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Waller

(54) **BLAST RESISTANT SHELTER**

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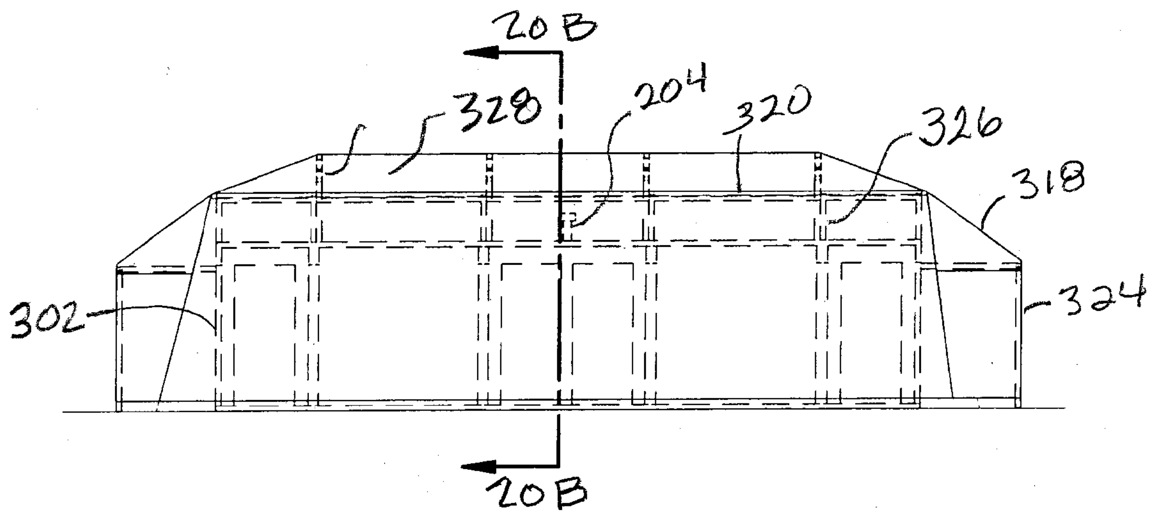
E04H 9/04	(2006.01)

(52) **U.S. Cl.** **109/79**; 109/80; 135/95; 52/173.1

(57) **ABSTRACT**

A blast resistant shelter apparatus includes a framework having at least an upper metal rail. A plurality of metal panels each have a C-shaped cross-section defined by a central flat web and two channel arms on the opposite sides of the central flat web. The metal panels are vertically mounted within the framework in a side by side relationship to define a wall. Each panel includes an upper and a lower end plate. A metal interior wall cladding is connected to the panels and spans the channel arms of each panel to close the cross-sections of the panels to define an interior space of each panel. The upper metal rail and the upper end plate of each panel have aligned fill openings defined therethrough for introducing a particulate material such as sand into the interior space of the associated panel.



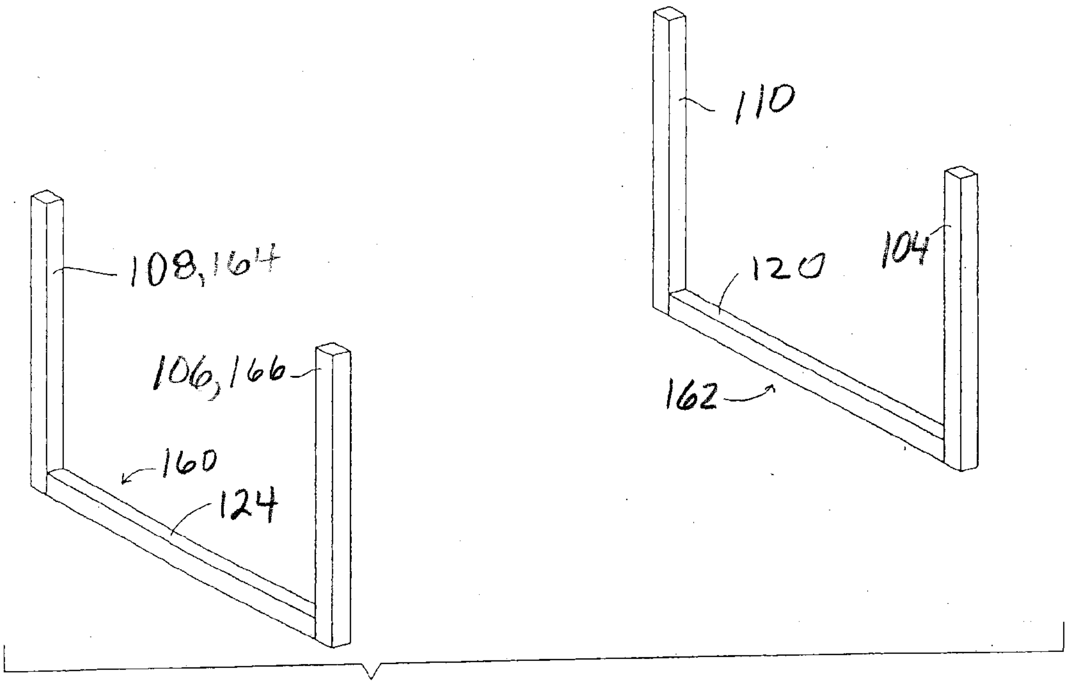

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FIG. 1A

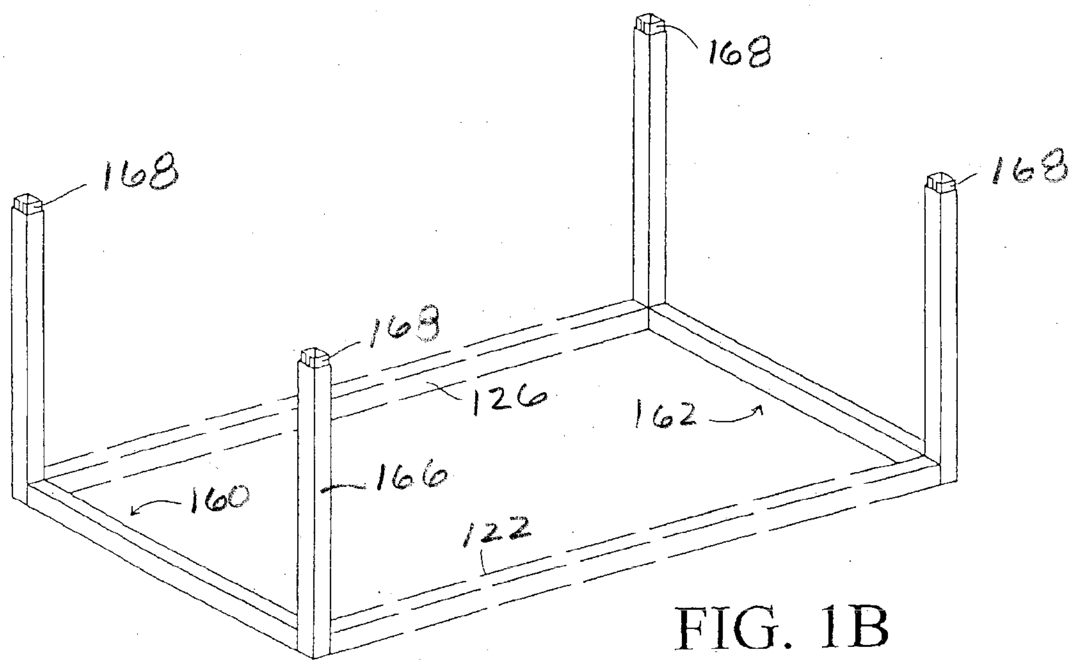
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FIG. 1B

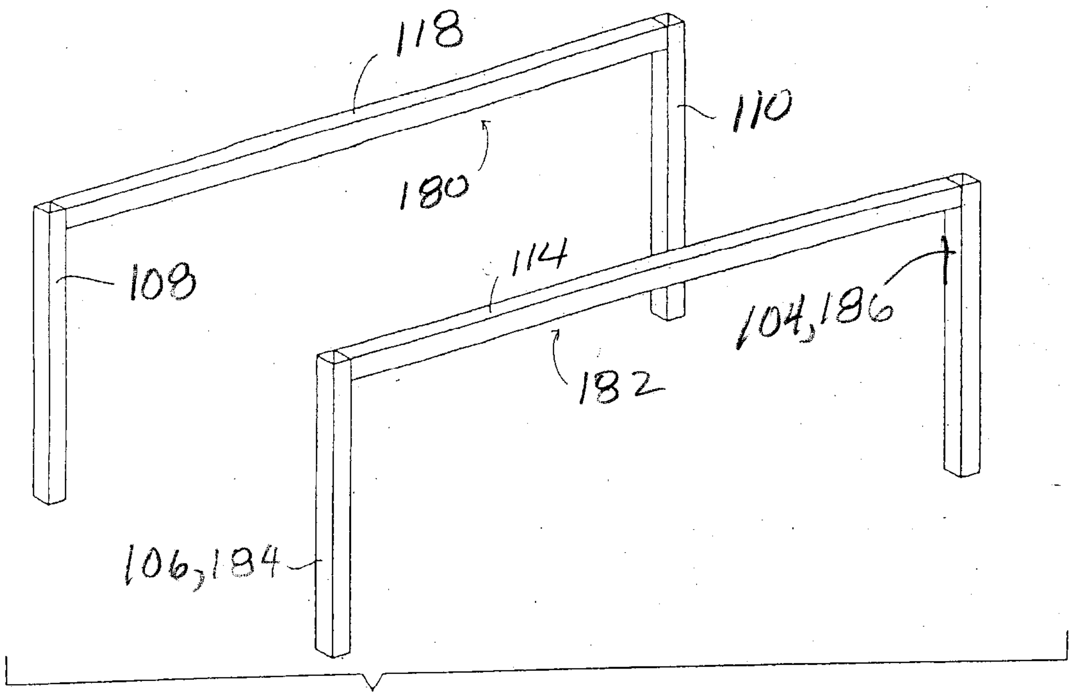
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FIG. 2A

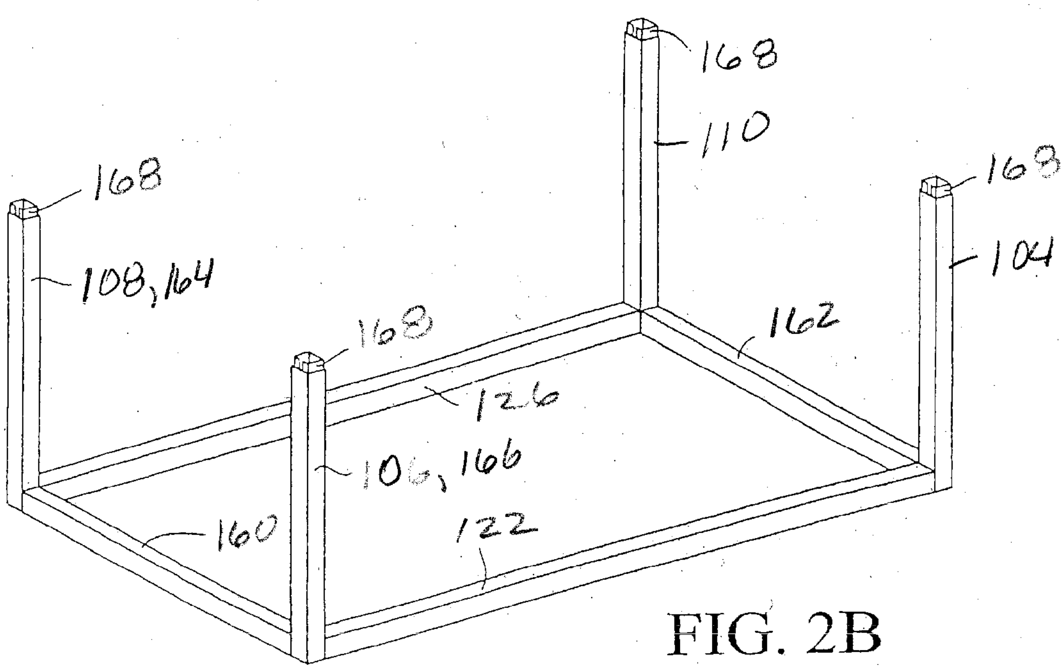
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FIG. 2B

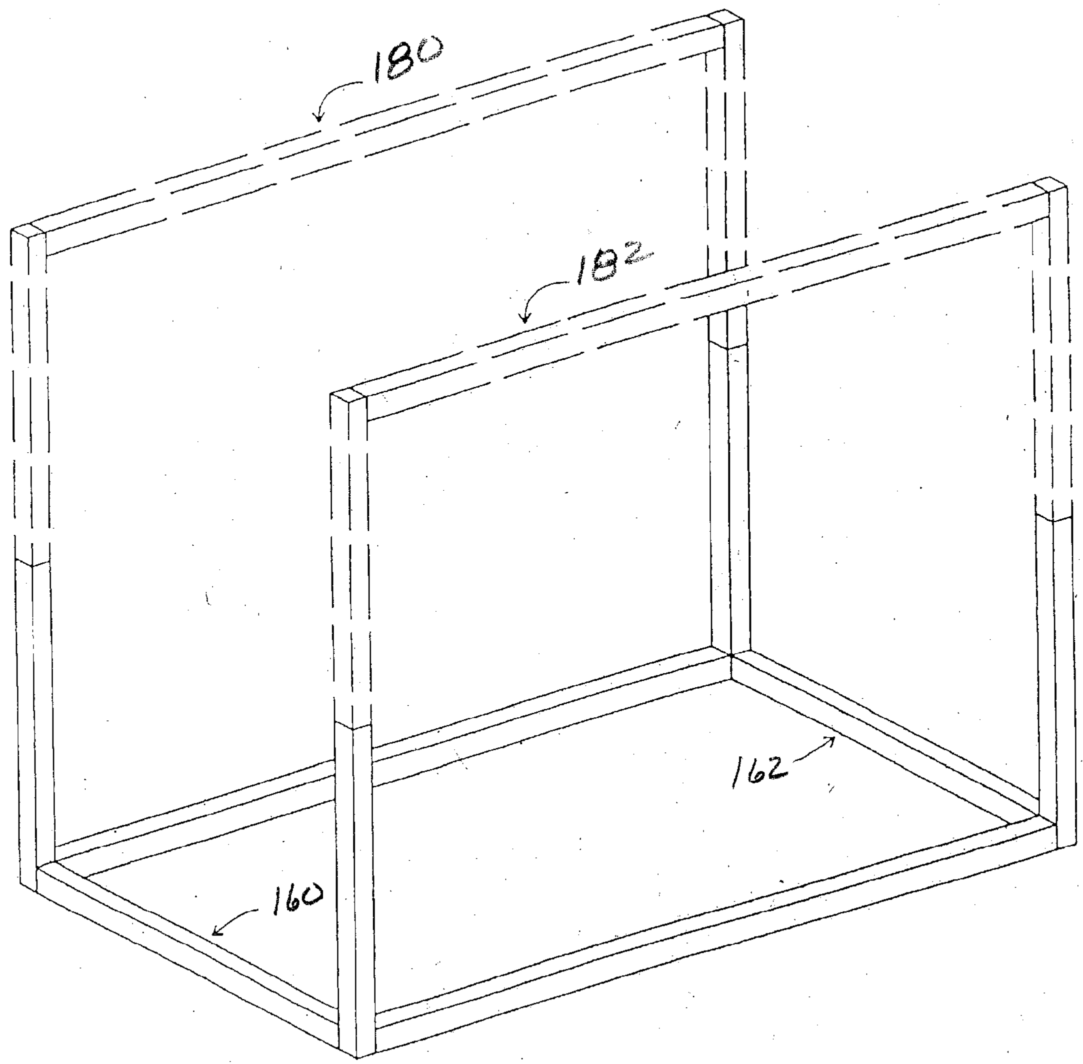


FIG. 3

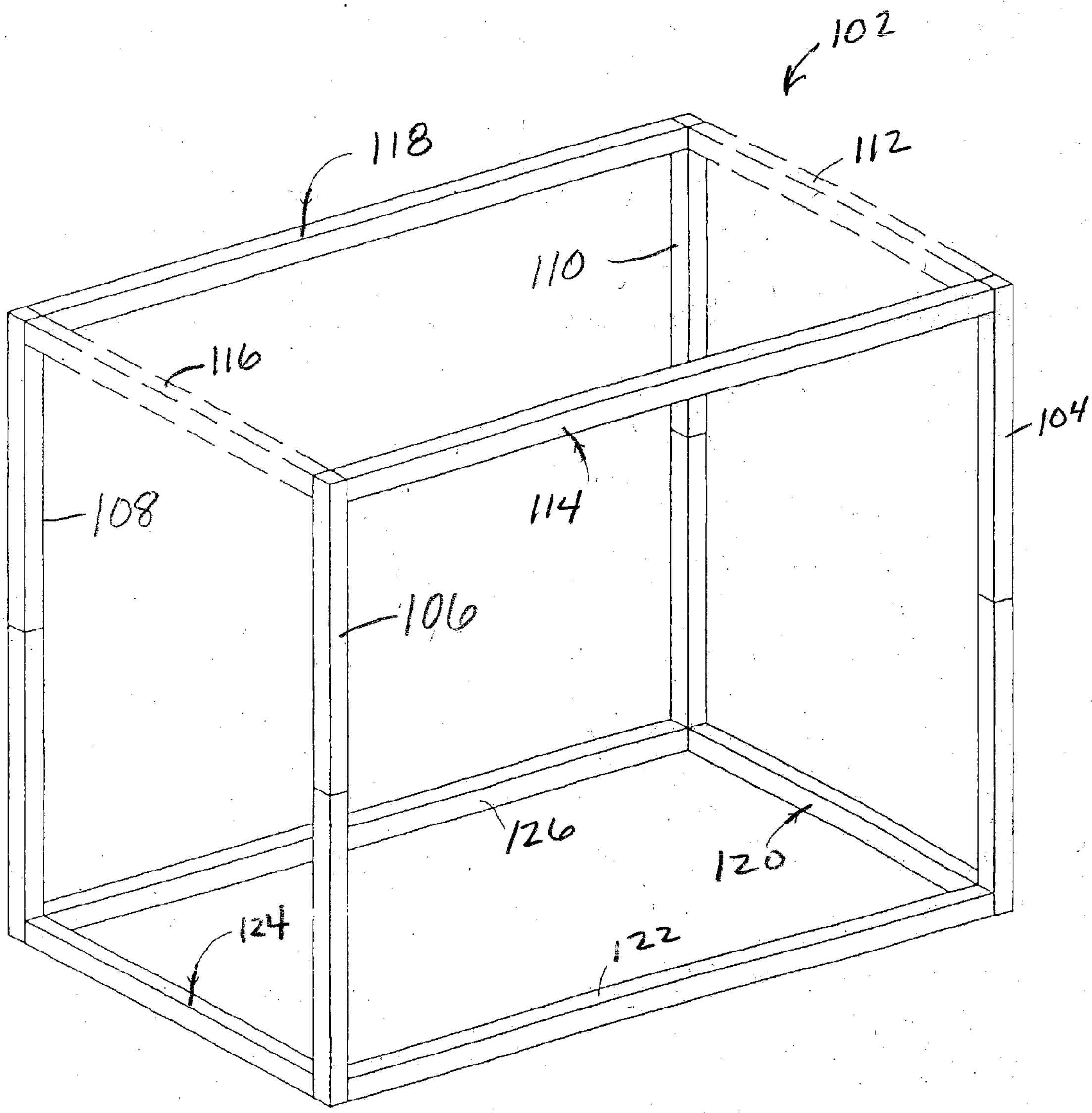
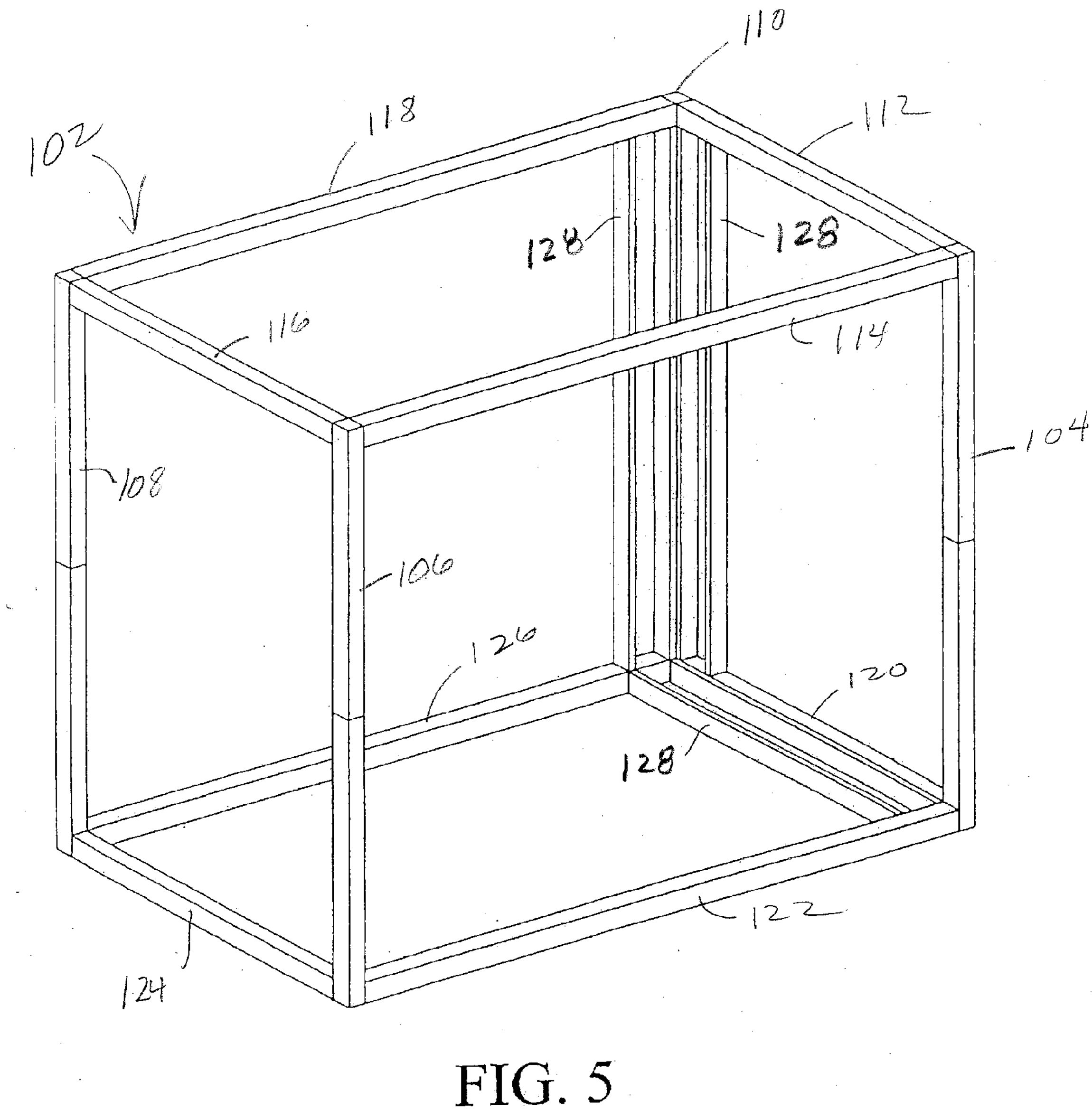


FIG. 4



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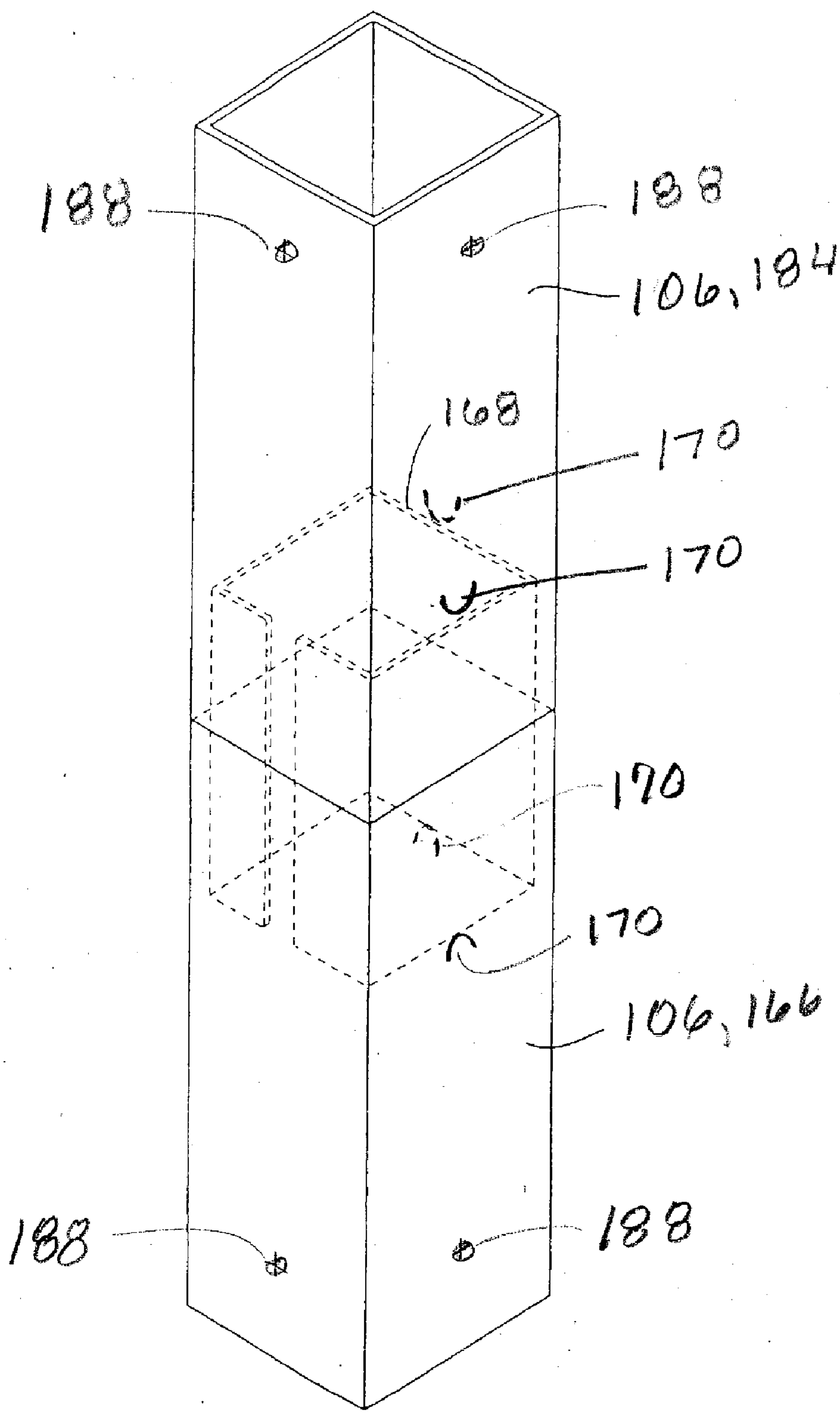

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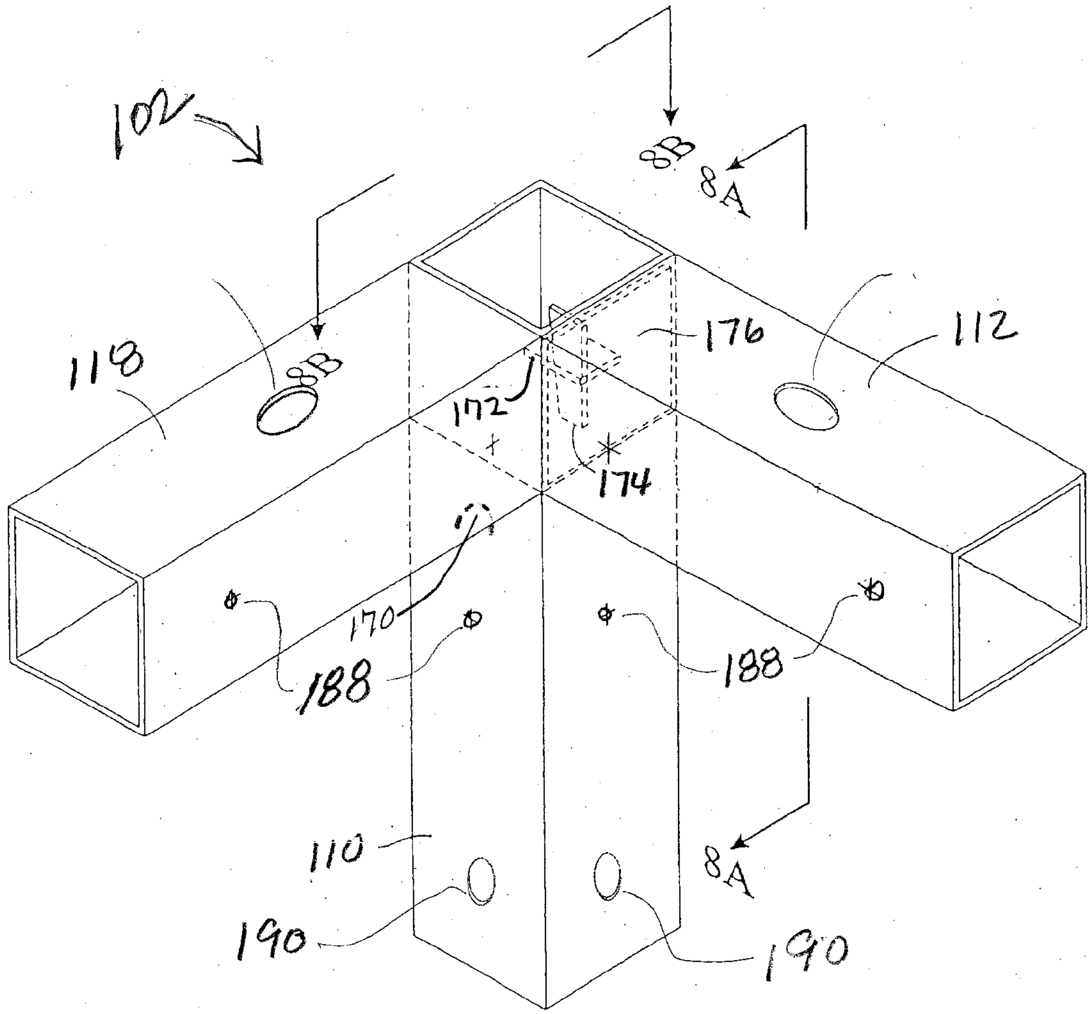


FIG. 7

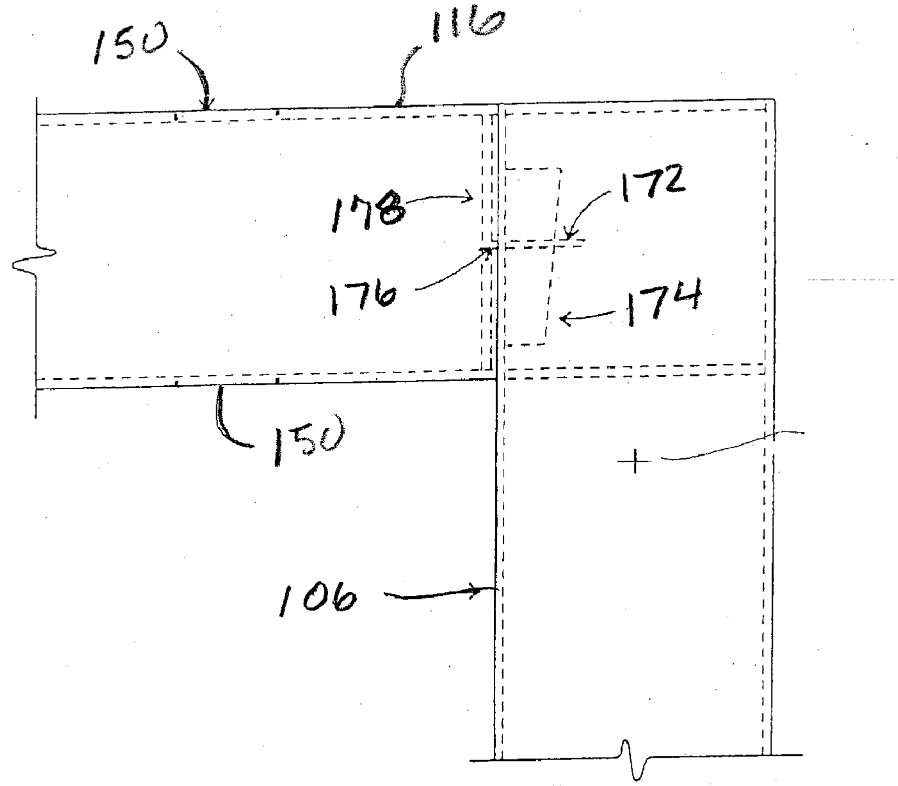


FIG. 8A

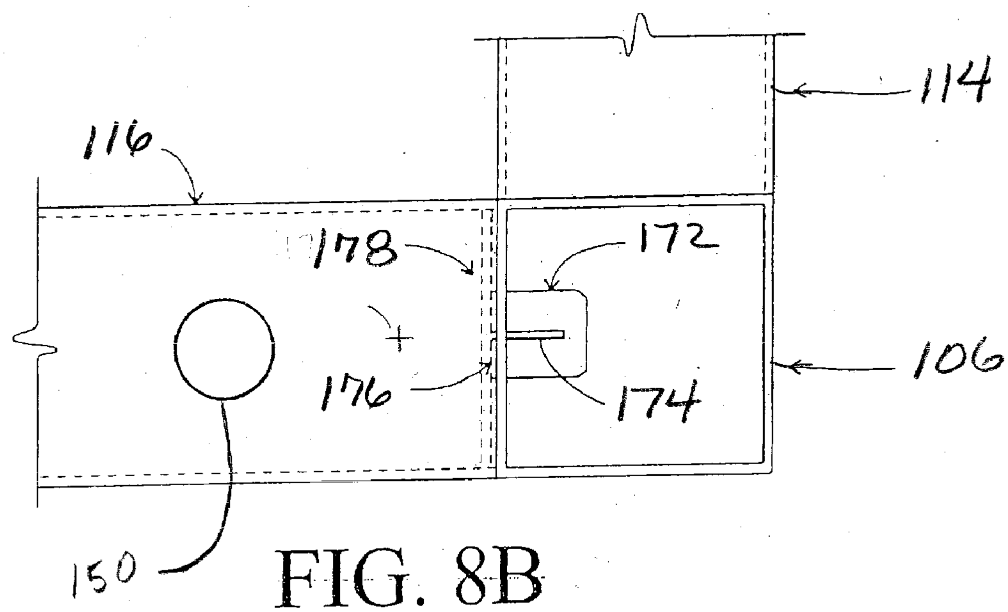
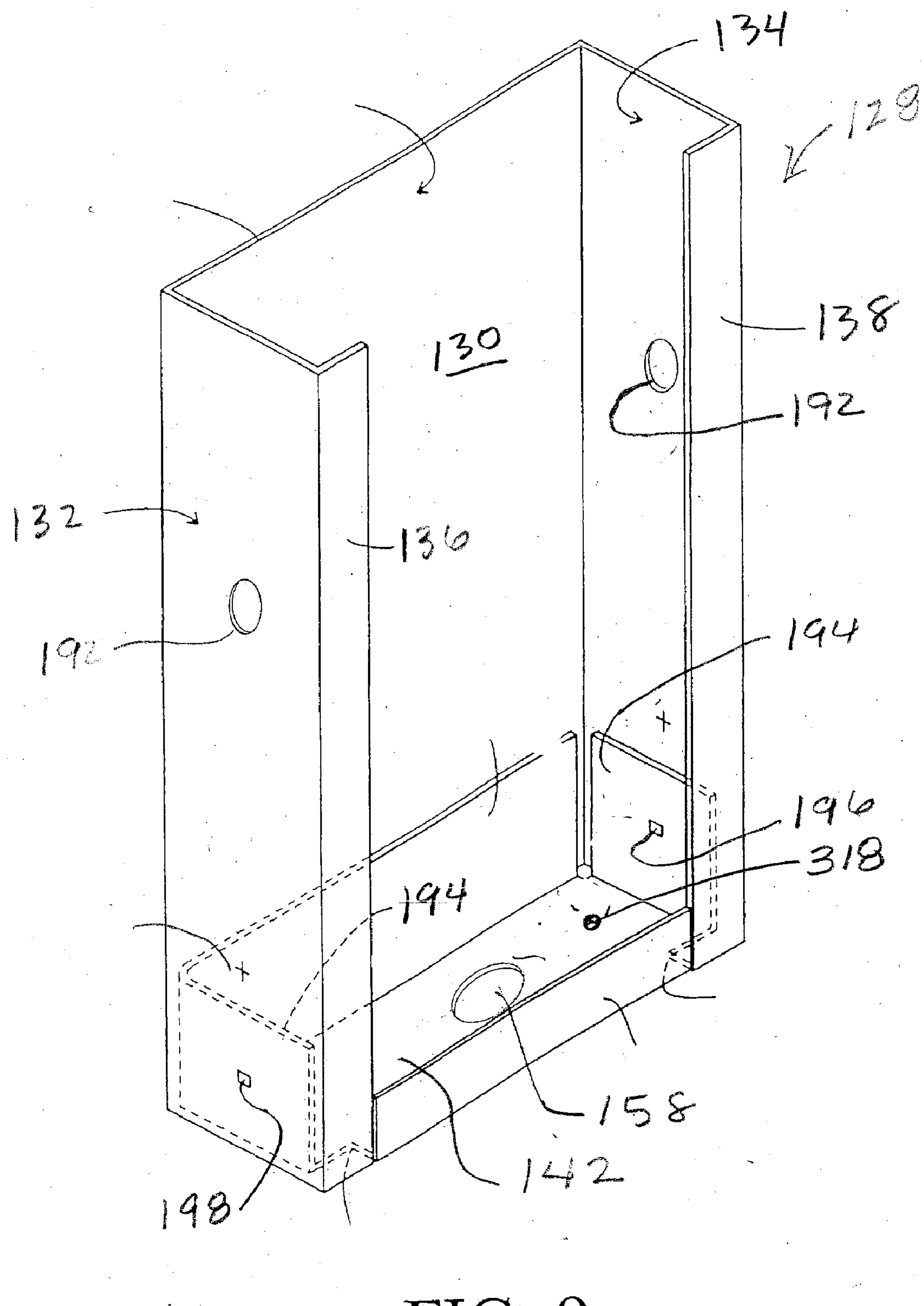


FIG. 8B



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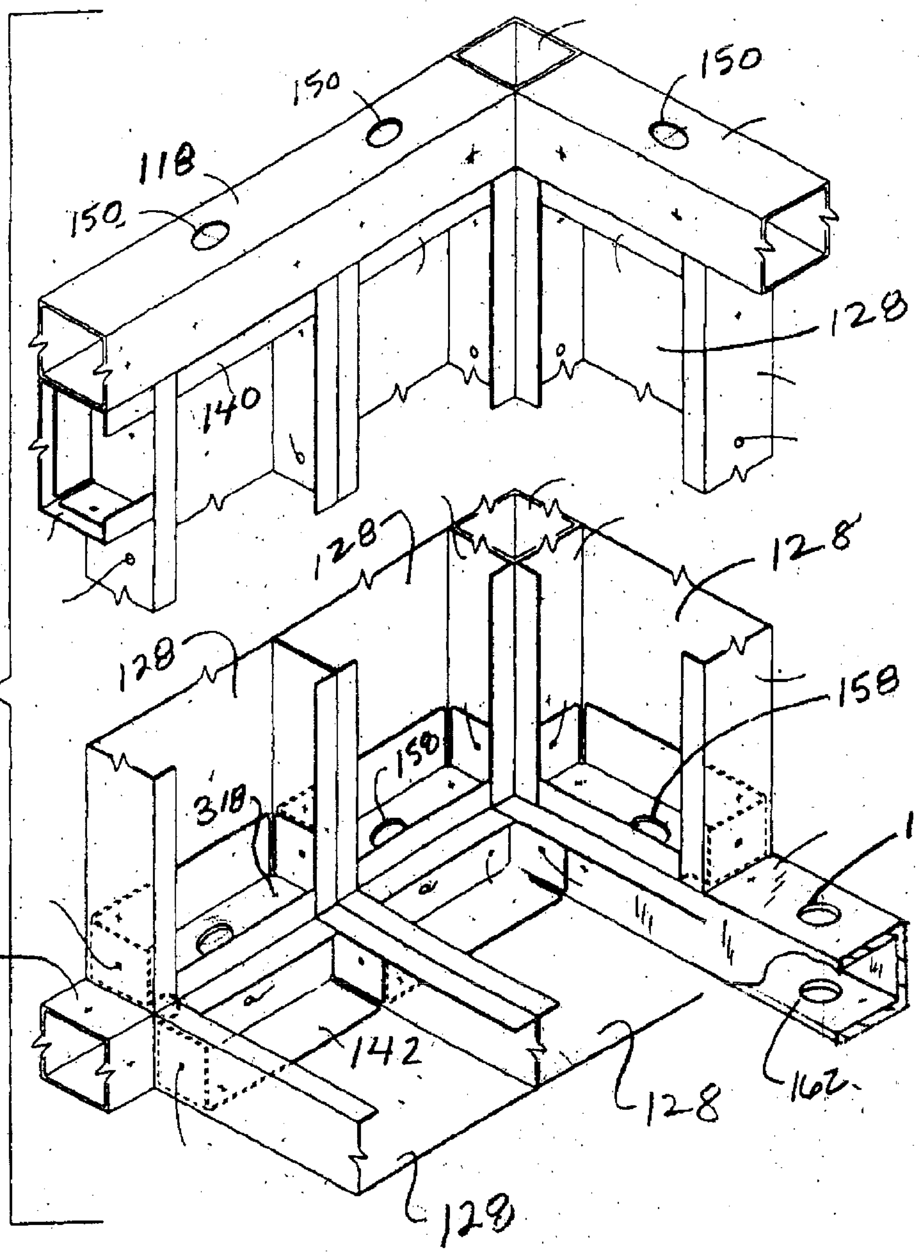
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FIG. 10

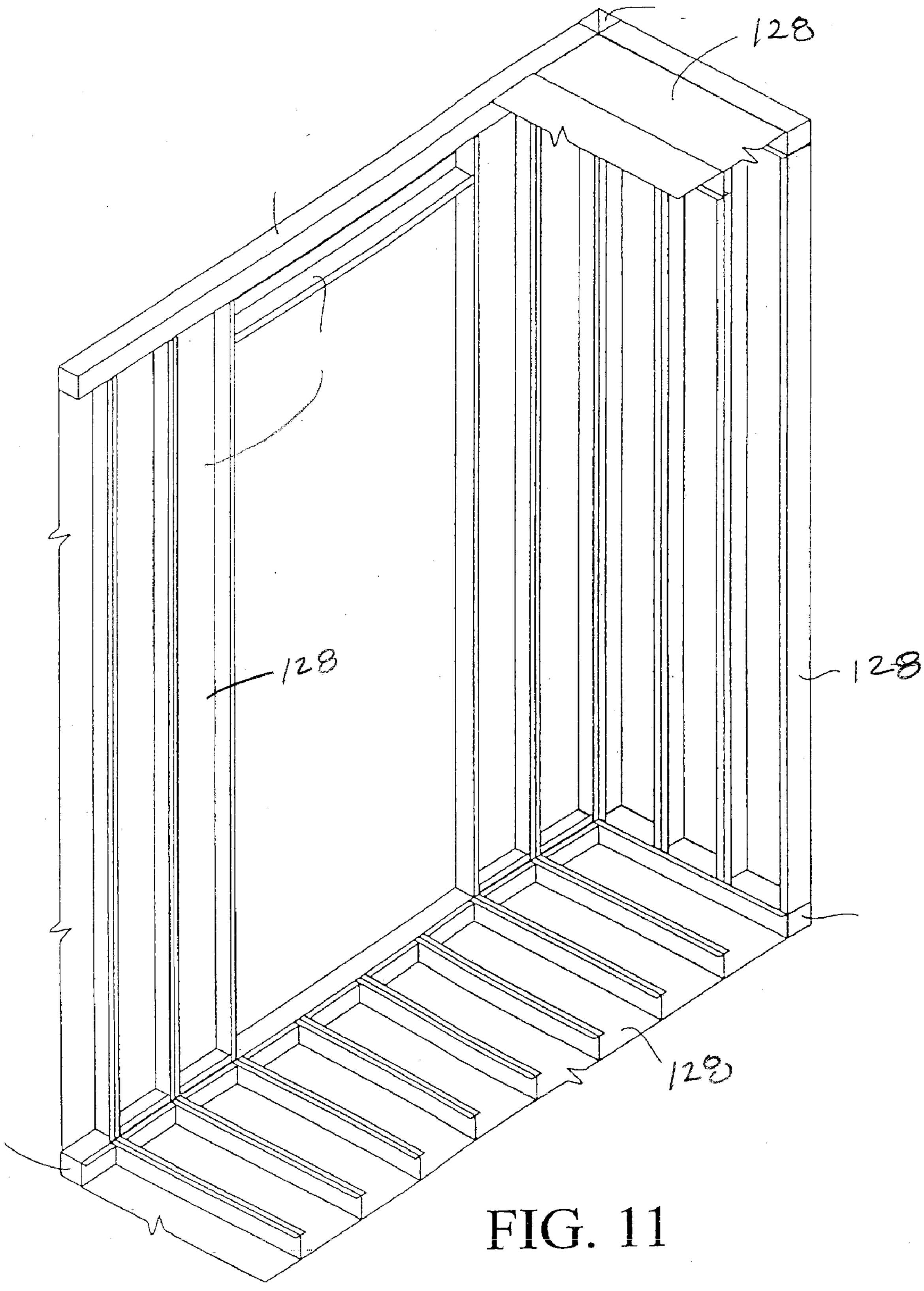

FIG. 11

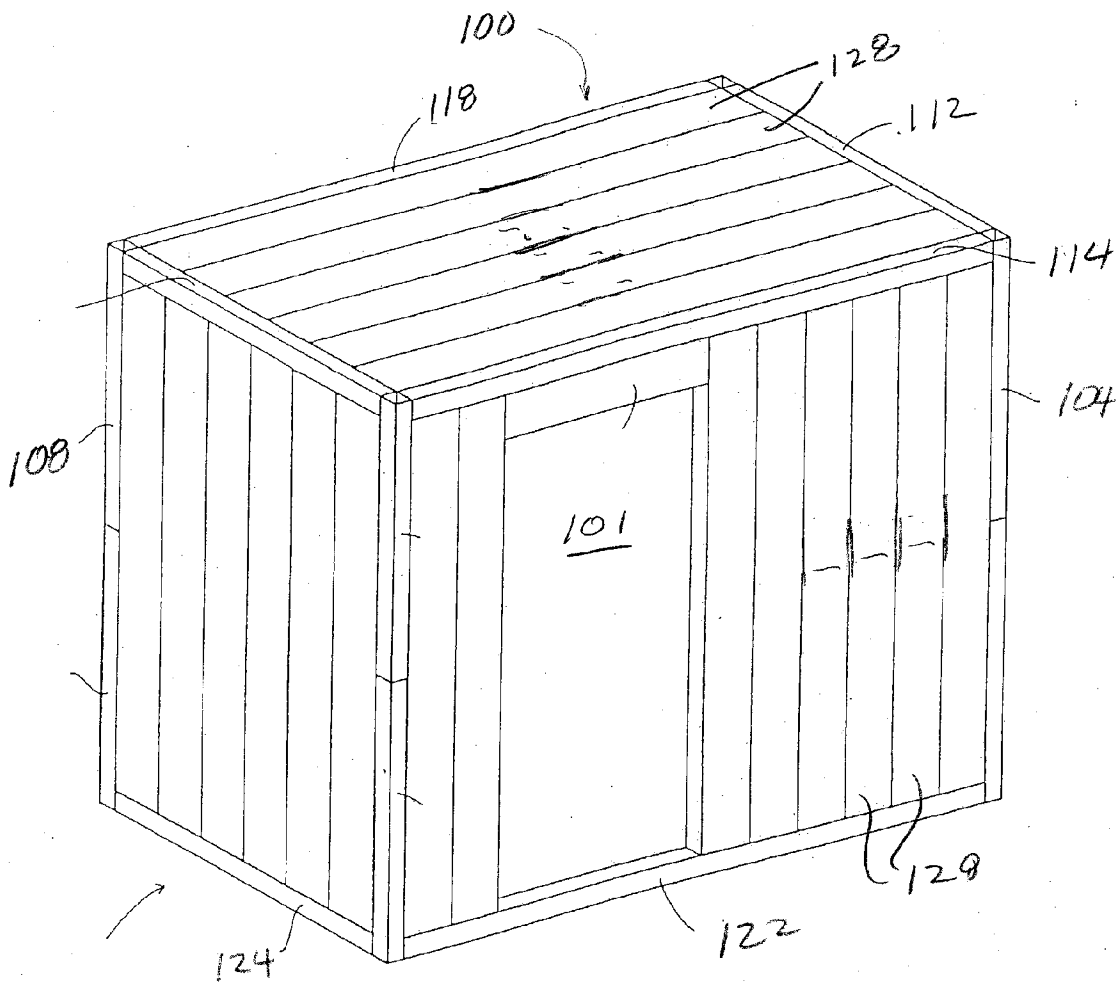

FIG. 12

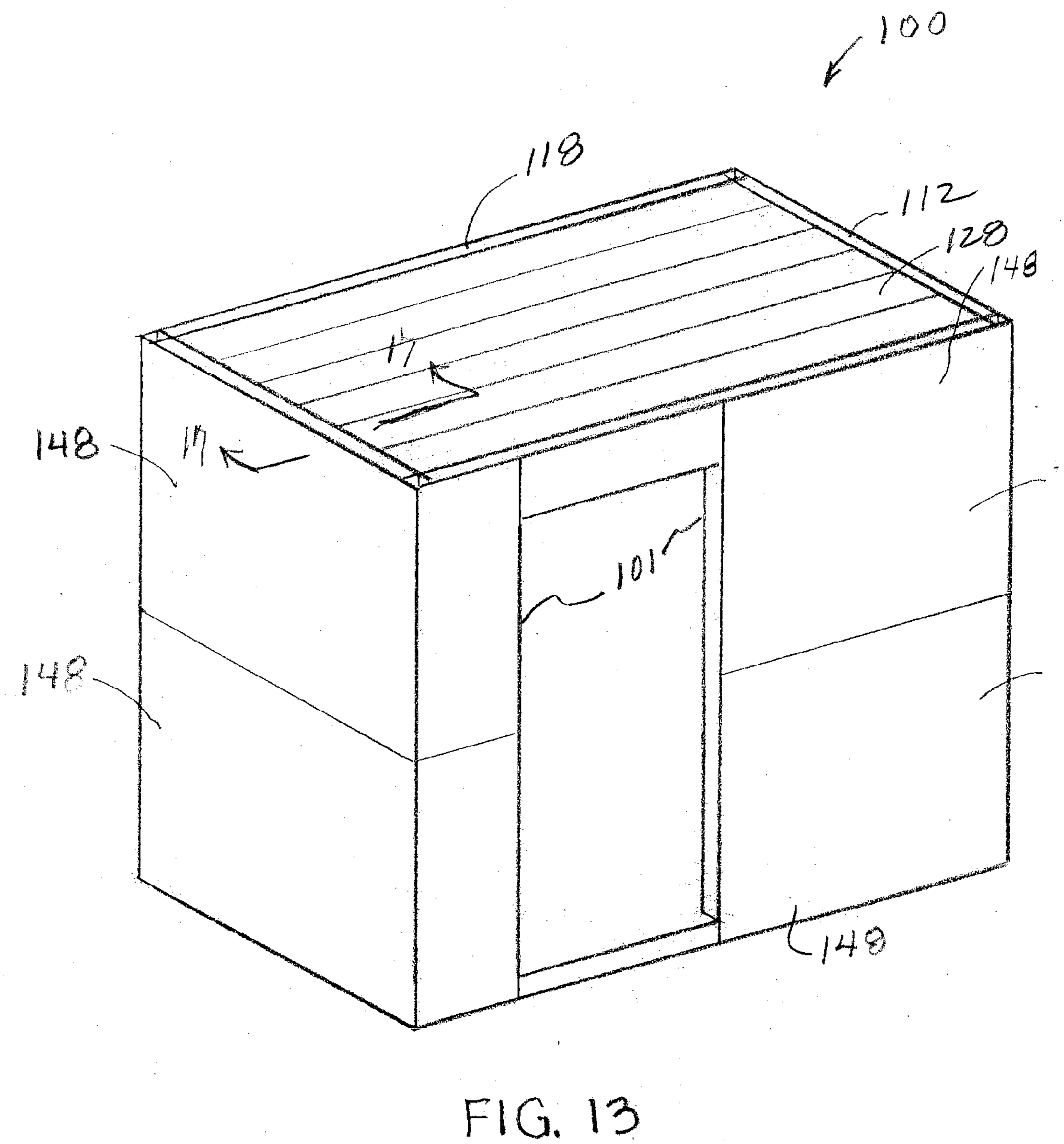

FIG. 13

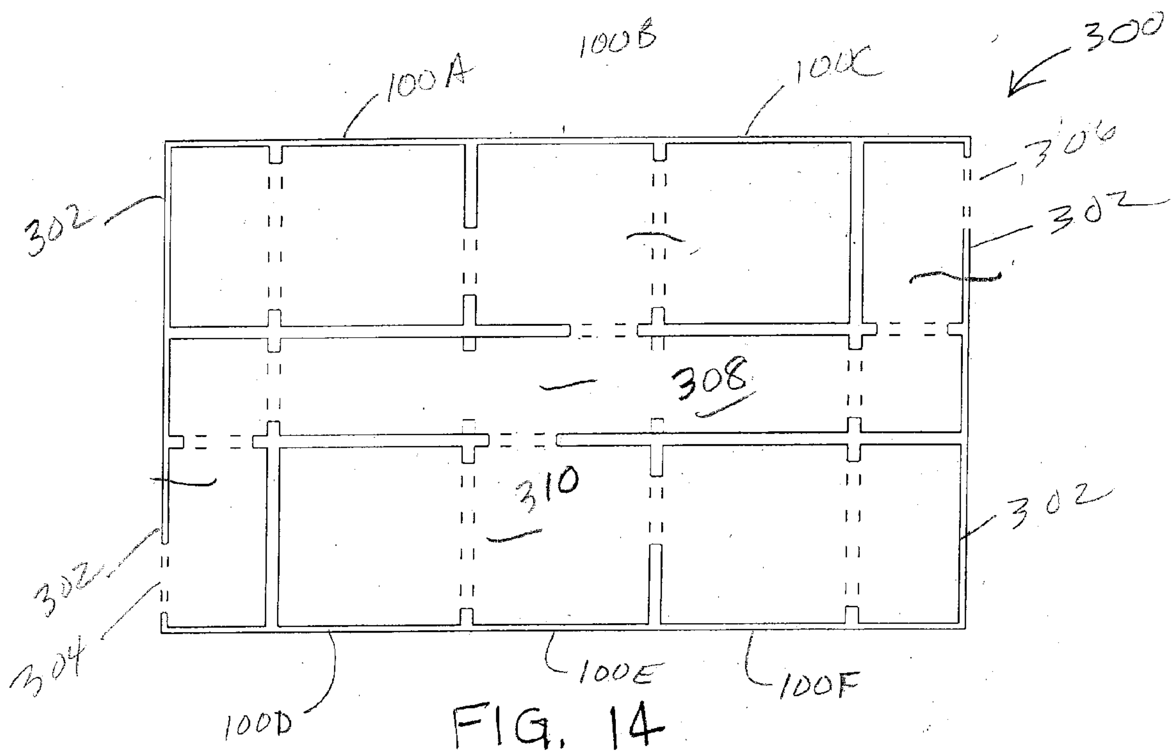
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FIG. 14

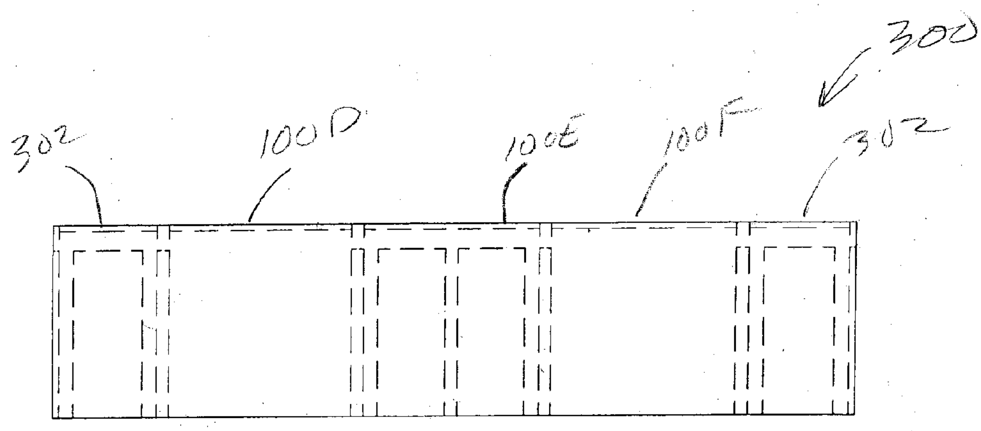
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FIG. 15

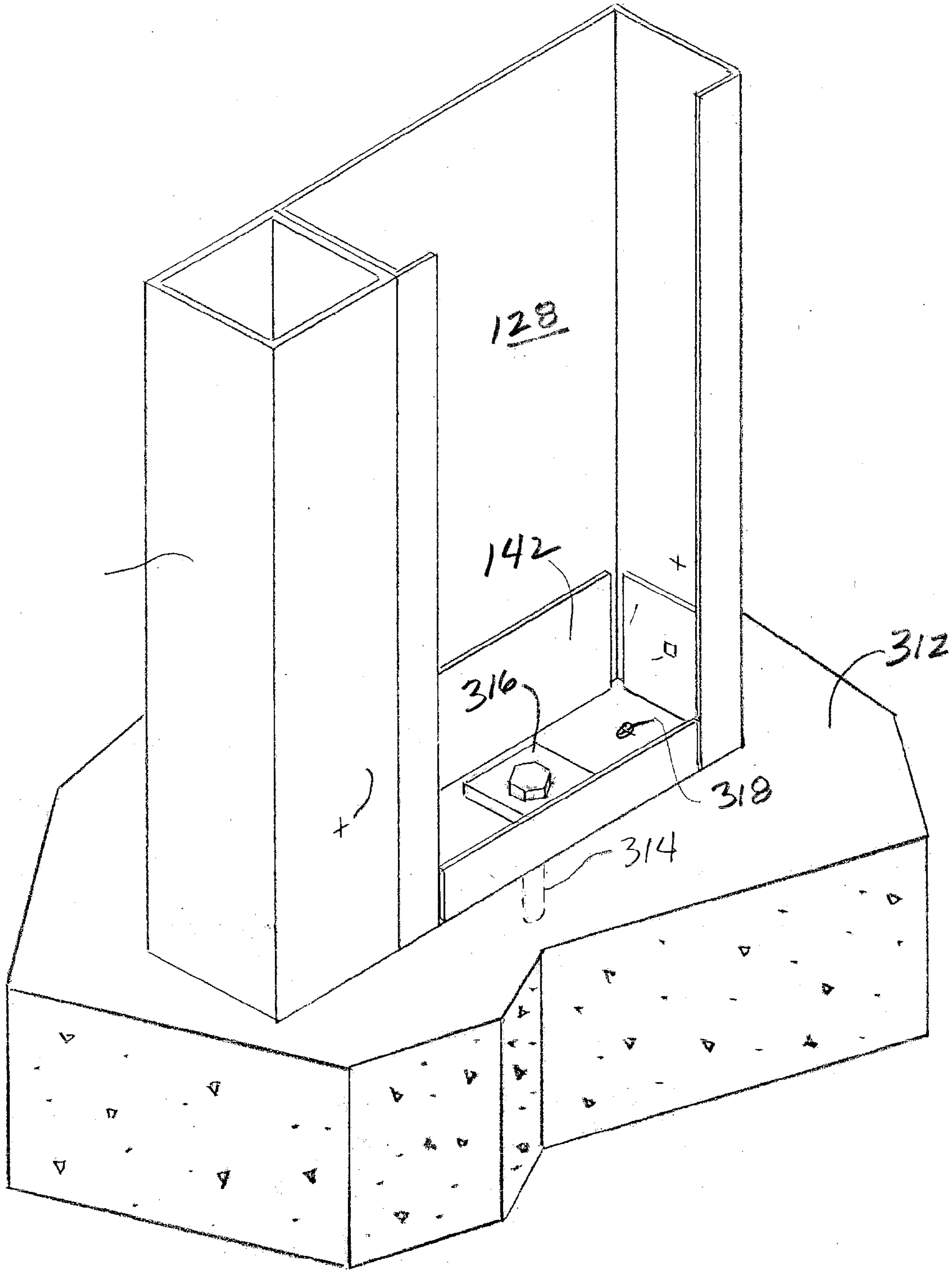

FIG. 16

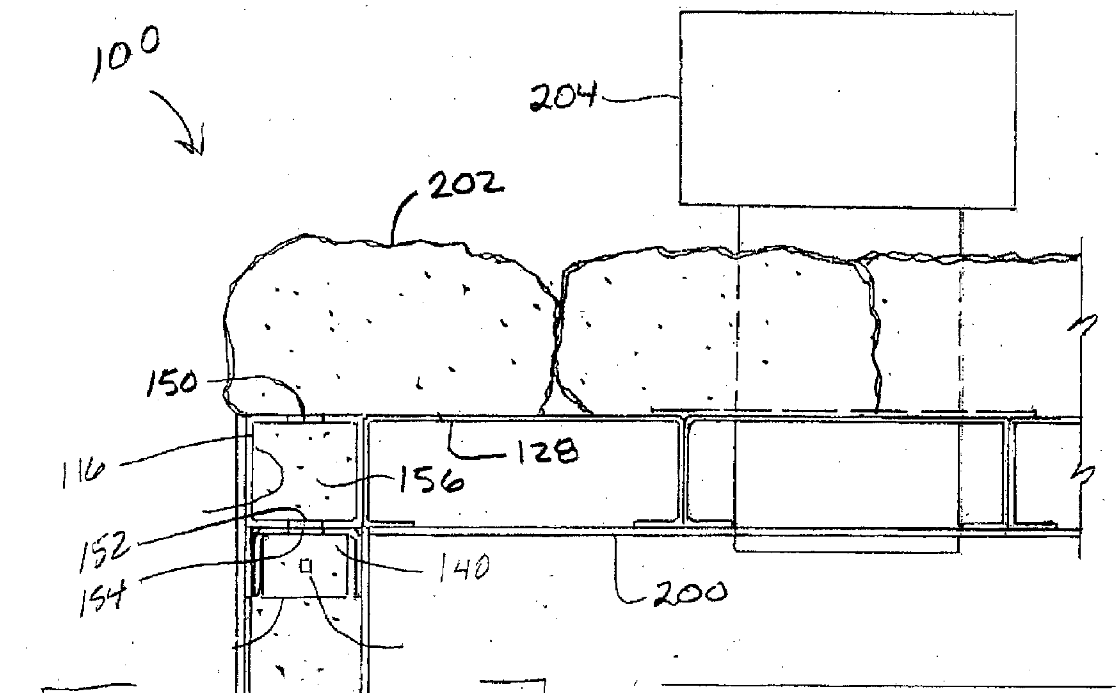

FIG. 17

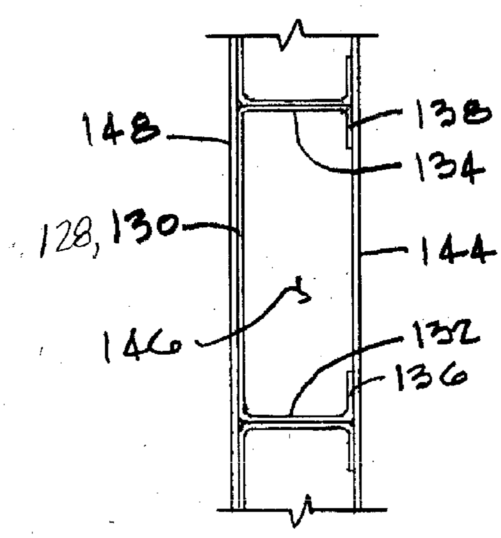

FIG. 17A

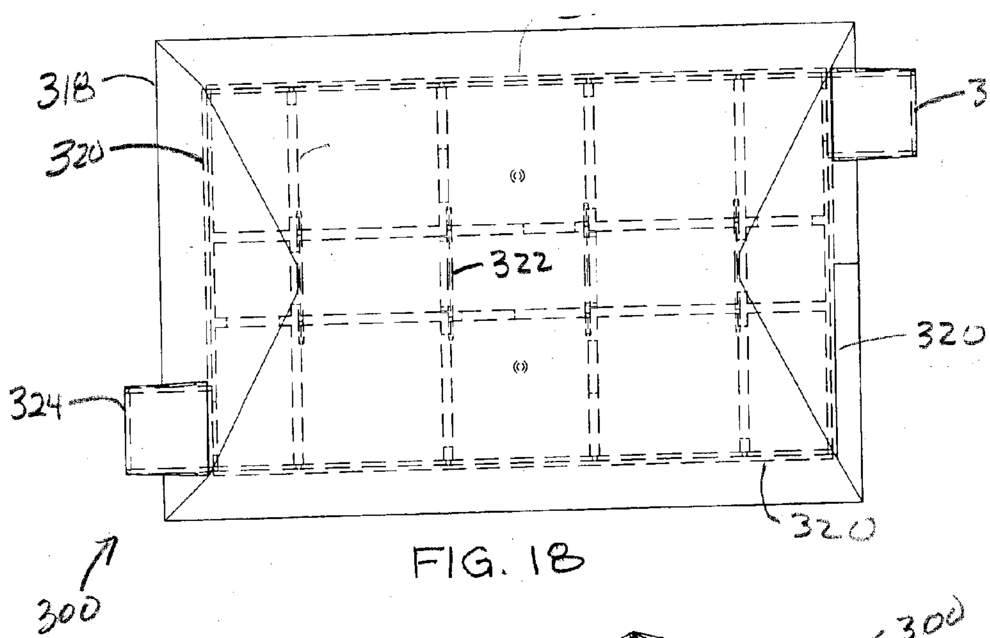

FIG. 18

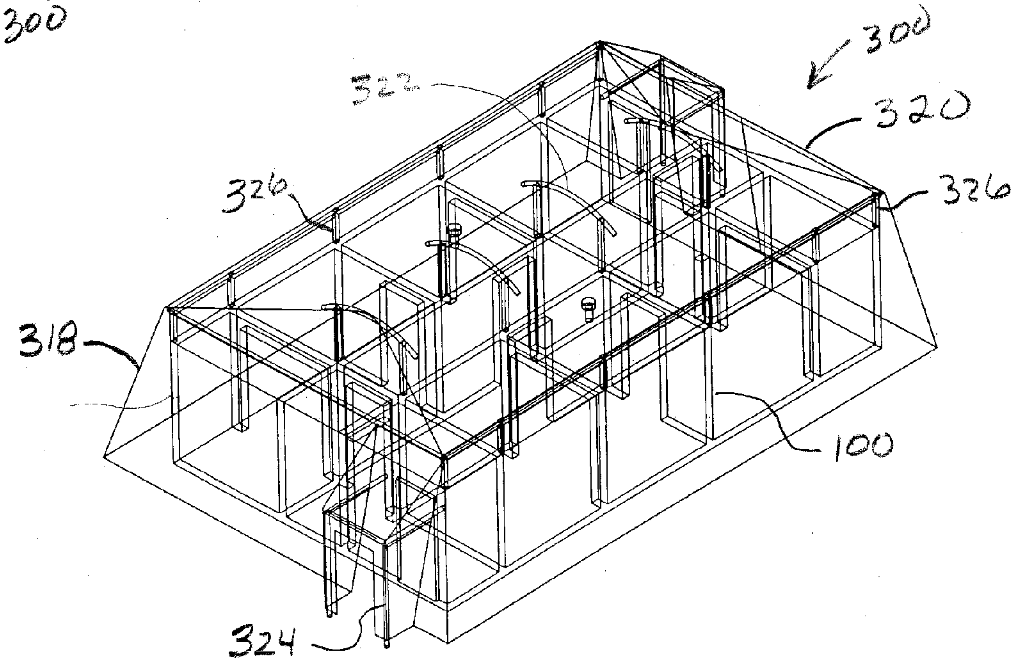

FIG. 19

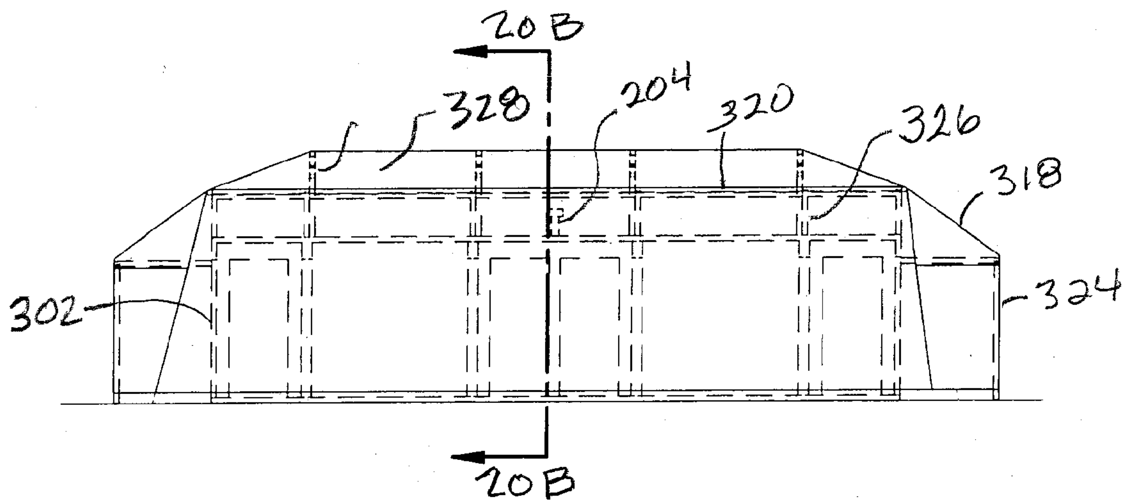

FIG. 20A

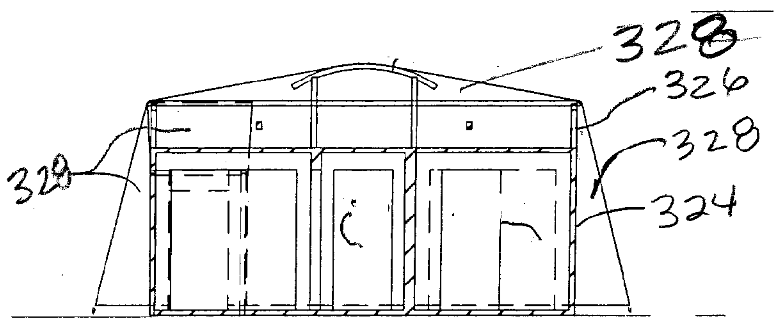

FIG. 20B

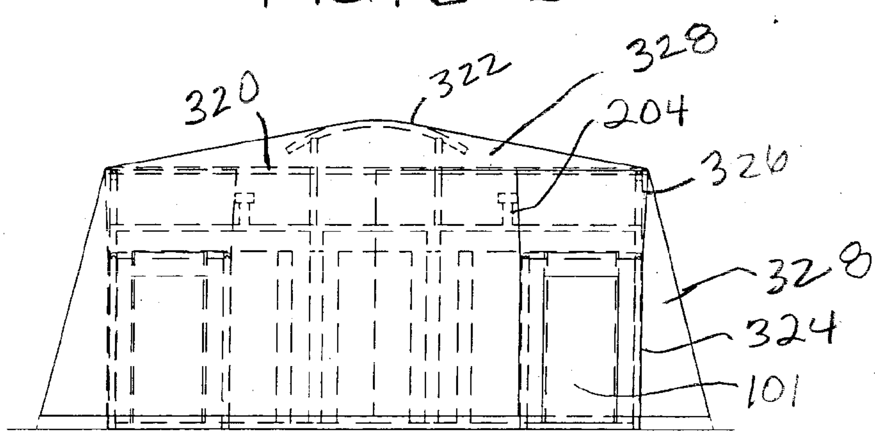

FIG. 21

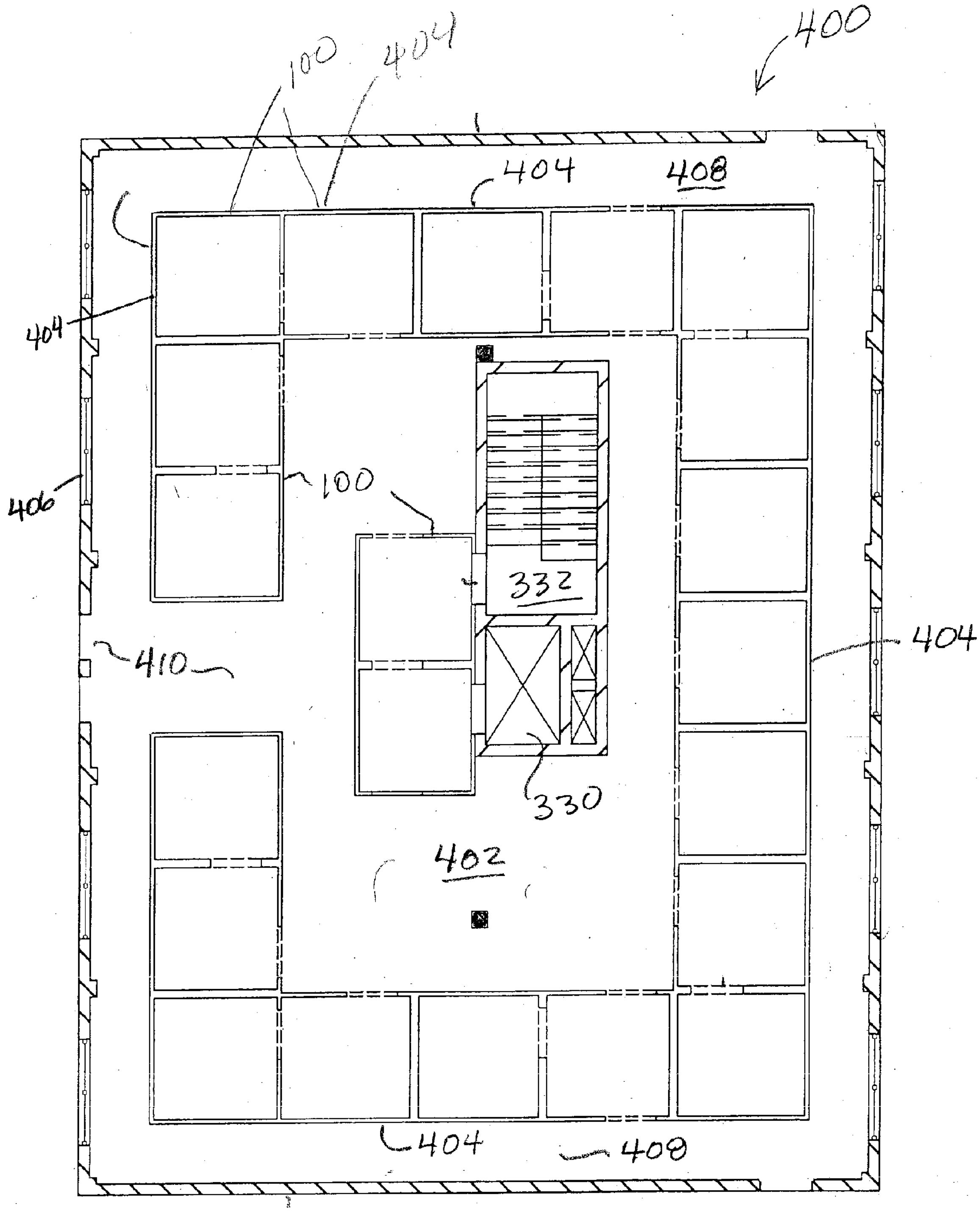

FIG. 22

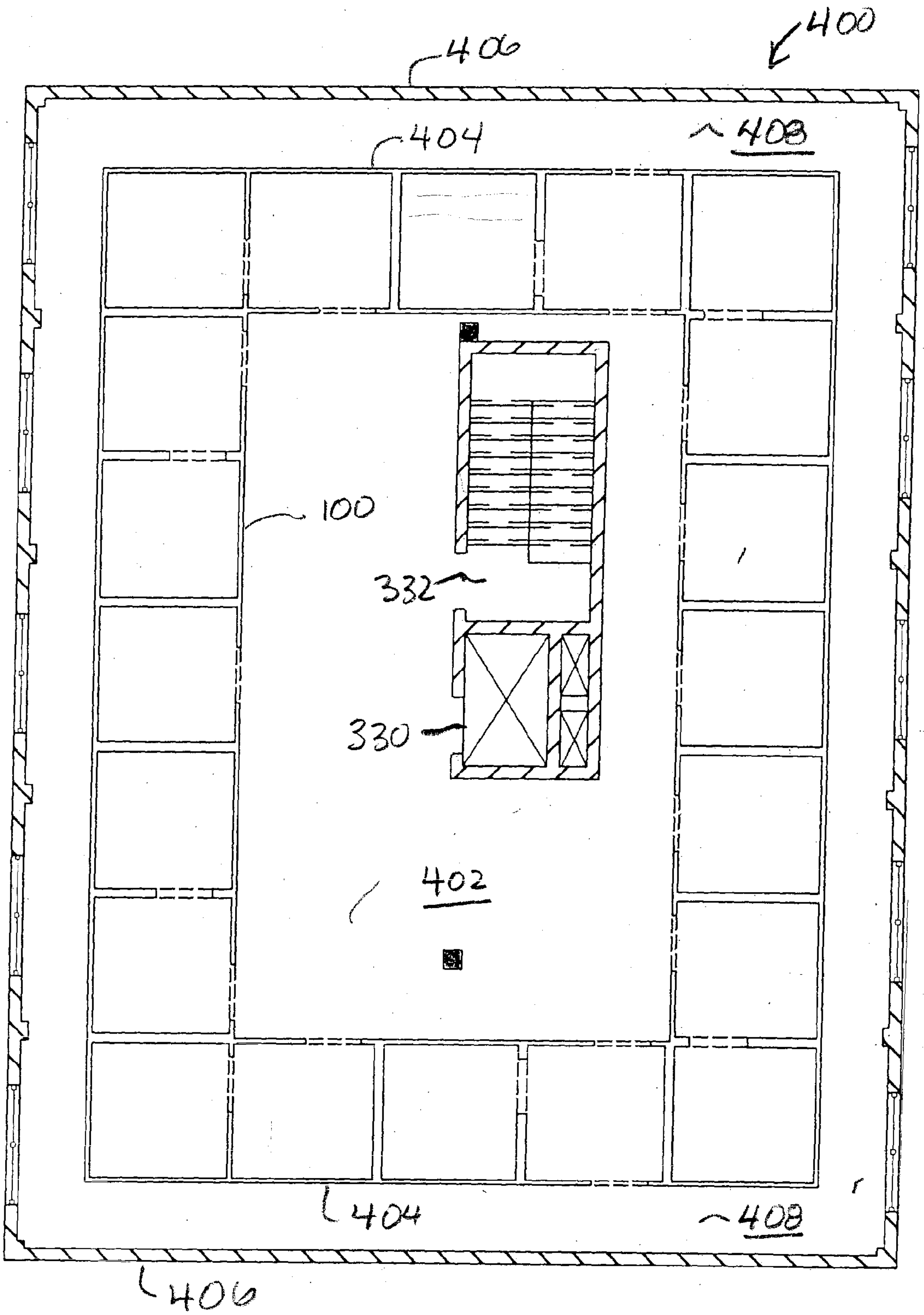

FIG. 23

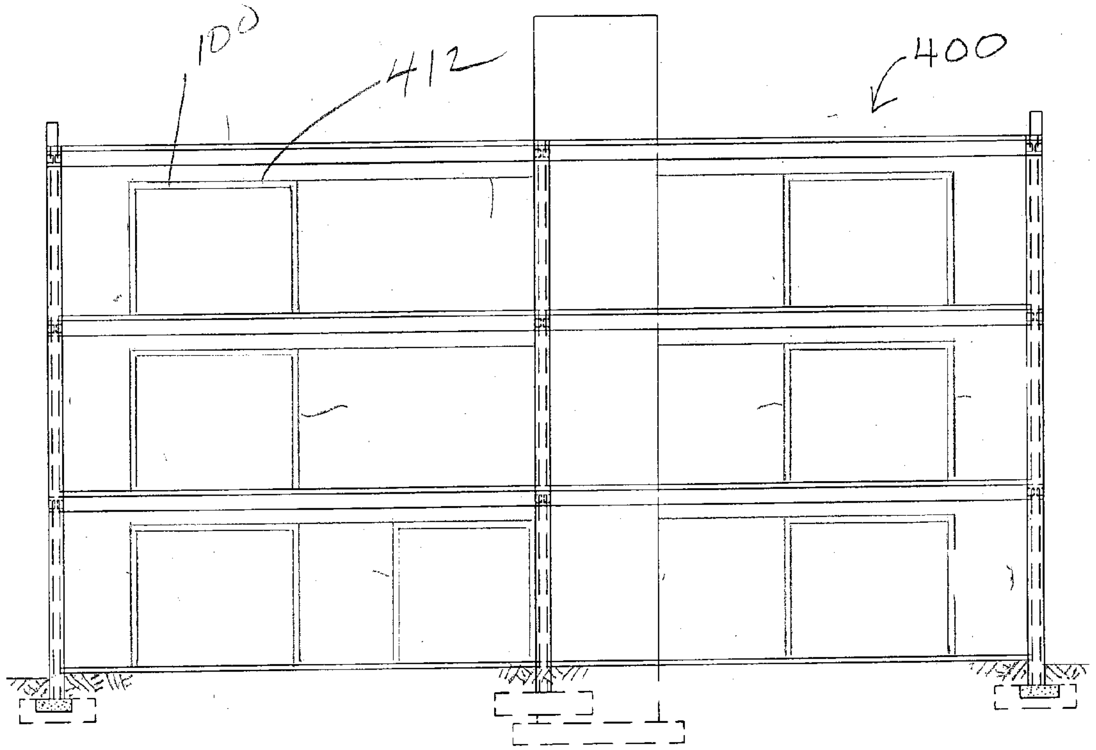

FIG. 24

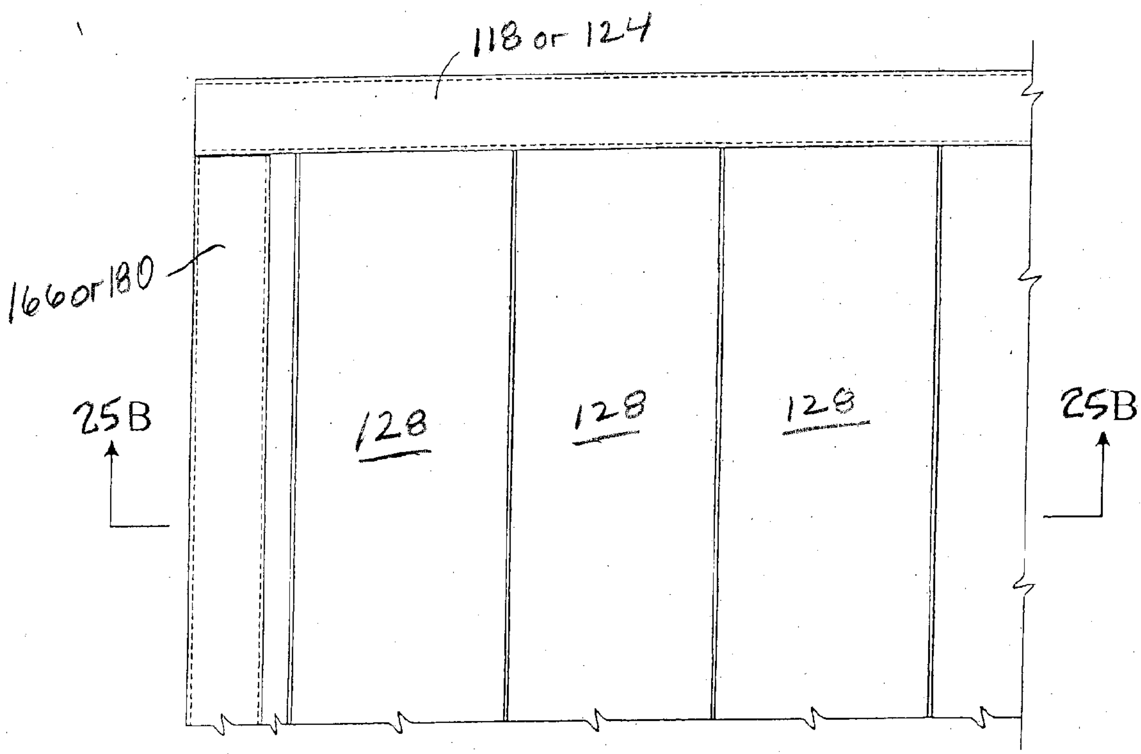

FIG. 25A

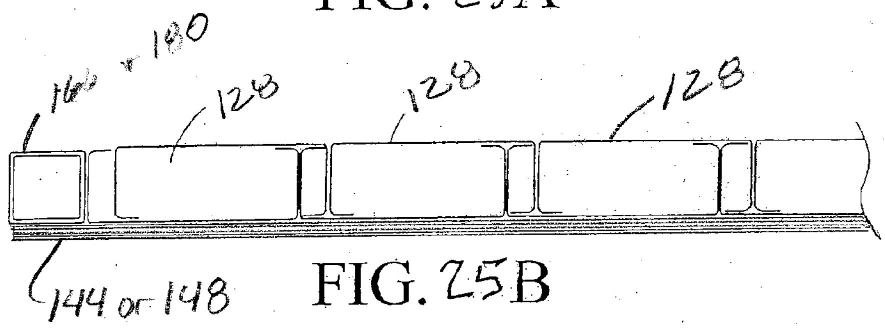

FIG. 25B

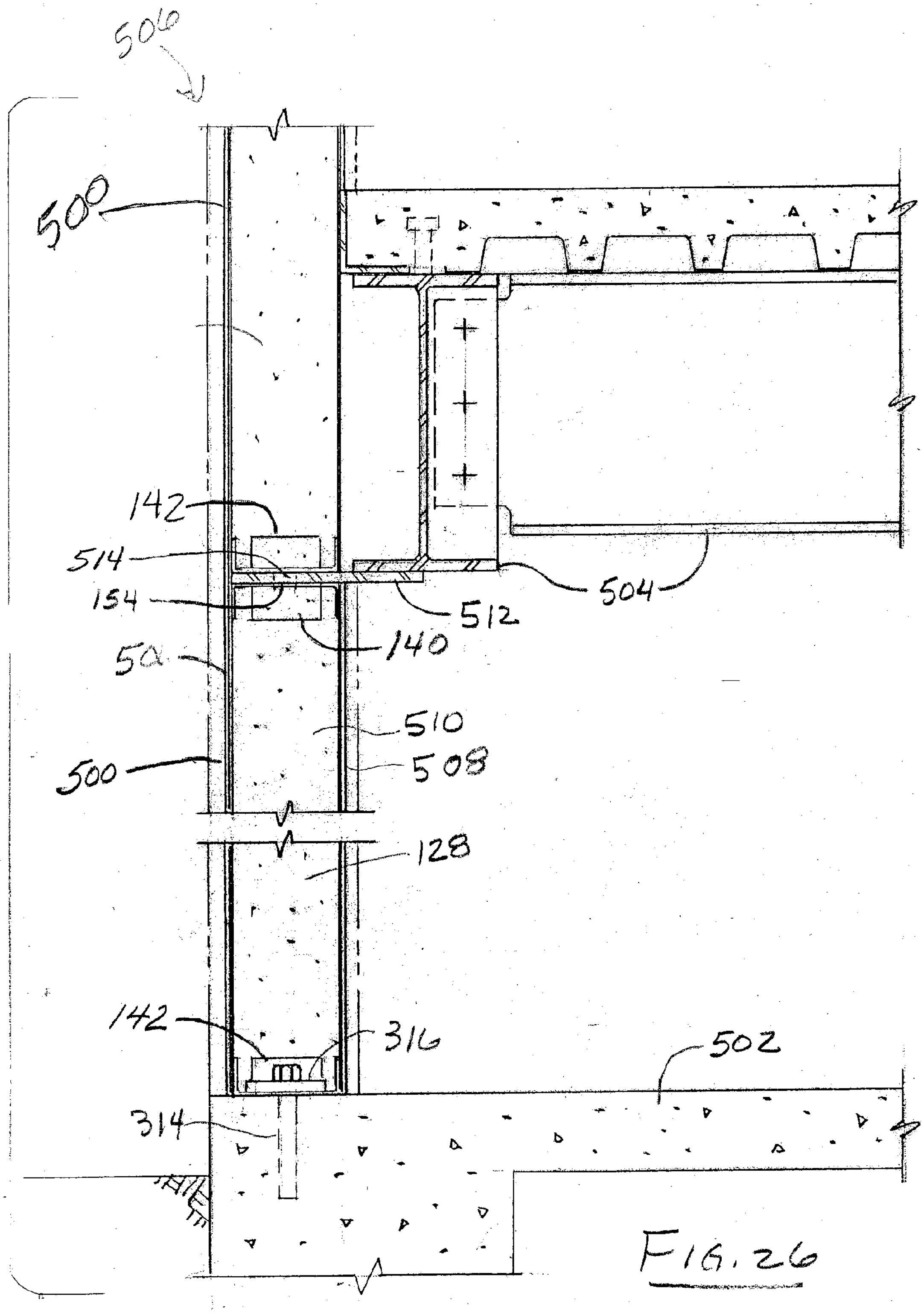
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FIG. 26

BLAST RESISTANT SHELTER

CROSS-REFERENCES TO RELATED APPLICATIONS

[0001] This application is a Non-Provisional Utility application which claims benefit of co-pending U.S. Patent Application Ser. No. 60/879,756 filed Jan. 10, 2007 entitled "Blast Proof Shelter" which is hereby incorporated by reference.

BACKGROUND OF THE INVENTION

[0002] 1. Field of the Invention

[0003] The present invention relates generally to blast resistant shelters, and more particularly, but not by way of limitation, to a blast resistant shelter of modular construction which serves as a safe harbor for personnel in hostile military or terrorist-prone areas.

[0004] 2. Description of the Prior Art

[0005] Historically field shelters for military combat operations have involved the use of sand bags arranged in a wall-like pattern around various temporary structures. Such sand bagged fortifications are labor intensive to construct, and have the disadvantage of being non-moveable and non-reusable.

[0006] U.S. Pat. No. 3,820,294 to Parker has proposed the use of modular constructed walls filled with sand for such field emplacements. Although the Parker system can be disassembled and reused, it is not capable of having the sand removed from the assembled structure so that it can be easily transported for reuse without disassembly of the assembled structure. The structure disclosed by Parker is focused on improvement of resistance to bullet penetration, and there is no discussion of blast resistance. There is also no indication that the walls constructed of plastic or plastic/woven material board and slotted connectors would provide any improvement in flexural dynamics characteristics that would improve its blast resistance.

[0007] Another approach to blast resistant shelters is seen in U.S. Pat. No. 6,412,321 to Palatin which provides for the construction of hollow walls which are then poured full of concrete to create a rigid permanent non-moveable blast resistant structure. Palatin's structure also suffers from the disadvantage of not being moveable to a new location. Furthermore, its rigid concrete walls do not provide the ductility necessary for absorbing blast forces by yielding without failure.

[0008] Structures have also been proposed for containing blast forces within the structure. An example of such a structure is seen in U.S. Pat. No. 3,832,958 to Hiorth which provides a building for containing explosive dangerous materials. The Hiorth structure provides two concentric cylindrical shells defining an annular cavity which is filled with sand. The Hiorth structure is not designed for relocation and reuse.

[0009] Also, the structures discussed above are not applicable to use within existing building structures or in combination with existing conventional building structures such as office buildings or the like.

[0010] The prior art also includes a number of modular constructions for storm shelters and/or security shelters which can be constructed either free-standing or within an existing building. One such structure is that shown in Waller U.S. Pat. No. 5,813,174 which provides a modular structure made from a steel framework and steel panels received within the framework. The structure can be assembled either free-standing or within an existing building to provide a security enclosure or as a storm shelter for protection from tornados and the like. The structure of the Waller '174 patent is designed more for protection against projectile impact and storm forces, and not for blast resistance to explosions. The Waller '174 structure does not utilize any sand fill or other particulate fill in the structure walls.

[0011] Also, U.S. Pat. No. 6,393,776 to Waller et al. discloses a modified version of the Waller '174 structure particularly designed as a tornado shelter for placement on a concrete foundation which utilizes a tub structure to form a part of the shelter. Again, the Waller '776 structure does not include any sand fill or other particulate fill in the structure walls.

[0012] Perhaps the best indication of the continuing need for the development of improved blast resistant structures is the recent solicitation by the U.S. government for proposals for new designs for blast and fragmentation resistant shelters to be utilized in high threat locations. That solicitation identified as "R2190 Blast and Fragmentation Resistant Construction" dated Mar. 3, 2006 reads as follows:

[0013] "Design, develop, model, and test an expeditionary construction method for blast and fragmentation resistant structures for high threat locations and forward operating bases. The construction method should use stay-in-place forms filled with a mixture of cement and indigenous materials or equivalent approach to create a structural framework with inherent blast and fragmentation protection capabilities. Protection should be provided for the exterior walls and roof, and include provisions for incorporating protective windows and doors in the building system. Detailed design drawings shall be developed for barrack type structures approximately 20 ft by 40 ft in plan, and allow modular construction for larger units. The structural framework must be lightweight to allow expedient air/sea transport, use material with high strength and ductility for blast resistance, achieve a final cost no greater than two times that of existing unprotected facilities, and be able to be erected in theater using local minimally-skilled labor. The design shall mitigate flammability and other life-safety issues related to military construction. Documentation for the final product must include: 1) a field manual detailing the construction method and a validated engineering level design model for determining resistance to blast threats; 2) a detailed technical report describing the results of appropriate laboratory component testing and full-scale blast experiments that validate the performance of the structures constructed using this method; and 3) participation with TSWG in the preparation of documentation that validates the construction process, cost estimate, mechanical properties of the stay-in-place forms and hazard reduction resulting from the full scale blast testing. This information will be implemented to a Unified Facilities Criteria document as maintained by the U.S. Army Corps of Engineers, Protective Design Center."

[0014] Thus it is seen that there is a continuing need for the development of such blast and fragmentation resistant structures.

SUMMARY OF THE INVENTION

[0015] The present invention provides a light-weight steel blast proof shelter structure which includes individual fabricated tubular steel and cold-formed, light gauge, cold rolled steel components which are compactly packaged and shipped loose with connecting hardware and structural adhesive. The components are assembled at the site by the end user to form a rectilinear frame and wall assembly with steel sheet, of varying thicknesses, bonded to exterior and interior faces of walls, and interior faces of roofs which require blast, fragmentation, and small arms fire terminal ballistics protection (fortified walls, roof).

[0016] Continuity of individual modular components is achieved by assembling tubular components with sleeve inserts and steel keys in slotted tongues inserted through rectangular holes in connected tubes and by bonding and connecting light gauge steel components with viscoelastic structural adhesive and sheet metal screws to like components and tubular components. Rectilinear tubular steel framing forms the construction skeleton for assembly of the remainder of the structure or structural module and forms the edges and corners of the structural unit. Tubular steel elements which lie along the tops of walls have circular holes in top and bottom walls which match holes of the same size in the cold-formed steel end brackets which connect modular wall panels. Interior light gauge steel sheets are bonded and screwed to the inside face of fortified walls, creating cavities in the walls which are formed by the closed channels. After assembly and final positioning of the structure or structural modules, sand or a sand-cement mixture, depending on whether the assembly is to be relocated or is a permanent installation, is introduced into the cavities of the walls which are to be fortified. Similar holes located in bottom tube components and bottom panel end brackets permit sand to be evacuated by lifting the fortified wall of the unit before structural units are relocated. Blast proof shelters which are to be permanently located at a site and which are to be anchored to concrete floor slabs for stability have holes in the bottom end brackets of wall panels, whether walls are fortified or not, which permit connection of the walls to concrete slabs using adhesive or expansion anchors and concrete screws. This construction provides for the support and attachment to interior, non-fortified walls of gypsum board, vinyl sheets, or wood panels. The installation of interior wall electrical outlets, switches, and fixtures, and attachment of air handling ducts to protected vent openings is also accommodated.

[0017] The rectilinear blast proof shelter may serve as a stand-alone shelter with four fortified walls and roof or may become a modular component of a larger shelter structure including an assemblage of two or more rectilinear modules whose exterior walls and roof are fortified to resist blast, fragmentation, and small arms fire. Interior walls of assemblages of individual modular components, although not required to be fortified, may be required to provide lateral resistance against the forces produced by blasts.

[0018] Cold-formed steel floor panels, which are required for structures or structural modules which will be relocated and which are not anchored permanently to concrete floors, are assembled in a manner similar to the wall panels and are of similar configuration. Floor panels, which are oriented with the open channel and flanged channel ribs facing up, are floored with wood panels or lumber to provide a walking surface. The floor decking is bonded and screwed to floor panel ribs. Sand or sand-cement infill is not used for the floor structure.

[0019] Cold-formed steel roof panels, where required, and their adhesive-bonded panel end brackets are assembled similar to floor panels, with open channels and flanged channel ribs facing down. Light gauge steel sheets are bonded and screwed to channel flanges of roof panels for fortified roofs. Sand or sand-cement infill is not placed in the cavities of the roof structure. Where terminal ballistics protection of the roof is required, sandbags may be placed on top of the roof and around protected openings in the roof. Selected modular panels of the roof, although similar in configuration to the wall and floor panels, are fabricated with protective openings which permit attachment of air handling ducts, electric power, communications, and other utilities to the roof surface.

[0020] This system also provides modular, welded, cold-formed steel door opening modules which are erected to the tubular steel skeletal frame in lieu of a fixed number of channel-shaped wall panels. Door modules are connected to tubular frames with adhesive and screws or they are connected to concrete floor slabs with adhesive or expansion anchors and concrete screws. Door opening modules located in fortified walls are filled with sand or sand-cement mixtures similar to fortified wall panels. Rough openings in door opening modules permit installation of a variety of blast and bullet-resistant doors. The system further provides for modular, welded, cold-formed steel window opening modules, erected similar to door opening modules, which permit installation of a variety of blast and bullet-resistant windows.

[0021] Blast proof shelters may be employed as stand-alone buildings or they may be constructed within new or existing buildings, including at upper floors, to provide blast and terminal ballistics protection to building occupants and equipment.

[0022] Blast walls, constructed and erected in a manner similar to those comprising blast walls in a blast proof shelter, may be erected and attached to building exteriors to create blast and terminal ballistics protective curtain walls.

[0023] In one embodiment the blast resistant shelter apparatus of the present invention can be summarized as comprising a framework including at least an upper metal rail. A plurality of metal panels, each panel having a C-shape cross-section defined by a central flat web and two channel arms on opposite sides of the central flat web are vertically mounted within the framework in side by side relationship to define a wall. Each panel includes an upper end plate. A metal interior wall cladding is connected to the panels and spans the channel arms of each panel to close the cross-sections of the panels to define an interior space of each panel. The upper metal rail and the upper end plate of each panel have aligned fill openings defined therethrough for introducing a particulate material such as sand into the interior space of the associated panel.

[0024] In another embodiment of the invention a blast resistant shelter apparatus includes a framework including at least an upper rail. A plurality of panels, each panel having an enclosed interior space, are vertically mounted within the framework in a side by side relationship and attached to each other and the upper rail to define a wall. A particulate material such as sand is received in the interior space of each panel of the wall. The wall preferably has a mass to stiffness ratio in the range of from about 0.03 to about 0.05 lb-sec^2/psi.

[0025] A plurality of room structures constructed in accordance with the present invention may be assembled together and covered with a tent enclosure. Such a construction provides a blast resistant shelter apparatus including a plurality of six-sided room structures arranged in a pattern to define a multi-room building. Each of the room structures has four room walls. Each of the room walls includes a plurality of panels vertically mounted in a side by side relationship to define the respective room wall. Each panel has an enclosed interior space. A particulate material such as sand is received in the interior spaces of the panels of at least some of the room walls to make those particulate-filled room walls blast resistant. A tent enclosure is arranged over the structures to define an attic space of the building which may receive utility connections and the like for the building.

[0026] In another embodiment of the invention a blast resistant shelter apparatus is provided which can be constructed within the interior of an existing building of conventional design. Such a blast resistant shelter apparatus includes a building having a plurality of structural exterior walls. A blast resistant interior wall is located within the building and spaced inwardly from the exterior walls. The interior wall has a hollow wall space and has a majority of the hollow wall space filled with a particulate material having a density of at least 90 pounds per cubic foot. At least one laterally extending interior support wall is connected to the blast resistant interior wall.

[0027] In another embodiment of the invention a blast resistant perimeter curtain construction is provided as a cladding for the exterior of a building otherwise of generally conventional structure. Such a blast resistant shelter apparatus includes a building having a foundation and a structural framework extending upward from the foundation. A blast resistant perimeter curtain is supported from the framework and at least partially defines a perimeter wall of the building. The curtain is of modular construction including a plurality of side by side vertically oriented metal panels, each panel having a hollow interior panel space having a width and a height greater than the width. At least the majority of the interior panel space is filled with a particulate material such as sand or sand-cement mixture.

[0028] Accordingly it is an object of the present invention to provide an improved blast resistant shelter apparatus.

[0029] Another object of the present invention is the provision of a blast resistant shelter apparatus which can be rapidly assembled from modular components in the field and then filled with a particulate material such as sand.

[0030] Still another object of the present invention is the provision of a blast resistant shelter apparatus having particulate filled walls which can be emptied to allow for ease of relocation of the shelter apparatus.

[0031] Still another object of the present invention is the provision of a blast resistant shelter apparatus having walls constructed in a manner to provide high ductility for absorption of blast forces without failure of the wall structure.

[0032] Still another object of the present invention is the provision of a blast resistant shelter apparatus providing a combination of a lightweight hollow metal wall construction assembled with viscoelastic adhesives so as to provide a highly ductile metal shell, which can then be filled with high density sand to provide a high density blast resistant wall structure which is still highly ductile for absorbing blast forces.

[0033] Still another object of the present invention is the provision of a blast resistant shelter apparatus which can be assembled into a multi-room structure and covered with a tent structure to provide an attic space for provision of utilities and the like to the building.

[0034] Still another object of the present invention is the provision of a blast resistant shelter apparatus which can be rapidly constructed within the interior of a conventional building either as a retrofit or as part of new building construction.

[0035] Still a further object of the present invention is the provision of a blast resistant shelter apparatus which can be constructed as a perimeter curtain on the exterior of a building.

[0036] Other and further objects features and advantages of the present invention will be readily apparent to those skilled in the art upon a reading of the following disclosure when taken in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0037] FIGS. **1-5** show the sequence of assembly of the tubular frame of the blast proof shelter.

[0038] FIG. **6** is a perspective view of the connection of the top tubular steel frame assembly to the bottom tubular steel frame assembly via the inserted steel sleeves.

[0039] FIG. **7** is a perspective view of the connector for connecting tubular frame elements.

[0040] FIG. **8**A is a cross sectional view taken along the line **8**A-**8**A of FIG. **7**.

[0041] FIG. **8**B is a cross sectional view taken along the line **8**B-**8**B of FIG. **7**.

[0042] FIG. **9** shows in perspective view a snap-in bent plate panel end connector fitted into one end of a C-shaped panel.

[0043] FIG. **10** is a perspective view of a portion of the tube assembly with wall and floor panels connected at a corner of the enclosure.

[0044] FIG. **11** is a perspective view in partial cross section of the assembled enclosure illustrating a roof panel and a door frame module.

[0045] FIG. **12** is an exterior view, in perspective, of the completely assembled enclosure except the door and the exterior wall blast shield.

[0046] FIG. **13** is an exterior view, in perspective, of the completely assembled enclosure except the door and with the exterior wall blast shield installed.

[0047] FIG. **14** is a floor plan of a multi-room blast proof shelter assembly, assembled from individual shelter assemblies.

[0048] FIG. **15** is an exterior side view of the shelter assembly of FIG. **14**.

[0049] FIG. **16** is perspective view of a bottom tube and wall panel illustrating the connection of the bottom panel end bracket connection to a concrete slab.

[0050] FIG. **17** is a sectional view through the roof and top of a wall of a shelter taken along line **17-17** of FIG. **13**.

[0051] FIG. **17**A is a cross-sectional view of a portion of the wall taken along line **17**A-**17**A of FIG. **17**, with no sand shown in the panel cavities, so as to show the arrangement of the various steel channels and sheets making up the wall structure.

[0052] FIG. **18** is a roof plan view of the shelter assembly of FIG. **14** showing a fabric tent enclosure and support framing attached to the shelter assembly.

[0053] FIG. **19** is a perspective view of the shelter assembly of FIG. **18** showing the supported fabric tent.

[0054] FIG. **20**A is an exterior side view of the shelter assembly and fabric tent of FIG. **18**.

[0055] FIG. **20**B is a cross sectional view through the shelter assembly and fabric tent of FIG. **18**, taken along line **20**B-**20**B of FIG. **20**A.

[0056] FIG. **21** is an exterior end view of the shelter assembly and fabric tent of FIG. **18**.

[0057] FIG. **22** shows a first floor plan of a building with a built-in assembly of blast shelters.

[0058] FIG. **23** shows a second and third floor plan of the building and built-in blast shelters of the building shown in FIG. **22**.

[0059] FIG. **24** is a cross sectional view through the building and built-in blast shelters of FIGS. **22** and **23**.

[0060] FIGS. **25**A and **25**B illustrate the unassembled modular panels, tube assemblies, and sheet steel positioned for compact packaging.

[0061] FIG. **26** shows a wall section through a blast and bullet proof, exterior curtain wall installed between the first floor slab and second floor framing of a building.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0062] Referring now to FIG. **13**, a perspective view is thereshown of one embodiment of a blast resistant shelter apparatus generally designated by the numeral **100**. The apparatus **100** is in the form of a six-sided free-standing structure having four walls, a ceiling and a floor as further described below. A door opening **101** is provided in one wall.

[0063] The shape of the apparatus **100** is generally determined by a skeletal structural framework **102** as shown in FIG. **4**.

[0064] The framework **102** includes four vertical members or corner posts **104**, **106**, **108** and **110**, four upper rails **112**, **114**, **116** and **118**, and four lower rails **120**, **122**, **124** and **126**.

[0065] Each wall of the apparatus **100** includes a plurality of metal panels **128** connected between an associated pair of the upper and lower rails. The construction of the panels **128** is best shown in FIG. **9**. Each panel **128** has a C-shape cross-section defined by a central flat web **130** and two channel arms **132** and **134** on opposite sides of the central flat web **130**. Panels **128** are preferably made of cold formed light gauge steel sheets. Each panel **128** includes two channel fingers **136** and **138** extending toward each other from the channel arms **132** and **134**.

[0066] Upper and lower end plates **140** and **142**, respectively, are assembled with the panels **138** to close the upper and lower ends of the channel thereof.

[0067] As best seen in FIGS. **10-12** a plurality of the metal panels **128** are vertically mounted within the framework **102** in side by side relationship to define each of the walls of the apparatus **100**. A typical wall is shown in elevation cross-section in FIG. **17**, and in horizontal cross-section in FIG. **17**A.

[0068] A metal interior wall cladding **144** is connected to each of the panels **128** and spans the channel arms **132** and **134** of each panel **128** to close the cross-sections of the panels to define an interior space **146** of each panel. A metal exterior blast shield **148** is attached to the central flat webs **130** of the panels **128**.

[0069] Each of the upper rails such as **116** has fill openings **150** and **152** therethrough which are aligned with a fill opening **154** of the upper end plate **140** of each panel **128** for introducing a particulate material **156** into the interior space **146** of the associated panel **128**.

[0070] As best seen in FIG. **9**, the lower end plate **142** of each panel **128** may have a drain opening **158** defined therein for draining the particulate material **156** from the interior space **146**.

[0071] Similarly drain openings **160** and **162** are located in each of the lower rails as shown in FIG. **10** and are aligned with the drain openings **158** in each of the bottom end panels **142**. The drain openings **158**, **160** and **162** permit the particulate material to drain out of the interior space when the structure **100** is lifted up off of the ground surface, thus greatly reducing the weight of the structure **100** so that it can be more easily relocated to a new location.

[0072] Applicant's blast resistant shelter apparatus **100** is packaged and shipped as a compact assembly of unassembled, prefabricated components for on site erection and assembly. FIGS. **25**A and **25**B show the unassembled modular panels and the tube assemblies positioned for compact packaging and shipment. The U-shape tube assemblies **160**, **162**, **180**, **182** have spacing between vertical legs such as **166** and **164** which are slightly larger than the length of modular panels **128**. This permits packaging of panels **128** lying between the legs of the tube assembly. FIG. **25**B shows a bottom layer of modular panels **128** on top of which a second layer of inverted modular panels **128** has been placed so that the two layers occupy nearly the same thickness as a single layer of panels. Prefabricated U-shape tube frames assemblies **160**, **162**, **180**, **182** create the perimeter of the package and provide protection of corners of the bundle for shipment. A single layer of the above-described packaged components is shown in FIG. **25**B lying on top of flat sheets of light gauge steel which comprise the exterior blast shield **148** or wall interior steel sheets **144**. The compactness of the packaged shelter materials provides economy for shipping and protection of the palletized package.

[0073] FIGS. **1-5** illustrate the sequence of assembly of the framework **102** of the apparatus **100** to which the modular components of the walls, floor, roof and door opening modules are later attached. This framework **102** provides a tubular skeleton for the blast resistant shelter apparatus **100** and is constructed of preformed, welded tubular elements.

[0074] FIG. **1**A shows two U-shaped welded tube assemblies **160** and **162** which include lower rails **124** and **120** which are welded to vertical post portions such as **164** and **166** which define the lower portions of the vertical members such as **108** and **106** seen in FIG. **4**. Light gauge steel sleeve connectors **168** are received in the upper ends of the vertical post portions such as **164** and **166** and in the lower ends of the vertical post portions such as **184** and **186**. As seen in FIG. **6**, laser cut half moon stops **170** limit the insertion of the sleeve connectors **168**.

[0075] The other two lower rails **122** and **126** are straight tube elements which are connected between the U-shaped assemblies **160** and **162** as seen in FIGS. **1**B and **2**B.

[0076] FIG. **2**B shows the assembled lower U-shaped assemblies **160** and **162** with the lower rails or straight tube elements **122** and **126**.

[0077] Then, upper U-shaped assemblies **180** and **182** shown in FIG. **2**A are connected to the post members such as **164** and **166** via the sleeve connectors **168**. That assembly is shown in FIG. **3**.

[0078] Then the upper rails **112** and **116** which may also be described as straight tube elements **112** and **116** are put in the locations as indicated in FIGS. **4** and **5**.

[0079] The straight tube elements **122**, **126**, **112** and **116** with the prewelded U-shaped assemblies are described with reference to FIGS. **7**, **8**A and **8**B.

[0080] FIGS. **7**, **8**A and **8**B show steel slotted tongue **172** and wedge shaped steel key connector **174** which, when inserted into and firmly seated in the slotted tongue **172**, provides continuity between the straight tube elements **122**,

126, **112** and **116** and the vertical arms such as **164** and **166** of the U-shaped welded tube assemblies such as **160** and **162**. Referring to FIGS. **8**A and **8**B, the straight tube section **116** is provided with a welded steel plate connector **176** which includes a base **178** and the slotted tongue **172**. The framework **102** further includes laser cut rectangular slots which receive the slotted tongues **172** of the straight tube elements **122**, **126**, **112** and **116**. The key **174** is tightly wedged into the slotted tongue **172**.

[0081] FIG. **6** illustrates the manner in which the lower vertical post portions such as **164** and **166** are connected to the upper vertical post portions such as **184** and **186** via the sleeve connectors **168**.

[0082] After the assembly of the skeletal framework **102** as shown in FIG. **5**, the panels **128** are connected within the framework to define the walls, floor and ceiling of the apparatus **100**.

[0083] The framework **102** has a plurality of laser cut screw holes **188** (see FIG. **7**) which align with screw holes provided in the panels **128** to aid in the assembly thereof. Similarly, utility holes **190** are provided in the framework **102** and align with utility holes such as **192** (see FIG. **9**) in the panels **128** to allow for the running of conduit and other utilities through the walls.

[0084] Once the framework **102** has been assembled to the point illustrated in FIG. **5**, the wall, floor and ceiling panels **128** can be installed. FIG. **5** shows wall panels **128** being assembled to the framework **102**. Wall, roof, and floor panels **128** with their associated panel end brackets **140** and **142** are preassembled by applying viscoelastic polyurethane adhesive to the contact surfaces between arms **194** of the end panels **140**, **142** and the C-shape modular panels **128** shown in FIG. **9**. FIG. **9** illustrates in more detailed the snap in features of the panel end brackets such as **142** to the C-shape panel **128**. Embossments **196** are provided on the arms **194** and extend outward from the panel end bracket **142** to form snaps for engagement with square holes **198** punched or otherwise preformed in the channel arms **132** and **134** of the C-shape panels **128**.

[0085] FIG. **10** is a cutaway perspective view of an inside corner of the shelter apparatus **100** midway during construction. In this view a number of panels **128** have been assembled with the walls of the structure, and a number of panels **128** have been assembled into the floor of the structure. None of the interior cladding sheets **144** or exterior blast shields **148** have yet been installed. As can be seen from FIG. **10**, multiple panels **128** are connected in side-by-side relationship to form the walls and floor for the shelter. Once the end panel brackets **140** and **142** have adhesive applied and are snapped into the ends of the panels **128**, the panels **128** are connected to the upper and lower rails such as **118** and **126** after liberally coating with adhesive the contact surfaces between the panels **128**, the end panel brackets **140** and **142**, and the skeletal framework **102** and screwing the end panel brackets **140** and **142** to the skeletal framework **102** through prepunched holes in the panel end brackets **140** and **142** and matching laser cut screw holes in the framework **102**. As previously noted, the upper rails and upper end brackets have aligned fill holes **150**, **152** and **154** therein. The fill holes serve two purposes. One is to permit electrical conduit to be routed through the walls and roof of the shelter apparatus. Another purpose is to provide a means for introducing particulate material such as sand or a sand cement mixture into the cavities of the walls after the interior cladding sheets **144** are installed. The lower end panels **142** and lower rails include drain holes **158**, **160** and **162** such as previously described to permit the evacuation of sand when the apparatus **100** is to be relocated.

[0086] Preferably the dimensions and construction of the metal panels and the volume of the interior space are such that the panels have a stiffness and the interior space of each panel has a volume such that if the interior space were filled with particulate material having a density of approximately 109 pounds per cubic foot, a mass to stiffness ratio of the panels would be in the range of from about 0.03 to about 0.05 lb-sec^2/psi.

[0087] While the framework **102** has been described as preferably being made from steel tubular members and steel channels, it will be appreciated that in its broader aspects the present invention contemplates a framework made of materials other than steel. Any suitable material that can resist penetration by bullets and provides the desired ductility may be utilized.

[0088] FIG. **13** is a perspective view of the apparatus **100** illustrating the placement of the exterior blast shields **148** which are bonded with polyurethane adhesive and screwed with self-drilling, self-tapping screws through pre-punched holes in blast shields **148** to the outside faces of the assembled walls seen in FIG. **12**. It should be noted that only those walls which will be exterior walls subject to blast require the blast shield **148**, since the apparatus **100** may be a modular component of a larger assembly of components such as illustrated in plan view in FIG. **14** and in side view in FIG. **15**.

[0089] FIGS. **17** and **17**A illustrate the attachment of the interior steel wall cladding **144** and ceiling cladding **200**. These interior sheet steel claddings are attached to the inside flanges of wall and ceiling panels **128** with viscoelastic polyurethane adhesive and self-drilling, self-tapping screws through pre-punched holes in interior steel wall cladding **144** and **200**. The attached interior wall cladding **144**, in connection with the open channel of the C-shape panels **128** form the wall cavities **146** into which particulate material **156** is introduced into the walls which are to be potentially exposed to blast forces. In addition, the attached interior wall cladding **144** and ceiling cladding **200**, acting compositely with the C-shape panels **128** produce a flexural cross-section whose moment of inertia (resistance to bending) and section modulus (ability to carry flexure) are substantially increased. FIG. **17** further illustrates the placement of particulate matter **156** into the cavities **146** of the framework **102** on the exterior wall of the blast resistant shelter apparatus **100**. FIG. **17** also shows the placement of sand bags **202** on the roof of the apparatus **100** to provide terminal ballistics protection for the roof, and a protected duct or ventilation opening feature **204** extending through the roof of the shelter apparatus **100**.

[0090] Although the shelter apparatus **100** is described herein primarily with regard to its use for blast protection such as for military personnel in hostile environments, it will be appreciated that the same apparatus **100** may be used for other purposes such as for a tornado or hurricane shelter or the like.

Dynamic Testing and Ballistics Testing

[0091] The uniqueness of the composite blast wall panels is illustrated by the performance of the panels when subjected to the following described dynamic testing and analyses, full scale blast testing, and terminal ballistics testing.

[0092] Dynamic testing was conducted on test wall panels of the blast proof shelter blast walls to determine dynamic performance when subjected to impulse loading. A piezoelectric acceleration sensor was mounted on the test specimen to determine accelerations, velocities, and displacements at the mid-span of the wall panel. Test panels were tested without sand infill in the cavities and with sand infill in the cavities. Test panels for each condition consisted of one 8 inch wide by 3 inch deep, 18 gauge steel wall panel **128** sandwiched between adhesive-bonded **12** gauge exterior blast shield **148** and **16** gauge interior steel cladding **144**. Sand-filled test panels were filled with cohesionless sand **156** weighing approximately 109 pounds per cubic foot. Tests indicated that the sand-filled blast panel, compared with the empty blast panel, had damping factors which were approximately 12 to 13 percent greater and periods of vibration in the fundamental mode of vibration which were approximately 88 percent greater. As shown by calculations set forth below, the mass to stiffness ratio was increased to approximately 338 percent of the unfilled value by the sand infill. The significance of the change of dynamic characteristics will be illustrated hereinafter.

[0093] Blast tests were conducted at the HTL blast range at Tahoka, Tex. on three 7 foot, 10 inch cubed blast proof shelters having walls constructed with 3 inch thick panels **128**. Dimensions and gauges of blast wall material were as described for the dynamic test wall panel previously described. The blast wall of the nearest blast proof shelter had a standoff distance of 20 feet from a 50 pound TNT explosive package. HTL reported a maximum positive transient displacement of the blast wall of approximately one inch, a maximum negative transient displacement of 0.4 inches, a total impulse of approximately 73.6 psi-ms, and a peak reflected pressure on the blast wall of approximately 14,250 pounds per square foot. There were no permanent deformations of the blast walls and no measurable lateral displacement of the unanchored shelters. The measured blast pressure versus time loading was modeled into a proprietary government blast dynamics analysis program (SDOF) using the dynamic properties of the sand-filled test wall panels and also the dynamic properties of the unfilled test wall panels. The test wall panels without sand would have had a maximum deflection approximately 1.9 times that for the sand-filled test wall panels. The test wall panels without sand would have been stressed beyond yield stress of the steel and would have had a residual, permanent deformation of the wall whereas the sand-filled test wall panels were found to have no residual displacement of the wall. The results of the SDOF analyses demonstrated the important contribution of the cohesionless sand infill in attenuating the effects of blast on the blast walls of the blast proof shelter.

[0094] Terminal ballistics tests were conducted on the 3 inch deep test blast wall panel assemblies consisting of multiple panels as described above to determine resistance to penetration of military small arms rounds. The test panels resisted 7.62 mm and .308 caliber military ball rounds when shot from a distance of 15 feet. Test blast wall panels also resisted 21 rounds of sustained and concentrated fire of 7.62 mm military ball rounds fired from a distance of 25 meters and sustained only one penetration after the sixteenth round.

Ductile Structures and the Mass to Stiffness Ratio

[0095] Ductility is defined as the ability of a structure or structural element to deform easily upon the application of a load or as the ability to withstand large plastic (inelastic) deformation without rupture or failure by instability. It is also defined as bendability and the ability to undergo large deformations before fracture. The opposite of ductility is brittleness. A ductile structure which can deform and absorb the energy of a blast without structural failure that would jeopardize the safety of persons within the structure is superior for blast protection purposes to a more rigid inflexible structure.

[0096] In the case of the present invention, the structure (the composite light gauge steel wall) is ductile by virtue of its ability to undergo large deformations without yielding and further to undergo plastic deformations in the material yield stress range without failing. The sand infill does not change this ductility. The sand only increases the mass of the structure and also provides additional dampening of vibrations, particularly at larger wall deformations under blast loads. One measure related to the ductility of the structure and its mass is the "mass to stiffness ratio" which is explained below. A high mass to stiffness ratio most demonstratively improves the ability of the combined structure and sand to resist blast forces. Increased damping of flexural systems were found from the SDOF program to result in the ability of the flexural systems to be able to resist higher explosive forces at the same standoff distance. An increased damping ratio or damping factor results in free vibration displacements of a structural system degrading more rapidly. A means of determining the damping factor is to measure the ratio of displacement amplitudes on successive cycles of vibration. A classical theoretical logarithmic decrement function was used to determine the damping ratio for the sand filled vs. the non-sand-filled test panels.

[0097] Following is a sample calculation of the "mass to stiffness" ratio and related parameters for the panels used in the field testing described above.

[0098] Based on the moment of inertia of the composite steel blast proof enclosure panel section, the mid-point deflection of the panel under a uniform pressure load is 0.0873 inches/psi pressure. This is the flexibility of the panel. The reciprocal of the flexibility is the stiffness, which equals

k=1/flexibility=1/0.0873 inches/psi=11.45 psi/inch

Weight of the composite steel panel only=0.6206 lbs/in×88 inch length=54.6128 lbs

[0099] The mass is the weight divided by gravity

m=54.6128 lbs/386 in/sec^2=0.1415 lb-sec^2/in

The mass to stiffness ratio=0.1415 lb-sec^2/in÷11.45 psi/in =0.0124 lb-sec^2/psi

[0100] The fundamental frequency of a uniformly loaded beam per the Raleigh method is

$$\omega_f = \prod^2 [EI/\mathrm{ml}^3]^{1/2}$$

$$= [29{,}000{,}000\ \mathrm{psi/in} \times 2.4656\ \mathrm{in}^4 \div 0.1415\ \mathrm{lb\text{-}sec}^2/\mathrm{in} \times (88\ \mathrm{in})^3]^{1/2}$$

$$= 268.756\ \text{radians per second}$$

$f_f=\omega_f/2\pi$=268.756/2π=42.774 cycles per second

[0101] The fundamental period of vibration of the panel without sand is

$T_f=1/f_f$=1/42.774 cps=0.0234 sec=23.379 ms

Weight of the composite steel panel with sand infill=2.1024 lbs/in×88 inch length=185.01 lbs

[0102] The mass is the weight divided by gravity

m=185.01 lbs/386 in/sec^2=0.4798 lb-sec^2/in

The mass to stiffness ratio=0.4798 lb-sec^2/in÷11.45 psi/in=0.0419 lb-sec^2/psi

[0103] The fundamental frequency of a uniformly loaded beam per the Raleigh method is

$$\begin{aligned}\omega_f &= \prod^2 [EI/\text{ml}^3]^{1/2}\\ &= [29{,}000{,}000\ \text{psi}/\text{in}\times 2.4656\ \text{in}^4 \div 0.4798\ \text{lb-sec}^2/\text{in}\times(88\ \text{in})^3]^{1/2}\\ &= 146.026\ \text{radians per second}\end{aligned}$$

f_f=ω_f/2π=146.026/2π=23.241 cycles per second

[0104] The fundamental period of vibration of the panel with sand infill is

T_f=1/f_f=1/23.241 cps=0.0430 sec=43.0 ms

[0105] Thus in summary:

[0106] The ratio of fundamental period of the panel with sand to that without sand is

Ratio=43.0 ms/23.379 ms=1.8393

[0107] The mass to stiffness ratio of the sand-filled panel to the unfilled panel is

Ratio=0.0419 lb-sec^2/psi÷0.0124 lb-sec^2/psi=3.38

[0108] Thus it is seen that the fundamental periods of vibration are directly related to the square root of the mass to stiffness ratios of the two systems.

[0109] The addition of sand weighing 109 pounds per cubic foot to the cavity in each panel increases the mass to stiffness ratio to 338 percent of the unfilled value and increases the fundamental frequency of the panel to 184 percent of the unfilled value.

[0110] The test blast enclosure which was at a 20 foot standoff distance had an initial positive deflection (inward) for a duration of 23 ms and then a negative (outward) deflection for a duration of 18 ms. These deflections resulted from the initial positive blast pressure which had a duration of 4 ms and then a negative blast pressure which had a duration of approximately 16 ms. Thus, it is seen that the total duration of the predominant blast wave was significantly less than the fundamental period of vibration of the sand filled wall panels.

[0111] A 6 inch thick reinforced concrete wall, having comparable structural resistance to the measured blast pressures, has a fundamental period of approximately 8.17 ms which is approximately one-fifth the fundamental period computed for the sand filled 3 inch thick composite steel panel.

The Particulate Material

[0112] The testing described above was done with a particulate material comprising dry silica sand having a density of approximately 109 pounds per cubic foot. It will be appreciated, however, that many types of particulate material could be utilized since the particulate material is not being used for structural purposes, but instead is being used for its density and damping properties.

[0113] With regard to the sand types there are numerous types and uses of sand and specifications for the same. ASTM 33 fine aggregate sand and AASHTO M-6 gradation sands are examples of structural sands in common use. Structural sand is typically silica based sand rather than limestone or coral based sand. But limestone or coral based beach sands can also be utilized for the present invention. Although a structural quality silica sand was utilized in the testing described, it will be appreciated that structural sand is not required for the present invention. Structural quality sands are not required for the present invention because even if infused with a cementitious binder it is not required to attain strength, such as are required for flexural concrete structures.

[0114] One alternative to the use of sand, is to use a low ratio cement to sand mixture having only enough cement to aid in the pumpability of the mixture into the interior spaces of the walls and also to provide some modest rigidity to the mixture to eliminate excessive outward pressures on the walls from the column of sand contained within the walls. For example, a cement to sand ratio in the range of from about 5% to about 15%, and preferably about 10% is satisfactory for those purposes. It will be appreciated by those skilled in the art that such a low ratio of cement does not produce a structural material and does not harden into a structural grout or concrete. The 1:10 cement mixture is contrasted to structural mortar which would typically be a 1:3 ratio. The intent of the cement, if used at all, is to increase the internal friction of the sand cement matrix which would permit the walls of taller wall cavities to resist lateral pressures from the infill materials.

[0115] It will also be appreciated that, particularly in remote field operations, any available native soil may be utilized as the particulate material and will, to a large degree, provide the benefits described.

[0116] The particulate material preferably has a density of at least 90 pounds per cubic foot, and more preferably in the range of from about 90 to about 115 pounds per cubic foot.

[0117] The sand fill provides the inertial mass resistance to blast induced accelerations and a significant portion of the wall vibration damping which, combined with the damping of the viscoelastic bonding adhesive sandwiched between the exterior and interior skins of the composite steel structure, creates a ductile wall with outstanding blast resisting characteristics. The compound wall structure is unique in that a significant portion of the kinetic energy from a non-penetrating impact is stored in the compound wall as potential energy which is slowly released over time. The dynamic response of the composite wall to high impulse waves of nearby blasts is attenuated to levels which result in flexural displacements and stresses below levels which would result in injury to occupants or damage to the structure.

[0118] The apparatus is designed to resist not only the high impulse blast waves of short standoff explosions but also the penetration by small arms rounds and fragmentation of military ordinance. The sand infill serves to resist penetration by bullets, shrapnel, or fragmenting portions of adjacent structures which penetrate the exterior steel wall.

The Embodiments of FIGS. **14-21**—Multi-Room Structure with Fabric Tent Covering

[0119] Referring now to FIGS. **14-21**, a multi-room building **300** is shown in plan view. The multi-room building **300** includes six of the six-sided structures **100** which have been designated as **100**A-**100**F. Smaller rectangular shaped modules **302** have been arranged at end locations to form baffled entryways **304** and **306** which prevent direct small arms fire trajectories into a protected interior corridor **308** and a protected occupied space **310**. It will be appreciated by those skilled in the art that an unlimited number of sizes and configurations of blast shelter modules can be assembled to create large blast proof shelter assemblies. It will also be appreciated that such modules can be superimposed one on top of the other to create multi-level blast resistant shelter assemblies.

[0120] FIG. **16** illustrates one manner in which the walls of the modules of FIG. **14** may be anchored to a concrete slab **312**. Also, as illustrated in FIG. **16**, it is possible to eliminate the lower rails from the framework when the module is going to be mounted directly on a concrete slab. Steel concrete screw anchors **314** are inserted through heavy square steel washers **316** and through prepunched holes in the center of the bottom panel end brackets **142** to engage the concrete slab **312**. In addition to concrete screw anchor **314**, two smaller concrete screws are preferably installed through prepunched holes **318** in the bottom end panel brackets **142** into holes drilled into the concrete slab **312**. It should be noted that the concrete slab anchors must be installed on the walls before the inside wall cladding **144** is installed.

[0121] FIGS. **18** and **19** illustrate a roof plan view and perspective view, respectively, of the multi-room building **300** of FIGS. **14** and **15** supporting a fabric tent covering **318** which is supported by means of steel support framing members **320**, **322**, **324** and **326** which are attached to the shelter apparatus modules **100** and **302**. Vertical support elements **326** are attached to the open tops of the vertical tubes such as **110** shown in FIG. **7** by means of light gauge steel tube sleeves like sleeve **168** shown in FIG. **6**, whose length of insertion is limited by a laser cut half moon stop **170**. FIG. **20**A shows an exterior side view of the fabric tent enclosure. FIG. **20**B shows a section cut through the tented blast shelter assembly along lines **20**B-**20**B of FIG. **20**A. An exterior end view is shown in FIG. **21**. An attic space **328** is defined between the walls of the blast resistant shelter modules **100** and the fabric tent covering **318**. The attic space **328** permits air flow through screened vents near the skirt of the tent and to tent ridge vents or other type roof vents, permits air ducts, electrical communications connections and the like to be placed in the attic space **328**, and permits the attachment of appurtenances such as vent structure **204** (see FIG. **17**) on the roof. It also provides a place for placement of sand bags **202** on the roof where required to provide roof terminal ballistics protection.

The Embodiment of FIGS. **22**-**24**—Protected Spaces within Buildings

[0122] FIGS. **22** and **23** show the first and upper floors, respectively, in plan view of a building **400**, which may be existing or new, wherein variously configured blast shelter assemblies **100** are installed on interior concrete floor slabs **402** of the three floors. The blast resistant walls **404** which are directly exposed to blast are filled with sand or sand cement mixture as previously described. The blast resistant walls **404** are set back from exterior walls **406** so as to create ingress and egress space **408** between the exterior walls **406** and the blast resistant walls **404**. This space **408** permits egress from the blast proof structures **100** into the corridors **408** whereby alternate egress routes from the building other than a normal front entrance **410**, elevator **330**, or interior stairway **332** are made available. This space **408** also permits access to the blast face walls **404** for the installation of metal exterior blast shield **148**.

[0123] FIG. **24** is a cross-sectional view of the three story building **400** illustrating the arrangement of the shelter walls of the various blast proof shelter apparatus **100** within the building **400** at each floor. It should be noted that the load path for resistance to lateral forces on the various modules **100** is provided by attachment of the tops of blast walls to roof diaphragms **412** connected to interior shelter walls, and the connection of the bottom of interior shelter walls to the concrete floor slabs such as **402** as illustrated in FIG. **16**. It should be noted that roof diaphragms **412** may extend either partially or fully over all the blast resistant shelter assemblies **100**.

[0124] It is also noted, that the interior blast proof walls may be constructed by an assembly of six-sided units **100** or by construction of individual blast proof walls constructed in accordance with the present invention and laterally supported by lateral support walls, roof diaphragms and attachment to floor slabs.

The Embodiment of FIG. **26**—A Perimeter Blast Resistant Curtain for a Building

[0125] FIG. **26** is an illustration of an exterior, blast resistant perimeter curtain wall **500** which is erected between the first floor concrete slab **502** and the second floor framing **504** of a building **506**.

[0126] The blast resistant perimeter curtain wall **500** is constructed in a manner similar to the walls of the apparatus **100** previously described and is made up of a plurality of side by side panels **128**. It will be appreciated that the panels **128** utilized in the perimeter curtain wall **500** may be thicker, longer and constructed of heavier steel material and connectivity than the similar panels **128** described previously with regard to the free-standing modules **100**. However, the dynamic performance of the composite, sand filled curtain wall blast panels would be similar to that of the panels of the free-standing shelters **100** previously described. Terminal ballistics protection is provided by an exterior steel sheet **506**, an interior steel sheet **508**, and the particulate material **510**. Connection of the bottom end panel bracket **142** to the concrete slab floor **502** is identical to that described above with regard to FIG. **16**. The top end panel bracket **140** is connected to a steel plate **512** in a manner similar to the connection of the top end brackets **140** of free-standing apparatus **100** to the framework **102** of the apparatus **100**. The steel plate **512** has matching holes for screw attachments of end brackets **140** and **142** and hole **514** for introducing sand or sand-cement mixture through end bracket holes **154** and is welded or bolted to the second floor framing **504**.

[0127] Thus the building **506** may be described as a building **506** having a foundation **502** and a structural framework **504** extending upward from the foundation **502**. The blast resistant perimeter curtain wall **500** is supported from the framework **504** and at least partially defines a perimeter wall of the building **506**. The curtain wall **500** is of modular construction including a plurality of side by side vertically oriented metal panels **128**, each panel having a hollow interior space having a width and a height greater than its width, at least a majority of which interior space is filled with a particulate material such as sand or the like.

[0128] As shown in FIG. 26, the building 506 is a multi-story building and the blast resistant perimeter curtain wall 500 spans the perimeter wall of at least the first and second floors of the building.

[0129] Thus it is seen that the apparatus of the present invention readily achieves the ends and advantages mentioned, as well as those inherent therein. While certain preferred embodiments of the invention have been illustrated and described for purposes of the present disclosure, numerous changes in the arrangement of parts may be made by those skilled in the art, which changes are encompassed within the scope and spirit of the present invention as defined by the appended claims.

What is claimed is:

1. A blast resistant shelter apparatus, comprising:

a framework, including at least an upper metal rail;

a plurality of metal panels, each panel having a C-shape cross-section defined by a central flat web and two channel arms on opposite sides of the central flat web, the metal panels being vertically mounted within the framework in side by side relationship to define a wall, each panel including an upper end plate;

a metal interior wall cladding connected to the panels and spanning the channel arms of each panel to close the cross-sections of the panels to define an interior space of each panel; and

wherein the upper metal rail and the upper end plate of each panel have aligned fill openings defined therethrough for introducing a particulate material into the interior space of the associated panel.

2. The apparatus of claim **1**, further comprising:

a metal exterior blast shield attached to the central flat webs of the panels of the wall.

3. The apparatus of claim **1**, wherein:

the adjacent channel arms of adjacent panels are attached to each other with screws.

4. The apparatus of claim **3**, wherein:

the upper end plate of each panel is attached to the upper metal rail of the framework with a viscoelastic adhesive and screws.

5. The apparatus of claim **1**, wherein:

each panel includes a lower end plate and the lower end plate of each panel has a drain opening defined therein for draining the particulate material from the interior space of the associated panel.

6. The apparatus of claim **5**, wherein:

the framework includes a lower metal rail, the lower metal rail having a plurality of openings defined therein aligned with the drain openings of the panels, for draining the particulate material.

7. The apparatus of claim **1**, wherein the panels have a stiffness and the interior space of each panel has a volume such that if the interior space were filled with particulate material having a density of approximately 109 pounds per cubic foot, a mass to stiffness ratio of the panels would be in the range of from about 0.03 lb-sec^2/psi to about 0.05 lb-sec^2/psi.

8. The apparatus of claim **1**, wherein:

each panel includes two channel fingers extending toward each other from the two channel arms; and

the interior wall cladding is attached to the channel fingers of each panel.

9. The apparatus of claim **1**, wherein:

the framework defines a six-sided structure having four walls, each of the four walls including a plurality of said metal panels;

the framework includes the metal upper rail and a metal lower rail for each of the four walls;

each panel includes a lower end plate; and

the lower end plates of each panel of the four walls and the lower metal rail of each wall have aligned drain openings defined therethrough to allow particulate material to drain from the interior spaces of the panels when the structure is lifted off a ground surface to thereby reduce a weight of the structure for transport and re-location of the structure.

10. The apparatus of claim **9**, wherein each of the panels of each wall is attached to the associated upper and lower metal rails of the framework by a visco-elastic adhesive and screws and to at least one adjacent panel by screws.

11. The apparatus of claim **9**, in combination with at least one additional such six-sided structure to define a multi-room building; and

a tent enclosure arranged over the structures to define an attic space for locating utilities extending to the building.

12. The apparatus of claim **1**, located within a building interior and connected to at least one laterally extending support wall of the structure and having the interior space of the panels filled with particulate material to at least partially define a protected space within the building.

13. The apparatus of claim **12**, wherein the upper rail of the framework is attached to a structural ceiling diaphragm.

14. The apparatus of claim **1**, hung on an exterior of a building and having the interior space of the panels filled with particulate material to define a blast resistant curtain for the building.

15. The apparatus of claim **1**, further comprising a particulate material received in the interior space of each panel of the wall, the particulate material having a density in the range of from about 90 pounds per cubic foot to about 115 pounds per cubic foot.

16. The apparatus of claim **15**, wherein the particulate material comprises sand.

17. The apparatus of claim **15**, wherein the particulate material comprises a low ratio cement to sand mixture having a cement to sand ratio in a range of from about 5% to about 15%.

18. A blast resistant shelter apparatus, comprising:

a framework including at least an upper rail;

a plurality of panels, each panel having an enclosed interior space, the panels being vertically mounted within the framework in a side by side relationship and attached to each other and the upper rail to define a wall; and

a particulate material received in the interior space of each panel of the wall, the wall having a mass to stiffness ratio in a range of from about 0.03 lb-sec^2/psi to about 0.05 lb-sec^2/psi.

19. The apparatus of claim **18**, wherein the panels are attached to adjacent panels with screws and to the upper rail by adhesive and screws.

20. The apparatus of claim **19**, wherein the panels and the upper rail are constructed of steel.

21. The apparatus of claim **18**, wherein the particulate material comprises primarily sand.

22. The apparatus of claim **21**, wherein the particulate material has a density in a range of from about 90 to about 115 pounds per cubic foot.

23. The apparatus of claim **18**, wherein the particulate material comprises a low ratio cement to sand mixture having a cement to sand ratio in a range of from about 5% to about 15%.

24. The apparatus of claim **18**, wherein:

the framework and an upper end of each panel have aligned fill openings therein, for filling the panels with the particulate material; and

the framework and a lower end of each panel have aligned drain openings therein for draining the particulate material from the wall.

25. The apparatus of claim **18**, wherein the framework defines a six-sided structure having four such walls.

26. The apparatus of claim **25**, in combination with at least one additional such six-sided structure to define a multi-room building; and

a tent enclosure arranged over the structures to define an attic space for locating utilities extending to the building.

27. The apparatus of claim **18**, erected within a building interior and connected to at least one laterally extending support wall of the structure and connected to a structural ceiling member of the structure to at least partially define a protected space within the building.

28. The apparatus of claim **18**, mounted on an exterior of a building to define a blast resistant curtain for the building.

29. A blast resistant shelter apparatus, comprising:

a plurality of six-sided room structures arranged in a pattern to define a multi-room building;

each of the room structures having four room walls;

each of the room walls including a plurality of panels vertically mounted in a side by side relationship to define the respective room wall, each panel having an enclosed interior space;

a particulate material received in the interior spaces of the panels of at least some of the room walls to make those particulate filled room walls blast resistant; and

a tent enclosure arranged over the free-standing structure to define an attic space of the building.

30. The apparatus of claim **29**, wherein:

within the pattern some of the room walls of adjacent room structures face each other to define interior room walls of the building, and the remaining room walls define exterior room walls of the building; and

substantially all of the exterior room walls of the building are filled with the particulate material to comprise said blast resistant room walls.

31. The apparatus of claim **29**, wherein:

each of the panels is made of steel sheet and has a C-shape cross-section defined by a central flat web and two channel arms on opposite sides of the central flat web, with a steel sheet cladding spanning the channel arms to close the cross-section to define the interior space of the panel.

32. The apparatus of claim **31**, further comprising:

an exterior sheet steel blast shield attached to the central flat webs of the panels of at least some of the room walls.

33. The apparatus of claim **29**, wherein:

the panels of the particulate filled room walls each have an upper end having a fill opening defined therein for introducing the particulate material into the interior space of the panel, and a lower end having a drain opening therein for draining the particulate material from the panel.

34. The apparatus of claim **29**, further comprising building utilities located in the attic space.

35. A blast resistant shelter apparatus, comprising:

a building having a plurality of structural exterior walls;

a blast resistant interior wall located within the building and spaced inwardly from the exterior walls, the interior wall having a hollow wall space and having a majority of the hollow wall space filled with a particulate material having a density of at least 90 pounds per cubic foot; and

at least one laterally extending interior support wall connected to the blast resistant interior wall.

36. The apparatus of claim **35**, further comprising:

a structural ceiling attached to the blast resistant interior wall.

37. The apparatus of claim **35**, further comprising:

a plurality of additional blast resistant interior walls arranged with the first blast resistant wall to define a blast resistant area within the building.

38. The apparatus of claim **35**, wherein:

the building comprises at least a first floor and a second floor located above the first floor; and

a plurality of said blast resistant interior walls are located on each of said first and second floors to define a blast resistant zone on each floor.

39. A blast resistant shelter apparatus, comprising:

a building having a foundation and a structural framework extending upward from the foundation; and

a blast resistant perimeter curtain supported from the framework and at least partially defining a perimeter wall of the building, the curtain being of modular construction and including a plurality of side-by-side vertically oriented metal panels, each panel having a hollow interior panel space having a width and a height greater than said width, at least a majority of which space is filled with a particulate material.

40. The apparatus of claim **39**, wherein adjacent panels are attached to each other with an adhesive.

41. The apparatus of claim **39**, further comprising:

a steel sheet exterior blast shield attached to said panels.

42. The apparatus of claim **39**, wherein:

the framework defines at least a first floor and a second floor located above the first floor; and

the blast resistant perimeter curtain spans the perimeter wall of at least the first and second floors.

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