

METHOD OF SEISMIC REINFORCEMENT OF A BEAM-COLUMN JOINT WITH HIGH STRENGTH FIBROUS SHEETS

BACKGROUND

[0001] The present invention generally relates to load bearing structures such as buildings, bridges, etc., and more particularly, to a method of reinforcing beam-column joints in load bearing structures with high strength fibrous sheets.

[0002] In many regions of the world classified as low to moderate seismic activity areas, structures are not designed to withstand the non-normal loading conditions that occur during earthquakes or tremors. Recently, earthquakes have become more common in these areas, particularly in Asia and Europe. Studies of structures not designed to withstand earthquake conditions have revealed that beam-column joints are structurally weak when subject to non-normal loading conditions. Accordingly, it is desirable to retrofit the beam-column joints in existing structures to withstand the non-normal loading conditions of earthquakes and tremors.

[0003] During a seismic event or other circumstances in which a structure is subjected to non-normal loading, the beam sections of beam-column joints are prone to developing shear cracks. Through testing, it has been determined that shear cracks are most likely to form on the vertically oriented beam faces of beam sections at a shear angle orientation skew with respect to the longitudinal axis of a beam section between 0° and 90° . More particularly, shear cracks are likely to form at about $\pm 45^{\circ}$ with respect to the longitudinal axis of a beam section.

[0004] There are known methods for retrofitting the beam-column joints of existing structures. Many of these methods are unduly expensive or severely limit the use of the structure while they are being performed. A steel plate could be used for strengthening the joint by increasing the ductility and shear capacity of the joint. However, steel plates may corrode over time, and would permanently deform ("bulge") if subjected to stress such as in a seismic event.

One less invasive and inexpensive method of reinforcing beam-column joints involves the application of high strength fiber reinforced polymer to the joint surface. While this method is less timely, costly, and disruptive than other known methods, no method of applying fiber reinforced polymer to a beam-column joint is known that can be applied to any beam-column joint orientation. Moreover, known methods of applying fiber reinforced polymer to beam-column joints do not effectively prevent shear cracking along vertically oriented beam surfaces. Accordingly, a method of reinforcing a beam-column joint that strengthens the joint against shear cracking is needed that can be applied to any known joint orientation without substantial adaptation.

SUMMARY

[0005] In one aspect, the present invention includes a method of reinforcing a beam-column joint in a load bearing structure with high strength fibrous sheets carrying a curable polymer. The beam-column joint comprises a column, a beam section extending outwardly from a perimeter of the column along a longitudinal axis of the beam section. The beam section also includes vertically oriented beam faces on opposite sides of the beam section and a horizontally oriented soffit surface on an underside of the beam. The column includes a soffit-adjacent surface adjoining the soffit surface at a juncture. The method comprises the following steps: A first fibrous sheet is applied to one of the vertically oriented beam faces. The first fibrous sheet has a majority of fibers arranged at a first angle skew to the longitudinal axis of the beam section. A second fibrous sheet is applied to said one vertically oriented beam face over the first fibrous sheet. The second fibrous sheet has a majority of fibers arranged at a second angle skew to the longitudinal axis of the beam section. The second angle is different from the first angle. The first and second fibrous sheets reinforce the beam section against shear cracks.

[0006] In another aspect of the invention, the invention comprises a method of reinforcing a beam-column joint in a load bearing structure with high strength fibrous sheets adapted to carry a curable polymer. The beam-column joint comprises a column, a first beam section extending outwardly from a perimeter of the column along a longitudinal axis of the first beam section. The first beam section includes vertically oriented beam faces on opposite sides of the first beam section and a horizontally oriented soffit surface on an underside of the first beam section. A second beam section extends outwardly from the perimeter of the column along a longitudinal axis of the second beam section. The column includes a soffit-adjacent surface adjoining the soffit surface of the first beam section at a juncture. The method comprises the following steps. (a) A first fibrous sheet is applied to a length of the soffit surface, the juncture and a length of the soffit-adjacent surface. (b) A second fibrous sheet is wrapped around a first length of the column. (c) A third fibrous sheet is wrapped around a second length of the column. The second length is different from the first length. (d) A fourth fibrous sheet is applied to a first length of the vertically oriented beam face. A majority of the fibers of the fourth fibrous sheet are arranged in a shear angle orientation skew to the longitudinal axis of the first beam section. (e) A fifth fibrous sheet is applied to a second length of the vertically oriented beam face. The second length of the vertically oriented beam face is at least as great as the first length of the first beam section. A majority of the fibers of the fifth fibrous sheet are arranged in a shear angle orientation skew to the longitudinal axis of the first beam section. (f) A sixth fibrous sheet is applied to a third length of the vertically oriented beam face. The third length of the vertically oriented beam face is at least as great as the second length of the beam section. (g) A seventh fibrous sheet is wrapped as at least a U-wrap around a

length of the first beam section. (h) A first row of fiber anchors is installed along the first beam section.

[0007] Other aspects of the present invention will be apparent in view of the following description and claims.

BRIEF DESCRIPTION OF THE DRAWINGS

[0008] Fig. 1 is a perspective of a load bearing building framework comprising beam-column joints reinforcable by way of the method of the present invention;

[0009] Fig. 2 is a fragmentary perspective of two beam-column joints prior to performance of any of the steps of the present invention;

[0010] Fig. 3 is a fragmentary perspective of two beam-column joints after performance of a first step of a first embodiment of the present invention;

[0011] Fig. 4 is a section taken in the plane including line 4-4 of Fig. 3;

[0012] Fig. 5 is an enlarged, fragmentary elevation of Fig. 1 showing the use of epoxy filler in a juncture;

[0013] Fig. 6 is a fragmentary perspective of two beam-column joints after performance of a second step of the first embodiment of the present invention;

[0014] Fig. 7 is a section taken in the plane including line 7-7 of Fig. 6;

[0015] Fig. 8 is a fragmentary perspective of two beam-column joints after performance of a third step of the first embodiment of the present invention.

[0016] Fig. 9 is a section taken along 9-9 of Fig. 8;

[0017] Fig. 10 is a fragmentary perspective of two beam-column joints showing the fourth and fifth steps of the first embodiment of the present invention, with parts exploded and parts broken away;

[0018] Fig. 11 is a section taken in the plane including line 11-11 of Fig. 10 with the exploded element of Fig. 10 applied to the structure;

[0019] Fig. 12 is a fragmentary perspective of two beam-column joints after performance of a sixth step of the first embodiment of the present invention;

[0020] Fig. 13 is a section taken in the plane including line 13-13 of Fig. 12;

[0021] Fig. 14 is a fragmentary perspective of two beam-column joints after performance of a seventh step of the first embodiment of the present invention;

[0022] Fig. 15 is a section taken in the plane including line 15-15 of Fig. 14;

[0023] Fig. 16 is a fragmentary perspective of two beam-column joints after performance of an eighth step of the first embodiment of the present invention;

[0024] Fig. 17 is a section taken in the plane including line 17-17 of Fig. 16;

[0025] Fig. 18 is a section taken in the plane including line 18-18 of Fig. 16 illustrating the use of fiber fasteners with a first preferred embodiment of the present invention;

[0026] Fig. 19 is a front side perspective of an eccentric beam-column joint after performance of a first step of a second embodiment of the present invention.

[0027] Fig. 20 is a back side perspective of an eccentric beam-column joint after performance of a fifth step of the second embodiment of the present invention.

[0028] Corresponding reference characters indicate corresponding parts throughout the drawings.

DETAILED DESCRIPTION OF THE DRAWINGS

[0029] Referring to Fig. 1, a load bearing structure comprising beam-column joints reinforcable by way of the method of the present invention is designated in its entirety by the reference number 20. Load bearing structures in which beam-column joints bear heavy loads are used extensively in the construction of buildings, bridges, etc. The method of the present invention can be used to reinforce structures that have been damaged, or undamaged structures.

[0030] The structure 20 includes an exterior corner beam-column joint 30 and an exterior center beam-column joint 50. The beam-column joint 30 includes a vertically oriented column 32 and a horizontally oriented beam 34. The beam includes beam sections 34A, 34B that extend outwardly from the perimeter of the column in perpendicular directions along the longitudinal axes of the beam sections. The beam-column joint 50 includes a vertically oriented column 52 and a horizontally oriented beam 54. The beam includes beam sections 54A, 54B that extend outwardly from the perimeter of the column 52 in opposite directions along the longitudinal axes of the beam sections. Many load bearing structures use exterior corner columns and exterior center columns as depicted. In addition, many other beam-column orientations are known, including both concentric and eccentric joints. In every known beam-column orientation, at least one beam section extends from the perimeter of a vertically oriented column. The method of the present invention may be applied to seismically reinforce any joint in which at least one beam section extends from the perimeter of a vertically oriented column. Accordingly, Figs. 1-18 should not be construed to limit the invention to exterior corner and exterior center joints. Rather, joints 30 and 50 are exemplary of two common orientations of beam sections with respect to vertically oriented columns. After describing the method of the present invention in detail with respect to joints 30 and 50, adaptation of the method to any known beam-column joint will be readily apparent.

[0031] In Fig. 2 as well as many of the subsequent drawings, the joints 30, 50 are depicted as supporting a surface, such as a roof, floor, road, or other surface. The beam sections 34A, 34B of joint 30 each have vertically oriented beam faces 36. The vertically oriented beam faces 36 are disposed on opposite sides of each beam section 34A, 34B. Each beam section 34A, 34B further includes a horizontally oriented soffit surface 38 on the underside of the beam section. The column 32 includes soffit-adjacent surfaces 40

that adjoin the soffit surfaces 38 at junctures 42. Likewise, the beam sections 54A, 54B of joint 50 each have vertically oriented beam faces 56. The vertically oriented beam faces 56 are disposed on opposite sides of each beam section 54A, 54B. Each beam section 54A, 54B further includes a horizontally oriented soffit surface 58 on the underside of the beam section. The column 52 includes soffit-adjacent surfaces 60 that adjoin the soffit surfaces 58 at junctures 62. Junctures 42, 62 are defined by the intersection of one of the beam sections 34, 54 with one of the columns 32, 52.

[0032] As will be discussed in more detail below, the method of the present invention contemplates the application of fiber reinforced polymer to beam-column joints such as the joints 30, 50. The basic form of the fragmentary perspective drawing of Fig. 2 will be repeated in several of Figs. 3-18, but sheets of high strength fibrous material will be shown applied to elements of the joints. For clarity, not all of the reference numbers in Fig. 2 will be carried through each of Figs. 3-18. However, it should be understood that the elements of the joints 30, 50 referenced in Fig. 2 do, in fact, carry through Figs. 3-18.

[0033] Sheets including high strength fibers are adapted to carry a curable polymer and may be applied to a structural element such as a column, beam, or juncture to increase the strength and ductility of the structural element as well as the structure as a whole. These sheets preferably have an elastic modulus that closely approximates the elastic modulus of the reinforced joint. For this reason, when the sheets are fully bonded to the joints, the reinforcing layers work as a composite together with the surfaces to which they are adhered and do not bulge when stressed. For clarity, the fibrous sheets are illustrated schematically so that the method sequence can be understood. Many types of high strength fabrics may be applied without departing from the scope of this invention. Preferred examples of high strength fabrics include glass fibers and carbon fibers. However, other

fibrous materials such as graphite, polyaramid, boron, KEVLAR™, silica, quartz, ceramic, polyethylene, and aramid may also be used. The fibrous sheets may be unitary or comprised of multiple layers and are preferably adapted to carry a curable polymer which may comprise any suitable polymer matrix. Examples of suitable polymer matrices, or resins, include but are not limited to polyester, epoxy, vinyl ester, cyanate, and polyamide. Preferably, the fibrous sheets are lightweight, with a preferred density of between 1.3 g/cm³ to 2.6 g/cm³. Preferably, the high strength fibrous sheets of the present invention have a majority of fibers extending in the same predetermined direction giving the sheet higher strength in that direction. The sheets may also have constituent fibers that are different from other fibers in the sheet. It may be that only these special fibers have the preferred orientation. In one preferred embodiment, the sheets are thin so that the profile of the beam and column are not dramatically altered by application of multiple, often overlying sheets. In another preferred embodiment the sheets have a thickness of between 1mm to 50mm.

[0034] The method of the present invention includes steps of applying or wrapping sheets of fiber reinforced polymer to a surface or surfaces of a beam-column joint. Prior to that, the surfaces of the beam-column joint are thoroughly cleaned to remove dirt and loose matter from the surfaces. The terms "applying" and "wrapping" refer to the process of adhering the fibrous sheets to the desired surface or surfaces. This adhering process may be accomplished through the use of adhesives sprayed on or otherwise applied to the desired surface or surfaces. However, in a preferred embodiment, the fibrous sheets are pre-impregnated or saturated with a synthetic curable resin, such as epoxy, urethane, or other adhesive polymer. Such a fibrous sheet is tacky enough to adhere to a surface on contact. Once initially adhered to the surface, the synthetic resin will cure over a period of time in ambient temperature. The cured resin impregnated fibrous

sheets firmly adhere to their underlying surfaces, improving the strength and ductility of the structural elements to which they are adhered. It will be understood that the resin can be applied to the fibrous sheets after they are positioned on the joint.

[0035] Figures 3-5 depict a first step of a first embodiment of the present invention. In the first step, for each beam section 34A, 34B and 54A, 54B, a single continuous fibrous sheet 70 is applied to a length of the soffit surface 38, 58, the juncture 42, 62, and a length of the soffit-adjacent surface 40, 60. Preferably, the fibrous sheet 70 extends at least about 500mm from the juncture along the soffit surface and at least about 500mm from the juncture along the soffit-adjacent surface, while covering the juncture. In the illustrated embodiment, the majority of fibers of sheet 70 are oriented parallel to the longitudinal axes of the soffit surfaces 38, 58 and the longitudinal axes of the soffit-adjacent surfaces 40, 60, respectively. The majority direction of fibers in each of the different fibrous sheets are indicated by lines within the fibrous sheet. In a preferred embodiment, the first fibrous sheet 70 is formed of carbon fibers impregnated with a curable resin.

[0036] Figure 5 depicts an optional aspect of the first step of the first embodiment of the present invention. With respect to Fig. 3, Fig. 5 depicts a close up sectional elevation of the left juncture 62. The same features may be present on any of the junctures 42, 62. Prior to applying the sheet 70 to the junctures 42, 62, it is preferable to fill the junctures with an epoxy filler 72. In a preferred embodiment, the epoxy filler 72 fills the junctures 42, 62 and has a radius of curvature of at least about 25mm. The radius of curvature is desirable because it prevents stress concentrations from forming on the fibrous sheets as they are bent or folded at sharp angles. The first fibrous sheet 70 is schematically shown as a thick line in Fig. 5, and is spaced from the soffit surface 58 and the soffit-adjacent surface 60.

However, in practice the sheet would conform to fit against these surfaces away from the juncture 62. By pre-applying an epoxy filler 72 to each of the junctures 42, 62, the transition between each of the soffit surfaces 38, 58 and each of the soffit-adjacent surfaces 40, 60 is made more gradual, reducing the likelihood of unwanted tearing.

[0037] Figures 6-7 illustrate a second step of the first embodiment of the present invention. The only difference between Figs. 3-4 and Figs. 6-7 is the application of the second step of the embodiment of the invention. Likewise, each successive step will utilize the same basic figures to illustrate the application of that step. In the second step, each of columns 32, 52 is wrapped with a second fibrous sheet 74 around a length of the column. Preferably, each column 32, 52 is wrapped from its juncture 42, 62 at least about 500mm down the column, but typically less than the full length of the column. As shown in Fig. 7, the second sheet 74 has overlapping ends 76, 78 which form an overlapping section 80 that has a generally uniform width. The width of the overlapping section 80 is preferably at least about 150mm. Different amounts of overlap may be used within the scope of this invention. In Fig. 7, second sheet 78 is shown slightly separated from each column 32, 53. This separation is only depicted for clarity in distinguishing between layers. Each successive sheet should preferentially be applied in complete contact to the surface beneath it without any spaces therebetween. As shown best in Fig. 6, the second sheet 74 of the illustrated embodiment preferentially comprises glass fibers, a majority of which are oriented horizontally.

[0038] Figures 8-9 illustrate a third step of the first embodiment of the present invention that is very similar to the second step. In the third step, each of columns 32, 52 is wrapped with a third fibrous sheet 82. Preferably, each column 32, 52 is wrapped from its juncture 42, 62 down the entire length of the column. As in step two, the third sheet 82 has overlapping ends 84, 86 which form an overlapping

section 88 that has a generally uniform width. The width of the overlapping section 88 is preferably at least about 150mm. Different amounts of overlap may be used within the scope of this invention. It is desirable, although not necessary to have the overlapped portion of the third fibrous sheet 82 lie on a different face of the column 32, 52, than the overlapped portion of the second fibrous sheet 74. In a preferred embodiment, the third fibrous sheet 82 includes glass fibers, a majority of which are preferentially oriented in a horizontal direction (as applied to the column). Figure 9 is a section taken more than 500mm from the junctures 42, 62. Therefore, in the illustrated embodiment, sheet 74 is not visible as it is covered by visible sheet 82 at that cross section.

[0039] In the fourth and fifth steps of the first embodiment of the present invention, depicted together in Figs. 10-11, fourth and fifth fibrous sheets 90, 92 are applied to the beam-column joints 30, 50. During the fourth step, each single continuous fourth sheet 90 is applied to the vertically oriented beam faces 36, 56 of one beam section 34a, 54a, across the columns 32, 52 and onto the vertical beam faces of the adjacent beam sections 34b, 54b. After the fourth sheet 90 is applied, each continuous fifth sheet 92 is likewise applied to the vertically oriented beam faces 36, 56 and column. In Fig. 10, beam-column joint 30 is depicted as it would appear following the application of the fifth sheet 92, with a portion of the fifth sheet broken away to show the fourth sheet 90. Beam-column joint 50 is depicted as it would appear immediately preceding the application of the fifth sheet 92. The fourth sheet 90 is shown applied to the joint 50, and the fifth sheet 92 is shown exploded away from the structure. Preferably, each continuous fourth sheet 90 and each continuous fifth sheet 92 extends along each vertically oriented beam face 36, 56 at least about 500mm from its respective juncture 42, 62 in the direction of each beam section 34A, 34B and 54A, 54B. Figure 11, as well as all

subsequent section views, depict layers 90, 92 as a combined layer for clarity.

[0040] As shown best in Fig 10, the fourth fibrous sheet 90 comprises carbon fibers that are preferentially arranged in a first shear angle orientation skew with respect to the longitudinal axis of the beams 34, 54 (indicated by the angled crosshatching on sheets 90, 92). Within the fifth fibrous sheet 92, a majority of the carbon fibers are arranged in a second shear angle orientation skew with respect to the longitudinal axis of the beams 34, 54 that is preferably equal in magnitude but opposite in direction to the fiber angle of the fourth sheet 90. As discussed above, during a seismic event or other circumstances in which a structure is subjected to non-normal loading, the beam sections of beam-column joints are prone to developing shear cracks. Shear cracks are most likely to form on the vertically oriented beam faces of beam sections at a shear angle orientation skew with respect to the longitudinal axis of a beam section between 0° and 90° . More particularly, shear cracks are likely to form at about $\pm 45^{\circ}$ with respect to the longitudinal axis of a beam section. The high strength fibrous fabric sheets used in the present invention provide the most strength in the direction of their fiber orientation. Accordingly, it is desirable to apply fibrous sheets in an orientation in which the majority of their fibers run perpendicular to the likely failure axis. Thus, in a preferred embodiment of the present invention, the fiber angle of the fourth fibrous sheet 90 is oriented at $+45^{\circ}$ with respect to the longitudinal axis of the beams 34, 54. The fiber angle of the fifth fibrous sheet 92 is then oriented at -45° with respect to the longitudinal axis of the beam sections 34, 54. In a preferred embodiment, the fourth and fifth sheets 90, 92 are each formed of carbon fibers oriented in their preferential skew angle and impregnated with a curable resin.

[0041] In Figs. 12-13, a sixth step of the method of the present invention is illustrated. In the sixth step, a sixth

fibrous sheet 94 is applied to the beam-column joints 30, 50. As in the fourth and fifth steps, the sixth single continuous fibrous sheet 94 is applied to the vertically oriented beam faces 36, 56 adjacent the perimeter of the columns 32, 52 along a length of each beam face. Preferably, each continuous sixth sheet extends along each vertically oriented beam face 36, 56 at least 1000mm from its respective junctures 42, 62 in the direction of each beam section 34A, 34B and 54A, 54B. The sixth sheet 94 is preferentially formed of glass fibers oriented parallel to the longitudinal axis of the beam 34, 54 to which it is adhered.

[0042] As discussed above, each of the fourth, fifth and sixth sheets 90, 92, 94 are applied to the vertically oriented beam faces 36, 56 of beam-column joints 30, 50. In the illustrated embodiments, beam-column joints 30, 50 include integrally formed columns 32, 52 and beams 34, 54 respectively. In alternative embodiments, columns may be attached to separate beams to form beam-column joints. In these embodiments, a single column may divide two or more beam sections that make up a separated beam. Likewise, a single, integrally formed beam may continue in two or more directions from the perimeter of a column. As will be seen, each of the steps of the present invention may be applied regardless of the beam-column arrangement. With respect to this invention, the term vertically oriented beam face includes any vertically oriented surface that is either aligned with the vertically oriented surface of a beam section or separates a vertically oriented beam surface from an adjacent vertically oriented beam surface. Accordingly, in the fourth, fifth, and sixth steps, the fourth, fifth, and sixth sheets should extend along the vertically oriented surface of a beam section past that beam section's associated juncture in two directions.

[0043] Typically a beam-column joint will include at least two beam sections. In such cases, each of the fourth, fifth, and sixth sheets should extend continuously along the vertically oriented faces of two adjacent beam sections. For

example, with respect to joint 30, the beam sections 34A, 34B are adjacent one another on both of the opposite vertically oriented beam surfaces 36 of the beam 34. The length of the exterior vertically oriented beam surface 36 to which the sheets 90, 92, 94 are applied is longer than the interior length of the vertically oriented beam surface to which the sheets are applied. This is because beam sections 34A and 34B extend in perpendicular directions and are adjacent to one another on both of their respective opposite vertically oriented beam faces 36. With respect to joint 50, the lengths of the opposite vertically oriented beam surfaces 56 are identical. In joint 50, the beam sections 54A and 54B are adjacent one another even though they extend in opposite directions because no other beam sections extend from the perimeter of the column between them.

[0044] If a beam-column joint includes more than two beam sections, each of the opposite vertically oriented beam faces of a beam section will be adjacent to a vertically oriented beam face of different beam sections. In such cases, single continuous fourth, fifth, and sixth sheets should be applied to adjacent vertically oriented beam faces. Therefore, a sheet applied to a first vertically oriented beam face of a first beam section may extend to a face of a second beam, while the sheet applied to the second opposite face of the first beam extends to a face of a third beam. In instances in which a beam-column joint only includes one beam section, the fourth, fifth, and sixth sheets should extend along each of the opposite vertically oriented beam faces past the juncture in both directions, terminating at one end at the column-edge of the beam face. As can be seen, the method of the present invention may be applied consistently to beam-column joints that include one, two, or more beam sections extending from the perimeter of a column. Accordingly, Figs. 2-18, which depict two types of joints 30 and 50, should be construed as merely exemplary of two common beam section orientations and not in a limiting sense.

[0045] Turning now to Figs. 14-15, a seventh step of the method of the present invention is depicted. In the seventh step, a seventh sheet of fibrous material 96 is wrapped transverse to the lengthwise extension of the beam sections 34a, 34b, 54a, 54b, forming a U-wrap. The U-wrapped seventh sheet 96 is applied to at least the two opposite vertically oriented beam faces 36, 56, as well as the respective soffit surfaces 38, 58 disposed therebetween. If no surface such as a road, floor, or roof is supported by the top surface of the beam sections 34A, 34B and 54A, 54B, then the seventh sheet 96 may be optionally wrapped around the entire perimeter of the beam section. Preferably, each seventh sheet 96 is wrapped around each beam section 34A, 34B and 54A, 54B from each juncture 42, 62 at least 1000mm along each beam section. In a preferred embodiment, each seventh fibrous sheet 96 is formed of glass fibers running in a generally uniform direction transverse to the longitudinal axis of each beam 34, 54. The glass fibers are preferentially impregnated with a curable resin.

[0046] Figures 16-18 depict an optional eighth step of the present invention. The use of fiber anchors to secure resin impregnated fibrous material sheets to structural elements is known in the art. The fabric sheets applied in the preceding steps may be secured to the beam-column joints 30, 50 with fiber anchors 98, preferentially of a type such as Tyfo® Composite Anchors available from Fyfe Co., LLC of San Diego, California, U.S.A. Such fiber anchors typically include a hank of fibers, usually of glass, carbon, or other fibrous material. A borehole 99, best seen in Fig. 18 is drilled in a desired fiber anchor location, and an anchor 98A is inserted into the borehole such that one end of the anchor sits in the borehole and another end is exposed. The borehole 99 is then backfilled with an epoxy material. The fibers in the exposed end are splayed apart against the surface of the fiber sheet and a resin is applied to the surface to adhere the splayed fibers to the surface. Other fiber anchors and

fibrous sheet securement methods may also be used without departing from the scope of the invention. Figure 17 shows the exposed end of the anchor 98 with its constituent fibers splayed against the surface of the seventh sheet 96.

[0047] In the illustrated embodiment, a single row of fiber anchors 98 is installed on each beam 34, 54. Preferably, the row of fiber anchors 98 is installed at least about 100mm from the top edge of each beam 34, 54. For each beam section 34A, 34B and 54A, 54B a first fiber anchor 98A is laterally spaced apart from the juncture by at least about 100mm in the longitudinal direction of the beam section. The second fiber anchor 98B is laterally spaced apart from the first anchor 98A by about 400mm or less. The third fiber anchor 98C is laterally spaced apart from the second fiber anchor 98B by about 400mm or less and, likewise, is laterally spaced apart from the first fiber anchor 98A by no more than about 800mm. Preferably, this fiber anchor arrangement should be applied for each of the beam sections 34A, 34B and 54A, 54B.

[0048] To install the fiber anchors 98, a hole 99 is drilled on one of vertically oriented beam faces 36. In one embodiment, the hole 99 has a depth of at least about 50mm and a diameter of about 10mm. An anchor 98 containing many small diameter fibers is then inserted into the hole 99 and into a corresponding hole through the adjacent reinforcing fibrous sheets applied to the vertically oriented beam face 36. The ends of the fibers are splayed out against the outer surface of the outermost fibrous sheet, and adhered to the outer surface of the outer sheet using a suitable resin or other adhesive compatible with the fibrous sheet. In one variation, the fibers of the anchor 98 could be splayed between adjacent fibrous sheets.

[0049] Beam-column joints may be either eccentric or concentric. Figures 1-18 depict the method of reinforcing two concentric joints 30, 50 according to the present invention. Figures 19-20 depict a second embodiment of the method of this

invention applied to an eccentric beam-column joint 130. The joint 130 includes a vertically oriented column 132 and a horizontally oriented beam 134. The beam 134 is made up of two beam sections 134A, 134B that extend in opposite horizontal directions from opposite edges of the perimeter of the column 132. The beam 134 includes a front vertically oriented beam surface 136A and a rear, column-adjacent vertically oriented beam surface 136B. The beam 134 further includes a soffit surface 138 on the underside of the beam. The column 132 includes a soffit-adjacent surface 140 that adjoins the soffit surface 138 at a horizontally extending juncture 142. In addition, vertically extending junctures 144A, 144B are disposed along the edges of the column 132 where it adjoins the column-adjacent beam surface 136B.

[0050] The steps of the method described in reference to Figs. 2-18 may also be applied to the eccentric beam-column joint 130. Figure 19 depicts the first step of the present invention applied to the beam-column joint 130. A first single continuous fibrous sheet 170 is applied to the soffit surface 138, the horizontally extending juncture 142, and the soffit adjacent surface 140. Preferably, the fibrous sheet 170 has a generally uniform width and extends from at least about 500mm from the juncture 142 along the soffit adjacent surface 140 to at least 500mm from the horizontal juncture. Depending on the width of the column, one end of the preferential first sheet 170 may extend across the width of the soffit surface 138 and along at least a portion of the front vertically oriented beam surface 136A, as shown. Steps two and three of the above described method may be adapted to be applied to the joint 130 essentially as described in reference to joints 30 and 50 above.

[0051] Figure 20 depicts a rear-side perspective of the beam-column joint 130 after step five of the present invention. To apply the fourth and fifth sheets of the present invention to the rear side of the eccentric beam-column joint 130, it is necessary to wrap three sides of the

column 132 with the continuous sheets 190, 192 that are to be applied to the column-adjacent vertically oriented beam surface 136B. As shown, the continuous fourth sheet 190 and fifth sheet 192 extend from about at least 500mm past the vertically extending juncture 144A along the surface 136B of beam section 134A to about at least 500mm past the vertically extending juncture 144B along the rear vertically oriented surface of beam section 134B. The ends of sheets 190, 192 may likewise be measured from the first and second end of the horizontal juncture 142. Because no additional beam section is disposed between the vertical beam surface 136B of the first beam section 134A and the same vertical beam surface of the second beam section 134B, the beam sections are adjacent to one another. Along the front vertical beam surface, fourth and fifth sheets 190, 192 may be applied according to the principles discussed above 136A (not shown). The continuous sheets 190, 192 may be applied to the front vertically oriented beam surface 136A along essentially the same length of the beam 134 as they are applied to the rear surface 136B. The sixth sheet of the second embodiment of the present invention (not shown) may be applied using essentially the same methodology as fourth and fifth sheets 190, 192. Steps seven and eight of the first embodiment of the method of the present invention may be applied to the joint 130 essentially as described in reference to joints 30 and 50 above.

[0052] Accordingly, it can be seen that the method of the present invention may be applied to all beam-column joints without significant alteration of existing structure. The fibrous sheets spread stresses out over the surfaces of the structural members, increasing the ductility of the structural members. The fibrous sheets also confine the structural members, which increases the shear capacity of the structural members. Thus, the structural members can withstand greater stresses and movement before fracturing and spalling than unreinforced structural members. The applied layers will not bulge when the joint is subjected to stress (e.g., as may

occur in an earthquake). Moreover, the layers are lightweight and do not add significantly to the static load already carried by the joint.

[0053] A technician engaged in reinforcing load bearing structures may be trained in a single, highly effective method of reinforcing a beam-column joint that is operable for all joint orientations. The method of the present invention guarantees improved strength and ductility of the reinforced beam-column joint, particularly along the axes of the joint most at risk of failure.

[0054] Having described the invention in detail, it will be apparent that modifications and variations are possible without departing from the scope of the invention defined in the appended claims.

[0055] When introducing elements of the present invention or the preferred embodiment(s) thereof, the articles "a", "an", "the", and "said" are intended to mean that there are one or more of the elements. The terms "comprising", "including", and "having" are intended to be inclusive and mean that there may be additional elements other than the listed elements.

[0056] As various changes could be made in the above constructions, products, and methods without departing from the scope of the invention, it is intended that all matter contained in the above description and shown in the accompanying drawings shall be interpreted as illustrative and not in a limiting sense.

WHAT IS CLAIMED IS:

1. A method of reinforcing a beam-column joint in a load bearing structure with high strength fibrous sheets carrying a curable polymer, the beam-column joint comprising a column, a beam section extending outwardly from a perimeter of the column along a longitudinal axis of the beam section, the beam section including vertically oriented beam faces on opposite sides of the beam section, and a horizontally oriented soffit surface on an underside of the beam, the column including a soffit-adjacent surface adjoining the soffit surface at a juncture, the method comprising:

applying a first fibrous sheet to one of the vertically oriented beam faces, the first fibrous sheet having a majority of fibers arranged at a first angle skew to the longitudinal axis of the beam section; and

applying a second fibrous sheet to said one vertically oriented beam face over the first fibrous sheet, the second fibrous sheet having a majority of fibers arranged at a second angle skew to the longitudinal axis of the beam section, the second angle being different from the first angle whereby the first and second fibrous sheets reinforce the beam section against shear cracks.

2. A method as set forth in claim 1 wherein the second angle is generally equal in magnitude but opposite in direction to the first angle.

3. A method as set forth in claim 2 wherein the first angle is one of 45° and -45° and the second angle is the other of 45° and -45° .

4. A method of reinforcing a beam-column joint in a load bearing structure with high strength fibrous sheets carrying a curable polymer, the beam-column joint comprising a column, a first beam section extending outwardly from a perimeter of the column along a longitudinal axis of the first beam section, the first beam section including vertically oriented beam faces on opposite sides of the first beam section, and a horizontally oriented soffit surface on an underside of the

first beam section, a second beam section extending outwardly from the perimeter of the column along a longitudinal axis of the second beam section, the column including a soffit-adjacent surface adjoining the soffit surfaces of the first beam section at a juncture, the method comprising:

(a) applying a first fibrous sheet to a length of the soffit surface, the juncture, and a length of the soffit-adjacent surface;

(b) wrapping a second fibrous sheet around a first length of the column;

(c) wrapping a third fibrous sheet around a second length of the column, the second length being different than the first length;

(d) applying a fourth fibrous sheet to a first length of the vertically oriented beam face, wherein a majority of fibers of the fourth fibrous sheet are arranged in a shear angle orientation skew to the longitudinal axis of the first beam section;

(e) applying a fifth fibrous sheet to a second length of the vertically oriented beam face, the second length of the vertically oriented beam face being at least as great as the first length of the first beam section, wherein a majority of fibers of the fifth fibrous sheet are arranged in a shear angle orientation skew to the longitudinal axis of the first beam section;

(f) applying a sixth fibrous sheet to a third length of the vertically oriented beam face, the third length of the vertically oriented beam face being at least as great as the second length of the first beam section;

(g) wrapping a seventh fibrous sheet as at least a U-wrap around a length of the first beam section; and,

(h) installing a first row of fiber anchors along the first beam section.

5. The method of claim 4 wherein said length of the soffit surface to which the first fibrous sheet is applied is at least 500 mm from the juncture and wherein said length of the soffit-adjacent surface to which the first fibrous sheet is applied is at least 500mm from the juncture.

6. The method of claim 4 wherein said first length of the column around which the second fibrous sheet is wrapped is at least 500mm from the juncture.

7. The method of claim 4 wherein said second length of the column around which the third fibrous sheet is wrapped equals the entire column.

8. The method of claim 4 wherein said first length of the vertically oriented beam face to which the fourth fibrous sheet is applied is at least 500mm.

9. The method of claim 4 wherein said second length of the vertically oriented beam face to which the fifth fibrous sheet is applied is at least 1000mm in the first beam direction.

10. The method of claim 4 wherein said third length of the vertically oriented beam face to which the sixth fibrous sheet is applied is at least 1000mm.

11. The method of claim 4 wherein the first row of fiber anchors is the only row of anchors in the first beam section.

12. The method of claim 4 wherein the first row of fiber anchors include a first, second, and third fiber anchor, the first, second, and third fiber anchors each installed about 100mm from the top edge of the first beam section, the first fiber anchor being laterally spaced apart from the juncture by at least about 100mm, the second fiber anchor being laterally spaced apart from the first fiber anchor by at least about 400mm, and the third fiber anchor being laterally spaced apart from the second fiber anchor by at least about 400mm and laterally spaced apart from the first fiber anchor by at least about 800mm.

13. The method of claim 4 wherein the first, second, third, sixth and seventh fibrous sheets include glass fibers, and the fourth and fifth fibrous sheets include carbon fibers.

14. The method of claim 4 wherein each of the fibrous sheets is impregnated with a curable polymer.
15. The method of claim 4 further comprising filling the juncture with an epoxy filler.
16. The method of claim 15 wherein filling the juncture includes applying the epoxy filler to form a radius of curvature of the epoxy filler of at least 25mm.
17. The method of claim 4 wherein the second and third sheets each comprise overlapping ends, the overlapping ends comprising overlap sections having a generally uniform widths.
18. The method of claim 17 wherein the widths of the overlap sections comprise lengths of at least 150mm.
19. The method of claim 4 wherein the beam-column joint comprises a concentric beam-column joint.
20. The method of claim 4 wherein the beam-column joint comprises an eccentric beam-column joint.
21. The method of claim 4 wherein the second beam section includes vertically oriented beam faces on opposite sides of the second beam section, and a horizontally oriented soffit surface on an underside of the second beam section, and wherein the method further comprises performing steps (a) and (d)-(g) for the second beam section and column.