

Modular Structure

5 The present invention relates to a modular structure for use in the construction of buildings such as for example high rise buildings and also to buildings constructed therefrom.

10 Prior art document US 4,118,905 discloses a modular structure for a plural level building formed of a plurality of box-like modular units. Each unit has side walls, a roof and a floor and may be formed as a monolithic unit. The units further have cantilevered portions to enable them to be stacked one above the
15 other in staggered configuration. In a structure constructed from this system, the weight of upper units would be borne directly by the units below them. Thus, the maximum number of storeys which could be constructed using this system would be directly
20 related to the strength of the units at the bottom of the building. Consequently, this system would not be practical for the construction of high-rise buildings for example.

25 Other modular construction systems are also known in the art. For example, US 3,990,193 discloses a modular construction system in which modules having side walls, a roof and a floor are constructed by joining four separate reinforced concrete panels
30 together (for example by welding). The modules are then assembled between concrete walls which are joined by a pin connection at each storey. Such panel construction systems have the disadvantage that the provision of jointing between the panels requires a
35 significant amount of work thus increasing construction time and costs. Further, the structure of the shear walls formed is not monolithic or continuous and so the walls cannot behave as a

conventional wall having no pin joints and full moment continuity throughout the height of a building.

Consequently, the system is not suitable for the construction of high-rise buildings as it is susceptible to progressive collapse and is generally lacking in strength.

The present invention therefore seeks to provide a modular structure which overcomes the above problems.

From a first aspect, the present invention provides a structure comprising a plurality of integrally cast reinforced concrete modules, the modules comprising two side walls joined together by a base and a ceiling, wherein the modules are joined together by load bearing structural walls formed by pouring concrete between adjacent modules.

This structure has the advantage that substantial cost savings can be obtained as the concrete modules can be prefabricated in a factory and then transported to a construction site ready for installation. This means that a structure can be assembled relatively quickly on site thus reducing the costs involved in construction due to the interest saved on the investment. Further, as the modules are joined together by load bearing structural walls, the modules do not have to carry all the weight of the modules above them. Still further, steel moulds may be used to produce the modules in the factory such that no timber wall soffit framework is required. This has the advantage that the use of reuseable steel moulds is more environmentally sound than the use of timber.

Preferably the lower external portions of the side walls of each module taper inwardly towards the base of the said module. This provides a direct vertical load path from the load bearing wall adjacent the base

of a module onto the top edges of the module below thus making the module side walls an integral structural part of the load bearing structure.

5 Each module could have walls at either end thereof so as to be fully closed. Preferably however, an open end of one module is configured to be joined to an open end of another module. This means that rooms larger than the internal dimensions of a single module
10 can be provided where required.

The open ends of the modules could be joined together by any appropriate means. For example, they could be bolted together. Preferably however, the one said
15 module includes a profile joint at the open end thereof, the profile joint being configured to mate with a cooperating profile joint provided at the open end of the other said module. This will provide a secure, accurate and quick means of joining the two
20 modules together.

Preferably both open ends of the one said module are configured to be joined to an open end of respective other modules.

25 Preferably means are provided for covering the join between the open ends of the said modules to obscure the join from the interior. This will provide a joint between the modules which is also secure against the ingress of fluids whilst at the same time being
30 aesthetically pleasing to occupants of a room inside the modules.

35 Separate steel reinforcement could be provided in the walls of the modules and in the concrete walls poured between them. However, this would mean that the steel in the concrete walls had to be fixed after installation of the modules which would be time

consuming and open to the increased incidence of error likely when work is carried out on site. Preferably therefore, one or more of the walls of the modules include steel reinforcement which projects outwardly therefrom such that the steel external of the modules is embedded in the concrete structural walls. This has the advantage that the steel reinforcement in the structural concrete walls is automatically installed by the installation of the modules and has the additional advantage of providing a structural link between the module walls and the poured concrete walls.

Preferably the reinforcement consists of a first set of steel bars embedded in said module wall and extending along the height thereof, and a second set of steel bars extending parallel to the first set of bars and joined thereto by a set of zigzag bars extending between the first and second bars.

Preferably during installation concrete is poured directly between adjacent modules to form the structural walls. This has an advantage in the time and costs saved by the reduced amount of formwork which is necessary.

Preferably, the modules in the structure span between the concrete structural walls.

Preferably a void is formed between the floor of an upper module and the ceiling of the module below it.

Still more preferably, means are provided for sealing the gap between upper and lower modules at the external faces thereof. This will prevent the ingress of bulk rain water into the voids.

Preferably the modules for external use further comprise a monolithic facade extending below the floor of the modules, and an upstand is provided on the ceiling of the modules, set back from the facade so as in use to stop any rain water from entering the void formed between upper and lower modules.

Still more preferably a drainage hole is provided in the module adjacent the vertical upstand.

Preferably seals are provided to seal the area between adjacent modules such that leakage during concrete pours to form the concrete structural walls will be reduced.

The seals preferably comprise horizontal seals of a suitable material such as rubber provided in recesses in the upper surface of the lower modules only in order to readily accommodate horizontal tolerances between the upper and lower modules.

Inflatable seals which nest in use in vertical recesses in adjacent external edges of the modules may also be provided.

Preferably the modules include one or more of the following: a stairway, a central circulation area, a light well, a lift shaft and a riser.

Still more preferably the structure further comprises a lobby area, the floor, roof and end walls of which are formed by pre-finished, precast panels.

Preferably an adjusting shim located in a fabricated shoe which is supported by a steel lifting pin is located at each of the four corners of the upper surface of each module such that when installed, the support points of a module arranged above the upper

surface of another module bear directly onto the adjusting shims. This has the advantage of providing a compact arrangement within the modules which provides a direct vertical load path through which the weight of the structure may be borne before the structural concrete walls have been formed in the assembled structure.

Still more preferably the shim is made of a material having a suitable yield strength or suitable elastic properties to ensure that the shim will deform if it becomes overloaded. This will provide a means of dissipating energy should the structure be overloaded for any reason.

One further advantage to a structure according to the invention including prefabricated modules is that the modules can be pre-surveyed in the factory before being transported to site. This will establish that the module dimensions are within tolerance and will also mean that any minor deviations from the ideal dimensions will be known in advance. The dimensions obtained from the pre-survey can be compared with an as-built site survey for a previously erected set of modules and corrections in the modules to be assembled can then be made in advance. This will reduce the delays in erecting the structure and will also allow the dimensions of the completed building to be within construction tolerances.

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

Figure 1A shows a module according to the invention having one external wall;

Figure 1B shows a module according to the invention having two open ends;

Figure 1C shows a module according to the invention having an external wall at the end opposite the
5 external wall of the module of Figure 1A;

Figure 2 shows a group of modules according to the invention arranged adjacent one another in several layers to form a three storey building;

10 Figure 3A shows a schematic plan layout of a block of flats constructed using a prior art method;

Figure 3B shows a schematic plan layout of a similar
15 block of flats constructed according to the invention;

Figure 4 shows a typical joint between the floors of two modules according to the invention;

20 Figure 5 shows a typical joint between the floors of two modules according to the invention where the joint is partially obscured by a partition wall;

Figure 6A is a schematic plan view of an end wall of
25 a module according to the invention;

Figure 6B is a sectional view along line CC of Figure 6A;

30 Figure 7 shows a section through a structural concrete wall joining two upper and two lower modules according to the invention;

Figure 8 shows a detail of a shim and lifting pin
35 arrangement at the intersection between upper and lower modules according to the invention;

Figure 9 is a plan view onto a concrete structural wall formed between two adjacent modules;
Figure 10 is a sectional view through the modules at point A of Figure 9;

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Figure 11 is a sectional view through the modules at point B of Figure 9;

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Figure 12A is a plan view onto a concrete structural wall formed between two adjacent modules and showing the seals provided;

Figure 12B is a section along line AA of Figure 12A in enlarged scale;

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Figure 13A is a side elevation of two modules according to the invention arranged one above the other; and

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Figure 13B is a detail of the region marked A in Figure 13A.

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As discussed above, the present invention provides a structure in which modules are joined together by concrete walls to form a structure such as for example a high-rise building. As shown in Figure 1, the modules of the preferred embodiment of the invention are made of reinforced concrete and are precast as integral units in factory conditions. The modules 1 comprise a base 2 and a ceiling 4, the base and ceiling being joined together by first and second side walls 6, 8 to form a four sided box structure.

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Depending on the type of structure to be built from the modules, the modules may include end walls at their front face 10 (as shown in Figure 1A), their rear face 12 (as shown in Figure 1C), or at both ends (not shown). Alternatively, the modules may be open at both ends (as shown in Figure 1B).

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The open ends of the modules are configured to allow attachment to a further module as will be described further below. As shown in Figure 2, the modules are arranged one above the other in use to form a multi storey building. The modules can be arranged in any desired configuration to provide a required building layout. In the arrangement of Figure 2, a first module 14 with an end wall at the front face thereof is joined to a module 16 which is open at both ends, the other end of the open module being joined to a module 18 with an end wall at the rear face thereof. Thus, the resulting structure will include a single room on each floor which is the width of one module but the length of three modules. As shown, further modules are then arranged in the same way on the second 20 and third 22 floors of the building. If required, modules can also be arranged side by side to provide a building of greater width. The prefabricated modules can include an external facade with all of its architectural features and can also include permanent internal fittings such as partition walls, floor and wall finishes, bathroom fittings, kitchen fittings, glazed windows, as well as electrical fittings, plumbing and other services.

As shown in Figure 3A, in a standard apartment block constructed using prior art methods, the external structure is defined by structural walls 24 which are constructed on site using traditional formwork methods together with precast facade elements 26 attached to the structural walls 24. The floor slabs of the structure are also cast on site. The construction of such structures therefore requires substantial on-site time. In contrast, a structure according to the invention can be assembled on site in a relatively short time as the modules are prefabricated in a factory. As shown in Figure 3B, a structure according

to the invention consists of modules 1 according to the invention which are joined together by load bearing reinforced concrete walls 28. The provision of load bearing concrete walls 12 makes the structure particularly suitable for the construction of high rise buildings (buildings having 20 floors or more). The way in which these walls are formed will be described further below.

- 10 The modules may also include stairways, central circulation areas, light wells, lift shafts, and risers and can be arranged to provide a commercially acceptable, high efficiency ratio of habitable to service areas within buildings which use the invention. They also permit the use of pre-finished, precast panels to form the floor, roof and end walls of the lobby area in a building.

20 In one preferred embodiment of a structure according to the invention, the modules are rectangular in shape and have a width of 2.5m to satisfy the transport requirements of Hong Kong. However, rooms of a width greater than 2.5m are often required. Thus, in the structure of the invention two or more modules can be joined together by their open ends in order to form a larger room. This means that the joints between modules will occur across the floors, ceilings and walls of rooms which are wider than 2.5m. A precise fit between the modules is therefore desirable both to provide a flush internal surface which is imperceptible to occupants of the room, to provide a strong mechanical connection between the modules and to provide adequate sealing in the joints against ingress of water and for fire safety.

35 As shown in Figures 4 and 5, the open edges of the modules are cast as respective halves of a profile cast joint 30 to enable the modules to be securely

fastened together. Figure 4 is a sectional view through the floors 2 of two modules. As can be seen, the edge of the first module is formed with a profiled projection 32 extending along the length thereof. The edge of the other module is formed with a corresponding profiled cast recess 34 for receiving the projection 32. During assembly of the modules, the projection and recess will be mated to automatically align the modules relative to one another. The profiles are locked together by integral keyways (not shown) so that the edge surfaces of the two module floors are flush to within about 2mm. These joints have the advantage that only a small amount of site finishing work is required.

Once the modules have been locked together, the joint is finished by applying a layer of thin bed adhesive 36 directly above the floors 2 of the modules. A timber floor 38 or other finish if preferred is then installed above the thin bed adhesive layer 36 but a gap is left directly above the joint. This gap is filled in by a strip of tile infill 40 as shown. This provides a joint which will not be visible to an occupant when inside the room formed by the modules. Alternatively, the modules may be dry fitted for installation of finishes and then split for transportation to site.

In order to ensure that the joint is also water and fire proof to the external environment, a suitable jointing compound is inserted into the gap between the two halves of the profile joint 30. This has the added advantage of making the joint grout tight to resist leakage during insitu concrete pours.

Figure 5 shows a variation of the internal finish to the joint in Figure 4. As shown, a partition wall 42 is provided in the first module adjacent the open edge

thereof. Thus, after the two halves of the joint have been locked together as described above, a layer of thin bed adhesive 36 is provided on the second module floor 2 and above the joint 30 but only extending as far as the partition wall at the edge of the first module. A timber floor 38 is then provided above the thin bed adhesive layer 36 and is arranged to end just short of the joint. A wooden skirting board 44 is then attached to the partition wall at the base thereof so as to overlap with the timber floor finish and so cover the joint 30. Thus again, the joint between the two modules would not be visible to an occupant of the room.

The structure is constructed by lifting all of the modules of a first storey into place and joining the open ends of modules together where required. As shown in Figure 3B and discussed briefly above, structural reinforced concrete walls are then formed between the modules to hold them together. As shown in Figures 6A and 6B, the precast side walls 6,8 of the modules include steel reinforcement. In the walls of the modules which will be adjacent the structural concrete walls 28, this reinforcement consists of latticed rebar which protrudes externally of the module wall 6,8. As shown in Figure 6B, the reinforcement comprises a first set of bars 46 embedded in the module wall 6 which is joined to a set of second parallel bars 48 external of the module wall by means of a set of zigzag bars 50. This arrangement gives adequate local lateral stability and reinforces the modules sufficiently to allow them to resist transportation forces, handling forces and the pressure produced by insitu concrete pours in which the walls of the modules are used as the temporary formwork. In addition, the rebar is compatible with the permanent structure built around the modules and the provision of external reinforcement allows the

module walls to behave compositely with the structural concrete walls formed between them.

5 The assembled modules are arranged such that gaps are left between certain adjacent modules for the formation of concrete structural walls 28. The external reinforcing bars 48 of the module walls 6,8 extend into these gaps. Concrete is then poured directly into the gaps, i.e. the module walls 6,8 are used as formwork for the concrete pour such that additional formwork only need be provided in areas where the modules do not extend on all sides of the wall to be poured. This results in substantial time and cost savings due to the reduction in fixing and striking of temporary formwork panels.

Further, the external reinforcing bars 48 of the module walls 6,8 form the reinforcement within the poured concrete walls. This has the advantage that the module walls 6,8 behave compositely with the structural concrete walls 28 so that the cumulative thickness of the module walls and the concrete structural walls can be minimised while retaining the required weight bearing capacity for the structure. Further, as the steel reinforcement for the concrete walls is prefixed to the module walls under factory conditions, there is reduced potential for steel fixing errors which can occur when steel is attached on site.

30 The provision of structural concrete walls which bind the modules together allows the formation of a structure acting as a single monolithic structure. As the module floor slabs are locked together by the concrete structural walls 28, the module floor slabs of the structure behave in a structurally similar manner to the conventional floor slabs of a frame-type high-rise structure and so maintain the advantages of

conventional insitu construction such as robustness, durability, fire resistance and insulation. In a preferred embodiment of the invention, modules held together by concrete structural walls are used both in the core and the wings of the structure. This will maximise the advantages of strength and stability provided.

The external edges of each module taper inwardly adjacent the base (see Figure 7). Thus, concrete poured between two adjacent modules will flow into the free area 52 left by the taper and rest on top of the upper corners 54,56 of the two modules below. Thus, the concrete provides a direct vertical load path from the concrete structural wall down onto the module walls 6,8 below. This enables the thickness of the module walls to be included in the total width of the structural load bearing wall for the assessment of load bearing capacity. The total width of the wall may also be used for the assessment of structural stiffness.

The structural walls described support the weight of each module in the structure, each module spanning between two walls. In modular structures where such structural weight bearing walls are not provided, each module has to support the cumulative weight of the modules above. This means that the height of the modular structure is limited by the structural strength of the modules at the base of the structure. Further, the provision of weight bearing structural walls means that the structure has inherent structural stability and so is resistant to progressive collapse in the same way as a conventional high-rise structure. Thus, damage due to the accidental loss of a module, due for example to a gas explosion, cannot propagate throughout the structure as the other modules in the

structure are all self-supporting and integral with the main structure.

Figure 8 shows the layout of a lifting pin 58 and shim 60 at the joint between upper and lower modules. As shown, the lifting pin 58 and shim 60 are arranged to be coincident and compact, reducing the plan area required for these elements and thus increasing structural and mechanical efficiency of the structure. The adjusting shim 60 is located in a fabricated shoe 62 which is located and supported by the steel lifting pin 58 of the lower module. A lifting pin and shim arrangement of this type is provided at each of the four corners of each module. The support point of the upper module when in position bears directly onto the shims 60, thereby providing a temporary direct load path vertically through the strong points of the module which are located at each of the four integral corner posts. Once the structural concrete walls have been formed then this load path will be redundant. The shim is made of material having a suitable yield strength or suitable elastic properties to ensure that the shim will deform plastically should it become overloaded in some way. Thus, the overloading will not cause damage to the module or the temporary clamping bolts.

The arrangement of the modules of the invention one above the other means that voids 63 are formed between the ceiling of a module and the floor of a module above. These voids are advantageous in increasing sound insulation between storeys of a building. They also increase thermal insulation thus providing potential savings in heating and air conditioning. A void 63 between the modules is shown in Figure 10 from which it can be seen that the gap 64 in the facade 66 between the front faces of upper and lower modules is sealed horizontally and additionally, a vertical

upstand 68 is provided behind the gap so that any rain penetrating through the gap will be held back by the upstand. A drainage hole 70 is provided just in front of the upstand 68 as shown in Figure 11.

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Because a drainage path is provided in the void 63, this provides an extra barrier against water from an upper module seeping into a lower module. To enhance drainage still further, free draining flashing is provided over the module roof junctions and the roof slabs of peripheral modules of a structure can be arranged to slope so as to drain outwards towards the drainage vent.

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Vertical, riser type of vents 72 are located between the junction of two adjoining facades as shown in Figure 9. They run vertically up the full height of the building and are vented internally behind the facades at each floor, to provide controlled ventilation of the floor voids 63 to prevent stagnation of the air.

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A further feature of the modules of the invention is that they are provided with seals to prevent grout leaking out when the concrete structural walls are poured using the modules as temporary formwork. Thus both horizontal 74 and vertical 76 seals are provided. The seals may accommodate a large range of gap widths between the modules. The horizontal seal 74 is located in a recess 78 in the top of the lower modules so that it will not be displaced when a module is placed above the lower module (see Figures 12A and 12B). The underside sealing surface 80 of the top module is totally flat so that it may be located in a slightly offset plan location without compromising the function of the seal. This allows the vertical alignment of the building to be adjusted and corrected as required during erection. The horizontal seal 74

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comprises a seal 50 of a suitable material arranged to extend along the adjacent sides of the two adjacent modules and to be joined in a loop at the join between the two modules. In the preferred embodiment, the seal is made of rubber and is square in cross section.

The vertical seals 76 provided between the modules are inflatable and reusable. As shown in Figures 12A, 12B, 13A and 13B, these seals are inserted into vertical circular recesses 82 formed between the adjoining ends of the facades 66 of two adjacent modules. These seals are not inserted until after the modules have been assembled as there is a strong likelihood that any seal would be knocked off during the installation of the adjacent module.

Using such methods in the construction of high-rise structures can result in a floor by floor construction cycle time of only two days as compared with a typical time of 5 days using conventional construction methods. Thus, the present invention provides a substantial saving in construction time and hence costs without compromising the quality of structures obtained.

The embodiments of the invention described above are preferred embodiments only and so are not intended to be limiting. Thus, the skilled person would understand that various alterations could be made to the structures described without departing from the scope of the invention as defined in the appended claims. For example, the modules shown are all rectangular in shape. However, this need not necessarily be the case and so the invention is also applicable to modules of any shape which can be assembled as required.

Claims

1. A structure comprising a plurality of integrally cast reinforced concrete modules, the modules
5 comprising two side walls joined together by a base and a ceiling, wherein the modules are joined together by load bearing structural walls formed by pouring concrete between adjacent modules.
- 10 2. A structure as claimed in claim 1, wherein the lower portions of the side walls of each module taper inwardly towards the base of the said module.
- 15 3. A structure as claimed in claim 1 or 2, wherein an open end of one module is configured to be joined to an open end of another module.
- 20 4. A structure as claimed in claim 3, wherein the modules include a profile joint at the open end of the one said module, the profile joint being configured to mate with a cooperating profile joint provided at the open end of the other module.
- 25 5. A structure as claimed in claim 2, 3 or 4, wherein both open ends of the one said module are configured to be joined to an open end of respective other modules.
- 30 6. A structure as claimed in any of claims 3 to 5, wherein means are provided for covering the join between the open ends of the said modules to obscure the join from the interior.
- 35 7. A structure as claimed in any preceding claim, wherein one or more walls of the modules include steel reinforcement which projects outwardly therefrom such that when installed the steel external of the modules is embedded in the concrete structural walls.



8. A structure as claimed in claim 7, wherein the reinforcement consists of a first set of steel bars embedded in said module wall and extending along the height thereof, and a second set of steel bars
5 extending parallel to the first set of bars and joined thereto by a set of zigzag bars extending between the first and second bars.

9. A structure as claimed in any preceding claim,
10 wherein during installation concrete is poured directly between adjacent modules to form the structural walls such that a reduced amount of formwork is required.

15 10. A structure as claimed in any preceding claim, wherein the modules span between the structural concrete walls.

20 11. A structure as claimed in any preceding claim, wherein when installed, voids are formed between the floor of an upper module and the ceiling of the module below it.

25 12. A structure as claimed in claim 11, wherein means are provided for sealing the gap between upper and lower modules at the external faces thereof.

30 13. A structure as claimed in claim 11 or 12, wherein the modules for external use further comprise a monolithic facade extending below the floor of the modules, and wherein an upstand is provided on the ceiling of the modules, set back from the facade so as in use to stop any rain water from entering the void formed between upper and lower modules.

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14. A structure as claimed in claim 13, wherein a drainage hole is provided in the module adjacent the vertical upstand.

5 15. A structure as claimed in any preceding claim, wherein seals are provided to seal the area between adjacent modules when installed such that leakage during concrete pours will be reduced.

10 16. A structure as claimed in claim 15, wherein the seals comprise horizontal seals provided in recesses in the upper surface of the ceilings of the modules.

15 17. A structure as claimed in claim 15 or 16, wherein the seals comprise inflatable seals which nest in use in vertical recesses in adjacent external edges of the modules.

20 18. A structure as claimed in any preceding claim in which the modules include one or more of the following: a stairway, a central circulation area, a light well, a lift shaft and a riser.

25 19. A structure as claimed in any preceding claim, the structure further comprising a lobby area, the floor, roof and end walls of which are formed by pre-finished, precast panels.

30 20. A structure as claimed in any preceding claim, wherein an adjusting shim located in a fabricated shoe which is supported by a steel lifting pin is located at each of the four corners of the upper surface of each module such that when installed, the support points of a module arranged above the upper surface of
35 another module bear directly onto the adjusting shims.

21. A structure as claimed in claim 20, wherein the shim is made of a material having a suitable yield



strength or suitable elastic properties to ensure that the shim will deform if it becomes overloaded.

