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Fyfe

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[54] **BLAST-RESISTANT BUILDING**

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[51] **Int. Cl.**[7] **E04B 5/00**

[52] **U.S. Cl.** **52/262**; 52/236.9; 403/231; 403/267

[58] **Field of Search** 52/167.3, 262, 52/236.9, 236.7; 220/62.15, 62.19, 62.22, 88.1; 403/231, 265, 266, 267

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[57] **ABSTRACT**

Blast-resistant building **(11)** includes a structural connection **(10)** including at least one layer of fiber reinforced composite **(90)** bonded to each connected structural element **(20,30)** along the length of the connection between structural panel **(20)** and elongate anchoring structures **(30)**, such as I-beam **(40)** or additional concrete panel **(50)**. Layer of fiber reinforced composite **(90)** spans peripheral seam **(36)**, internal seam **(37)**, or both between the connected elements, providing a tensile force under load which tends to hold the elements together and to strengthen the connection while simultaneously providing ductility along the seam, lessening the risk of fracture of either element or the connection under atypical loading, such as from a blast. Connection **(10)** includes an elongate tension member, such as bolt **(80)**, for attaching the various elements, and a force dampener, such as a rubber isolation washer **(89)**, to increase the ductility of the connection. In another embodiment, connection **(10)** includes an elongate fastener, such as bolt **(70)**, for securing layer **(90)** to each structural element **(20,30)** and preventing layer **(90)** from separating from the surface to which it is bonded under load.

13 Claims, 3 Drawing Sheets

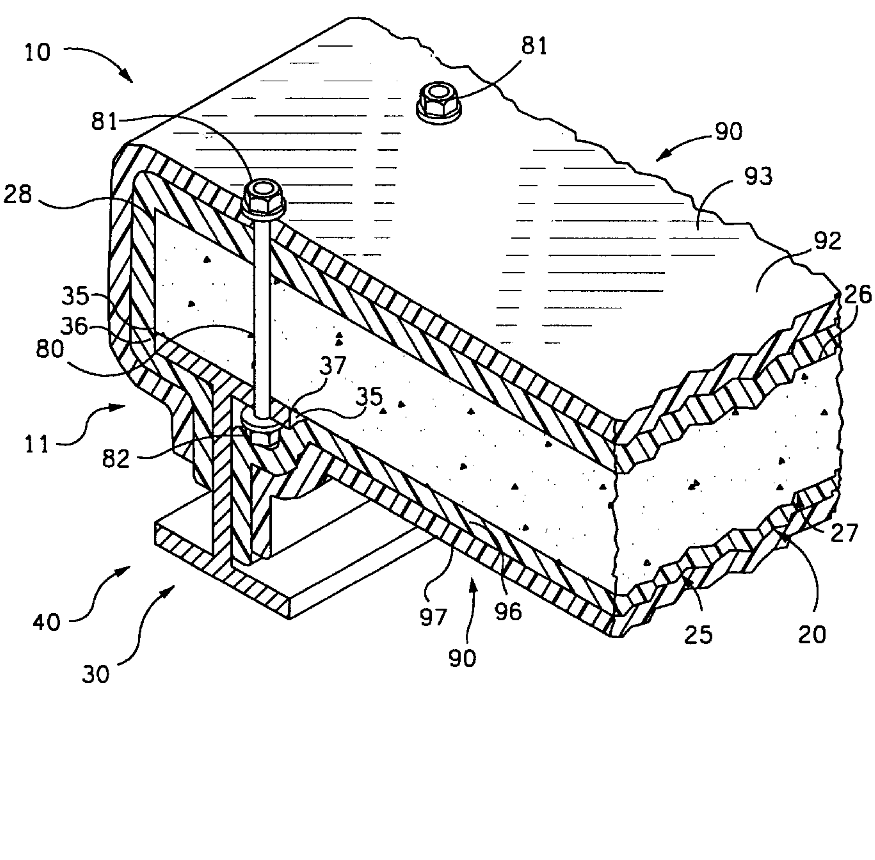
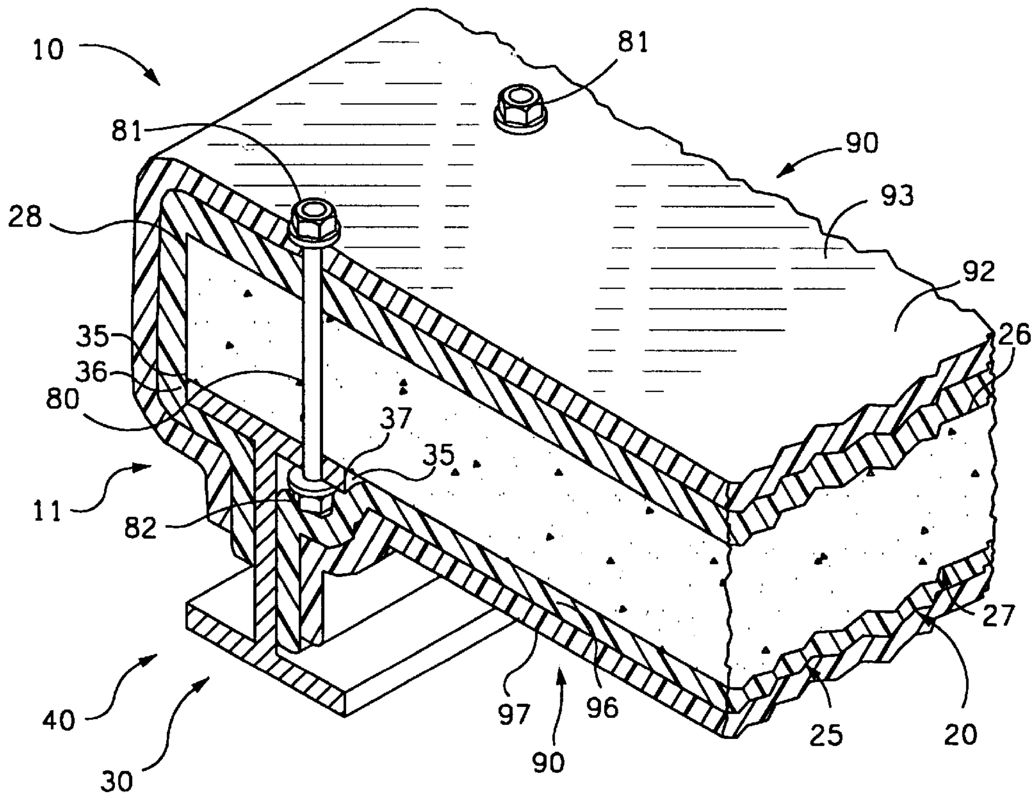


FIG.1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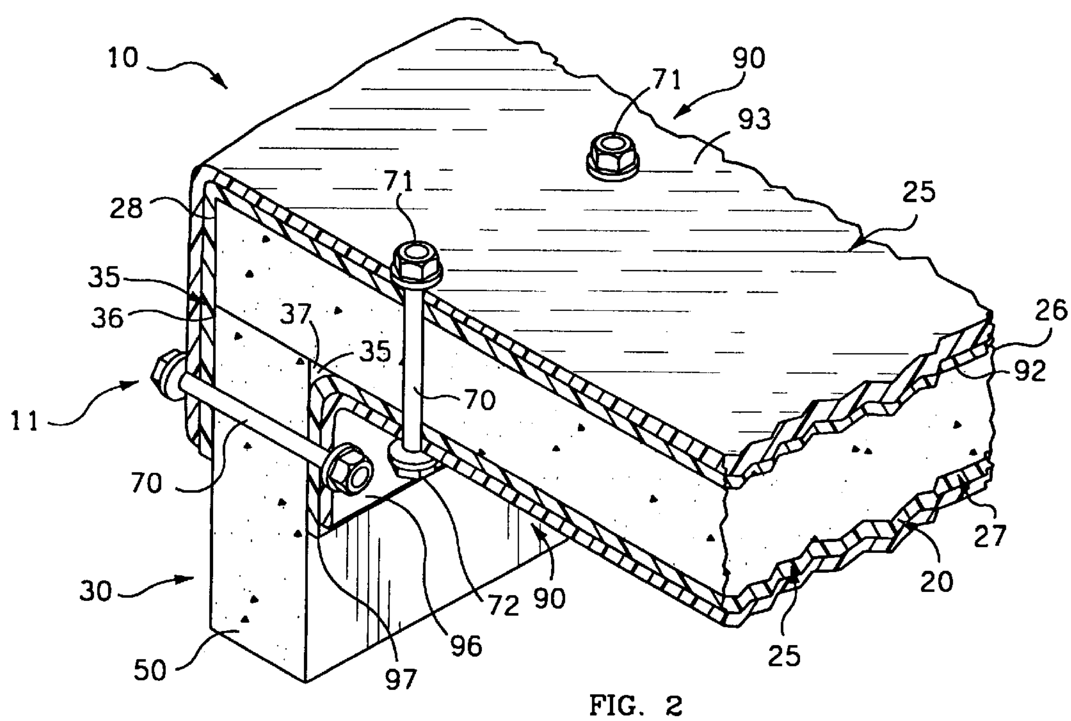
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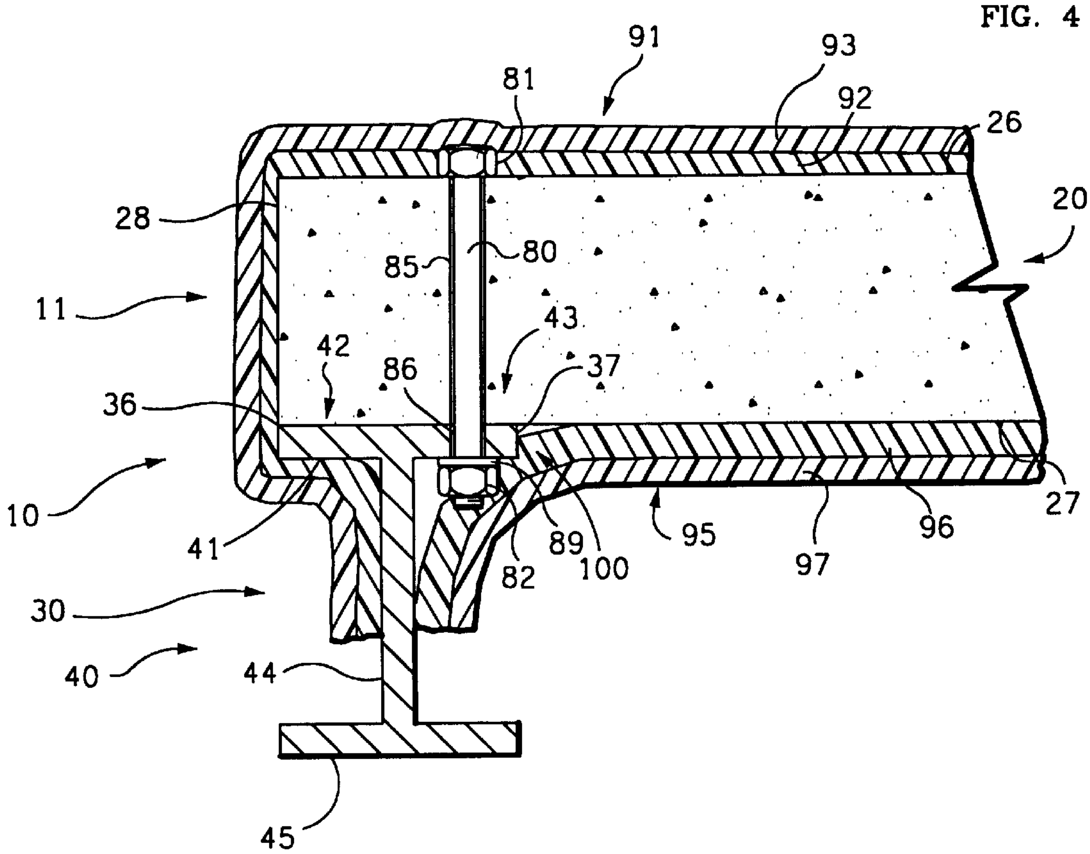
FIG. 2

FIG. 4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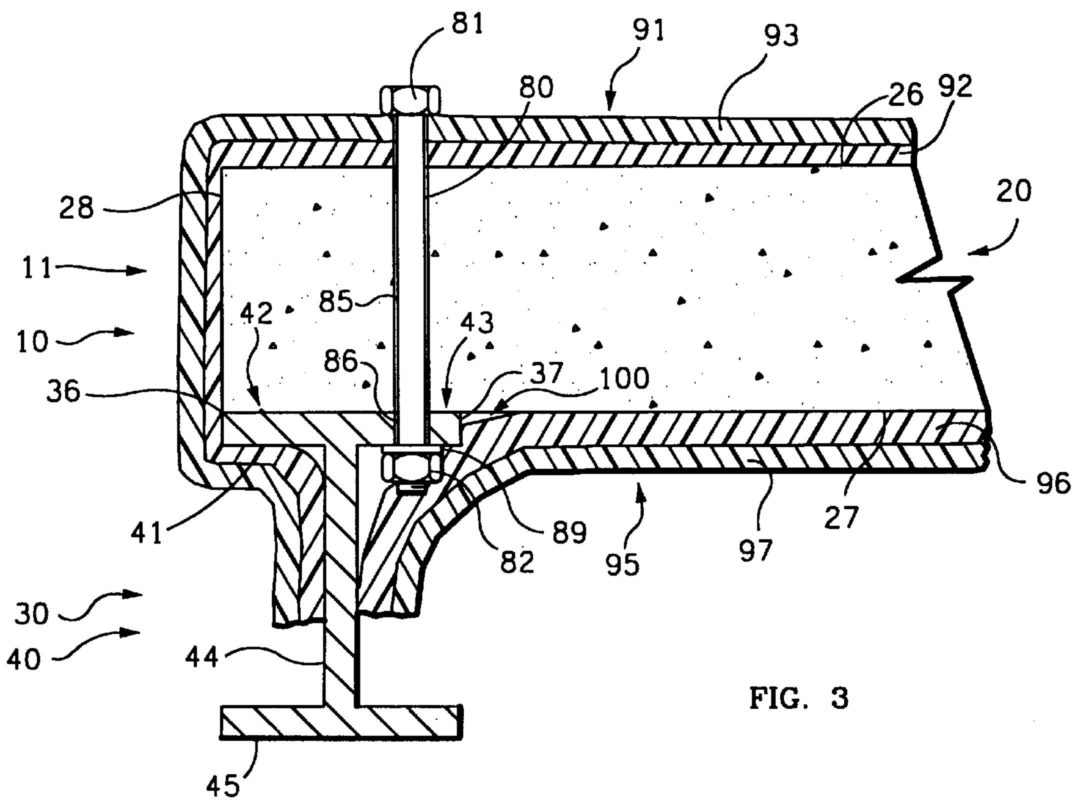
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FIG. 3

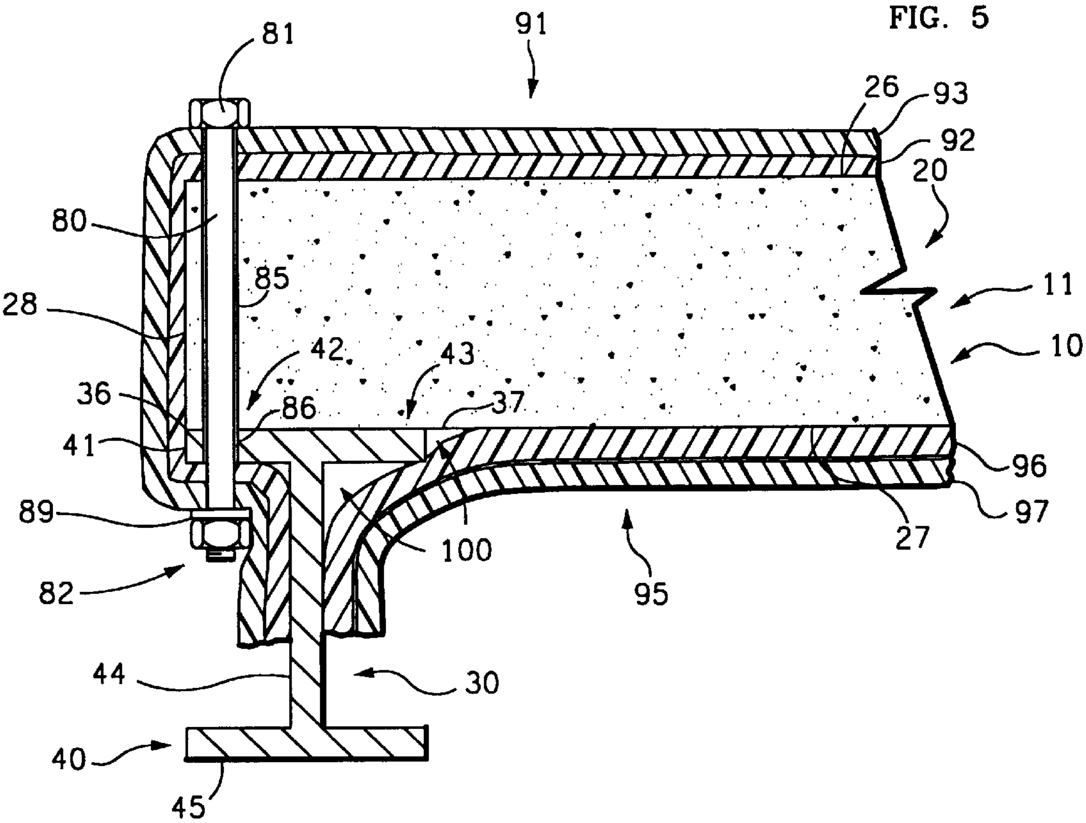

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FIG. 5

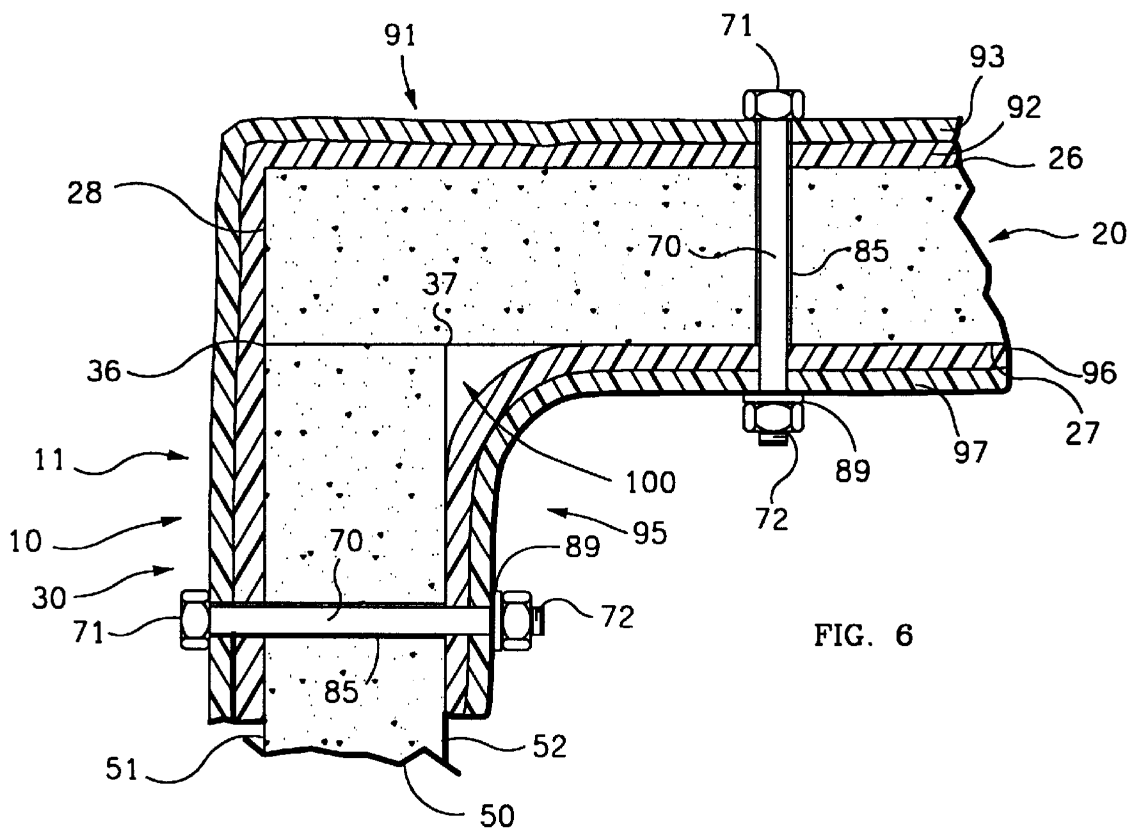

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FIG. 6

BLAST-RESISTANT BUILDING

FIELD OF THE INVENTION

This invention relates to a blast-resistant building, and more particularly to a building having reinforced connections between concrete structural panels and adjacent support members providing for increased structural stability under fluctuating loads, such as during a blast or explosion.

BACKGROUND OF THE INVENTION

Many conventional buildings constructed of reinforced concrete are generally not well suited to withstand large seismic forces, and such buildings typically are not designed to withstand blast loading. Seismic forces can cause the structural elements in a building to vibrate or to deform, resulting in transfer of forces at the connections between the elements. A blast external to a building first creates a strong inward force (implosion), and then a resulting reflexive expansion (explosion) of the structure. If one force does not destroy the building, the other may well destroy it.

It has been proven by test and shown by analysis that the increased strength and ductility of building structural members achieved by applying fiber reinforced composites to concrete columns, beams, walls, slabs, and other elements can assist in preventing damage and collapse of these elements. When stresses, particularly shear stresses, are transferred between these individual elements, however, fracture and even catastrophic failure of the whole structure can occur at the connections between otherwise structurally sound elements.

Therefore, there has been a need for a building having improved connections between structural elements such that the reinforced connections can withstand atypical or fluctuating loads associated with earthquakes, explosions and other concussive forces, or the like.

Furthermore, it is additionally desirable to retro-fit existing building structures with the improved reinforced connections.

SUMMARY OF THE INVENTION

A blast-resistant building includes a structural panel, an elongate anchoring structure, and at least one layer of fiber reinforced composite which is bonded to each attached structural element along the length of the connection between the two structural elements. The layer of fiber reinforced composite spreads any applied forces over the entire covered area, thereby lessening the force applied at a particular point. The layer of fiber reinforced composite spans the seam between the elements, providing a tensile force under load which tends to hold the elements together and to strengthen the connection while simultaneously providing ductility along the seam, lessening the risk of fracture of either element or the connection under atypical loading.

The reinforced connection includes elongate tension members, such as bolts or rivets, extending through the structural panel and at least part of the elongate anchoring structure for rigidly connecting the members. Force dampening elements, such as rubber isolation washers, are included to increase the ductility of the connection.

The bolts or rivets may also secure the layer of fiber reinforced composite to each structural element to prevent the layer from separating under load from the surface to which it is bonded.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a perspective partial cross-section view of a first preferred embodiment of the blast-resistant building of the invention.

FIG. **2** is a perspective partial cross-section view of a second preferred embodiment of the blast-resistant building of the invention.

FIG. **3** is an enlarged front elevation view of the connection of FIG. **1**.

FIG. **4** is an enlarged front elevation view similar to FIG. **3** showing a second embodiment of the elongate tension member.

FIG. **5** is an enlarged front elevation view similar to FIG. **3** showing a third embodiment of the elongate tension member.

FIG. **6** is an enlarged front elevation view of the connection of FIG. **2**.

DETAILED DESCRIPTION OF THE INVENTION

With reference now to the drawings, and particularly to FIGS. **1** and **2** thereof, FIG. **1** is a perspective partial cross-section view of a first preferred embodiment of the blast-resistant building **11** of the invention, and FIG. **2** is a perspective partial cross-section view of a second preferred embodiment of the blast-resistant building **11**. Building **11** generally comprises a structural panel **20**, an elongate anchoring structure **30**, and a connection **10** comprising one or more layers of fiber reinforced composite **90** spanning seams **35**, and a plurality of fasteners **70,80**. Common structural panels **20** include floors, walls, ceilings and roofs or portions thereof, such as floor, roof, wall and ceiling slabs, and beams and columns. Structural panel **20** may be made of steel reinforced concrete, unreinforced concrete, masonry material, or other material common in construction. Panel **20** has faces **25**, including an external face **26** and an internal face **27**, and a peripheral edge **28**. Panel **20** is anchored to elongate anchoring structure, denoted generally as **30**.

Common anchoring structures **30** include floors, walls, ceilings and roofs or portions thereof, such as floor, roof, wall and ceiling slabs, and beams and columns. Although FIGS. **1–6** illustrate anchoring structures **30** vertically supporting panel **20**, the invention also encompasses buildings **11** having non-vertically supporting blast-resistant structural connections **10**, such as between a wall and a floor, connections **10** between a wall and a ceiling, and also connections **10** between adjacent walls. Also, while the figures show only one end of panel **20** supported by anchoring structures **30**, the other end of panel **20**, not shown in the figures, is similarly supported; a round panel would be peripherally supported.

Anchoring structures **30**, such as structural I-beam **40** and structural panel **50**, shown and described, are representative of typical conventional anchoring structures connected to structural panels **20**. Structural panel **50** may be similar to panel **20**. As best seen in FIGS. **3–6**, each anchoring structure **30** is attached along its length to internal face **27** of structural panel **20** proximal peripheral edge **28** and defines a pair of seams **35**, peripheral seam **36** and internal seam **37**. Seams **35** run the length of the connection between panel **20** and anchoring structure **30**. While the embodiments of seams **35** described herein and shown in the drawings are generally linear, it should be noted that the invention also encompasses angled, curved, or other non-linear seams **35** resulting from the connections of non-linear panels **20**, non-linear anchoring structures **30**, or both.

FIG. **3** is an enlarged front elevation view of the connection **10** of FIG. **1** showing an elongate tension member, such as bolt **80**. In FIG. **3**, the connection **10** to be reinforced includes a structural panel **20** having an external face **26**, an internal face **27**, and a peripheral edge **28** and a structural I-beam **40** including a proximal flange **41**, a web **44**, and a distal flange **45**. Proximal flange **41** includes peripheral portion **42** and internal portion **43**.

Although an I-beam **40** is shown and described, the invention also encompasses similar structures such as box beams, concrete beams, or other elongate structures that are well known and commonly used in construction. A peripheral layer of fiber reinforced composite **91**, which may include one or more layers of fiber reinforced composite such as first peripheral layer **92** and second peripheral layer **93**, is bonded, by means well-known in the art, such as by epoxy, to external face **26** of panel **20**. Preferably, peripheral layer **91** covers entire external face **26** to provide panel **20** with increased ductility and shear resistance. First peripheral layer **92** spans peripheral seam **36** and is further bonded directly to structural I-beam **40**. When applied forces, such as from a blast, would otherwise cause panel **20** and I-beam **40** to tend to separate, layer **92** acts as a tension element, holding the structural members together at peripheral seam **36**. Layer **92** also spreads shear forces over its entire area, lessening the magnitude of local forces at a particular point and providing ductility at peripheral seam **36**.

FIG. **3** also shows a reinforced internal seam **37**. An internal layer of fiber reinforced composite **95**, which may include one or more layers of fiber reinforced composite such as first internal layer **96** and second internal layer **97**, is bonded, by means well-known in the art, such as by epoxy, to internal face **27** of panel **20**. Preferably, internal layer **95** covers entire internal face **27** to provide panel **20** with increased ductility and shear resistance. First internal layer **96** spans internal seam **37** and is further bonded directly to structural I-beam **40**. When applied forces, such as from a blast, would otherwise cause panel **20** and Ibeam **40** to tend to separate, layer **96** acts as a tension element, holding the structural members together at internal seam **37**. Layer **96** also spreads shear forces over its entire area, lessening the magnitude of local forces at a particular point and providing ductility at internal seam **37**.

In the preferred embodiment of such a reinforced internal seam **37**, a layer of ductile adhesive material **100**, such as epoxy, is deposited along internal seam **37** beneath first internal layer **96**. Adhesive material **100** is bonded to both internal face **27** of panel **20** as well as to internal portion **43** of proximal flange **41** of structural I-beam **40** to strengthen and to add ductility and stress resistance to connection **10**.

FIG. **6** is an enlarged front elevation view of the connection **10** of FIG. **2** showing a plurality of elongate fastening members, such as bolts **70**. In FIG. **6**, the connection **10** to be reinforced includes a structural panel **20** having an external face **26**, an internal face **27**, and a peripheral edge **28** and an additional structural panel **50** having an external face **51** and an internal face **52**. Peripheral layer of fiber reinforced composite **91**, including first peripheral layer **92** and second peripheral layer **93**, is bonded, by means well-known in the art, such as by epoxy, to external face **26** of panel **20**. First peripheral layer **92** covers external face **26**, spans peripheral seam **36**, and is further bonded directly to external face **51** of panel **50**. When applied forces, such as from a blast, would otherwise cause panels **20,50** to tend to separate, layer **92** acts as a tension element, holding the structural members together at peripheral seam **36**. Layer **92** also spreads shear forces over its entire area, lessening the magnitude of local forces at a particular point and providing ductility at peripheral seam **36**.

FIG. **6** also shows a reinforced internal seam **37**. Internal layers of fiber reinforced composite **95**, including first internal layer **96** and second internal layer **97**, are bonded, by means well-known in the art, such as by epoxy, to internal face **27** of panel **20**. First internal layer **96** covers internal face **27**, spans internal seam **37**, and is further bonded directly to internal face **52** of panel **50**. When applied forces, such as from a blast, would otherwise cause panels **20,50** to tend to separate, layer **96** acts as a tension element, holding the structural members together at internal seam **37**. Layer **96** also spreads shear forces over its entire area, lessening the magnitude of local forces at a particular point and providing ductility at internal seam **37**.

In the preferred embodiment of such a reinforced internal seam **37**, a layer of ductile adhesive material **100**, such as epoxy, is deposited along internal seam **37** beneath first internal layer **96**. Adhesive material **100** is bonded to both internal face **27** of panel **20** as well as to internal face **52** of panel **50** to strengthen and to add ductility and stress resistance to connection **10**.

Returning now to FIG. **3**, a preferred embodiment of a blast-resistant structural connection **10** is shown including rigid attachment means for rigidly attaching panel **20** to structural I-beam **40**. Such rigid attachment means may include a plurality of elongate tension members, such as bolts **80** dispersed along seam **37**. Each bolt **80** has an external compressive terminus, such as bolt-head **81**, and an internal compressive terminus, such as nut **82**. Bolt **80** may be extended through a bore **85** in panel **20** or it may be integral with panel **20**, held in place while the concrete was allowed to set. Bolt **80** further is extended through bore **86** in proximal flange **41** of I-beam **40**. Although bolt **80** is shown and described, it will be apparent to one skilled in the art that the invention also encompasses the use of rivets, screws, or similar structural fasteners. Preferably a plurality of bolts **80** are dispersed along the length of seam **37**.

Bolt **80** extends through peripheral layer of fiber reinforced composite **91** and bolt-head **81** bears on layer **91**. In the embodiment shown in FIG. **3**, bolt-head **81** serves the additional function of securing layer **91** to panel **20**. While FIG. **3** shows bolt-head **81** bearing on layer **91**, it should be noted that other embodiments are contemplated. For example, FIG. **4** is an enlarged view of the connection **10** of FIG. **1** showing a second embodiment of bolt **80** wherein bolt-head **81** bears on external face **26** of panel **20** for applying a compressive force thereto. Bolt-head **81** may also be countersunk.

In FIGS. **3** and **4**, nut **82** bears on proximal flange **41** of structural I-beam **40** for applying a compressive force thereto. In the preferred embodiment, force dampening means, such as a compressible member, such as rubber isolation washer **89**, absorbs shock and reduces fluctuating or atypical forces transmitted through bolt **80** between panel **20** and I-beam **40**. Rubber washer **89** is interposed either between nut **82** and the surface upon which it bears (i.e. proximal flange **41**) or between bolt-head **81** and the surface upon which it bears (i.e. layer **91** as in FIG. **3**, or external face **26** of panel **20** as in FIG. **4**) to reduce effectively transmitted forces.

FIG. **5** is an enlarged view of the connection **10** of FIG. **1** showing a third embodiment of the elongate tension member. In FIG. **5**, bolt **80** extends through peripheral layer of fiber reinforced composite **91** at a point where layer **91** is bonded to structural panel **20**, through panel **20** itself, through peripheral portion **42** of proximal flange **41** of I-beam **40**, and once again through layer **91** at a point where layer **91** is bonded to proximal flange **41**. Bolt **80** thereby extends through layer **91** on each side of peripheral seam **36**.

In this embodiment, in addition to rigidly attaching panel **20** to I-beam **40**, bolt **80** performs another function in that both bolt-head **81** and nut **82** bear on layer **91**. Layer **91** is thereby secured by mechanical means both to panel **20** and I-beam **40** on either side of peripheral seam **36**. Securing layer **91** in this manner reduces the risk that layer **91** will separate from panel **20** or I-beam **40** under load. Preferably a plurality of bolts **80** are dispersed along the length of seam **36**.

Returning now to FIG. **6**, an enlarged front elevation view of the connection **10** of FIG. **2** is shown with elongate fastening members, such as bolts **70**, extending through each panel **20,50** as well as through layers of fiber reinforced composite **91,95**. Bolts **70** may be extended through bores **85** in panels **20,50** or may be integral with panels **20,50**, held in place while the concrete was allowed to set. Bolts **70** each include an internal compressive terminus, such as nut **72**, and an external compressive terminus such as bolt-head **71**. Preferably a plurality of bolts **70** are dispersed along each seam **36,37**.

Peripheral layer **91** is bonded to, and preferably substantially covers, external face **26** of panel **20**, spans peripheral seam **36**, and is further bonded directly to external face **51** of panel **50**. Internal layer **95** is bonded to, and preferably substantially covers, internal face **27** of panel **20**, spans internal seam **37**, and is further bonded directly to internal face **52** of panel **50**. Bolt **70** extends through layers **91,95**, bolt-head bears on peripheral layer **91**, and nut **72** bears on internal layer **95**.

Although FIG. **6** shows both peripheral layer **91** and internal layer **95** and each layer **91,95** having two layers **92,93** and **96,97** respectively, it can be seen that bolt **70** can be utilized if either layer **91,95** is not present or if either layer has only one constituent layer **92,96**. In the manners described above, layer **90** is thereby secured by mechanical means both to panel **20** and panel **50** on either side of reinforced seams **35**. Securing layer **90** in this manner reduces the risk that layer **90** will separate from panels **20,50** under load.

It is desirable to select a fiber cloth with elongation properties acceptable for use within the range of expected loading, or to use other materials with higher elongation properties for use in reinforcing the composite layer.

In many instances, the fiber cloth used in reinforcing composite layers has a general fiber direction; i.e. the majority of the fibers are oriented such that they are substantially parallel to each other. Where such a unidirectional cloth is employed, both the cloth itself and the layer of composite reinforced with it generally exhibit greater tensile performance in the direction of the fibers. For this reason, given the tensile role of layer of fiber reinforced composite **90**, it is preferred that such a layer **90** employing unidirectional fibers be applied such that the fibers therein are oriented at an angle of at least 45 degrees relative to the reinforced seam **35**. In another preferred embodiment, layer of fiber reinforced composite **90** is applied such that the fibers therein are oriented substantially perpendicular to the reinforced seam **35**. With the fibers crossing seam **35**, greater tensile strength at connection **10** increases structural stability.

If second layers **93,97** are employed as shown in FIGS. **1–6**, preferably the direction of their fibers is substantially perpendicular to the direction of the fibers contained in their respective underlying layer **92,96**.

Preferably, composite layer **90** spans entire face **25** of structural panel **20** and covers seams **35** on each side.

It can be seen that the present invention provides a building having very reliable structural connections reinforced to withstand blast loading or fluctuating seismic forces. Such connections may be perfected while the structure is under construction, or an existing structure may be retro-fitted with the improved blast-resistant connections.

Although particular embodiments of the invention have been illustrated and described, various changes may be made in the form, composition, construction, and arrangement of the parts without sacrificing any of its advantages. Therefore, it is to be understood that all matter herein is to be interpreted as illustrative and not in any limiting sense, and it is intended to cover in the appended claims such modifications as come within the true spirit and scope of the invention.

Having thus described my invention, I claim:

1. A blast-resistant structure comprising:

at least one structural panel having an external face, an internal face, and a peripheral edge;

an elongate anchoring structure; said elongate anchoring structure attached along its length to said internal face of said structural panel proximal said peripheral edge and defining a peripheral seam and an internal seam;

a first layer of fiber reinforced composite bonded to at least one of said faces of said structural panel, spanning at least one of said seams, and further bonded to said elongate anchoring structure; and

an elongate tension member extending through said structural panel and at least part of said elongate anchoring structure; said elongate tension member including:

a first compressive terminus applying a compressive force to said structural panel; and

a second compressive terminus applying a compressive force to said elongate anchoring structure.

2. The blast-resistant structure of claim **1** wherein said first layer of fiber reinforced composite is bonded to said internal face of said structural panel, spans said internal seam, and is further bonded to said elongate anchoring structure.

3. The blast-resistant structure of claim **1** wherein said first layer of fiber reinforced composite is bonded to said external face of said structural panel, spans said peripheral seam, and is further bonded to said elongate anchoring structure.

4. The blast-resistant structure of claim **1** wherein said first layer of fiber reinforced composite is bonded to said external face of said structural panel, spans said peripheral seam, and is further bonded to said elongate anchoring structure, and further comprising:

a second layer of fiber reinforced composite bonded to said internal face of said structural panel, spanning said internal seam, and further bonded to said elongate anchoring structure.

5. The blast-resistant structure of claim **1** wherein said first layer of fiber reinforced composite is applied such that the fibers therein are oriented at an angle of at least 45 degrees relative to said spanned seam.

6. The blast-resistant structure of claim **5** further comprising:

a second layer of fiber reinforced composite bonded to said first layer of fiber reinforced composite wherein the fibers in said second layer are oriented substantially perpendicular to the fibers in said first layer.

7. The blast-resistant structure of claim **1** wherein said first layer of fiber reinforced composite is applied such that the fibers therein are oriented substantially perpendicular to said spanned seam.

8. The blast-resistant structure of claim **1** wherein said elongate tension member further extends through said first layer of fiber reinforced composite and wherein at least one of said compressive terminuses is adapted to apply a compressive force to said first layer of fiber reinforced composite.

9. The blast-resistant structure of claim **1** further comprising:

at least one compressible member interposed between at least one of said compressive terminuses and the surface upon which said compressive terminus bears for reducing fluctuating forces transmitted therebetween.

10. The blast-resistant structure of claim **3** wherein said elongate tension member further extends through:

said first layer of fiber reinforced composite at a point where said first layer is bonded to said structural panel; said structural panel; part of said elongate anchoring structure; and said first layer of fiber reinforced composite at a point where said first layer is bonded to said elongate anchoring structure; said elongate tension member thereby extending through said first layer of fiber reinforced composite on each side of said peripheral seam; and

wherein each said compressive terminus of said elongate tension member applies a compressive force to said first layer of fiber reinforced composite.

11. The blast-resistant structure of claim **10** further comprising:

a second layer of fiber reinforced composite bonded to said internal face of said structural panel, spanning said internal seam, and further bonded to said elongate anchoring structure.

12. The blast-resistant structure of claim **1** further comprising:

one or more additional elongate tension members dispersed along said spanned seam; each said additional elongate tension member extending through said structural panel and at least part of said elongate anchoring structure and including:

a first compressive terminus applying a compressive force to said structural panel; and

a second compressive terminus applying a compressive force to said elongate anchoring structure.

13. The blast-resistant structure of claim **1** wherein said structural panel is composed of concrete.

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