell such that a plurality of undulations extend along, and protrude from, each of said elongate recesses.

Advantageously, an undulating cable provides superior resistance to tensile and shear forces when the wall panel is joined to a like wall panel to connect two adjoining PPVC modules, compared with techniques used in the prior art. The undulating cable provides a tie force to prevent splitting failure, to thus achieve monolithic wall behaviour. In particular, the projecting undulations of the undulating cable can generate a tensile force in the direction of the undulation to resist the shear along the wall panel to transfer to the other wall panel, which is very efficient.

In certain embodiments, embedded portions of the at least one undulating cable are looped around a reinforcement cage inside the concrete shell. This further improves the ability of the wall panel to resist tensile and shear forces that develops at the grout/concrete interface.

The wall panel may comprise at least two undulating cables located at each of said elongate recesses, wherein the at least two undulating cables are parallel to each other. For example, undulations of respective undulating cables may be half a period out of phase with each other.

The present invention also provides a prefabricated prefinished volumetric construction (PPVC) module, comprising at least one wall panel as disclosed herein.

The present invention further provides a modular building structure comprising:

a first prefabricated prefinished volumetric construction (PPVC) module comprising a first wall panel as disclosed herein;

a second PPVC module comprising a second wall panel as disclosed herein; and

a cementitious layer connecting the first and second wall panels;

wherein the elongate recesses of the first and second PPVC modules are aligned with each other to form respective channels within which the projecting undulations of the first wall panel are proximate the undulations of the second wall panel, and wherein the projecting undulations are embedded within the cementitious layer.

The modular building structure may comprise a vertical reinforcing bar disposed within each said channel.

The present invention further provides a method of constructing a modular building, comprising:

providing a first PPVC module comprising a first wall panel as disclosed herein;

providing a second PPVC module comprising a second wall panel as disclosed herein;

positioning the first and second wall panels relative to each other with a gap therebetween, the elongate recesses of the first and second wall panels being aligned to form respective channels within which the projecting undulations of the first wall panel are proximate the projecting undulations of the second wall panel; and

pouring a cementitious slurry into the gap between the first and second wall panels to thereby fill the channels; and

curing the cementitious slurry to form a cementitious layer to secure the first and second wall panels together with the projecting undulations embedded within the cementitious layer.

Some embodiments of the method comprise inserting a vertical reinforcing bar into each said channel prior to curing the cementitious slurry.

The present invention yet further provides a method of fabricating a wall panel for a prefabricated prefinished volumetric construction (PPVC) module, the method comprising:

placing an undulating cable in a jig having a first component and a second component, such that first portions of the undulating cable are seated in the first component and second portions of the undulating cable are seated in the second component;

retaining the first portions of the undulating cable to the first component;

removing the second component to leave the second portions of the undulating cable exposed;

casting the second portions of the undulating cable into a concrete shell such that the second portions are embedded in the concrete shell at an elongate recess of a plurality of elongate recesses formed in an outer surface of the concrete shell; and

removing the first component of the jig;

whereby the first portions of the undulating cable form a plurality of cable loops that extend along, and protrude from, said elongate recesses.

Certain embodiments of the method comprise inserting horizontal rebars of a reinforcement cage through the second portions prior to casting the concrete shell, whereby embedded portions of the at least one undulating cable are looped around the reinforcement cage inside the concrete shell.

Brief Description of the Drawings

Preferred embodiments of the present invention are hereafter described, by way of non-limiting example only, with reference to the accompanying drawings in which:

Figure 1 is an isometric view of a PPVC module according to an embodiment in which two sets of undulating cables are used for coupling the PPVC module to another PPVC module;

Figure 2 is a partial elevation view of a side wall of the PPVC module of Figure 1;

Figure 3 is a schematic illustration showing cutaway views of two side wall panels of adjacent PPVC modules consistent with that in Figure 1;

Figure 4 shows the two side wall panels of Figure 3 secured together;

Figure 5a is a vertical cross section through the line 5a-5a of Figure 4;

Figure 5b is a close-up at 5b of Figure 5a;

Figure 6 is an horizontal cross section through the line 6 of Figure 5b;

Figure 7a is a vertical cross-section through two connected side wall panels according to another embodiment where four sets of undulating cables are used for coupling the side wall panels together;

Figure 7b is a close-up at 7b of Figure 7a;

Figure 8 is a schematic illustration showing a cutaway view of one of the side wall panels of Figure 7a; and

Figure 9 schematically illustrates the positioning of an undulating cable for fabrication of a PPVC module side wall according to an embodiment.

Detailed Description

Referring initially to Figure 1, a PPVC module 10 comprises a pair of side wall panels 12a and 12b, a ceiling panel 14a, and a floor panel 14b. The side wall panels 12a and 12b may be coupled to the ceiling panel 14a and the floor panel 14b in any suitable fashion. A PPVC module 10 as shown in Figure 1 may be fabricated off-site, and then secured to one or more like PPVC modules on-site in a manner which will be described below.

The PPVC module 10 may also be fitted out off-site. For example, mechanical and electrical services may be installed off-site. Further, blockwall installation and waterproofing applications may also be performed off-site. Advantageously, a module 10 such as that shown provides robustness to the element at the fitting-out stage, as well as during transportation, lifting, and securing to other modules to form a permanent structure. Finishes that installed off-site are also protected, especially fixed glass panels and shower screens. Module 10 may also be provided with features to ensure water-tightness on all sides to protect high end finishes already installed off-site.

Each PPVC module 10 may have a different configuration to form, for example a 2 bedroom apartment or 3/4 bedroom apartment with or without a balcony.

A PPVC module 10 may also be fitted off-site with windows, door frames and balcony railings (not shown). Additionally, drywall partition frames and boards as well as tiles and floor finishing may be installed off-site. After the PPVC module 10 is completed off-site, it is transported on-site and lifted, for example with a tower or crawler crane. A special lifting frame may be used to effectively lift and install heavy modules at the same time, ensuring safety.

The side wall panel 12a of PPVC module 10 comprises a concrete shell having a plurality of elongate recesses 20 that extend an entire height of the side wall panel 12a. The concrete shell has at least one undulating cable 16 (Figures 2 and 3) partially embedded therein at each elongate recess 20. Accordingly, at least one set of projecting undulations 18, corresponding to the parts of cable 16 that are not embedded in the shell, extend from each elongate recess 20. As best shown in the elevation view of Figure 2, in the illustrated embodiment, each recess 20 has two undulating cables 16, and thus two sets of projecting undulations 18 extending therefrom. It will be appreciated, though, that a single undulating cable, and thus a single set of projecting undulations 18, may be provided in some embodiments, for example if lower loading is applied on the wall.

The projecting undulations 18 are exposed portions of an undulating cable 16 that weaves in and out of the concrete shell of wall panel 12a. Accordingly, portions 17 of the undulating cable that are intermediate the exposed portions 18 are embedded inside the concrete shell (as shown in the cross sectional views of Figures 5a, 5b, and 6).

Although details of only the first side wall panel 12a of PPVC module 10 are shown, it will be appreciated that the second side wall panel 12b that is opposite the first side wall panel 12a may also have elongate recesses 20 along which projecting undulations 18 extend.

Figures 3 and 4 show partial cutaways of the PPVC module 10 and a second, adjoining, PPVC module 110 to which the PPVC module 10 is to be secured. Reference numerals for parts of PPVC module 110 are incremented by 100 relative to those of PPVC module 10.

As shown, the concrete shell of the side wall panel 12a of the first PPVC module 10 has a reinforcement cage, formed by horizontal reinforcing bars 26 and vertical reinforcing bars 28 arranged in a grid. The reinforcement cage 26, 28 is embedded in the concrete shell. Likewise, the side wall panel 112b of the second PPVC module 110 has a reinforcement cage formed by horizontal reinforcing bars 126 and vertical reinforcing bars 128 arranged in a grid. The reinforcement cage 126, 128 is embedded in the concrete shell of the second PPVC module 110.

To secure the first PPVC module 10 and second PPVC module 110 together, the two modules are brought into alignment such that the recesses 20 of the wall panel 12a of

the first PPVC module 10 align with the recesses 120 of the wall panel 12b of the second PPVC module 110. Further, the projecting undulations 18 of the first wall panel 12b are brought into close proximity with the projecting undulations 118 of the second wall panel 112a as shown in Figure 6, for example such that undulations 18 contact or nearly contact undulations 118. In the aligned position as shown in Figure 6, a channel 44 is formed between the surface 22 of recess 20 and the surface 122 of recess 120, and a vertical reinforcing bar 30 may be inserted into that channel 44 to provide structural continuity between building levels. Vertical reinforcing bars 30 of vertically adjacent modules may be placed in lapped arrangement. The wall panels 12a, 12b are spaced at a predetermined spacing from each other (e.g. 20 mm) and a cementitious material, such as a cementitious grout or chipping concrete, is poured into the gap between the wall panels 12a, 112b and cured to form a cementitious layer 40 that connects the wall panels 12a, 112b.

The connection between the modules 10, 110 therefore makes use of projecting undulations 18 and (for example) cementitious grout 40 positioned at the interface between the modules. This combination provides the structure with the capacity to resist the tensile and shear forces that develop at the module interface when loaded. For example, the grout 40 may be high strength non-shrink grout G70 cube strength which conforms to EN445, EN446 and EN447. This allows the fluid to be able to fill cavities and to bond with the side wall panels 12a and 112b together to allow the system to act as a monolithic wall.

Through the use of partially embedded undulating wire cables 16 in the recesses 20, 120, when the modules 10, 110 are installed in their final position, the undulating wire cables of two adjacent modules are positioned in opposition, resulting in the exposed sections 18, 118 of the undulating wire cable being placed in very close proximity. These protruding parts 18 are used to create a continuity between the concrete elements once the gap between the panels 12a, 112b is filled up with cementitious grout 40. The positioning of the cable in a recess 20, 120 provides sufficient anchoring depth for the resisting force to develop.

Importantly, the undulating cable 16 is uninterrupted along the entire height of the wall 12a, providing continuity. In some embodiments, as depicted in Figure 6, the embedded portions 17 of the cable inside the concrete 12a weave around the reinforcement cage 26, 28, providing an efficient restraining capacity. In particular, the embedded portions 17 may be woven around the horizontal reinforcement bars 26 (and likewise for

embedded portions 117 and horizontal reinforcement bars 126). As such, the pitch (or period) of the undulations 18 will typically follow that of the horizontal reinforcement bars 26 (and likewise for undulations 118 and horizontal reinforcement bars 126).

The connection between the modules 10, 110 resists tensile force by transferring the force from the concrete shell 12a, 112b to the grout 40 through the undulating cable 16. The grout 40 then transfers the tensile force from the wire cable 16 of one module to the other 116. With respect to the shear force, the recesses 20, 120 that are formed at the concrete surface are used to develop the resisting force at the grout/concrete interface. The role of the undulating cables 16, 116 is then to keep the concrete and grout section in contact so that the shear resistance capacity can develop along the entire face of element 12a and 112b that is in contact with the infill grout 40. In particular, each undulating cable 16, 116 is partially embedded in the concrete wall 12a, 112b and partially embedded in the grout 40, and extends the entire height of the concrete wall 12a, 112b, such that a continuous connection is provided between the concrete and the grout.

In some embodiments, the exposed portions 18 of the undulating cable 16 are of greater length than the embedded portions 17, such that more of the undulating cable 16 is embedded in the grout 40 than in the concrete shell of wall panel 12a.

The walls 12a, 12b, 112a, 112b are preferably 75 to 90mm thick so as to support the top slab 14a and bottom slab 14b during lifting and transportation. Preferably, the 20mm gap will be site in-fill from top with grouting to make up the overall 200mm thick composite structural wall. If a thicker shell or wider gap is desired, an alternative cementitious layer may be used for joining, for example chipping concrete.

As shown in the Figures, the undulating cable 16, 116 has a sinusoidal shape, with arcuate cable portions 18, 118 projecting into the cavity 20. The radius of curvature of the portions 18, 118 that project into the cavity 20 is made as large as possible to avoid crushing of the concrete shells 12a, 112b.

Each undulating cable 16, 116 is flexible, and may be formed into the desired shape using a jig, for example. It will be appreciated, though, that in some embodiments each undulating cable may be substantially rigid.

The undulating cables 16, 116 may each have a 6mm diameter. A smaller cable diameter may also be used in some embodiments. In cases where higher loading of the walls is required, a larger cable diameter (up to 10 or 12mm diameter) may be used. The cables 16, 116 may be formed from 7 x 19 galvanised steel wire rope, but it will be appreciated that other types could also be used.

Figures 7a and 7b and Figure 8 show an alternative embodiment in which each wall panel 12a, 112b comprises at least one pair of undulating cables located at each elongate recess 20 thereof. For example, wall panel 12a comprises at least a first pair 16a, 16b of undulating cables and wall panel 112b comprises at least a first pair 116a, 116b of undulating cables. In Figure 7b, the first cable 16a, 116a of the respective cable pairs is shown with heavier line weight for clarity. It will be appreciated that in general, the cables of each pair will have substantially the same thickness.

The undulations of the first cable 16a are half a period out of phase with the undulations of the second cable 16b, i.e. the peaks of the first cable 16a coincide with the troughs of the second cable 16b, and vice versa.

The first undulating cable 16a of the pair is partially embedded in the wall panel 12a and partially embedded in the grout 40, and loops around horizontal reinforcing bars 26 in the first wall panel 12a, as shown in Figure 7b. First portions 17a of first cable 16a that are embedded in the concrete shell of wall panel 17a loop around horizontal bars 26. Second portions 18a of the first cable 16a extend into the channel 20 between the first wall panel 12a and second wall panel 112b and are embedded in grout 40.

The second undulating cable 16b is also partially embedded in the concrete shell of wall panel 12a and partially embedded in the grout 40. However, by contrast with the first undulating cable 16a, first portions 17b of the second undulating cable 16b that are embedded in the concrete shell do not loop around horizontal reinforcing bars 26. It will be appreciated, though, that depending on the detailing of the reinforcement cage, in some embodiments the first portions 17b may loop around horizontal reinforcing bars 26 in the same manner as first portions 17a. Second portions 18b of the second undulating cable 16b extend into the channel 20 between the first wall panel 12a and second wall panel 112b and are embedded in grout 40, as for the second portions 18a of the first undulating cable 16a.

In some embodiments, the second portions 18a, 18b are of greater length than the first portions 17a, 17b, such that more of the undulating cable 16a, 16b is embedded in the grout 40 than in the concrete shell of wall panel 12a.

The above discussion regarding the first pair of undulating cables 16a, 16b applies equally to the second pair of undulating cables 116a, 116b of the second wall panel 112b (but with all reference numerals incremented by 100 relative to those of the first pair of undulating cables 16a, 16b).

The use of opposed pairs of undulating cables that are half a period out of phase with each other is advantageous where a high capacity connection is required. With this arrangement, there is always a section of cable embedded in the concrete (e.g. sections 18a, 18b) and a section of cable embedded in the grout (e.g. sections 17a, 17b) along the entire module height, as shown in Figures 7a, 7b, and 8. This is to be contrasted with the embodiment shown in Figures 1-6, where the cable protrudes intermittently into the grout between the first and second wall panels.

Turning now to Figure 9, there is shown a jig assembly 702 for use in maintaining an undulating cable in the desired shape and in alignment during fabrication of a wall panel. As shown at (a), the jig assembly 702 comprises a first member 702a that may be placed in alignment with a second member 702b. Each of the first 702a and second 702b members carries recesses within which one half of the undulating cable 16 can be seated for alignment and shaping purposes as shown at (b). A top mounting aid 704 can then be placed on top of those parts of the undulating cable 16 that are seated in the first member 702a of the jig 702, as shown at (c). The second member 702b can then be removed, as shown at (d). This leaves portions 17 of the cable 16 exposed. The mounting aid 704 may be left in place on first member 702a to enable horizontal reinforcing bars 26 to be passed through the portions 17 such that the portions 17 loop around the horizontal reinforcing bars 26 and can be cast into a concrete shell for a wall panel 12a, whilst retaining its sinusoidal shape, as shown in Figures 5b and 6. The mounting aid 704 and first member 702a can then be removed.

Many modifications will be apparent to those skilled in the art without departing from the scope of the present invention.

In this specification and the claims that follow, unless stated otherwise, the word "comprise" and its variations, such as "comprises" and "comprising", imply the inclusion

of a stated integer, step, or group of integers or steps, but not the exclusion of any other integer or step or group of integers or steps.

References in this specification to any prior publication, information derived from any said prior publication, or any known matter are not and should not be taken as an acknowledgement, admission or suggestion that said prior publication, or any information derived from this prior publication or known matter forms part of the common general knowledge in the field of endeavour to which the specification relates.

Claims

1. A wall panel for a prefabricated prefinished volumetric construction (PPVC) module, comprising:

a concrete shell having a plurality of elongate recesses formed in an outer surface thereof and extending along a length of the concrete shell; and

at least one undulating cable located at each elongate recess, the at least one undulating cable being partially embedded in the concrete shell such that a plurality of projecting undulations extend along, and protrude from, each of said elongate recesses.

2. A wall panel according to claim 1, wherein embedded portions of the at least one undulating cable are looped around a reinforcement cage inside the concrete shell.

3. A wall panel according to claim 1 or claim 2, comprising at least two undulating cables located at each of said elongate recesses, wherein the at least two undulating cables are parallel to each other.

4. A wall panel according to claim 3, wherein undulations of respective undulating cables are half a period out of phase with each other.

5. A prefabricated prefinished volumetric construction (PPVC) module, comprising at least one wall panel according to any one of claims 1 to 4.

6. A modular building structure comprising:

a first prefabricated prefinished volumetric construction (PPVC) module comprising a first wall panel according to any one of claims 1 to 3;

a second PPVC module comprising a second wall panel according to any one of claims 1 to 4; and

a cementitious layer connecting the first and second wall panels;

wherein the elongate recesses of the first and second PPVC modules are aligned with each other to form respective channels within which the projecting undulations of the first wall panel are proximate the projecting undulations of the second wall panel, and wherein the projecting undulations are embedded within the cementitious layer.

7. A modular building structure according to claim 5, comprising a vertical reinforcing bar disposed within each said channel.

8. A method of constructing a modular building, comprising:

providing a first PPVC module comprising a first wall panel according to any one of claims 1 to 4;

providing a second PPVC module comprising a second wall panel according to any one of claims 1 to 4;

positioning the first and second wall panels relative to each other with a gap therebetween, the elongate recesses of the first and second wall panels being aligned to form respective channels within which the projecting undulations of the first wall panel are proximate the projecting undulations of the second wall panel; and

pouring a cementitious slurry into the gap between the first and second wall panels to thereby fill the channels; and

curing the cementitious slurry to form a cementitious layer to secure the first and second wall panels together with the projecting undulations embedded within the cementitious layer.

9. A method according to claim 8, comprising inserting a vertical reinforcing bar into each said channel prior to curing the cementitious slurry.

10. A method of fabricating a wall panel for a prefabricated prefinished volumetric construction (PPVC) module, the method comprising:

placing an undulating cable in a jig having a first component and a second component, such that first portions of the undulating cable are seated in the first component and second portions of the undulating cable are seated in the second component;

retaining the first portions of the undulating cable to the first component;

removing the second component to leave the second portions of the undulating cable exposed;

casting the second portions of the undulating cable into a concrete shell such that the second portions are embedded in the concrete shell at an elongate recess of a plurality of elongate recesses formed in an outer surface of the concrete shell; and

removing the first component of the jig;

whereby the first portions of the undulating cable form a plurality of projecting undulations that extend along, and protrude from, said elongate recesses.

11. A method according to claim 10, comprising inserting horizontal rebars of a reinforcement cage through the second portions prior to casting the concrete shell, whereby embedded portions of the at least one undulating cable are looped around the reinforcement cage inside the concrete shell.