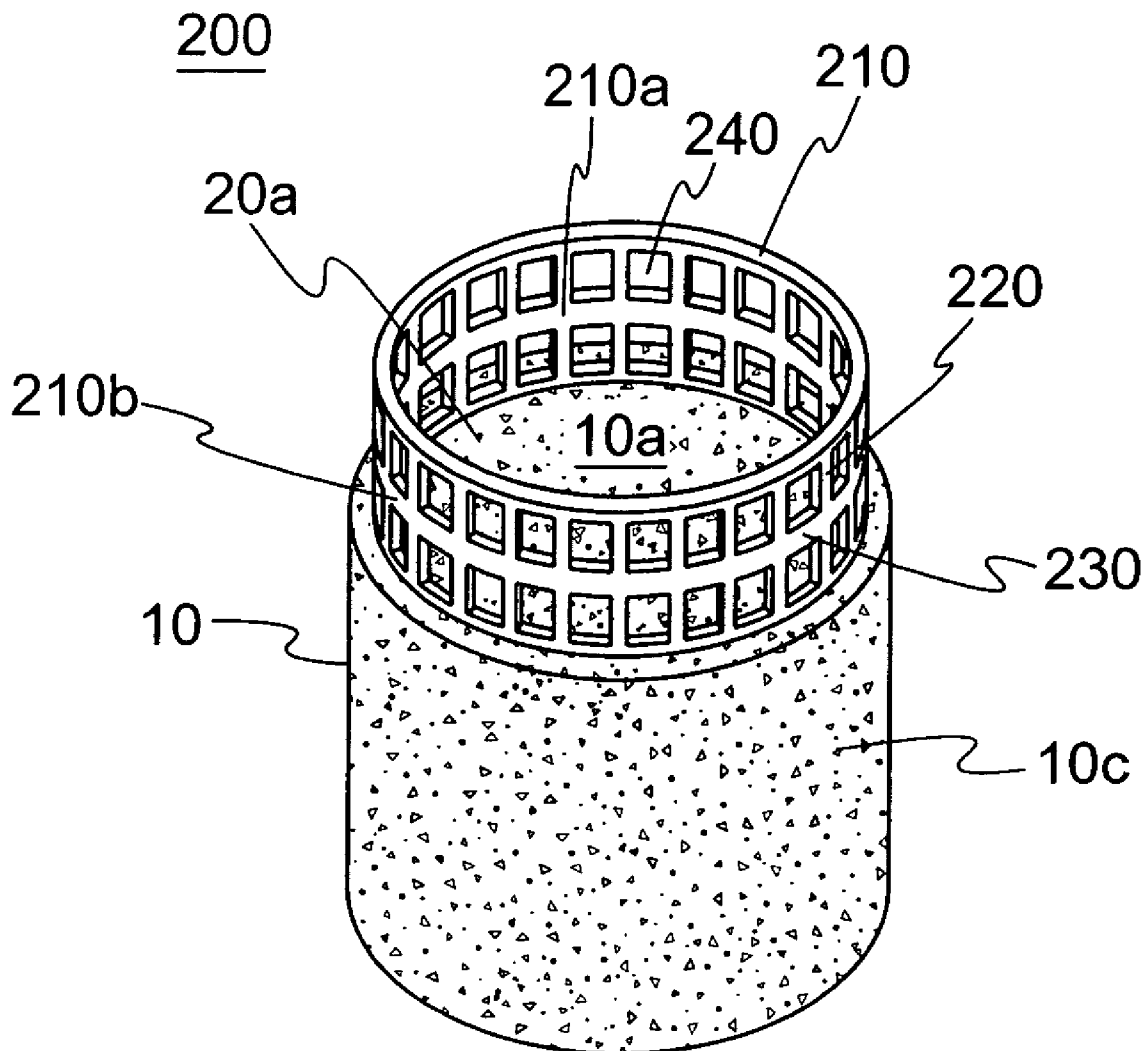




US 20090120025A1

(19) **United States**(12) **Patent Application Publication**
Sezen et al.(10) **Pub. No.: US 2009/0120025 A1**(43) **Pub. Date: May 14, 2009**(54) **PREFABRICATED CONCRETE
REINFORCEMENT SYSTEM****Publication Classification**(76) Inventors: **Halil Sezen**, Columbus, OH (US);
Mohammad Shamsai, Westerville,
OH (US)(51) **Int. Cl.**
E04B 1/30 (2006.01)
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E04B 1/19 (2006.01)(52) **U.S. Cl.** **52/340; 52/649.2; 52/745.19**Correspondence Address:
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One Dayton Centre, Suite 1300, One South Main
Street
Dayton, OH 45402-2023 (US)(57) **ABSTRACT**

A device for reinforcing concrete. The device is of one-piece construction and includes a perforate load-bearing member with first and second surfaces around which concrete can be placed. Apertures in the perforate load-bearing member form connectivity points between concrete disposed on the first and second surfaces to promote bonding of the concrete such that a contiguous mass of concrete forms upon curing. In various embodiments, the device can be configured as a joint, beam, shear wall, retaining wall or footer. In addition, the device can be prefabricated, thereby reducing the time and cost of formation of a reinforced concrete structural member.

(21) Appl. No.: **11/244,310**(22) Filed: **Oct. 5, 2005****Related U.S. Application Data**(60) Provisional application No. 60/616,174, filed on Oct.
5, 2004.

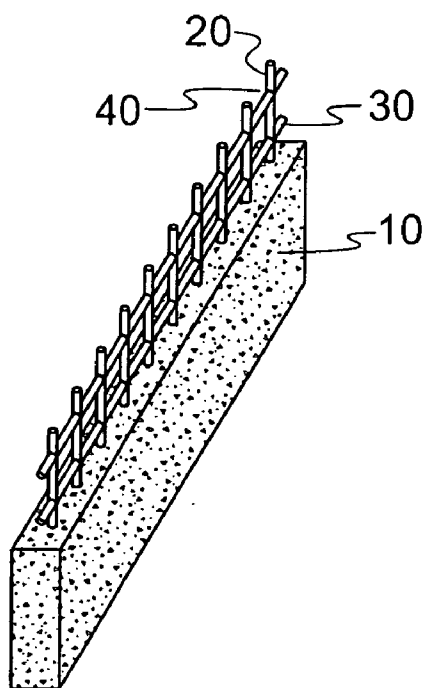


FIG. 1A
(PRIOR ART)

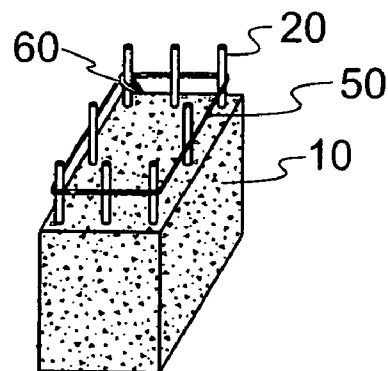


FIG. 1B
(PRIOR ART)

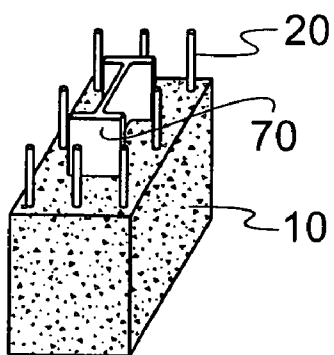


FIG. 1C
(PRIOR ART)

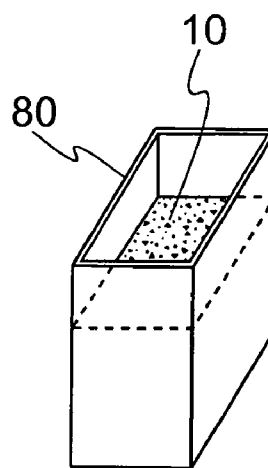


FIG. 1D
(PRIOR ART)

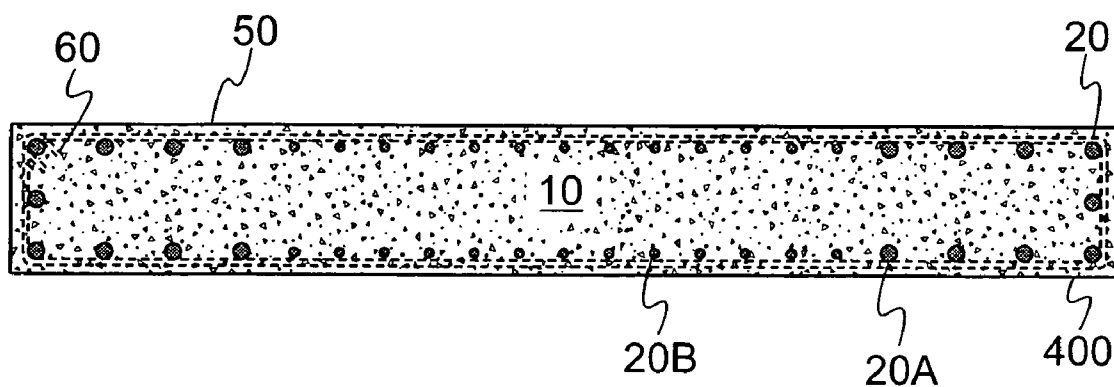


FIG. 1E
(PRIOR ART)

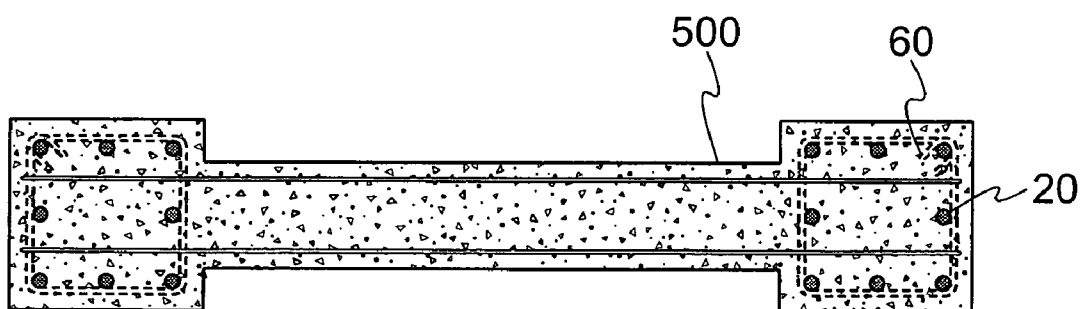


FIG. 1F
(PRIOR ART)

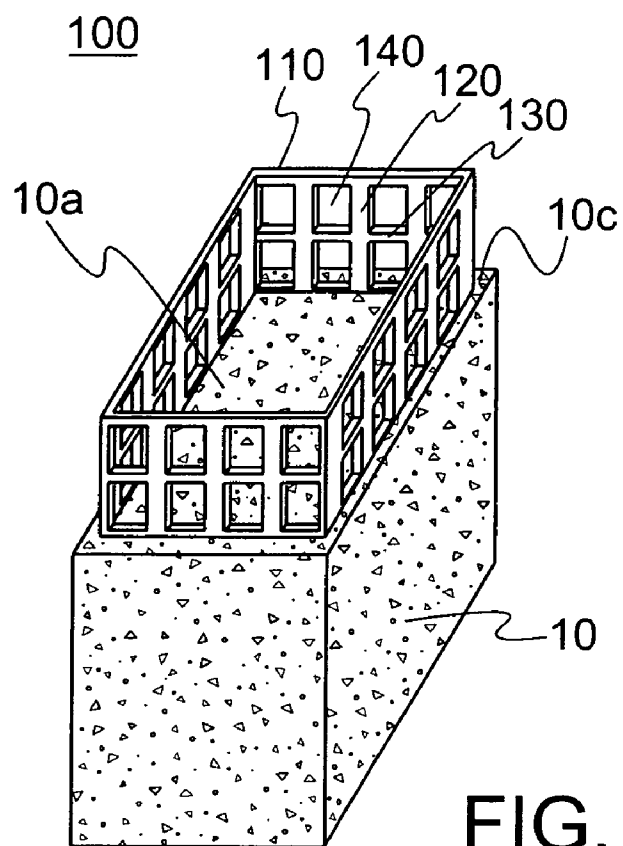


FIG. 2

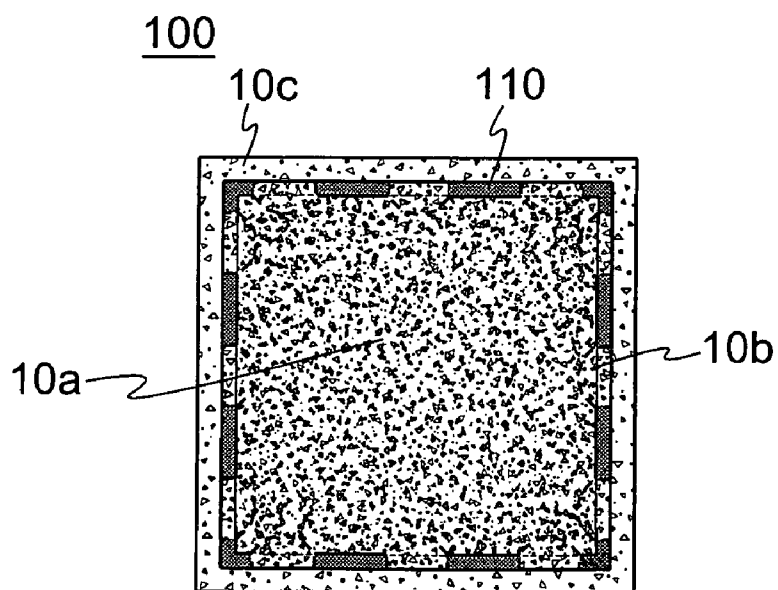


FIG. 3

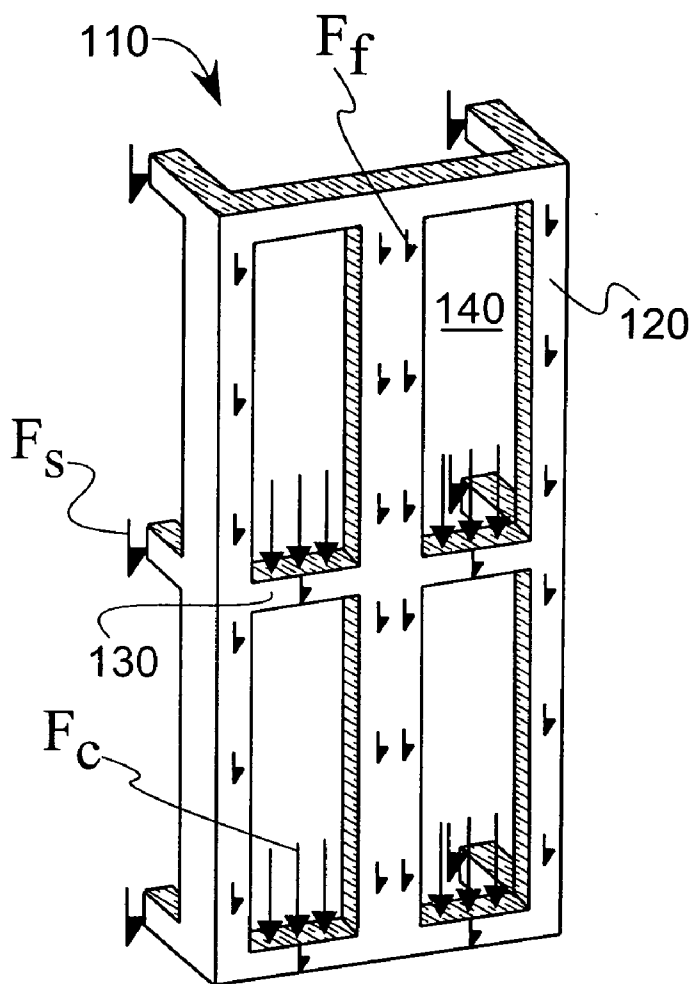


FIG. 4A

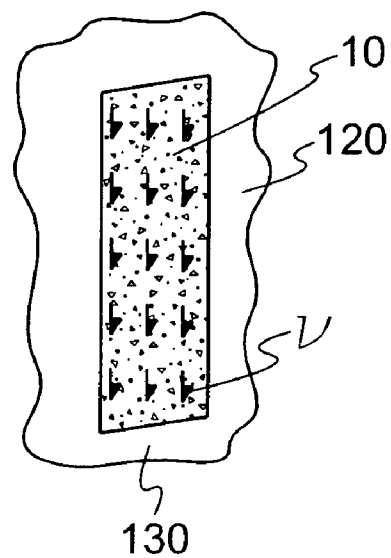


FIG. 4B

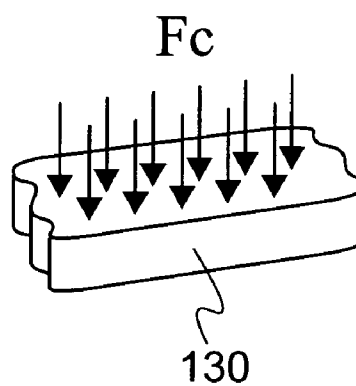


FIG. 4C

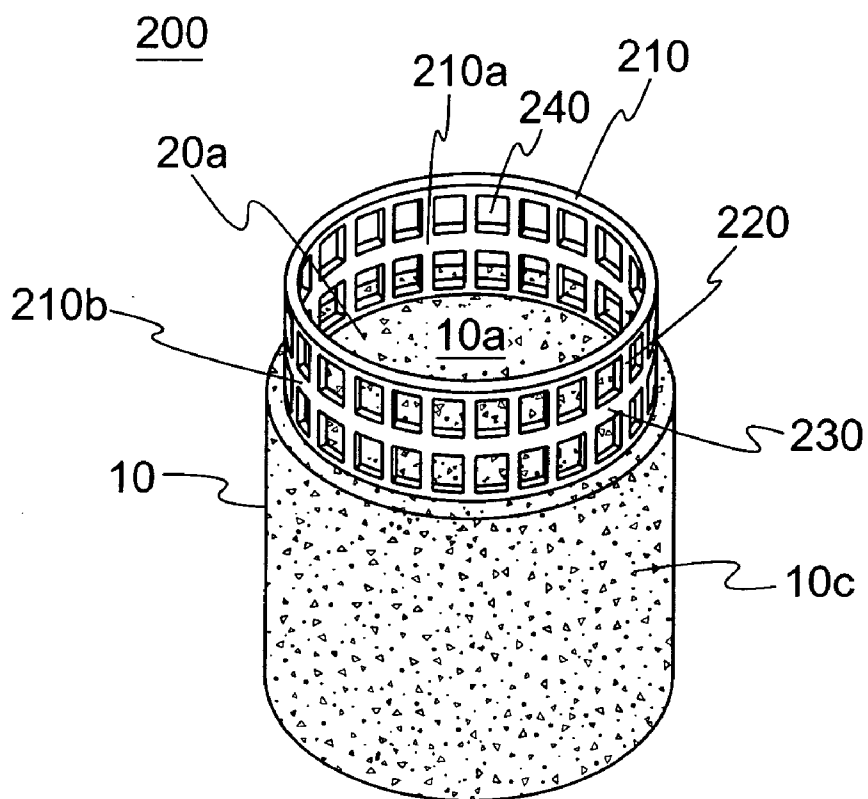


FIG. 5

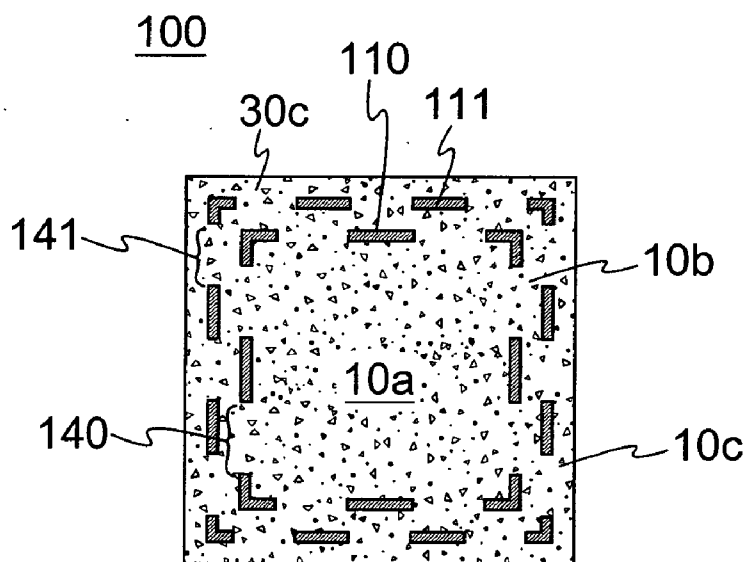


FIG. 6

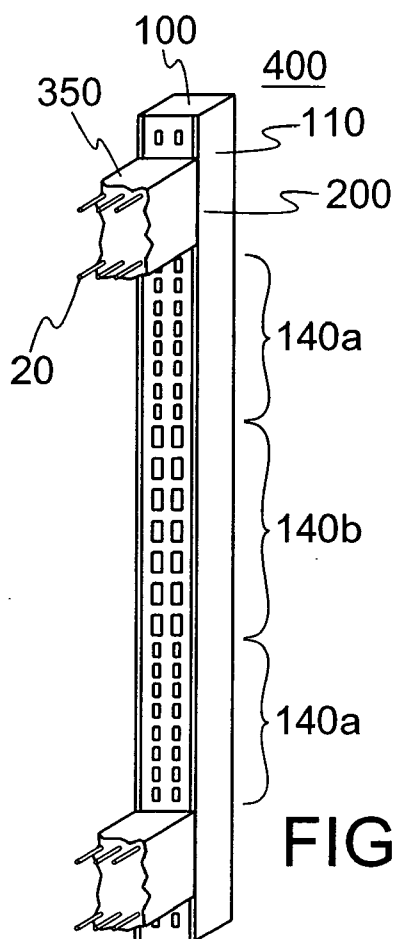


FIG. 7

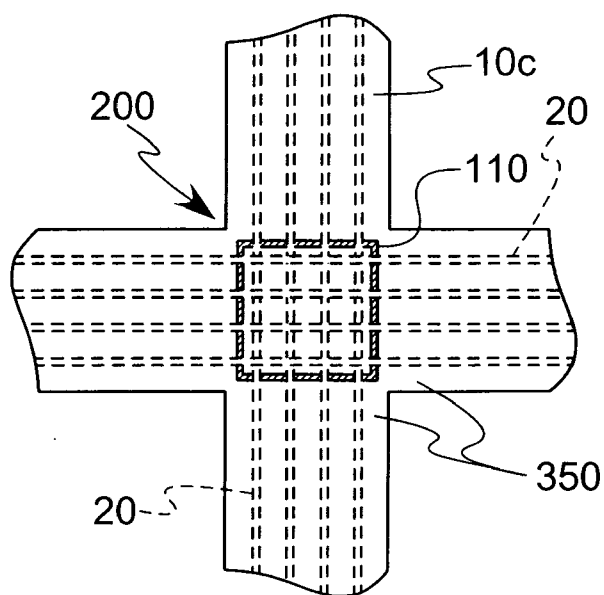


FIG. 8

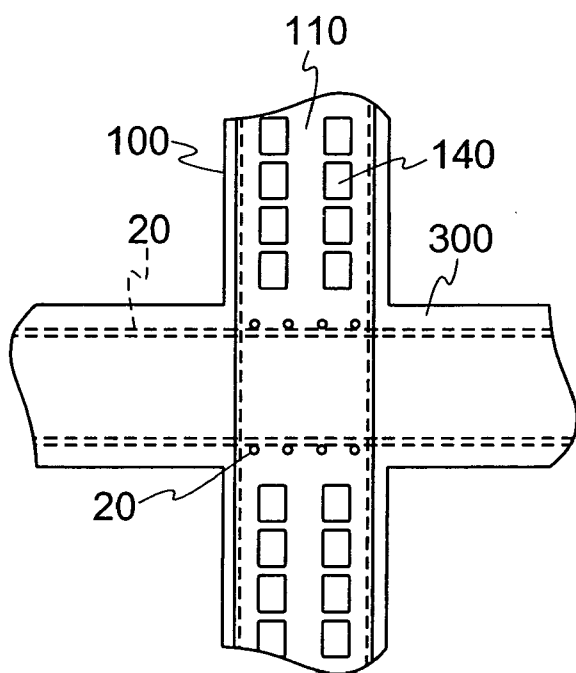


FIG. 9

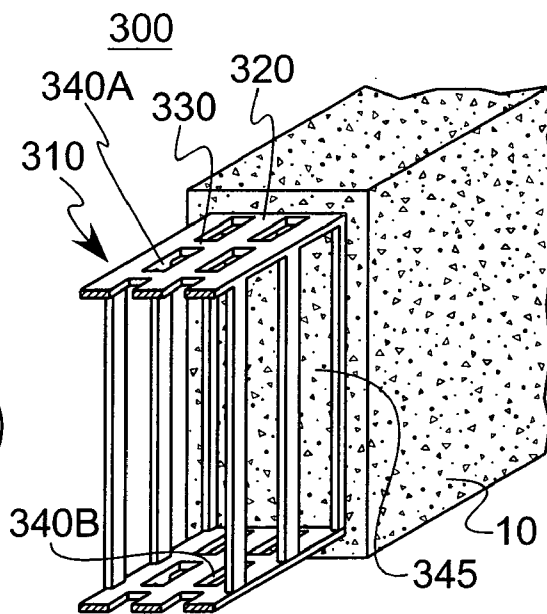
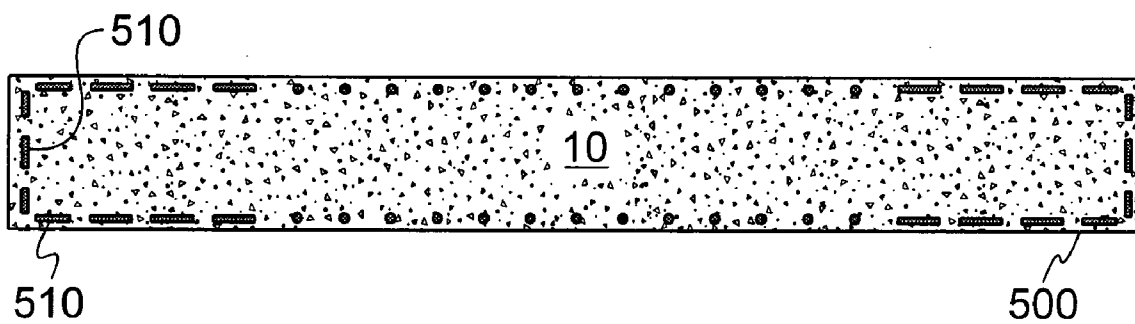
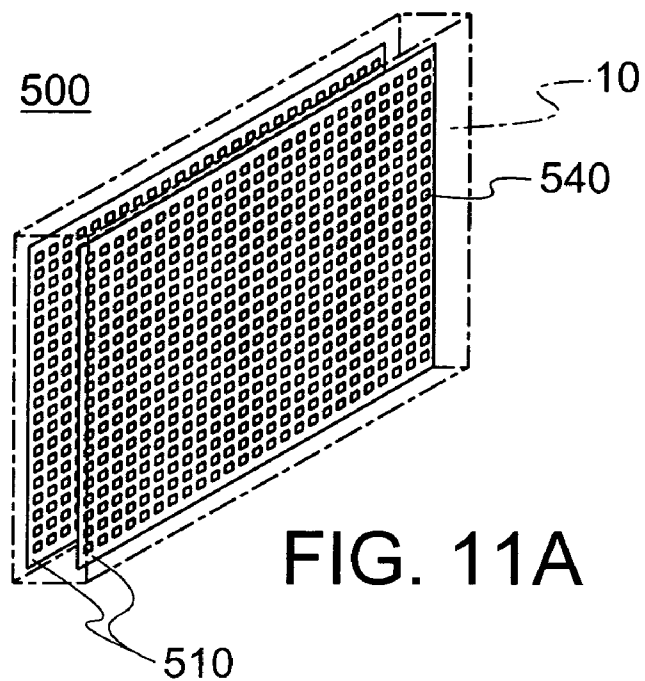


FIG. 10



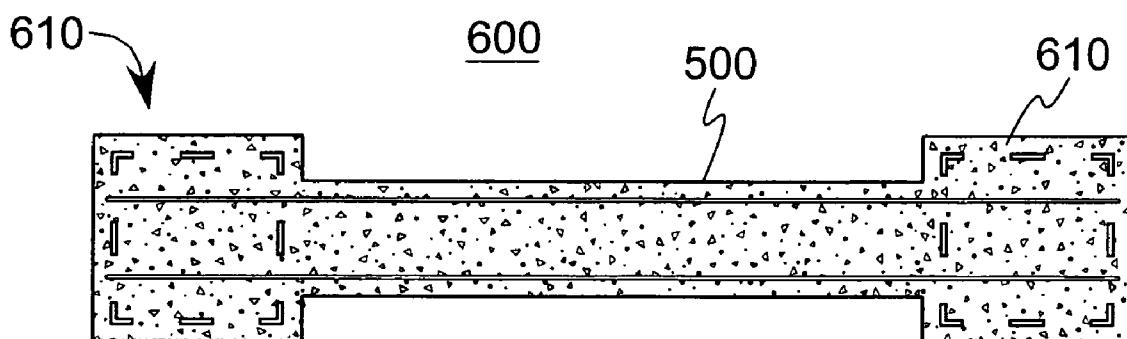


FIG. 12

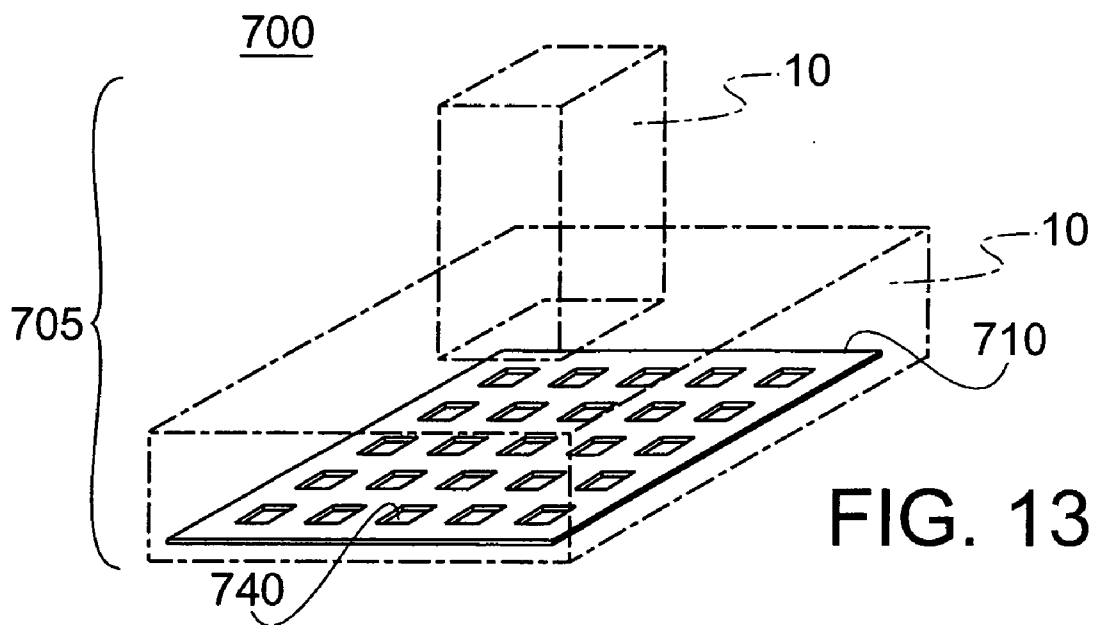


FIG. 13

PREFABRICATED CONCRETE REINFORCEMENT SYSTEM

[0001] This application claims the benefit of the filing date of U.S. Provisional Application No. 60/616,174, filed Oct. 5, 2004.

STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH OR DEVELOPMENT

[0002] This invention was supported by the government under Contract No. CMS-0355321 awarded by the National Science Foundation (NSF). The government has certain rights in the invention.

BACKGROUND OF THE INVENTION

[0003] The present invention generally relates to a reinforcement system for use in building structures, and more particularly to a concrete reinforcement system of unitary construction that acts as both longitudinal and lateral reinforcement.

[0004] The use of reinforced concrete members is well-known in the building art. Some of steel's outstanding properties, such as high tensile strength, high ductility and availability are combined with concrete's beneficial properties, including high compressive strength, good formability, low cost and high temperature and fire resistance. Combinations employing these two materials are a good choice for designing members used in bridges, tunnels, stadiums, multistory commercial and residential dwellings and related structures, hereinafter collectively referred to as buildings or building structures. Examples of steel/concrete combinations used in building structures include conventional reinforcing bar (rebar) reinforced concrete systems, concrete-filled tubular systems, steel-concrete composite systems, and welded wire fabric systems.

[0005] Typical rebar-based systems employ cylindrical steel rebar interlocked into a skeletal frame inside a concrete matrix. In such systems, steel rebar is used for carrying the tensile stresses and improving member ductility. The rebar is usually used as longitudinal and lateral (transverse) reinforcements in such systems for columns, beams and other related reinforced concrete structures. The process of arranging numerous longitudinal and transverse reinforcement with tie wires into a skeletal frame, then placing forms around the frame pouring concrete into the interstices is labor intensive, and hence expensive. Moreover, the complexity of such systems increases the likelihood of loose tolerances and related lowering of load-carrying capacity.

[0006] In steel-concrete composite systems, steel profiles (for example, I-beams) are placed inside the member to provide higher axial strength. This system helps provide a high strength in a relatively small cross-sectional area to avoid the limitations of traditional rebar-based systems, where the spacing of the bars in a relatively small section may be less than the allowable amount. Composite sections are usually used in high rise buildings, where a high axial strength with the minimum area provided for columns are desirable. The concrete cover protects the steel against fire, moisture and other environmental elements. The high metal reinforcement ratio, as well as its placement near the center of the reinforced concrete member, may result in a relatively inefficient system with limited ductility, flexural and torsional resistance.

[0007] In the concrete-filled tubular system, a hollow steel section like a pipe or a rectangular box is filled with concrete. This system is useful especially when very high axial strength and concrete confinement with the least cross-sectional area is desirable. One of the chief attributes of the tubular system is its efficiency of structure, where the tensile strength is mainly provided by the steel, which is at the outer most level from the center. Nevertheless, because the steel is situated at the outermost portion of the system, it is exposed and therefore subject to fire and corrosion damage.

[0008] In the welded wire fabric system, a prefabricated wire steel system is used for carrying the tensile stresses. In the welded wire system, steel wires/bars are laid in two perpendicular directions and are welded at intersections using rollers and roll welding process. This system is usually used for providing reinforcements in planar sections such as tunnels and shear walls. The steel wires are usually the same in diameter and spacing in both directions, but they can be produced to be different in the two directions.

[0009] What is needed is reinforcement for concrete structures that can satisfy the stringent load-carrying and environmental requirements of building components. What is additionally needed is such reinforcement that is easy and inexpensive to fabricate and allows for fast construction.

SUMMARY OF THE INVENTION

[0010] These needs are met by the present invention, where a reinforcement for reinforced concrete members is disclosed. In a first aspect of the invention, a building structure made up of a first load-bearing member (also referred to as reinforcement or reinforcing member) and a mass (or quantity) of concrete is disclosed. The load-bearing member defines a unitary (one-piece) construction and having a first and second surfaces. Apertures formed in the member extend from the first surface to the second surfaces. The portion of the surfaces that remain surrounds each of the apertures. In a preferred (but not necessary) configuration, the remaining surface portions form repeating grids or arrays. In any event, the remaining surface portions define transverse and longitudinal reinforcements (also referred to as longitudinal and lateral reinforcement stripes). Inherent in the unitary construction of the structure is that the intersections of longitudinal and lateral reinforcement stripes define a continuous and uninterrupted structure. Within either of the surfaces, the transverse and longitudinal reinforcements are substantially coplanar with one another. The structure is configured such that upon placement of concrete into cooperative arrangement with the surfaces, at least a portion of the concrete occupies the apertures. Thus, when the concrete cures, it forms a contiguous mass on both surfaces, tied together by the concrete in the apertures. By curing the concrete around the member, the two form into an integral structure.

[0011] Optionally, the material making up said first member is metal. The structure may be formed in either a substantially two-dimensional (i.e., planar) or three-dimensional shape. In one particular three-dimensional embodiment, the first member is configured as a cage such that the first surface is substantially inward facing and the second surface is substantially outward facing. Regardless of whether the reinforcing member is configured to be planar, cage-shaped or some shape in-between, the apertures can be arranged in a substantially repeating pattern (such as along rows and columns), and may be formed in numerous preferred shapes, such as rectangles (with or without rounded corners), circles or the like.

It will be appreciated by those skilled in the art that apertures formed from rectangular or related sharp-cornered shapes can be rounded to reduce stress concentration in corners. In one embodiment, all of the apertures are substantially similar in size, while in another, they can be of various sizes. In this latter configuration, larger apertures can be used near the middle portion of the reinforcing device used as column reinforcement, where less transverse reinforcement is required, while the dimensions of the apertures can be reduced with less spacing near the top and bottom of the device to promote enhanced shear strength under high lateral load conditions. In situations where the structure is made of joined components, such as with a joint, the smaller apertures may align with reinforcements from the connecting component. As the amount of transverse reinforcement is increased by using smaller spacing, the shear resistance of that part of the column also increases.

[0012] The structure may be configured as (among other things) a beam, pile, shear wall, retaining wall, foundation, slab (for example, for a footer) or joint between a column and beam. In addition, the structure can be coupled with other reinforcement schemes (such as the aforementioned rebar reinforcement). It will be appreciated by those skilled in the art that other applications involving the use of reinforced concrete members are possible. For example, any beam or column-like member such as a tapered bridge pier, pier with interlocked reinforcement, and coupling beams can be reinforced with the system of the present invention. Furthermore, the system of the present invention can also be used in uncommon structural components, such as precast folded plates and reinforced concrete shell structures.

[0013] In cases where the structure forms a joint, a second load-bearing member is angularly connected to the first member. Reinforcements projecting from the second member can extend through at least a portion of the apertures to couple to the first member. Upon proper securing of the projections to the first member (such as through detailing), a first joint is created. The reinforcements projecting from the beam may be made from rebar or other load-bearing devices. A third load-bearing member may be angularly connected in a manner similar to that of the second load-bearing member. Where a joint is being created by the connection of the three members, the second and third may form beams. In one form, angles formed by the connection of the second and third members are substantially ninety degrees to both each other and the surface of the column to which they are connected, thereby defining an orthogonal structure.

[0014] The structure may take on other configurations. For example, another load-bearing member (which may be substantially identical to the first member) may be spaced substantially parallel to the first member such that each of the first and second members substantially face one another. Such a configuration can improve the shear resistance of a wall, where a thickness dimension is less than a width or height dimension and where the spacing between the first and second members is along the thickness dimension. Third load-bearing members that extend along the thickness dimension between the spaced first and second members can also be used. It will be appreciated by those skilled in the art that references to dimensions are purely contextual. For example, a thickness (front-to-back) dimension of a structure configured as a vertically-oriented wall may be construed as a depth (top-to-bottom) dimension if such wall were a horizontally-oriented slab. Likewise, length and width terms can be used

interchangeably with height, depending on the structure's orientation. Accordingly, conventions associated with viewing perspective will dictate dimension nomenclature.

[0015] The structure may also define a retaining wall, where a pair of columns are spaced apart from one another. A wall extends between the columns and connects to them such that a rigid assembly is defined. The thickness dimension of the wall is less than a width dimension or a height dimension, and is also less than a thickness dimension of the columns. As with the joint, the projections (which may be rebar, for example) in the wall extend through at least a portion of the apertures to effect a reinforced connection between the wall and the columns.

[0016] In another form, the structure defines a footer and includes a slab that has the first member and the quantity of concrete. The slab includes a depth dimension that is less than a width dimension or a length dimension. The column is connected to and extends from the slab, where such extension is typically in a substantially normal direction from the face of the slab. The column may include reinforcements that extend through at least a portion of the apertures of the first member disposed in the slab. This promotes (in a manner similar to that of the aforementioned joint) a reinforced connection between the slab and the column.

[0017] In still another form, the structure defines a column with concentric cage reinforcement. In such configuration, the first load-bearing member is shaped as a cage defining a first exterior dimension. The column further includes a second load-bearing member shaped as a cage with a second exterior dimension that is less than the exterior dimension of one of the members is disposed concentrically around the other within the column.

[0018] In yet another form, the structure defines a pile. The pile may be made from a substantially cylindrical shape along its longitudinal axis. The structure of the pile may generally resemble a column, but is typically fabricated in-place. In this way, the perforate load-bearing member is first arranged in the desired shape, after which concrete is poured around it to form the completed whole.

[0019] According to another aspect of the invention, a reinforced concrete joint is disclosed. The joint includes a quantity of concrete and a first load-bearing member defining a unitary construction and having a first surface and a second surface. The first member further defines numerous apertures extending between the first and second surfaces such that the surfaces surrounding the apertures define transverse reinforcements and longitudinal reinforcements that are substantially coplanar with one another within each of the surfaces. In this way, the transverse and longitudinal reinforcements can define a grid-like latticework around the apertures. The structure is configured such that upon placement of the quantity of concrete in cooperative arrangement with the surfaces, at least a portion of the quantity of concrete flows into and sets within the apertures to effect a contiguous mass that forms the first structure. A second structure extends through at least a portion of the apertures and is coupled to the first member to effect connection between the first and second structures. In a specific embodiment, the first structure is a column and the second structure is a beam. In a more particular embodiment, the column is substantially rectangular in shape along its longitudinal axis. In a particular form, the second member extending from the beam comprises rebar.

According to yet another aspect of the invention, a method of reinforcing a building is disclosed. The method includes con-

figuring a first load-bearing structure to resemble one or more of the previously-disclosed structures, and placing the structure in a position in the building such that it carries at least a portion of a structural load of the building. As before, the structure includes a first load-bearing member defining a unitary construction and including a numerous apertures that are surrounded by surface that define transverse and longitudinal reinforcements. The shape of the surface is such that the transverse and longitudinal reinforcements are substantially coplanar with one another. As with the previous aspects, the structure could be a beam, a wall (including a retaining wall or shear wall), a joint, a column (including a concentric cage-reinforced column) or pile.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWINGS

[0020] The following detailed description of the preferred embodiments of the present invention can be best understood when read in conjunction with the following drawings, where like structure is indicated with like reference numerals and in which:

[0021] FIG. 1A illustrates a welded wire fabric system of a reinforced concrete column according to the prior art;

[0022] FIG. 1B illustrates a rebar reinforced concrete column according to the prior art;

[0023] FIG. 1C illustrates a steel-concrete composite reinforced concrete column according to the prior art;

[0024] FIG. 1D illustrates a concrete-filled tubular column according to the prior art;

[0025] FIG. 1E illustrates a rebar reinforced shear wall according to the prior art;

[0026] FIG. 1F illustrates a rebar reinforced shear wall with boundary elements according to the prior art;

[0027] FIG. 2 illustrates a prefabricated load-bearing member configured as a cage according to an embodiment of the present invention being used to reinforce a rectangular concrete column;

[0028] FIG. 3 illustrates a plan view of a square variation of the rectangular reinforced concrete column of FIG. 2;

[0029] FIG. 4A illustrates three bonding mechanisms for the prefabricated load-bearing member of FIG. 2;

[0030] FIG. 4B illustrates the resisting mechanism between adjacent concrete surfaces at apertures formed in the cage of FIG. 2;

[0031] FIG. 4C illustrates the resisting mechanism due to concrete bearing on the lateral reinforcing strip of the prefabricated cage of the system of FIG. 2;

[0032] FIG. 5 illustrates an alternate embodiment of a reinforced concrete column; and

[0033] FIG. 6 illustrates an alternate embodiment of the rectangular reinforced concrete column of FIG. 3, this time with concentrically-placed cages.

[0034] FIG. 7 illustrates a joint between a column according to the present invention and a conventional beam and is used, where the prefabricated cage is formed from varying aperture sizes;

[0035] FIG. 8 illustrates a plan view of another embodiment of a joint between a column and a pair of rebar-reinforced beams;

[0036] FIG. 9 illustrates an elevation view of the joint of FIG. 8;

[0037] FIG. 10 illustrates a prefabricated cage according to another embodiment of the present invention being used to reinforce a concrete beam;

[0038] FIG. 11A illustrates a perspective view of a pair of planar prefabricated load-bearing members according to another embodiment of the present invention being used to reinforce a shear wall;

[0039] FIG. 11B illustrates a plan view of the shear wall of FIG. 11A with additional planar load-bearing members at the ends of the wall;

[0040] FIG. 12 illustrates a pair of planar prefabricated load-bearing members and a pair of prefabricated cage elements being used to reinforce a shear wall according to another embodiment of the present invention; and

[0041] FIG. 13 illustrates a planar prefabricated load-bearing member used as a foundation.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0042] Referring first to FIGS. 1A through 1F, various forms of concrete reinforcement by the prior art are shown, where the load-bearing abilities of a concrete mass 10 are augmented by various longitudinal and lateral reinforcements.

[0043] Referring with particularity to FIG. 1A, a welded wire fabric system is shown. In the system, rebar 20 is laterally spaced and connected by wire or other rebar 30 with welds 40 at contact points. Although reasonably capable of carrying large shear forces, the welded wire fabric system is not well-suited to supporting axial loads, including having a rather high susceptibility to buckling. While able to carry some flexural loads, its torsion resistance is limited when used as a planar member such as a shear wall.

[0044] Referring with particularity to FIG. 1B, a conventional rebar system to form a column is shown. In it, rebar 20 is given supplemental hoopwise assistance by column ties 50 (which could in the alternate be transverse rebar) looped around the periphery of and secured to the rebar 20 with ties and end-hooks 60. Together, rebar 20, column ties 50, and hooks 60 define a skeletal frame that is impregnated with concrete to form the reinforced concrete column. This system is extremely sensitive to how well the hooks 60 are detailed, such that torsional resistance can be easily compromised. In addition, the longitudinal rebar 20 can buckle under high axial loads. Furthermore, fabrication efforts are difficult, as detailing (the process of securing column ties 50 and end-hooks 60 to longitudinal rebar 20, and the calculation of rebar spacing) takes a significant investment in time. This detailing can cause reinforcement congestion and can especially be hard to construct in heavily reinforced columns and joints in structures with special or intermediate moment-resisting frames. This fabrication process, by virtue of being individually performed on the job site for a particular structural member, is not considered to qualify as "prefabricated".

[0045] Referring with particularity to FIG. 1C, the composite system, while capable of carrying high shear and axial forces, and less prone to fabrication mistakes than rebar system of FIG. 1B, doesn't provide good bonding unless some shear studs (or related protrusion) are attached to the steel profiles located near the column center. The shear studs increase the bonding through concrete bearing on them and through the friction between steel and concrete. The stronger the bonding between concrete and steel, the stronger the member as the tensile or compressive stresses in the member can be resisted by both materials without separation or splitting failure. The flexural capacity and efficiency of the composite system is reduced if the standard steel profile 70

(shown as an I-beam in FIG. 1C) is placed close to the center relative to the rebar 20, which is typically the case.

[0046] Referring with particularity to FIG. 1D, the presence of the encapsulating tubular wall 80 in the system gives it high axial, torsional and shear strength. Because the steel of tubular wall 80 is disposed on the outer portion of the system, it is susceptible to fire and corrosion.

[0047] Referring with particularity to FIGS. 1E and 1F, variations on prior art shear walls are shown. Similar to the rebar-based system of FIG. 1B, the shear walls include ties 50 looped around the periphery of and secured to the rebar 20 with ties and end-hooks 60. Rebar 20 may be of single size, or may be made up of larger 20A and smaller 20B elements. The shear walls may be further built up by including column-like boundary elements disposed at the ends of the shear wall, as shown with particularity in FIG. 1F.

[0048] Referring next to FIGS. 2 and 3, a reinforced concrete structure, in the form of a generally rectangular column 100, is shown. Column 100 includes concrete mass 10 and a reinforcing device, presently shown in the form of a cage 110. In applications such as column 100, which requires three-dimensional attributes, the reinforcing device, which is generally fabricated from a plate, can be rolled or bent to a desired cylindrical or box shape to produce cage 110. In this latter form, opposing edges of the plate are brought together and welded or otherwise joined. In an alternative form, the cage 110 can be made from a tube-shaped member; this form eliminates the need to bend and join the plate. Another alternative may be to manufacture the whole system as a cage by known casting methods. The cage 110 can be prefabricated and brought to the construction site before casting concrete. In the present context, components such as the cage that make up a concrete reinforcing system are considered "prefabricated" when they are put together, typically (although not necessarily) in a factory or related off-site facility, prior to their use within a particular concrete member, thereby removing the need for individually manufacturing the components at the job site. Cage 110 includes numerous longitudinal reinforcements 120 and transverse reinforcements 130 that together make up a lattice-like structure that defines apertures 140 between the reinforcements 120 and 130. Each aperture 140 defines a channel that extends from one (inward-facing) surface 110a of the cage 110 to the opposing (outward-facing) surface 110b. Concrete 10 can flow into the channels defined by the apertures 140, and once cured, forms a bond between concrete formed against inner and outer surfaces 110a, 110b of cage 110. The longitudinal reinforcements 120 function similar to the longitudinal rebar 20 of the rebar system of FIG. 1B, while the lateral reinforcements 130 provide enhanced load-carrying capacity relative to the transverse reinforcement 50 of FIG. 1B or the wires 30 of the welded wire fabric system of FIG. 1A. Concrete mass 10 includes well-confined (i.e., core) concrete 10a disposed inside cage 110 such that it cooperates with inward-facing surface 110a, unconfined (i.e., external) concrete 10c formed outside cage 110 such that it cooperates with outward-facing surface 110b, and partially-confined (i.e., transitional) concrete 10b that forms in apertures 140 and is used to bond or link well-confined concrete 10a to unconfined concrete 10c so that the entire concrete mass 10 is contiguous, thereby forming an integral column 100 reinforced with cage 110 to give the column 100 a composite-like structure. The unconfined concrete 10c protects the cage 110 from environmental and thermal effects. Moreover, the presence of apertures 140

in cage 110 is beneficial for other reasons as well; when used in locations where seismic activity is of particular concern, where after significant seismic events (such as a big earthquake), even if the unconfined concrete 10c spalls off, the well-confined concrete 10a performs better as it is confined by the cage 110. Also, the confined concrete can be observed through the apertures 140, thereby facilitating post-event inspection.

[0049] Referring with particularity to FIG. 3, the nature of the interconnection of concrete 10 throughout the column 100 is exemplified by the well-confined concrete 10a, partially-confined concrete 10b and unconfined concrete 10c forming a single, contiguous structure. As in the rebar system of FIG. 1B, the concrete mass 10 can envelop the reinforcement, providing a solid combination of concrete and steel. This promotes a stronger bond with an additional resisting force due to the partially-confined concrete 10b passing through the apertures 140. In contrast to the rebar system of FIG. 1B and the composite system of FIG. 1C, the closed nature of the reinforcement provides a considerable amount of confinement for the concrete mass 10 inside the cage 110. In fact, it provides levels of confinement approaching that of the tubular system of FIG. 1D, while possessive of higher structural efficiency, metal protection and ductility. In addition, the bonding and the interaction forces acting between cage 110 and concrete mass 10 will be much higher (for reasons mentioned above) compared to the composite system.

[0050] Column 100 of FIGS. 2 and 3 has additional advantages over the traditional rebar system of FIG. 1B. For example, the cage 110 can be built ahead of time (i.e., prefabricated) and be transferred to the construction site, reducing the construction time considerably. If the transverse reinforcement 50 of the rebar system is not precisely placed relative to the longitudinal rebar 20, the system won't work properly. In addition, if transverse rebar 50 fractures, or if end-hook 60 is opened, the whole connection between them may become compromised. In contrast, the integral formation between the lateral reinforcements 130 and longitudinal reinforcements 120 of the present system 100 ensures structural integrity even if the lateral reinforcement 130 is damaged locally. As previously mentioned, a cage 110 of the prefabricated cage system 100 can be formed in numerous geometric shapes, where circular and rectangular cross-sections are the most common. The reinforcement system of the present invention is expected to perform well in torsion due to its inherent rigidity and structural continuity.

[0051] The inherent rigidity and structural continuity enabled by the unitary construction of cage 110 results in very efficient transfer of loads between the longitudinal and transverse reinforcements 120, 130. This helps provide a higher load-carrying capacity with the same amount of steel, resulting in a more efficient use of the longitudinal reinforcement 120. As previously mentioned, such a configuration also eliminates weak points in the cage 110 due to the mistakes in construction as well as decreasing the time spent assembling it. In addition, tailored structural properties are easily integrated into the device (whether in plate or cage form), as the dimensions and spacing of the apertures 140 need not be the same over the height of the column 100.

[0052] Referring next to FIGS. 4A through 4C, there are three bond resisting mechanisms acting on the cage 110 and concrete 10, including the friction bonding forces F_f acting at the surface of the lateral and transverse reinforcements 120, 130, the shear resistance F_s of the transverse reinforcement

130, and the compressive concrete reaction forces F_c bearing on the transverse reinforcement **130** at the bottom of the apertures **140**. The shear forces v depicted in FIG. 4B are those that exist between adjacent layers of concrete **10**, for example, between partially-confined concrete **10b** passing through the apertures **140** and unconfined concrete **10c** that forms a protective cover over cage **110**. In operation, the adjacent concrete surfaces produce some friction and resistance between them before the unconfined concrete **10c** spalls off. The total bonding will be the summation of these three forces. $F_b = F_f + F_c + F_s$. These mechanisms are either nonexistent or work differently in the structural members illustrated in FIG. 1A through 1D. For example, the bonding mechanism in the reinforced concrete column shown in FIG. 1B is basically through the friction resistance F_f alone.

[0053] There are at least three possible methods for fabricating the apertures **140** into cage **110**. In one method, a punching system can be used to punch the apertures **140** into the plate. The thickness of the plate, size of the apertures **140**, and the distance between adjacent horizontal and vertical apertures **140** can be made to vary depending on the longitudinal and transverse strength needs. In a second method, the apertures **140** can be cast directly into the plate, where melted steel is cast through a framework in the shape of the cage **110**. This approach has the advantage of allowing the cage **110**, including the apertures **140** to be cast in multiple shapes, including cylinder or box shapes, avoiding the necessity of performing additional steps such as shaping, forming, cutting or welding. In yet another method, various cutting approaches, such as laser, flame, plasma, abrasive jet, electrochemical machining, electrical discharge machining, milling or related automated or semi-automated schemes, can be used to form apertures **140**. The choice of which of the different methods to use is driven by various factors, including cost, quantity, need for precision, finished product or the like. Producing various cages **110** with different thicknesses and different aperture **140** sizes is possible and easy with these methods.

[0054] In FIG. 6, a variation on the reinforced rectangular column of FIGS. 2 and 3 is shown. Here, two cages (shown as inner cage **110** and outer cage **111**) are placed in concentric arrangement relative to each other, while both are embedded within concrete **10**. While the cages **110**, **111** are presently shown with substantially overlapping arrangement such that apertures **140**, **141** do not align, it will be appreciated that they can be arranged such that the apertures **140**, **141** do substantially align. As with the column of FIG. 3, the concrete regions include well-confined concrete **10a**, partially-confined concrete **10b** and unconfined concrete **10c**, all forming a single, contiguous structure with the cages **110** and **111**.

[0055] It will be appreciated by those skilled in the art that the cage **110** of FIGS. 2, 3 and 6 need not be rectangular, and that other cage reinforcement shapes are possible. Referring next to FIG. 5, reinforced cylindrical column **200** according to an alternate embodiment of the present invention is shown. The column **200** is formed by cage **210** and concrete **10**, and as can be seen, is cylindrical along its longitudinal axis. As before, apertures **240** form channels that allow partially-confined concrete **10b** (not presently shown) to form a contiguous concrete structure with well-confined concrete **10a** and unconfined concrete **10c**. Inward-facing surface **210a** and outward-facing surface **210b** are oriented similar to those of the previous embodiment.

[0056] Referring next to FIG. 10, the reinforcement system of the present invention can also be used as a cage **310** to provide both the longitudinal and transverse reinforcement in reinforced concrete beams **300**. In one particular form, it can be used in constructing precast beams; such prefabricated uses allow for easier, time-shortened construction. As discussed in conjunction with columns of FIGS. 2, 5 and 6 above, the shape, dimensions, and spacing of the apertures **340** can be changed depending on the amount of longitudinal and transverse reinforcement required. In this case, the large spacing between the two longitudinal reinforcements produces (by virtue of its large moment of inertia) an enhanced flexural capacity. In this configuration, the apertures **345** on the sides are much larger than those **340A**, **340B** at the top and bottom of the member. The longitudinal reinforcements **320** at top and bottom of the beam **300** are at a greater distance from each other compared to beams reinforced with rebar, resulting in a higher moment of inertia and corresponding flexural strength. The longitudinal reinforcements **320** are placed at the same level of the transverse reinforcement **330** resulting in a larger effective depth and higher flexural strength. As can be seen, longitudinal and transverse reinforcements **320** and **330** occupy the same plane. Also in members where the total height is limited by architectural constraints, the system of the present invention can perform better by increasing the effective depth of the beam **300**. The width of the apertures **345** on the sides can be determined based on the amount of transverse reinforcement necessary to satisfy the design requirements. By reducing the aperture **345** width on the sides, the shear strength of the beam **300** can be improved significantly. Moreover, the system of the present invention can be used to reinforce simply supported reinforced concrete beams, such as those used in parking garages, bridges and related structures.

[0057] Referring next to FIGS. 7 through 9, the use of the reinforcement of the present invention in joints **400** made from a combination of previously-discussed columns **100** and beams **300** is especially beneficial, as the reinforcement detailing of conventional beam-column joints can be complicated and difficult to implement. The detailing requirements found in code standards can result in reinforcement congestion inside a conventional joint. It can especially be difficult to construct heavily reinforced joints in structures with special or intermediate moment resisting frames. In fact, the difficulty due to reinforcement congestion is exacerbated by the presence of additional structural members meeting at a common location. Here, column **100** is reinforced with a variation on previously discussed cage **110**, now including varying aperture dimensions **140a**, **140b**. By using the present invention with smaller aperture sizes **140a** of cage **110** at the joint region, the plastic moment capacity of the column **100** in the region of joint **400** will increase, forcing the plastic hinge to form closer to the center of the reinforced member, which is a more desirable load-bearing location for columns **100** and related structures. By the use of smaller apertures **140a** and increased spacing between them, load-bearing capability remains high, while the concrete **10** (not presently shown) in the region of the joint **400** between can be confined effectively. As shown with particularity in FIGS. 7 and 8, at the joints **400** formed by the column **100** and a conventional rebar-reinforced beam **350**, the longitudinal reinforcement bars **20** of the beam **350** can easily pass through the joint **400** via apertures **140** in the cage **110**, making joint detailing and construction convenient, fast, and reliable. Referring with

particularity to FIGS. 8 and 9, the plan and side views of reinforced joints 400 are shown, highlighting the ease with which reinforcement bars 20 may be fitted into the apertures 140 of cage 110. This simplifies the design of joints 400 in comparison to other reinforcement systems, such as the afore-described composite or tubular sections of FIGS. 1C and 1D, where openings hitherto not provided must be made.

[0058] As with columns 100 and 200, the system of the present invention can be a superior alternative for longitudinal and transverse reinforcements in reinforced concrete piles, as it can easily be placed in an underground formwork resulting in cheaper and faster construction. Especially in construction of long piles, the present invention shows its advantage over rebar reinforced piles, where the steel rebar cage can be damaged during the placement of the cage inside the formwork. In the case of application of drilled shaft piles, a cage 210 (as shown in FIG. 6) formed by the present invention can be dropped inside the shaft, resulting in minimum required onsite work.

[0059] In contrast to the previously-discussed embodiments, which were used to give the concrete structure being reinforced three-dimensional attributes, other applications exist that require a substantially two-dimensional reinforcement geometry. For example, shear walls can benefit from the device of the present invention when it is left in its plate-like form. Referring next to FIGS. 11A through 13, the system of the present invention can also be used in a flat plate configuration to reinforce concrete shear walls 500 and their boundary elements, as well as for foundations and retaining walls 600. Referring with particularity to FIGS. 11A and 11B, the present invention can be used to perform the function of reinforcement in a heavily reinforced shear wall 500. This application can eliminate the time-consuming process of tying the horizontal and vertical bars of a rebar system together and putting the reinforcement cage together. The system of the present invention also increases the interaction between the reinforcements, resulting in a more effective and reliable reinforcing system. The reinforcements on the foot and face of retaining walls can be substituted by plate-shaped reinforcements of the present invention.

[0060] The application of the present invention in retaining walls is similar to its application in shear walls, where it can be easily placed in the formwork making the construction easier, faster, and at the same time more reliable. Referring with particularity to FIG. 1B, the shear wall 500 is reinforced with four planar reinforcements 510 connected at wall the corners. As can be seen in the figure, the dimensions of the planar reinforcements 510 can be made to conform to the need. As compared with the rebar reinforced shear wall of FIG. 1E, the aperture 540 dimensions and spacing can be varied to tailor the amount of longitudinal and transverse reinforcement at each location.

[0061] The reinforcements used in shear walls 510 can also be used on the foot, heel, and face of retaining walls. For example, referring with particularity to FIG. 12, enhanced footprint boundary elements 610 (which are similar to cage 110 depicted in FIG. 3) can be placed at opposing ends of relatively tall and slender shear walls 510 to form a retaining wall 600, where the two- and three-dimensional reinforcements can be used to replace the longitudinal and transverse reinforcing bars in the boundary element. As will be appreciated by visual inspection of the plan view depicted in FIG. 12, this configuration embodies aspects of the cage-like and plate-like members 110, 510 discussed previously, where

now the boundary elements can be reinforced with cages 510. As with the previously-discussed features, the aperture dimensions and spacing can be configured to provide the desired longitudinal and transverse reinforcements. The horizontal reinforcement of the shear wall 500 can easily pass through the apertures formed the boundary elements, making the connection fast and easy.

[0062] Referring with particularity to FIG. 13, the application of the system of the present invention can also be used in slabs 700, where the combined shape is that of a footer 705 in building foundations. The application of a plate-like reinforcement 710 according to the present invention is more advantageous in case of relatively heavy reinforced slabs where the reinforcement spacing is smaller. Especially when the slab 700 thickness is limited by architectural purposes or deflection considerations, the reinforcement can be easily substituted by the reinforcement 710 of the present invention. The system of the present invention can be used to reinforce single footings, strapped footings, and mat foundations, where the configuration is generally the horizontal equivalent of that used in the aforementioned shear walls 500. Reinforcement 710 (with a perforate surface, as with the previous embodiments) is used to reinforce slab 700 to define a single footing foundation 705, where the columnar post-like structure (similar to that previously shown) is made of concrete 10. The dimensions of apertures 740 and their spacing in slab 700 can be chosen to match the required reinforcement in the two perpendicular (in-plane) directions. The present invention can be especially useful in heavily reinforced foundations, where larger bars are used with smaller spacing. Although the column is shown as not being reinforced, it will be appreciated by those skilled in the art that it could be reinforced with either a cage similar to that of FIG. 3 or 6, or could be reinforced with conventional rebar. In the latter case, the rebar can be made to extend through the apertures, and can be connected to the slab 700 at or around the apertures to make a joint.

[0063] Having described the invention in detail and by reference to preferred embodiments thereof, it will be apparent that modifications and variations are possible without departing from the scope of the invention defined in the appended claims. More specifically, although some aspects of the present invention are identified herein as preferred or particularly advantageous, it is contemplated that the present invention is not necessarily limited to these preferred aspects of the invention.

We claim:

1. A building structure comprising:
 - a quantity of concrete; and
 - a first load-bearing member defining a unitary construction and having a first surface and a second surface, said first member further defining a plurality of apertures extending between said first and second surfaces such that the portion of said surfaces that surrounds each of said apertures define transverse reinforcements and longitudinal reinforcements that are substantially coplanar with one another within each of said surfaces, said structure configured such that upon placement of said quantity of concrete in cooperative arrangement with said surfaces, at least a portion of said quantity of concrete occupies said apertures to effect a contiguous mass of said quantity of concrete that upon curing around said first member forms said structure.

2. The structure of claim 1, wherein material making up said first member comprises a metal.

3. The structure of claim 2, wherein said first member is formed as a cage such that said structure defines a beam.

4. The structure of claim 1, wherein said apertures defined in said first member are arranged in a substantially repeating pattern.

5. The structure of claim 4, wherein said apertures are substantially rectangular in shape.

6. The structure of claim 4, wherein all said apertures are substantially similar in size.

7. The structure of claim 2, further comprising a second load-bearing member angularly connected to said first member such that reinforcements projecting from said second member extend through at least a portion of said apertures to couple to said first member, thereby effecting creation of a first joint.

8. The structure of claim 7, wherein said second member comprises a beam.

9. The structure of claim 8, wherein said reinforcements projecting from said beam comprise rebar.

10. The structure of claim 7, wherein said first member is shaped to define a cage such that said cage and said concrete cured therearound define a column.

11. The structure of claim 10, wherein at least one surface of said cage defines an outer surface of said column.

12. The structure of claim 10, wherein said apertures comprise a plurality of sizes along a longitudinal dimension of said column.

13. The structure of claim 12, wherein said apertures through which said projecting reinforcements pass are smaller than at least a portion of a remainder of said apertures.

14. The structure of claim 10, further comprising a third member angularly connected to said first and second members such that reinforcements projecting from said third member pass through at least a portion of said apertures to effect creation of a second joint thereby.

15. The structure of claim 10, wherein said third member comprises a beam.

16. The structure of claim 15, wherein angles formed by said angular connection of said second and third members are substantially ninety degrees relative to the surface of said column connected to said second and third members.

17. The structure of claim 2, further comprising a second member spaced substantially parallel to said first member such that each of said first and second members substantially face one another.

18. The structure of claim 17, wherein said second member is substantially identical to said first member.

19. The structure of claim 18, wherein said structure comprises a wall with a thickness dimension that is less than a width dimension or a height dimension, wherein spacing between said first and second members is along said thickness dimension.

20. The structure of claim 18, further comprising a third load-bearing member extending along said thickness dimension between said spaced first and second members.

21. The structure of claim 2, wherein said structure defines a retaining wall and comprises:

- a pair of columns spaced apart from one another, said columns including said first member and said quantity of concrete; and

- a wall extending between and connecting to each of said columns, said wall including a thickness dimension that

is less than a width dimension or a height dimension, and wherein said thickness dimension is less than a thickness dimension of said columns.

22. The structure of claim 21, wherein reinforcements in said wall extend through at least a portion of said apertures to effect a reinforced connection between said wall and said columns.

23. The structure of claim 22, wherein said reinforcements in said wall comprise rebar.

24. The structure of claim 2, wherein said structure defines a footer and comprises:

- a slab including said first member and said quantity of concrete, said slab including a depth dimension that is less than a width dimension or a length dimension; and
- a column connected to and extending in a substantially normal direction from said slab.

25. The structure of claim 24, wherein said column comprises reinforcements that extend through at least a portion of said apertures of said first member disposed in said slab to effect a reinforced connection between said slab and said column.

26. The structure of claim 2, wherein said structure defines a pile.

27. The structure of claim 26, wherein said pile comprises a substantially cylindrical shape along its longitudinal axis.

28. The structure of claim 2, wherein said structure defines a column, and wherein said first member is shaped as a cage defining a first exterior dimension, said structure further comprising a second load-bearing member shaped as a cage and defining a second exterior dimension that is less than the exterior dimension of said first member such that said first member is disposed concentrically around second member within said column.

29. A reinforced concrete joint comprising:

- a first structure comprising:

- a quantity of concrete; and

- a first load-bearing member defining a unitary construction and having a first surface and a second surface, said first member further defining a plurality of apertures extending between said first and second surfaces such that said surfaces surrounding said apertures define transverse reinforcements and longitudinal reinforcements that are substantially coplanar with one another within each of said surfaces, said structure configured such that upon placement of said quantity of concrete in cooperative arrangement with said surfaces, at least a portion of said quantity of concrete occupies said apertures to effect a contiguous mass of said quantity of concrete that upon curing around said first member forms said first structure; and

- a second structure comprising a second load-bearing member therein, said second member projecting from said second structure and extending through at least a portion of said apertures and coupled to said first member to effect connection between said first and second structures.

30. The structure of claim 29, wherein said first structure is a column and said second structure is a beam.

31. The structure of claim 30, wherein said column comprises a substantially rectangular shape along its longitudinal axis.

32. The structure of claim 31, wherein said second member extending from said beam comprises rebar.

33. A method of reinforcing a building, said method comprising:

configuring a first load-bearing structure to comprise a first load-bearing member defining a unitary construction with a first surface and a second surface, said first member further defining a plurality of apertures extending between said first and second surfaces such that the portions of said surfaces that surround each of said apertures define transverse reinforcements and longitudinal reinforcements that within each of said surfaces are substantially coplanar with one another, said structure configured such that upon placement of concrete in cooperative arrangement with said surfaces, at least a portion of said concrete occupies said apertures to effect a contiguous mass of said concrete that upon curing around said first member forms said structure; and

placing said structure in a position in said building such that it carries at least a portion of a structural load of said building.

34. The method of claim **33**, wherein said structure is a beam.

35. The method of claim **33**, wherein said structure defines a wall.

36. The method of claim **35**, wherein said wall defines a retaining wall.

37. The method of claim **35**, wherein said wall defines a shear wall.

38. The method of claim **33**, wherein said structure defines a joint, said joint comprising a connection between said first structure and a second load-bearing structure, said second structure comprising a second load-bearing member therein, said second member projecting from said second structure and extending through at least a portion of said apertures and coupled to said first member to effect connection between said first and second structures.

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