# SELF-ALIGNING CONNECTION SYSTEM FOR STEEL MODULAR INTEGRATED CONSTRUCTION (MiC)

## Field of the Invention:

[0001] The invention relates to connection systems for multi-storey buildings composed of prefabricated steel modules, such as Modular Integrated Construction (MiC) and, more particularly, to connection of prefabricated steel modules with self-aligning connection systems that include fastener connections to tie the upper and lower components of the connection system together.

## Background:

[0002] Traditional construction of multi-storey buildings such as high-rise apartment buildings and office buildings is both time-consuming and expensive. Construction may be delayed or damaged due to inclement weather 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.

[0003] In order to accelerate building construction and improve quality control, various modular construction techniques are being adopted. Modular Integrated Construction (MIC) involve the advance 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.

[0004] Conventional steel modular construction systems typically use rectangular parallelepipeds as a unit , as seen in FIG. 1 (prior art). Plural rectangular parallelepipeds may be aligned in the same storey or adjacent stories together to form a building, as seen in FIG. 2 (prior art). For columns of adjacent units, connections need to be made between two to four units in a single

storey and up to an additional four units in an adjacent storey. Thus, at a minimum, two units must be connected to each other in the first storey and then interconnected with at least two units in the adjacent storey above the two units. Conventionally, bolts or rivets are used to connect the adjacent units as well as the units in the succeeding storey.

[0005] As seen in FIG. 1, each steel unit is lowered into place at the construction site, typically by a large crane. As will be appreciated, alignment of each succeeding module in a module stack is critical in order to minimize the erection tolerances needed to enhance the structural performance of the column connection. Attaining this high degree of alignment is difficult when at the construction site as the module is lowered, requiring considerable manpower to guarantee proper placement.

[0006] Thus, there is a need in the art for improved connection systems for steel modular integrated construction, and, in particular, a need for connection systems that can promote proper alignment between adjacent modules as they are stacked during multi-storey module assembly. There is a further need in the art for improved connection systems in which upper and lower components of the connection system can be bolted together to provide the required tension resistance, effectively right within the column.

**Brief Description of the Drawings:**

[0007] FIG. 1 depicts a conventional steel module for modular construction being positioned at a construction site.

[0008] FIG. 2 schematically depicts a skeleton for steel module depicting steel columns to be interconnected .

[0009] FIG. 3 schematically depicts adjacent steel modules indicating the position for different types of connections among modules.

[0010] FIGS. 4 and 4(a) depicts a perspective view of an exemplary self-centering connection system used in a Type 1 column joint between steel modules in both the same and adjacent stories of a multi-storey structure.

[0011] FIGS. ~~5~~5 and 5(a) depicts a perspective view of a further exemplary self-centering connection system used in a column joint between steel modules in both the same and adjacent stories of a multi-storey structure.

[0012] FIGS. 6A-6B depict cross-sectional views of the column joints of FIGS. 4 and 4(a)~~4~~.

[0013] FIG. 7 depicts a perspective view of a further exemplary self-centering connection system used in a column joint between steel modules in both the same and adjacent stories of a multi-storey structure.

[0014] FIGS. 8A-8F depict cross-sectional views of column joints.

[0015] FIGS. 9A and 9B depict cross sectional views of a Type 2 column joint connection used with the system of the present invention.

[0016] FIGS. 10A and 10B depict a cross-section of a complementary receiving surface in an upper module column used with the connection system of FIGS. 5 and 5(a)~~5~~.

[0017] FIGS. 11A and 11B depict a capping plate used in the connection system of FIGS. 5 and 5(a)~~5~~.

[0018] FIG. 12 depicts a perspective view of an alternate embodiment of a connection system with a frustoconical projection.

[0019] FIG. 13(a) depicts a perspective view of the connection system of FIGS. 4 and 4(a).

[0020] FIG. 13(b) is an enlarged view of the connecting plate of the connection system according to FIG. 13(a).

[0021] FIGS. 14 and 14(a)-14(h) depicts details of the connection system of FIG. 12.

[0022] FIGS. 15, 15(a)-15(c) depicts further details of the connection system of FIG. 12.

[0023] FIGS. 16, 16(a)-16(e) depicts further details of the connection system of FIGS. 4 and 4(a).

[0024] FIGS. 17 and 17(a) depicts further details of the connection system of FIGS. 5 and 5(a).

**Summary of the Invention**

[0025] The present invention overcomes the disadvantages of prior-art prefabricated construction modules through the use of a self-aligning connection system for multi-storey steel modular structures. The connection system includes the vertical connection between the columns of the upper and lower modules, providing more accurately column alignment with the invented Type 1 connection, and the horizontal connection with a connection plate configured to attach across two adjacent steel modules in a first storey of a multi-storey structure. The connection plate includes two or more apertures, and each aperture configured to receive a fastener for attaching the connection plate to a respective module of the two adjacent steel modules in the first storey.

[0026] Two or more projections , each attached on or integrally-formed at the top of columns in the first-storey steel modules below, extends in a upward direction through apertures in the connection plate; each of the projections is configured with a cross-section that is a first width at a proximal, base portion adjacent to the connection plate, and a second width at a distal projection portion extending upwardly from the top of columns below the connection plate, the second width being narrower than the first width. Each of the projections includes a central aperture configured to receive a fastener for attaching one of the two adjacent steel modules to an upper steel module in a second storey positioned above the first storey.

[0027] A complementary receiving surface includes a central receiving surface aperture for receiving a fastener. The complementary receiving surface is attached to or integrally-formed in the upper steel module for engaging one of the two or more projections such that the upper steel module is accurately aligned with one of the two adjacent first-storey steel modules. The complementary surface centers the projection and aligns the projection central aperture with the receiving surface central aperture. In this manner, the same fastener can pass through both the projection and receiving surface apertures, thereby aligning the upper steel module with one of the two first-storey adjacent steel modules, to provide the required tension resistance at an effective location within the column.

**Detailed Description:**

[0028] The invention relates to a connection system for steel modules in MiC construction that overcomes some of the drawbacks of conventional steel modular construction. The present inventive connection system is self-aligning such that when a new steel module is lower into place upon an existing steel module, the new module is accurately aligned with the lower module through the action of the self-aligning feature. The inventive connection system also includes easy-to-access fastener apertures, allowing rapid union of the new, upper module to the existing, lower module.

[0029] A skeleton for a steel module 100 for MiC construction is shown in FIG. 2 and includes plural columns 110 that extend in the approximately vertical direction. In connecting adjacent modules, both in the same level/storey of the building structure and between successive stories in different levels, the steel columns 110 are employed.

[0030] Turning to FIG. 3, top view of steel modules in depicted; in FIG. 3, the location of various types of connections is depicted. At all the positions labelled 10, a “type 1” connection is formed. In this type of connection, two columns from adjacent modules are connected within the same building storey by the common connecting plate; these two columns are respectively joined to two columns from two adjacent steel modules in a second storey positioned above the first storey.

[0031] At all the positions labelled “20”, a “type 2” connection is formed with flat column ends without a self-aligning function needed. In this type of connection, a single column from a lower module in a first storey is joined to the corresponding single column in the upper module by bolt connection inside the column. The connected upper and lower vertical column is connected with the corresponding column in the adjacent module through a common connecting plate.

[0032] It will be appreciated that in modular construction, there are a number of different types of connections that are formed between adjacent modules in the same or different stories; not all

of these connections are the subject of the present application and are therefore not discussed in detail in this section.

[0033] FIGS. 4, 4(a) and FIGS. 13(a)-13(b) depict an embodiment of the connection system 400 of the present invention used to join steel columns in the same storey, e.g., joining column 210 to column 220, in addition to joining columns in adjacent stories, e.g., joining column 210 to column 610 or joining column 220 to column 620. Connection system 400 includes a connecting plate 300 configured to attach across the span of columns 210 and 220 and secured by plural fasteners, for example, bolts 310. Extending upwardly through the connecting plate 300 are one or more projections 320, as seen in FIG. 13(a), the projections 320 extend through plate projection aperture 396; in the embodiment of FIGS. 4, 4(a) and 13(a)-13(b), the projections 320 include intersecting plates 322, 323 and 324. When assembled together, plates 322, 323, and 324 form a projection 320 with a cross-sectional profile in which a distal tip portion 326 (FIG. 6A) of the projection cross-section is about 30-40 percent narrower that a base, proximal portion 328 of the projection. In other embodiments, the distal tip portion 326 may be 10-90 percent narrower than the proximal base portion 328. In approximately the center of the projection 320 is an aperture 330 configured to receive a fastener, such as a bolt, that will be used to connect steel column 210 to steel column 610. As will be seen in further detail below, this projection configuration permits the connection to be self-centering when cooperating with a receiving surface that "guides" the project towards accurate vertical alignment between adjacent steel modules. By "accurate" it is meant that the adjacent steel modules are aligned within 0.5-2.5 mm. Alternatively, projections 320 may be attached to connecting plate 300 rather than being attached to the column positioned beneath the connecting plate.

[0034] Attached to or integrally-formed with steel column 610 is a receiving surface 500 for guiding the projection 320 such that the adjacent steel modules are accurately aligned in both vertical and horizontal alignment with each other. Receiving surface 500 may include an approximately complementary surface portion 510 that guides the projection 320 such that the

projection aperture 330 (FIG. 13(a)) is accurately aligned with receiving surface aperture 530 such that the same fastener, for example, a bolt, may pass through both apertures to join columns 210 and 610. When projection 320 meets surface 510, the projection will slide across the surface until the projection properly mates within the complementary receiving surface. Optionally, for the configuration of intersecting plates 322, 323, and 324, the receiving surface 510 may optionally include recesses 512 that engage the plates, ensuring precise alignment of the modules. Alternatively, the receiving surface may be a smooth surface as depicted in FIG. 4. It will be appreciated that while the upper steel module is being hoisted into place, the respective projection and receiving surfaces may be guided together while the module weight is borne by the crane that is lifting the upper steel module into position on the lower steel module. In this manner, the upper steel module is interlocked with the lower steel module even prior to connecting the fastener.

[~~0030~~0035] The self-aligning capability of the internal Type 1 column connection (with flat column ends) will substantially reduce the magnitude of additional tolerance required for the erection of the building, with the same benefit applicable also to the remaining column alignment using Type 2 connections. In this type of connection, depicted in FIGS. 9A and 9B, a single column 940 from a lower module in a first storey is joined to the corresponding single column 950 in the upper module by a bolt connection 930 inside the column. The connected upper and lower vertical columns are then connected with the same 940 and 950 in the adjacent module through a common connecting plate 910, which is connected to both the adjacent lower column by bolts 920.

[0036] To facilitate access by construction workers for module joining, lower steel column 210 ~~[0035]~~ includes an access side opening in the column, together with the use of steel channel connecting beam 240 (with free space in one side) that permits access into the column interior so that a bolt maybe affixed through central apertures 330 and 530 to join columns 210 and 610. Optionally, the channel section may include a removable door or plate such that ongoing joint

inspection and maintenance may be performed. Similarly, upper column 610 includes an access portion 640 for affixing a fastener that passes through the apertures 330 and 530.

[0037] FIG. 6A depicts the connection system of FIG. 4 in cross-section. As seen in FIG. ~~[0036]~~ 6A, bolts 310 affix connecting plate 300 across columns 210 and 220 to join adjacent modules in the same storey/floor of the building structure while central bolt 410 connects upper column 610 to lower column 210 via projection aperture 330 and receiving surface aperture 530. FIG. 6A shows the cross-sectional profile of projection 320, the proximal base 328 being wider than the distal tip 326; an edge 329 of the projection may be curved or stepped in order to facilitate guidance of the projection in the receiving surface until the apertures are accurately centered upon each other.

[0038] It will be appreciated that other, alternate projection shapes may be used that also ~~[0037]~~ facilitate accurate alignment between upper and lower steel modules in both the horizontal and vertical directions. FIGS. ~~5 and~~5, ~~17~~17 and 17(a) depict alternate projection shapes 700 and 720 with an elongated profile and a curved surface that extend from the lower columns projecting up through apertures in the connecting plate 300 to interlock the two columns together in the horizontal direction. Using complementary receiving surfaces to engage projections 700 and 720 causes an "interlocking" between the top steel module and the bottom steel module, even before connection using fasteners.

[0039] FIGS. 10A and 10B depict the two cross-sectional profiles of the complementary profile ~~[0038]~~ receiving surface 1010; the projections 700 and 720 (from FIG. 5) can only engage with the module in the correct orientation, the profiled projection will allow the receiving surface (after the first contact) to slide down (by its self-weight) to its final correct ~~position, providing~~position, providing an additional degree of connection assurance. Bolt 710 passes through aperture 730 to connect the columns.

[0040] FIGS. 8C-8D depict the cross-sectional profiles of the projections 700, 720 before

~~[0039]~~ placing the 30 mm thick connecting plate and erection of upper modules- while FIGS. 8E-8F depict a connected joint. In the connected joint, bolt 710 passes through the aperture 730 to join columns 610 and 210. The proximal base portion 728 is substantially wider than the distal tip portion 726 (FIG. 8C); distal tip portion 726 is approximately 10-40 percent narrower than the base.

[0041] FIGS. 11A-11B respectively depict the top capping plate 1100 of a column with

~~[0040]~~ projection -700 and connecting plate 300 (-not labelled in FIG 11B) with apertures 770 for the penetration of the projections 700, 720. Each of the plates includes plate apertures 760 to receive bolts or rivets to attach the plates to the respective column heads in addition to the central apertures 730 to receive the central bolt to attach the upper and lower columns.

[0042] FIG. 7 depicts another alternate projection shape to facilitate accurate alignment

~~[0041]~~ between upper and lower steel modules in both the horizontal and vertical directions. In FIG. 7, projection 800, which extends through an aperture in the connecting plate, has an approximately hemispherical shape, with an approximately flattened out section adjacent to aperture 830 (best seen in FIG. 8B) for receiving a bolt. The distal tip portion 810 is approximately 90 percent narrower that the proximal base portion 820 (FIG. 8B). The curved profile of the hemisphere facilitates alignment when paired with a hemispherically concave receiving surface. The smooth hemisphere projection surface and the concave receiving surface can slide against each other with minimal friction as the upper steel module is properly positioned on the lower steel module. Note that a plate holding the complementary receiving surface may be bolted to or otherwise affixed to the base of upper steel module column 610 in much the same way that the connector plate 300 is affixed to the lower steel module column 210.

[0043] During module assembly, lubricant or other surface additives may be positioned on the

~~[0042]~~ projections and/or receiving surfaces to facilitate proper positioning of the projecting surface against the receiving surface. The projections advantageously provide a visual indication to proper alignment as workers guide the upper steel module onto the lower steel module. In

alternate embodiments, the projection may be affixed to the base of an upper column with the recessed surfaces in the lower columns being affixed across two lower modules through the common connecting plate two apertures to allow for penetration and the associated inter-locking effect. Further, alternating projections and recessed surfaces may be employed. Other projection shapes may also be used in the present invention as long as the projection shapes cooperate with mating recessed complementary surface shapes to create self-centering connection system.

[0044] Returning to FIG. 3, Type 2 column joints 20 may be positioned at edges of the modular ~~[0043]~~ containers where there is a joint with an upper column that does not require a self-centering connection system as with Type 1 joints. An example of a Type 2 connection is depicted in cross-section in FIGS. 9A and 9B. Because of the self-centering Type 1 joint used in the same module, the various connection elements in the Type 2 joints will have been properly aligned through the internal Type 1 connection. Due to the projections of the Type 1 connections, the self-centering system will make contact and will align first, automatically aligning the simpler connections of the Type 1 connections. FIG. 9A uses a connection plate 910 held in place on lower column 940 through fasteners 920 which may be bolts or other fasters such as rivets. A fastener 930 passes through an aperture 941 which may be located anywhere on the connection plate but is optionally centrally located. Access panel 942, as in the Type 1 embodiment, permits a worker to affix the fastener 930. Advantageously, the self-centering Type 1 joints permit the use of the less expensive Type 2 joints at the positions indicated in FIG. 2, making the overall system extremely cost-effective and efficient to erect.

[0045] FIG. 12 depicts an alternate embodiment for joining upper steel modules 610 and 620 ~~[0044]~~ to lower steel modules 210 and 220. As seen in FIG. 12, a connecting plate 300 attaches the two lower modules 210 and 220 in the horizontal direction when the plate is fastened through apertures 380. A pair of frustoconical projections 1210, 1220 are attached to upper portions of lower steel modules 210, and 220, respectively. The projections 1210 and 1210 extend through a

pair of plate projection apertures 370 in the connecting plate 300 and will mate with complementary receiving surfaces attached to upper steel modules 610 and 620.

[0046] FIGS. 14, 14(a)-14(h) provides further detail of the connection system of FIG, 12,

~~[0045]~~ giving various dimensions. The projection 1220 may, in one embodiment, be fabricated from an approximately 90 mm high circular cylinder solid steel rod of diameter 100mm for the bottom section 35mm high, and reducing upward to 60mm at the top with -26mm diameter bolt hole at the top for bolt connection between the upper and lower columns of the module to provide the required tension resistance. The receiving surface at the upper column- is approximately 60mm deep , with the upper 35mm matching the profile of the projection in contact for shear transmission. The sloping angle of the projection 1220 is not too steep or not too gentle providing a more efficient self-aligning capability and is easily machined.

[0047] FIG. 15, 15(a)-15(c) provides further details of the connection system of FIGS. 12, ~~and~~ 14

~~[0046]~~ and 14(a)-14(h), showing the intersection of the various steel beams within the module. A box 1510 with the projection attached thereto receives module beams labelled B, C, and D in the lower module. Similarly, 1520 is a receiving surface box that engages beams H, I, and G. For the Type 2 connection, no projection is required and box 1530 does not include a projection and the mating plate 1540 is also flat.

[0048] Various of the above-disclosed and other features and functions, or alternatives thereof,

~~[0047]~~ may be combined into many other different systems or applications. Various presently unforeseen or unanticipated alternatives, modifications, variations or improvements therein may be subsequently made by those skilled in the art, each of which is also intended to be encompassed by the disclosed embodiments.