United States Patent [19]

Morohashi et al.

[11] **3,916,592**

[45] **Nov. 4, 1975**

[54] **STRUCTURAL MEMBERS FOR BUILDINGS AND BUILDINGS CONSTRUCTED THEREFROM**

[76] Inventors: **Takashi Morohashi; Yuji Morohashi,** both of Universal Corporation Engineering Consultant Co. Ltd., Sagamidai 1-15-9, Sagamihara, Kanagawa-Prefecture, Japan

[22] Filed: **Oct. 29, 1974**

[21] Appl. No.: **518,861**

Related U.S. Application Data

[63] Continuation-in-part of Ser. No. 298,641, Oct. 18, 1972, abandoned, which is a continuation of Ser. No. 53,137, July 8, 1970, abandoned.

[30] **Foreign Application Priority Data**

Aug. 16, 1969 Japan 44-64467

[52] **U.S. Cl.** **52/252;** 52/263; 52/414; 52/723; 52/736

[51] **Int. Cl.²** **E04B 1/04**

[58] **Field of Search** 52/724, 263, 251, 252, 52/736, 600, 602, 414, 653, 723; 57/144–148

[56] **References Cited**

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Primary Examiner—Ernest R. Purser
Assistant Examiner—Henry Raduazo
Attorney, Agent, or Firm—Cushman, Darby & Cushman

[57] **ABSTRACT**

A reinforced concrete structural member for buildings or the like which has notably excellent resistance to earthquake, heat and explosion, and is organic in structure, comprising: a concrete column including a plurality of special-type extra coarse-laid wire ropes embedded in the concrete column in a three-dimensional array, longitudinally vertically extending substantially straight through the concrete column but under untensioned or unstrained state and further including an open-work wrapping of steel wires or the like disposed around the steel wires to reinforce the concrete column; a concrete beam including a plurality of special-type extra coarse-laid wire ropes longitudinally, horizontally embedded substantially straight in the concrete beam but under untensioned or unstrained state, in a fashion intersecting the wire ropes of the column at right angles; and connecting means integrally fastening the wire ropes of the column to the wire ropes of the beam at the intersecting points, thereby instantly dispersing the external forces applied to the structural member which thus has toughness and flexibility, throughout the whole structure where they are employed.

6 Claims, 33 Drawing Figures

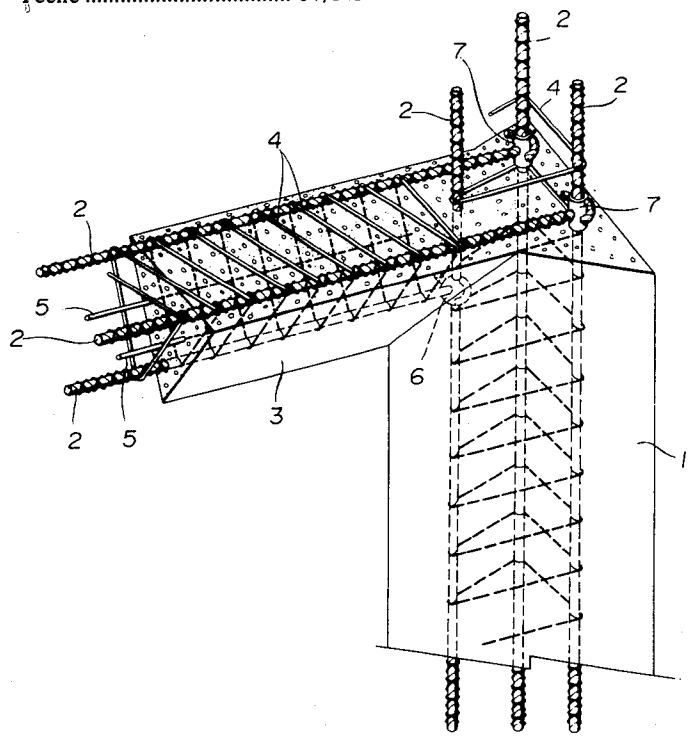


FIG. 1

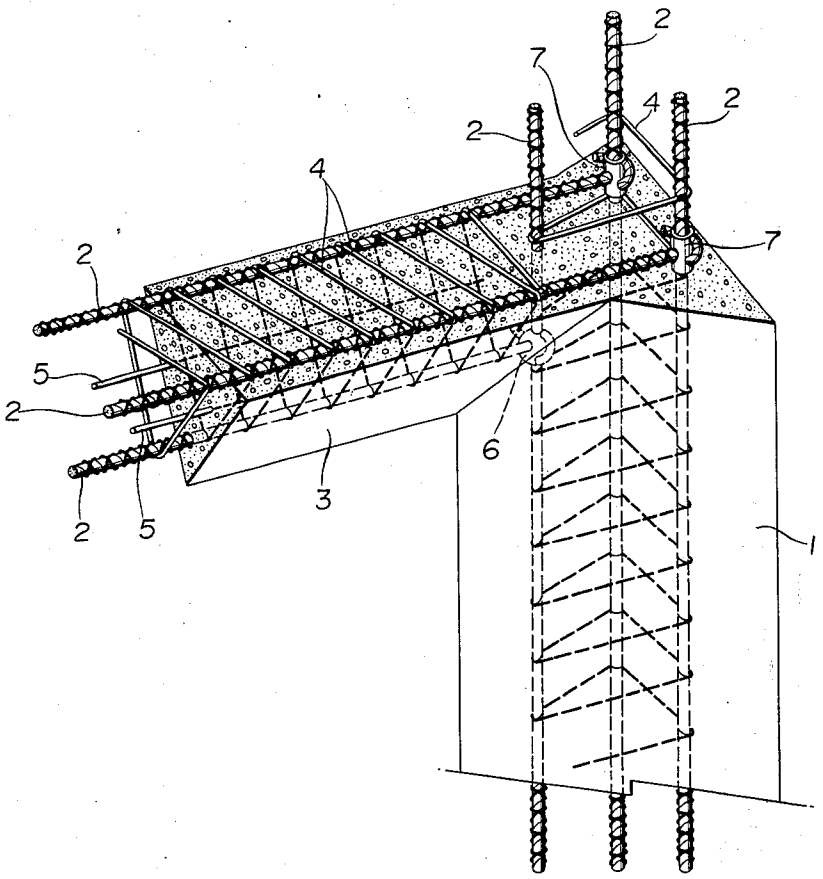


FIG. 2

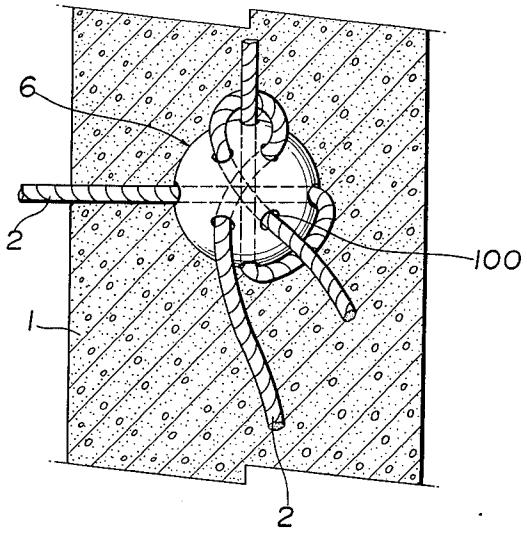


FIG. 3

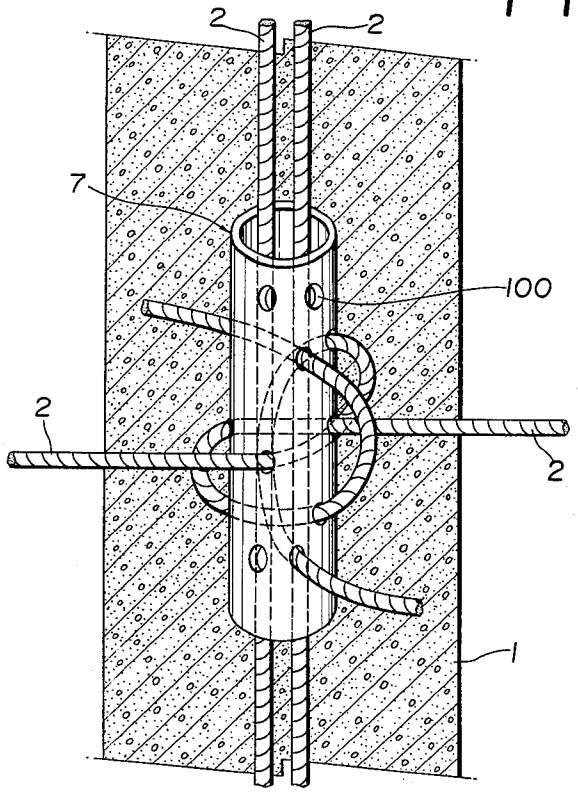


FIG. 4

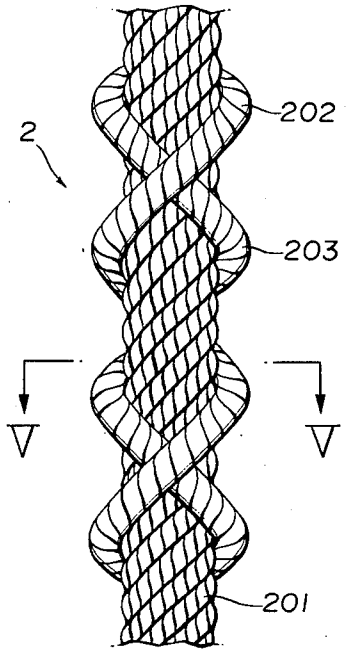


FIG. 5

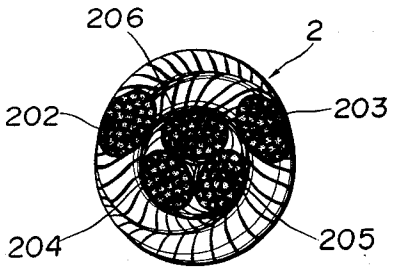


FIG. 6

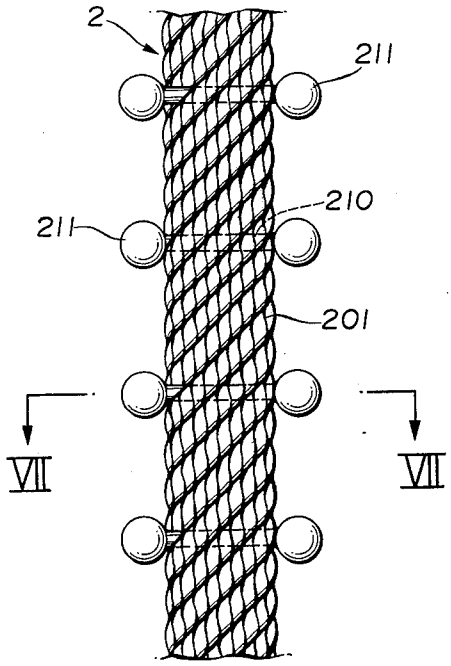


FIG. 7

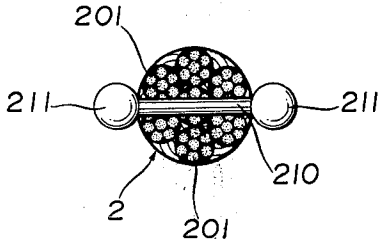


FIG. 8

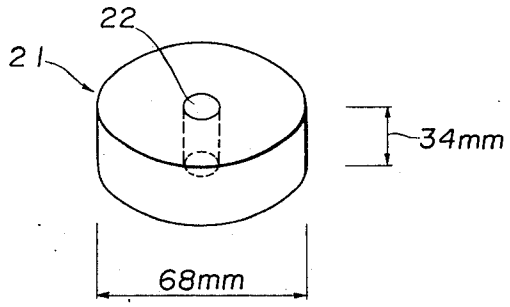


FIG. 9

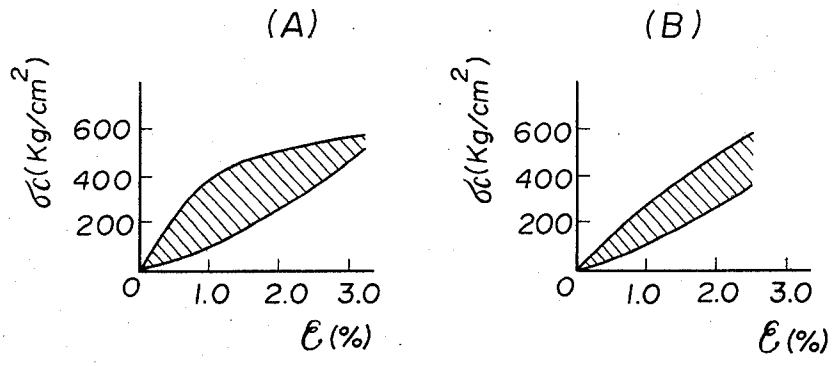


FIG. 10

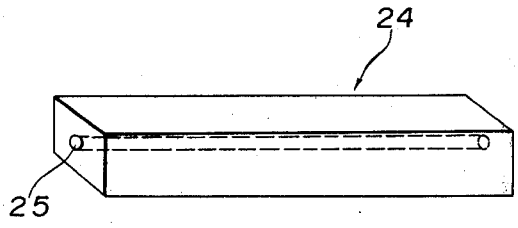


FIG. 11

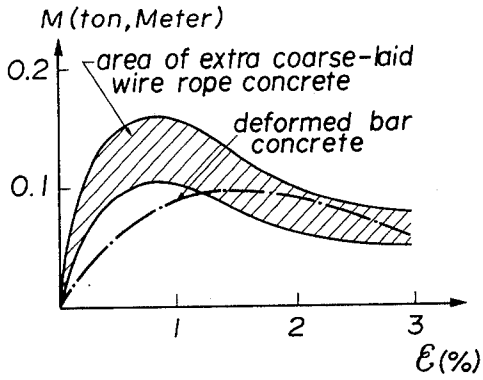


FIG. 12

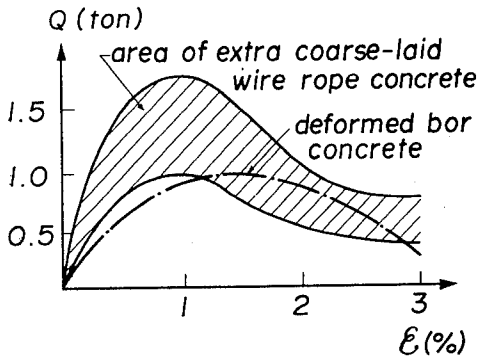


FIG. 13

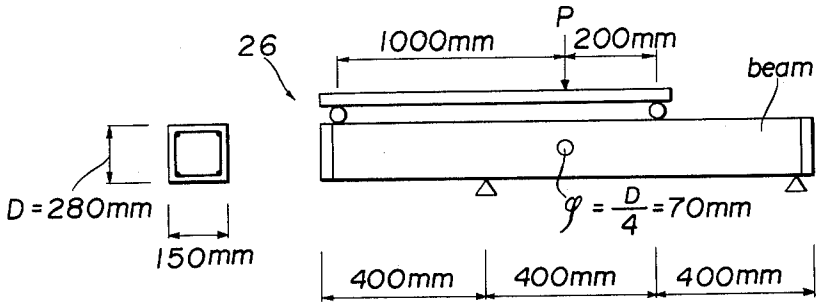


FIG. 14

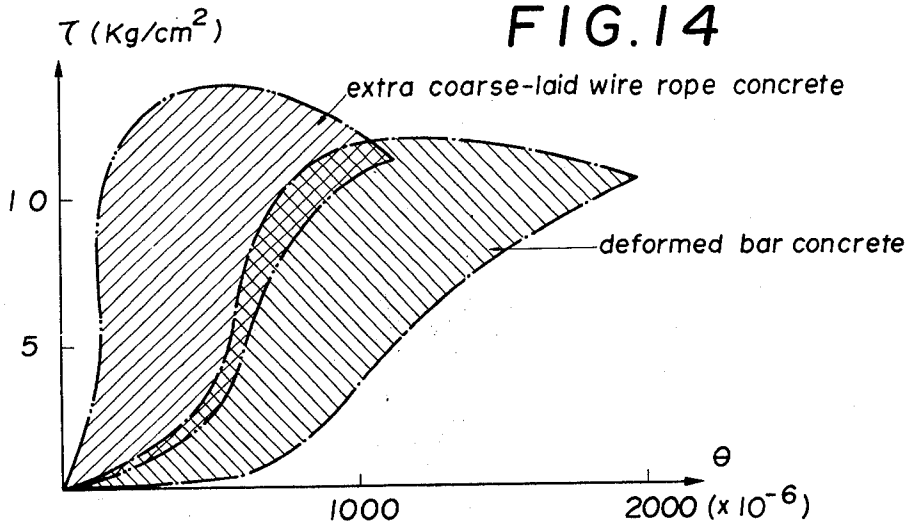


FIG. 15

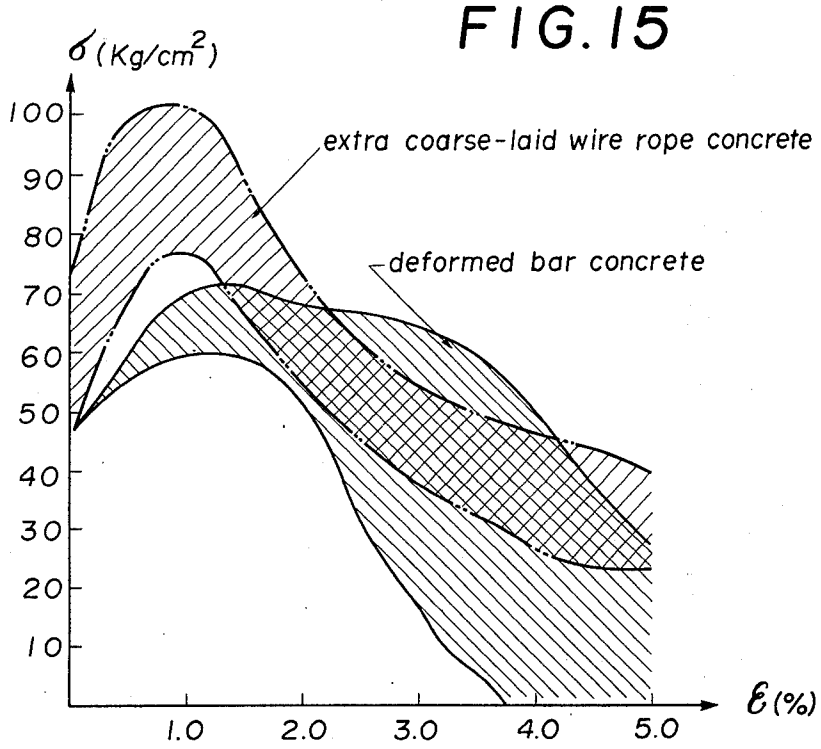

σ (Kg/cm²)
100
90
80
70
60
50
40
30
20
10
extra coarse-laid wire rope concrete
deformed bar concrete
1.0
2.0
3.0
4.0
5.0
ε (%)

FIG. 16

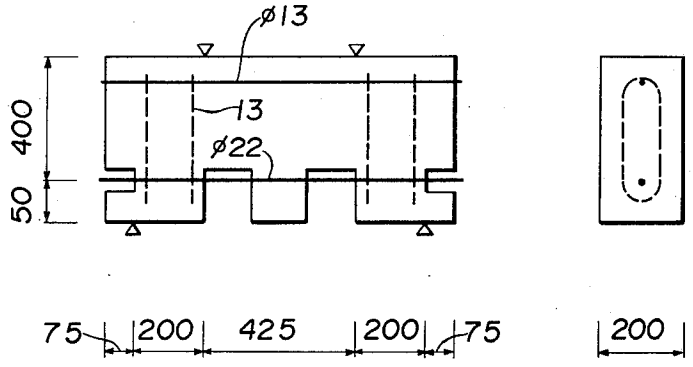

ø13
13
ø22
400
50
75
200
425
200
75
200

FIG. 17

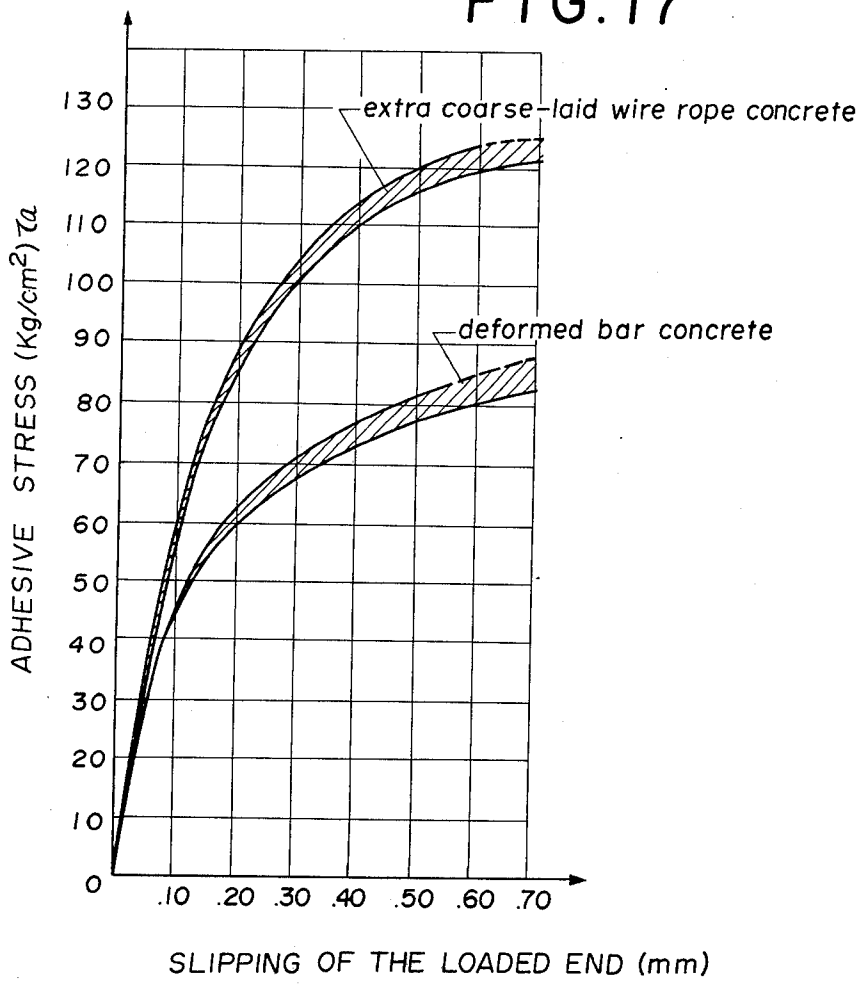

extra coarse-laid wire rope concrete
deformed bar concrete
ADHESIVE STRESS (Kg/cm²) τa
130
120
110
100
90
80
70
60
50
40
30
20
10
0
.10 .20 .30 .40 .50 .60 .70
SLIPPING OF THE LOADED END (mm)

FIG. 18

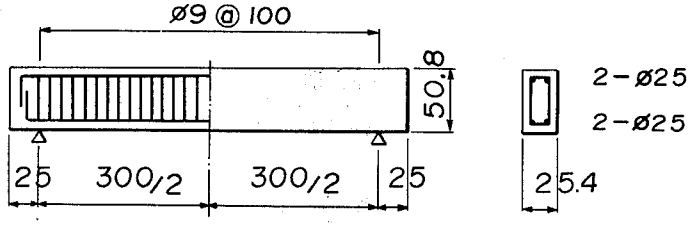

ø9 @ 100
50.8
2-ø25
2-ø25
25
300/2
300/2
25
25.4

FIG. 19

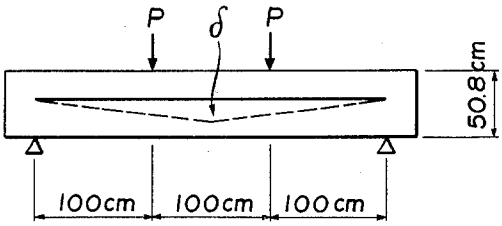

P
δ
P
50.8cm
100cm
100cm
100cm

FIG. 20

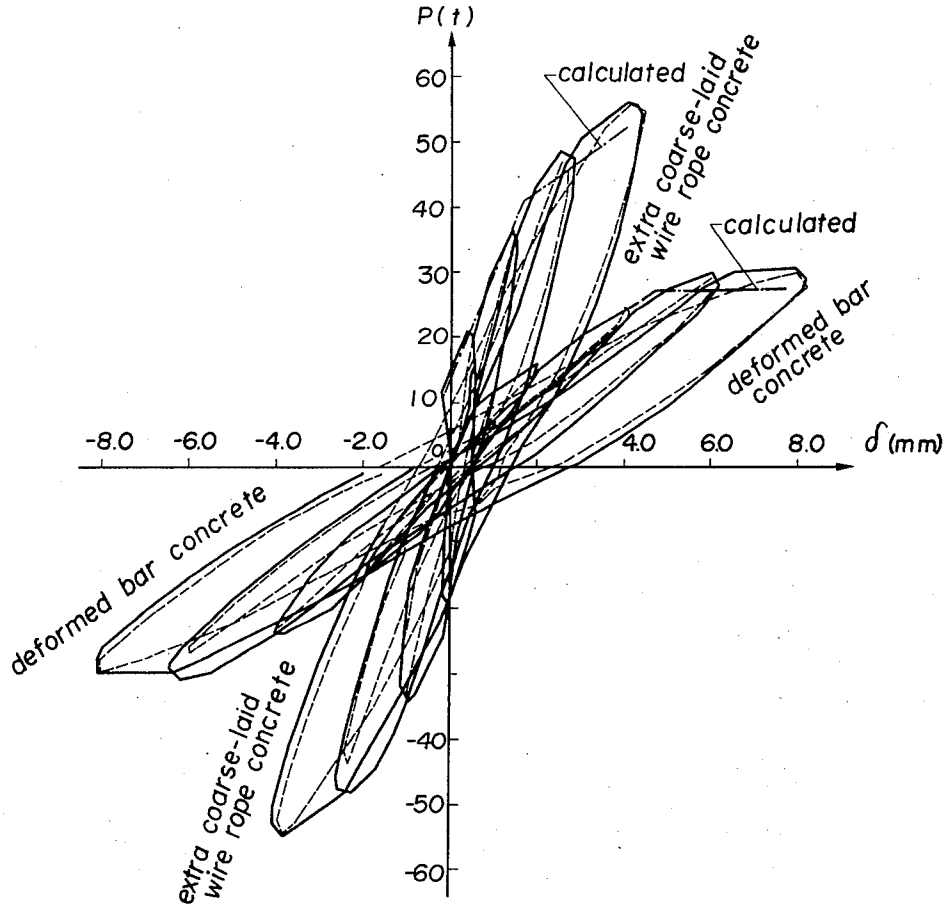

P(t)
60
50
40
30
20
10
-8.0
-6.0
-4.0
-2.0
0
4.0
6.0
8.0
δ(mm)
-40
-50
-60
calculated
extra coarse-laid wire rope concrete
calculated
deformed bar concrete
deformed bar concrete
extra coarse-laid wire rope concrete

FIG. 21

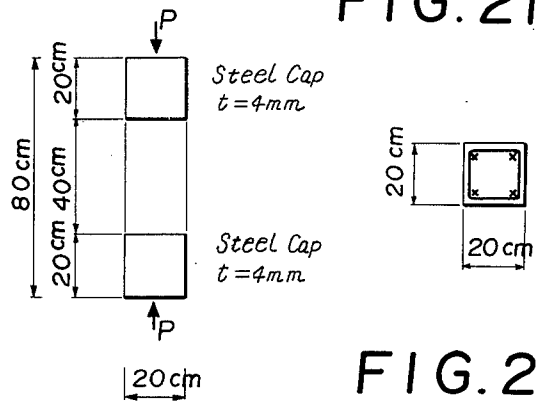


FIG. 22

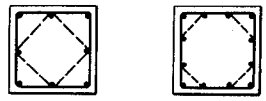


FIG. 23

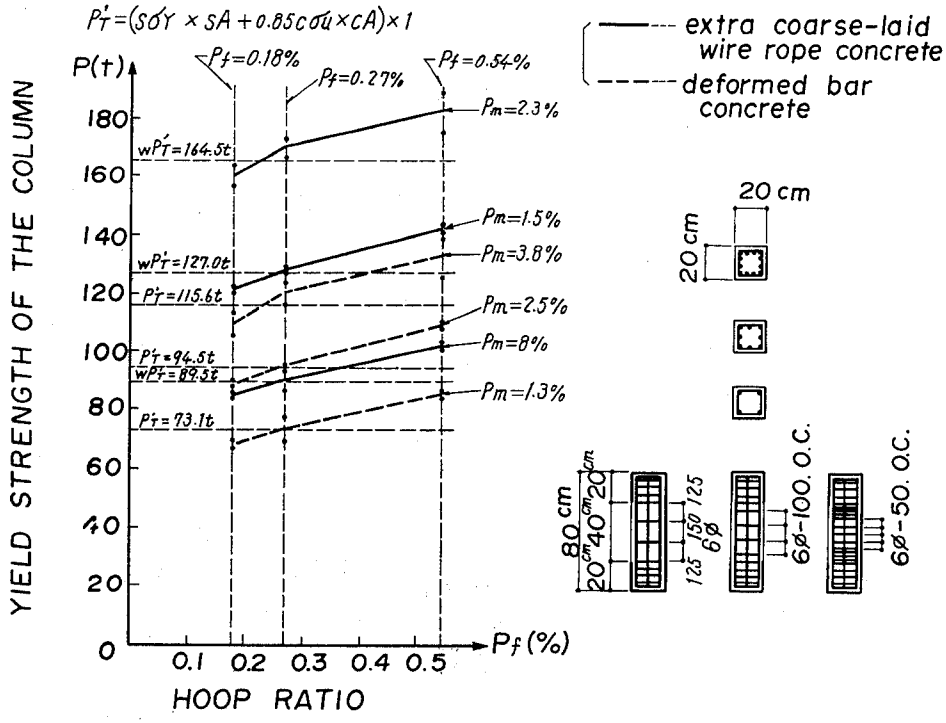


FIG. 24

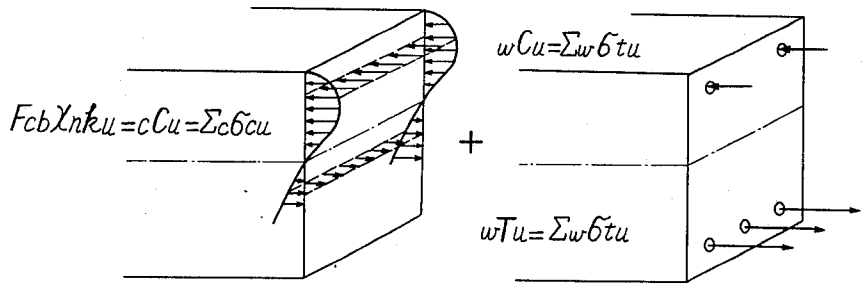


FIG. 25

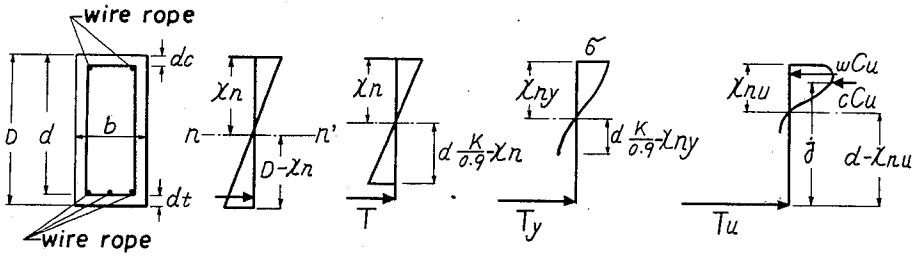


FIG. 27

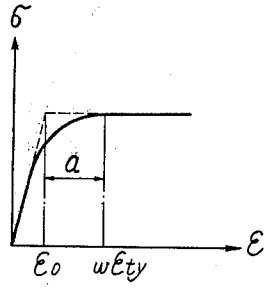


FIG. 26

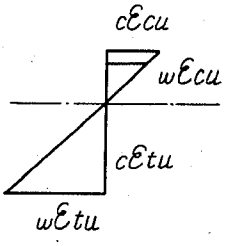


FIG. 29

FIG. 28

FIG. 30

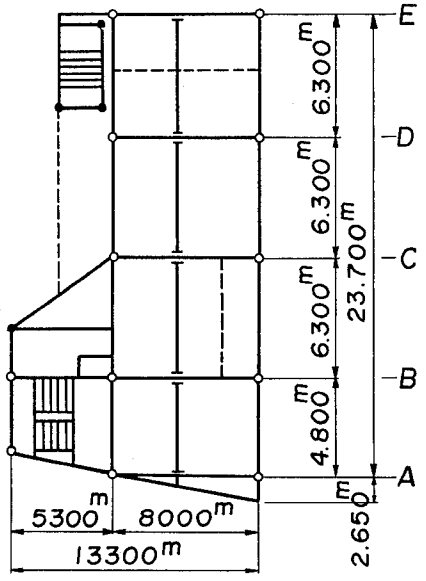


FIG. 31

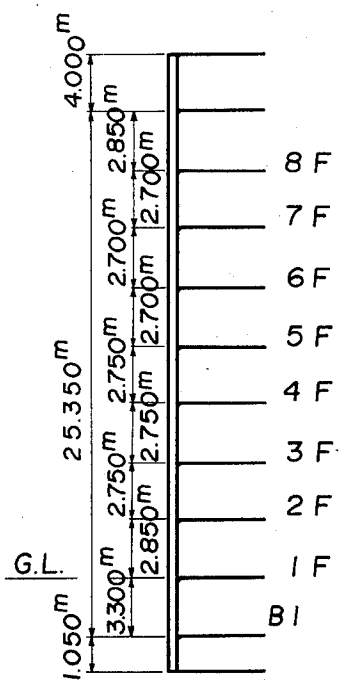


FIG. 32

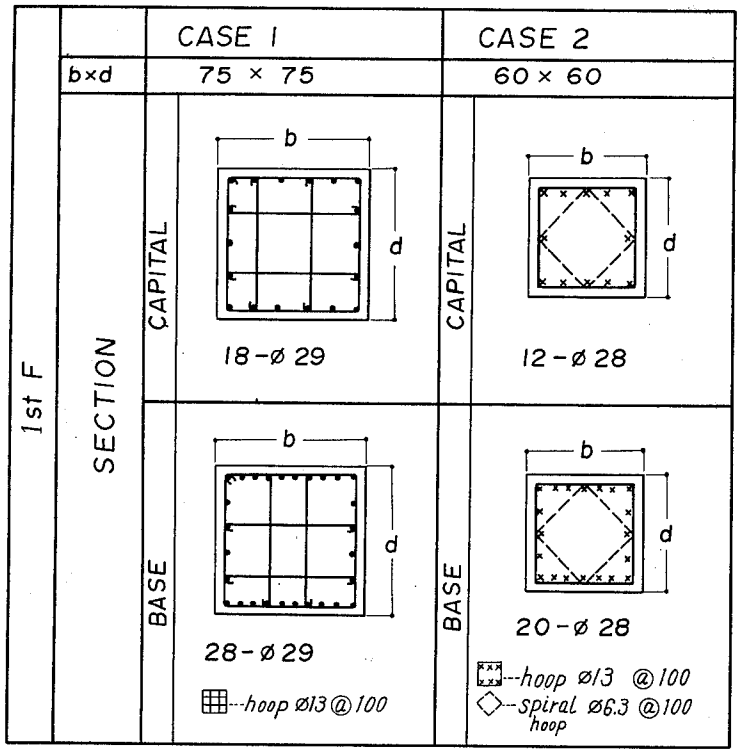
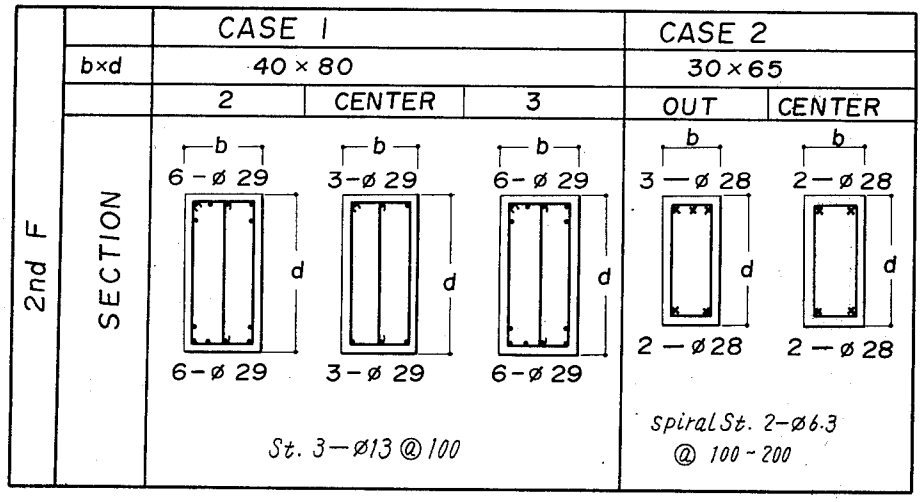

1st F
SECTION
CASE 1
b×d
75 × 75
CAPITAL
b
d
18-ø 29
BASE
28-ø 29
hoop ø13@100
CASE 2
60 × 60
12-ø 28
20-ø 28
hoop ø13 @100
spiral ø6.3 @100
hoop

FIG. 33


2nd F
SECTION
CASE 1
b×d
40 × 80
2
CENTER
3
6-ø 29
3-ø 29
6-ø 29
6-ø 29
3-ø 29
6-ø 29
St. 3-ø13 @100
CASE 2
30×65
OUT
CENTER
3-ø 28
2-ø 28
2-ø 28
2-ø 28
Spiral St. 2-ø6.3
@ 100-200

STRUCTURAL MEMBERS FOR BUILDINGS AND BUILDINGS CONSTRUCTED THEREFROM

This is a continuation-in-part application of our pending parent application Ser. No. 298,641, filed Oct. 18, 1972; now abandoned; and which is a continuation of our grandparent application Ser. No. 53,137 filed July 8, 1970; now abandoned.

BACKGROUND OF THE INVENTION

a. Field of the Invention

The present invention relates to a reinforced concrete structural member well adapted, particularly, for use as column and beam in high rise buildings, and in long span sections of highways or bridges, and even for use in earthquake-proof dams or earthquake resistant hanger walls for atomic reactors. The structural member according to the invention essentially comprises a concrete column reinforced by a plurality of special extra coarse-laid wire ropes, to be described hereinafter, longitudinally vertically embedded directly in the column concrete in a fashion straight but without special tension being applied thereto, and further reinforced by steel wires, steel bars or the like wrapped around the wire ropes; a concrete beam also reinforced by a plurality of special extra coarse-laid wire ropes longitudinally horizontally embedded in the beam concrete in a fashion straight but without tension being applied thereto and further reinforced by steel wires or the like wrapped around the wire ropes; and special-type connecting means integrally fastening together the wire ropes of both the column and the beam at the intersecting points, thus to integrally connect together the column and beam. As described, the above-mentioned vertical and horizontal extra coarse-laid wire ropes thus mutually joined together are provided throughout the whole structure of a building or the like which, therefore, results in that when the external forces are applied to the structural members, they are instantly transmitted via the straight wire ropes to any other places in the whole structure thus to be dispersed in all directions and effectively damped. Accordingly, the structural member according to the invention exhibits excellent characteristics particularly in earthquake resistance, heat resistance and explasion resistance. The above-described extra coarse-laid wire rope used in the present invention was invented by the inventors of the instant invention to highly enhance the adhesive power of wire ropes to concrete, and is now patented in the United States under U.S. Pat. No. 3,716,982. This extra coarse-laid wire rope, when used in place of conventional reinforcing steel bar or steel frame, exhibits so extremely higher adhesion with respect to concrete that the wire ropes and the concrete become integrally joined enough to avoid rubbing of the wire ropes against the concrete when they expand and contract, and to make moderately flexible the structural body in which they are used. As another merit, the extra coarse-laid wire rope has much increased mechanical strength, which results in reduced cross sectional area of the column or the beam where it is used. Thus, a concrete structure which chiefly employs the extra coarse-laid wire rope is lightweight as a whole, and is easy and simple to build up, which may lead to a shortened period of construction of the building constructed of such structures.

b. Description of the prior art

Conventional structures particularly for buildings include a reinforced concrete structure (RC), a steel framed reinforced concrete structure (SRC), a prestressed concrete structure (PS), or a steel framed simple fire-proof covered structure (SPC), etc. Choice of these structures depends upon the sorts of buildings to be built. For instance, for high-rise buildings which have recently been increasing in number also in Japan is particularly required a earthquake-resistant and fire-proof structure. Most suitable for this purpose are RC or SRC structures which are based upon the theory of rigid construction. But, since these structures are more or less short of flexibility and toughness, their earthquake-resistance is doubtful. Further, they are heavy in weight, and therefore regarded as unfit for high-rise buildings. In the earthquake which happened off the coast of Tokachi of Hokkaido, Japan in 1968, many buildings constructed of the RC structure fell down. The building of Hakodate College, which was a four-story building of RC structure became known for having fallen down in that earthquake. Its collapse was due to the ill adhesion between the reinforcing bars and the concrete which caused rubbing of the reinforcing bars against the concrete when the shocks were given to them. Further, in the earthquake which took place in Los Angeles, the United States in 1971, the building of Olive View Hospital made of RC structure fell down for almost the same reason as that for the earthquake of the Tokachi offing. Particularly the column portions of the building where no spiral hoops were used showed far more violent collapse than the other column portions where spiral hoops were used. This was also caused by the ill adhesion between the reinforcing bars and the concrete which prevented the building structure from having sufficient strength in compression, and shearing. Nowadays, in consideration of the above-mentioned technical problems, particularly, in earthquake resistance and economy, the SPC structure is mainly adopted for high-rise buildings, which differs completely from the two precedings in that it is based upon the theory of flexible construction. This SPC structure has a merit that its columns and beams may be made more slender than those of the precedings, and, it has been, therefore, most adopted for construction of high rise buildings. However, since the steel frame is covered with a fire-proof material with the aid of an adhesive or by spraying, the adhesive loses its function if fire should happen (the upper limit of temperature at which the adhesive still acts effectively is about 200° C according to the present level of technology) and thus the covering is separated from the steel frame, thus being inferior in fire resisting property. Thus, this structure is not a completely fire-proof structure, though it is rather noninflammable.

Conventional steel frame and reinforcing bar used in the RC SRC structure have low restitution coefficient so that they are weak against larger external forces caused, for instance, by earthquake.

Besides, steel frame and reinforcing bars have remarkably high conduction of heat owing to nonpresence of internal air-gaps, and has little internal air gaps for heat to be absorbed in as possessed by wire ropes and further there is a large difference in coefficient of thermal expansion, between the steel bar and the concrete, so that their rubbing against the concrete becomes intensified in the event of a fire. For these reasons, the high-rise buildings of RC or SRC structures are limited in height to have sufficient safety, specially

in a country like Japan where earthquakes take place frequently which may cause fires, while the SRC structure exclusively adopted for construction of high-rise buildings are limited in safety and may not be completely free from danger as yet, for the aforestated reason.

Besides the preceding structures, there is also employed a pre-stressed concrete structure. This structure is intended to eliminate the demerit of much inferior tensile strength common to the conventional concrete structures, by previously applying compressive stress to those portions where there may occur tensile stress by means of PC steel wires, so as to increase apparent tensile strength of the concrete used. For this PC structure are now employed two methods called "Pre-tensioning Method" and "Post-tensioning Method."

SUMMARY OF THE INVENTION

A principal object of the present invention is to provide a structural member which is organic in structure, and excellent in earthquake resistance and explosion resistance by virtue of its construction comprising a plurality of extra coarse-laid wires (to be described in detail hereinafter), in place of steel frame or reinforcing bars, which wires are laid in columns and beams throughout the whole building or the like in a fashion straight, untensioned and unloosened, and special connecting means integrally fastening the wires of the columns and beams to one another, thus forming a wire rope concrete structure (hereinafter called "WRRC"). With this arrangement, when an external force, for instance, by earthquake is applied to the structural members which thus already have toughness and flexibility, the force is instantly transmitted to any other places through the extra coarse-laid wire ropes of the columns or beams provided throughout the building or the like.

A further object of the invention is to provide a thermally insulated structural member which employs, in place of steel frame or reinforcing bars, extra coarse-laid wire ropes which are abundant in internal air-gaps apt to absorb heat energy, so that there may be a much smaller difference in coefficient of thermal expansion between the wire ropes and the concrete, thus effectively preventing rubbing of the wire ropes against the concrete.

Another object of the invention is to provide an economical structural member which is free from rubbing of wire ropes against the concrete, and has higher tenacity and consequently increased mechanical strength, by virtue of its construction comprising a plurality of extra coarse-laid wire ropes in place of steel frame or reinforcing bars which wires have much higher adhesion with the adjacent concrete, thus being able to be made considerably smaller in sectional area.

A still further object of the invention is to provide a structural member which is lighter in weight by employing extra coarse-laid wire ropes in place of steel frame or reinforcing bars.

Still another object of the invention is to provide a structural member which is unlikely to cause cracking, collapsing or shearing and breaking of the concrete used by employment of steel wires, steel bars or the like wrapped around the extra coarse-laid wire ropes in the columns and the beams for reinforcement of the latter.

BRIEF DESCRIPTION OF THE DRAWING

The above objects and other features and advantages of the present invention will be better understood upon

consideration of the following detailed explanation in connection with the accompanying drawing, in which:

FIG. **1** is a partially sectional view showing an example of the structural member according to the present invention,

FIGS. **2** and **3** are partially fragmentary front elevations showing examples of the connecting means adapted for use in the structural member according to the present invention, and embedded in concrete structures,

FIG. **4** is a front elevation showing an example of the extra coarse-laid wire rope to be used in the structural member according to the present invention,

FIG. **5** is a cross sectional view taken along line V — V of FIG. **4**,

FIG. **6** is a front elevation showing another example of the extra coarse-laid wire rope,

FIG. **7** is a cross sectional view taken along line VII — VII of FIG. **6**,

FIG. **8** is a schematic representation showing a test piece of mortar for use in a compressive strength test to be described hereinafter,

FIG. **9** (A) and (B) are graphs showing results on the compressive strength properties of an extra coarse-laid wire rope and a deformed bar, obtained by a compressive strength test employing test pieces as shown in FIG. **8**,

FIG. **10** is a schematic representation showing a test piece for use in a simple beam bending test to be described hereinafter,

FIGS. **11** and **12** are graphs showing results on the bending strength of an extra coarse-laid wire rope and a deformed bar, obtained by a bending test employing test pieces as shown in FIG. **10**,

FIG. **13** is a diagrammatic view showing a test piece for use in a sleeve beam test to be described hereinafter,

FIGS. **14** and **15** are graphs showing, respectively, $\tau - \theta$ and $\sigma - \epsilon$ envelopes obtained by a sleeve beam test employing test pieces as shown in FIG. **13**,

FIG. **16** is a diagrammatic view showing a test piece for use in a beam adhesive strength test to be described hereinafter,

FIG. **17** is a graph showing results obtained by a beam adhesive strength test,

FIG. **18** is a diagrammatic view showing a test piece for use in a beam bending strength test to be described hereinafter,

FIG. **19** is a diagrammatic view showing the direction in which the load is applied to the test piece as shown in FIG. **18**,

FIG. **20** is a graph showing load-deformation curve obtained by the beam bending strength test,

FIG. **21** is a diagrammatic view showing a test piece for use in a column center compressive strength test to be described hereinafter,

FIG. **22** is a cross sectional view showing diagonal hoops for use in the same column center compressive test,

FIG. **23** is a graph showing the effects by main reinforcement and diagonal hoops upon the column yield strength, resulting from the column center compressive test,

FIG. **24** is a diagrammatic view showing compressive stress block factor of extreme concrete fiber referred to in the formula as will be described later,

FIG. **25** is a diagrammatic view explaining change of stress distribution referred to in the formulas,

FIG. 26 is a diagrammatic view showing strain distribution referred to in the formulas,

FIG. 27 is a graph showing a stress-strain curve of an extra coarse-laid wire rope referred to in the formulas,

FIG. 28 is a cross sectional view showing an example of extra coarse-laid wire rope,

FIG. 29 is a cross sectional view showing another example of extra coarse-laid wire rope,

FIG. 30 is a schematic plan view showing an example of structure in actual designing,

FIG. 31 is a longitudinally sectional schematic view showing the same example,

FIG. 32 is an explanatory view for comparison in column design between the WRRC structure and the conventional one, and

FIG. 33 is a similar view to FIG. 32 for comparison in beam design.

DETAILED DESCRIPTION OF THE INVENTION

Referring now to FIG. 1, description is hereinbelow made with respect to the fundamental structure of the present invention. FIG. 1 shows a partly sectional view of a structural member according to the invention, in which reference numeral 1 designates a column having three sides of which the interior contains three extra coarse-laid wire ropes 2 near the surfaces of the column. As mentioned above, the extra coarse-laid wire rope as herein used was invented by the present inventors in order to obtain reinforcing members having higher stickiness to the concrete. The number of the extra coarse-laid wire rope to be arranged in the column is optional (but at least plural) depending upon the mechanical strength required for the structural member.

These three extra coarse-laid wire rope 2 are respectively longitudinally laid in the column 1 in a manner straight, and unloosened without being particularly tensioned. The phrase "without being particularly tensioned" does not mean that previous wire tensioning as employed in the pre-stressed concrete structure is not adopted for a special purpose, but merely means that the wire ropes are laid straight under little tension of such an extent as to remain unloosened. All the extra coarse-laid wire ropes having the above-mentioned purposes are arranged in the structural member in the above-explained manner. Reference numeral 3 represents a beam extending horizontally, the interior of which includes, as in the case of the column 1, three extra coarse-laid wire ropes 2 (In this specification like reference numbers designate like or corresponding parts having the same functions) which are longitudinally laid straight near the surfaces of the beam without being particularly tensioned, respectively. Thus, longitudinally arranged in the column and beam in the vertical and horizontal directions, the extra coarse-laid wire ropes 2 are disposed in a fashion intersecting one another at the cojoining points of the column and beam, with the intersecting points fastened by special connecting means (fastening means) 6, 7. In this manner, all the extra coarse-laid wire ropes of the column are joined to the corresponding extra coarse-laid wire ropes of the beam, but are not joined with non-corresponding extra coarse-laid wire ropes of the beam. That is, there are no extra coarse-laid wire ropes which are not joined with any corresponding extra coarse-laid wire ropes and in a so-called floating state. Reference numeral 4 represents reinforcing spiral hoops of wire disposed in a fashion wound around the plural extra coarse-laid wire ropes disposed within the column or the beam. In place of such spiral hoops of wire, there may be used wire gauzes or the like as such reinforcing members. Reference numeral 5 designates ordinary reinforcing bars which are of conventional type. Since prevention is effectively made of cracking of the concrete, these members 4, 5 also effectively serve to prevent collapsing or shearing and breaking of the concrete thereby to enhance the mechanical strength of the structural member according to the invention.

Also the above-described fastening means 6, 7 were invented by the inventors of the present invention for the purpose of improving the connection between the wire ropes embedded in the concrete, for which a patent application was filed Dec. 16, 1969 under Japanese application Ser. No. 44-101075, and is still pending. FIGS. 2 and 3 show details of such fastening means. The fastening means 6 shown in FIG. 2 has a hollow spheric body, and has its surface formed, at random, with a plurality of wire insertion through holes 100 for insertion of end portions of the extra coarse-laid wire ropes therethrough. In the present embodiment, the wire ropes of the column and beam are inserted through the respective corresponding insertion holes 100, in such a fashion that, for instance, an end of the wire rope is first inserted optionally into a first hole and pulled out of a second hole, and then again inserted through third and fourth holes, to be followed by further inserting the same end through fifth and sixth holes. In this case, the wire ropes are inserted in any optional holes so as to be acutely curved in random directions according to the holes, so that the curved portions of the wire rope may be brought into urging and frictional engagement with the mouth edges of the individual holes by resilient force of the wire rope. Thus, the wire rope thus inserted through the various holes may not so easily extracted therefrom.

As an advantage of this fastening means, merely by altering the diameters of the holes, various wire ropes with different diameters may be used for this fastening means, thus dispensing with the need of using other ones of such fastening means with different body sizes. Further, there is no need of untieing the ends of the wire ropes, since the ends of the wire ropes need not be tied to each other, according to this fastening means. The fastening means 6 may be made of metal or hard synthetic resin, or any other suitable materials.

Shown in FIG. 3 is another type of fastening means 7. This fastening means 7 represents a hollow tubular configuration, and may be made of a material similar to that of the fastening means 6. Over the surface of the fastening means 7 are formed a plurality of wire insertion holes for receiving therethrough the respective corresponding wire ropes 2 of the column and beam which are to be fastened to one another. Thus, by means of the fastening means having various configurations such as spheric or tubular ones, the wire ropes 2 in the column and beam are connected to one another in a rigid and stable manner. Further, such fastening means enable the fastening operation to be simply and quickly effected.

The above-mentioned are the main component elements of the present invention. Now, description is made more in detail with respect to the extra coarse-laid wire ropes. As stated above, this extra coarse-laid wire rope, which is of a quite novel structure, was invented by the inventors of the present invention with the intention of largely improving the connection be-

tween the wire ropes and the concrete, and is already patented under U.S. Pat. No. 3,716,982 in the United States. The present wire rope, as distinct from the conventional wire ropes, has its surfaces formed in special configurations so as to possess much higher adhering power to the concrete adjacent to the wire ropes. In the embodiment as shown in FIGS. **4** and **5**, the extra coarse-laid wire rope comprises, for instance, a lay **201** which is built up of strands **204, 205, 206,** each incorporating a plurality of wires laid helically in the same angular sense; and at least two strands **202, 203,** each incorporating a plurality of wires, the at least two strands **202, 203,** each being of at least as great diameter as the first-mentioned strands and being helically wound in two angularly opposite senses upon said built-up lay so as to cross one another at a phase angle of about 180°; the at least two strands being spaced to expose said lay exteriorly of the wire rope, between the at least two strands so the wire rope has a substantially greater diameter at the crossings of said at least two strands than where said lay is exposed exteriorly of the wire rope, thereby forming the extremely coarse-laid surface of the wire rope **1.**

FIGS. **6** and **7** show another example of extra coarse-laid wire rope. In this example, in place of the at least two strands **202, 203,** there are used a plurality of metallic cross pieces **210** which are incorporated in the lay **201** in a fashion transversely extending, axially regularly spaced from one another, and having both ends of each piece protruding substantially outwardly of the lay **201.** On the protruding ends of each cross piece are securred ball means **211.**

Several tests were conducted to compare the adhesive strength of the extra coarse-laid wire rope with respect to the concrete and that of the conventional deformed bars with respect to the concrete, of which the results are introduced in the following:

Incidentally, in a series of tests to be described in the following were used deformed bars, reinforcing steel bars, and extra coarse-laid wire ropes which are in accordance with the below stated standards:

Table 1

Symbol	Yield point	Tensile strength	Remark
SR24	2400 kg/cm² or more	3900–5300 kg/cm² or more	JIS* G3112, 1964
SR30	3000 kg/cm² or more	4900–6300 kg/cm² or more	"
SD30	3000 kg/cm² or more	4900–6300 kg/cm² or more	"
SD35	3500 kg/cm² or more	5000 kg/cm² or more	"
SD40	4000 kg/cm² or more	5700 kg/cm² or more	"
WD120	12200 kg/cm² or more	16500 kg/cm² or more	

SR: reinforcing steel bar
SD: deformed bar
WD: extra coarse-laid wire rope
*: JIS= Japanese Industrial Standard

First, description is made of the results of a comparison test on the compressive strength of mortar incorporating an extra coarse-laid wire rope and a mortar incorporating a steel-made deformed bar. Pieces of mortar each of a shape as designated at **21** in FIG. **8** was put to the test, and the mortar had a water - cement ratio of 65%, a specific gravity of 3.17, and a compressive strength of 413 kg/cm² after the lapse of 28 days after mixing. Each mortar piece **21** assumed a cylindrical shape having a diameter of 68mm, a height of 34mm, with an extra coarse-laid wire rope or a deformed bar longitudinally embedded in the center **22** thereof. Compressive force was added to the test pieces, the results of which are shown in FIG. **9** in which (A) shows the resulting compressive strength of the extra coarse-laid wire rope mortar, and (B) that of the deformed bar mortar. Here, symbol σC represents applied compressive pressure, ϵ deformation. These figures (A), (B) show, respectively, the strength ranges within which the test pieces are able to endure the compressive force applied thereon. As seen in the two figures, it was found that as regards the deformed bar mortar, the deformed bar may not adhere to the mortar, and may be easily separated from the mortar, while in the extra coarse-laid wire rope mortar, the extra coarse-laid wire rope may adhere to the mortar so closely as not to be easily separated therefrom.

Next, a simple beam test was run under the following conditions: Lightweight sand of a grain size smaller than 2.5mm, and lightweight gravel of a grain size smaller than 15mm were mixed with cement and water into a slurry having a slump of **21cm.** Then, the slurry was water cured at a temperature of 20° ± 3°C, to obtain a test piece **24** (simple beam) as shown in FIG. **10** which had a mixing strength of 180kg/cm², a sectional area of 10cm × 10cm, and a length of 40cm, having an extra coarse-laid wire rope or a deformed bar vertically inserted through the center **25** thereof. The test pieces were subjected to bending. FIGS. **11** and **12** show the test results. In FIG. **11,** M represents momentum (ton × meter), and ϵ deformation. In FIG. **12,** Q means shearing force (ton). From these tests, it was found that the extra coarse-laid wire rope concrete beam is smaller in strain and larger in yield strength: Since the adhesion area between the extra coarse-laid wire rope and the concrete is larger, they may cooperate so as to better exhibit their respective properties.

Explanation is now made with respect to the results of a sleeve beam test conducted on beams incorporating an extra coarse-laid wire rope or a deformed bar, under the following conditions:

The test piece sleeve beams were made of concrete from a slurry of a slump of 19mm and had a 28 day post-mixing compressive strength of 28Fc = 180kg/cm² and an air volume of 5%, and also having a central through bore. The extra coarse-laid wire rope embedded in the sleeve beam had a size of $3 \times 7 - 18\phi$, while the deformed bar to be used as a stirrup had a size of SD – 19ϕ, and a stirrup size of 2 – 9 ϕ at 200. The sleeve beam **26,** which is shown in FIG. **13,** had a sectional area of 280mm × 150mm, with a central through bore of a diameter of 70mm. The extra coarse-laid wire rope had no hook, while the deformed bar had hooks. P denotes a direction in which the pressure is applied to the test beams. Shown in FIGS. **14, 15** are the results of the present test on the extra coarse-laid wire rope sleeve beam and the deformed bar sleeve beam. In FIG. **14,** τ represents shearing unit stress, and θ joint translation angle (kg/cm²). In FIG. **15,** σ means stress (kg/cm²), and ϵ deformation. From the obtained results, it could be concluded that the extra coarse-laid wire rope sleeve beam showed remarkably excellent properties in restitution coefficient, stress-strain development curve, joint translation angle, residual unit strain, and toughness.

Lastly, a pull-out test was conducted on concrete blocks respectively incorporating an extra coarse-laid wire rope and a deformed bar. The same concrete was

used for all the test piece concrete blocks, as that used in the preceding tests. In testing under the tensile force of 3.6 ton/cm^2, the deformed bar was easily extracted from the concrete block. While, the extra coarse-laid wire rope was not extracted from the concrete block until the later became fractured. This shows more excellent adhesion of the extra coarse-laid wire rope with respect to the concrete.

Besides a series of tests as introduced above, further tests were conducted on actual applications of the extra coarse-laid wire rope according to the present invention to columns and beams for buildings, in respect of the adhesive strength of the extra coarse-laid wire rope, the bending strength of the beams, or the compressive strength of the columns in comparisons with the deformed bar applications. The present series of tests were made in accordance with the testing methods described in the below-listed publications:

1)	
Issue date:	August, 1971
Writer:	Hajime Umemura et al
Title:	Methods of Designing Deformed Bar Concrete Structures
Publisher:	The Kozaikurabu (a corporation)
2)	
Issue date:	August, 1971
Writer:	Yuji Morohashi et al
Title:	Wire Rope Concrete Structures (a treatise)
Publisher:	R.I.L.E.M. Israel International Symposium
3)	
Issue date:	January, 1972
Writer:	Yuji Morohashi et al
Title:	Methods of Designing Extra Coarse-laid Rope Concrete Structures
Publisher:	Universal Consulting Engineering, Inc.
4)	
Issue date:	December, 1973
Writer:	Yuji Morohashi Takashi Morohashi S. Saeed Mirza
Title:	Extra Coarse-laid Wire Rope Concrete Structures (a treatise)
Publisher:	Canada Institution of McDill University
5)	
Issue date:	December, 1961
Writer:	John A. Blume Nathan M. Newmark Leo H. Corning
Title:	Design of Multistory Reinforced Concrete Buildings for Earthquake Motions
Publisher:	Portland Cement Association

1. Adhesive strength tests

The following three kinds of tests are generally adopted as typical ones for testing adhesive strength:

a. Pull-Out Test

b. Bilateral Pull Test

c. Beam Adhesive Strength Test

Here in this specification is described only the test of the item (*c*). This test consisted of the steps of applying shearing force to test pieces of a beam-like shape to cause adhesive stress in the shared span portion of the pulled deformed bar or extra coarse-laid wire rope, and determining the relationship between the adhesive strength and an amount slipping of the loaded end or of the free end of the test piece with respect to the concrete. FIG. **16** shows a test piece in which the test piece size and the directions in which the test piece receives loads. The test conditions were provided as follows: The concrete was used which had a compressive strength of Fc = 220kg/cm^2. The extra coarse-laid wire rope had a strength corresponding to class WD 120 having a diameter of 22.4mm whose yield point was σr = 12.2ton/cm^2, and whose tensile strength was σmax = 16.5ton/cm^2, and the deformed bar had a strength corresponding to Class SD 35 having a diameter of 22mm whose yield point was σr = 3.8ton/cm^2, and tensile strength was σmax = 5.7ton/cm^2. The test results are shown in FIG. **17**, and in which the adhesive stress was determined by the following formula:

$$\tau a = \frac{Q}{\phi j}$$

or

$$\tau a = \frac{T}{\phi l}$$

where

Q: shearing force (ton),

j: distance between centers of tension and compression,

ϕ: circumferential length of tension deformed bar or tension wire rope (cm),

T: tensile strength of the loaded end of deformed bar or extra coarse-laid wire rope (to be determined by measuring the stress of the exposed portion of deformed bar or extra coarse-laid wire rope),

l: length of the sheared span portion.

As seen from the test results, the extra coarse-laid wire rope concrete exhibited about 150% of the adhesive strength of the conventional deformed bar concrete, enough to effectively prevent the rubbing of the wire ropes against the concrete.

2. Beam bending strength test

Now, described in the following are the results of the bending strength test. This bending strength test comprised a step of repeatedly applying positive and negative forces with respect to the test pieces of an extra coarse-laid wire rope concrete beam and a deformed bar concrete beam. The test conditions were as follows: The test pieces were constituted by a deformed bar concrete beam (25ϕ) and an extra coarse-laid wire rope concrete beam (25ϕ), each having a size of 25.4cm (10 inches) width × 50.8cm (20 inches) height. The test pieces were repeatedly given concentrated positive and negative forces at three predetermined equi-interval points thereof. The deformed bar and the extra coarse-laid wire rope embedded in the concrete beams had the following sizes:

	Tension bar or wire rope				Concrete		
	Dia. (mm)	*sAt.*(*wAt*) (cm^2)	*sσtY* (*wσtY*) (t/cm^2)	*sσmax* (t/cm^2)	*cσu* (kg/cm^2)	*cεu* (%)	E* (×10^{5}kg/cm^2)
Test piece of deformed bar concrete	25	5.07	3.25	4.90	242	180	2.58

-continued

	Dia. (mm)	Tension bar or wire rope $sAt.(wAt)$ (cm^2)	$s\sigma tY$ ($w\sigma tY$) (t/cm^2)	$s\sigma max$ (t/cm^2)	Concrete $c\sigma u$ (kg/cm^2)	$c\epsilon u$ (%)	E* ($\times 10^5 kg/cm^2$)
Test piece of extra coarse-laid concrete	25	5.07	12.20	16.50	242	180	2.58

Note: Mark* represents second modulus at point 1/4 $c\sigma s$. where,

sAt:	sectional area of tension reinforcing bar
wAt:	sectional area of tension wire rope
$s\sigma tY$:	yield point of tension main reinforcement
$w\sigma tY$:	yield point of tension main wire rope
$c\sigma u$:	concrete strength
$c\epsilon u$:	strain of concrete at the ultimate load
E^*:	modulus of elasticity (Young's modulus)

FIG. **18** shows the size of the test piece, FIG. **19** shows how to apply loads to the test piece, and FIG. **20** indicates the load-deformation curve (by applying forces in plus and minus directions) which represents the relationship between the total loads P and the deformation σ of the center of the beam relative to the supporting point. In the figure, the dotted lines show values in accordance with the theoretical calculation. These theoretical values are approximately in conformity to the enveloping lines corresponding to the measured values.

The theoretical formula (by Hayato Umemura): $Mc = (4.2 + 3.7\ Pt)\ bD^2$,

$$Pt = 100.\ \frac{At}{bD}$$

where

At: sectional area of tension bar or wire rope (cm^2),

b: width of beam (cm),

D: height of beam (cm), and

Mc: cracking moment (kg/cm).

Remark: The deformation of the central portion of the beam is expressed in coefficient of elasticity and rigidity obtained from the test piece with a built-in deformed bar or wire rope.

From the test results shown in FIG. **20,** it was found that the test piece of extra coarse-laid wire rope beam had four to six times as much bending strength as the test piece of deformed bar concrete beam, per the same deformation δ (mm). This is of course, considered to be attributable to the higher strength or higher adhesive power of the extra coarse-laid wire rope.

From the foregoing, it is to be noted that the extra coarse-laid wire rope concrete structure (WRRC structure) according to the invention is structurally more advantageous than the conventional RC structure.

3. Column center compressive strength test

Next, a further similar comparison test was carried out, which consisted of a step of applying compressive strength to the centers of the test piece columns composed of deformed bar concrete or extra coarse-laid wire rope concrete.

The test conditions were as follows:

The sectional area of the test piece: $B \times D = 20 \times 20$ cm^2

Main Reinforcement: **SD40** (13mm in dia.)—$s\sigma r = 4.20\ t/cm^2$; **WD120** (12.5mm in dia.)—$s = 12.20t/cm^2$

Hoop—**SR30** (6mm in dia.) $s\sigma r = 3.85 t/cm^2$

Concrete—$c\sigma u = 153 kg/cm^2$

The configuration of the test piece is shown in FIG. **21.**

The following test pieces were used:

Main reinforcement: Deformed bar	Main reinforcement: Extra coarse-laid wire rope	Hoop
4 - 13ϕ (Pm = 1.27%)	4 - 12.5ϕ (Pm = 0.77%)	6ϕ at 50 O.C (P_f = 0.54%) 6ϕ at 100 O.C (P_f = 0.27%) 6ϕ at 150 O.C (P_f = 0.18%)
8 - 13ϕ (Pm = 2.54%)	8 - 12.5ϕ (Pm = 1.54%)	Ditto
12 - 13ϕ (Pm = 3.81%)	12 - 12.5ϕ (Pm = 2.30%)	Ditto

where

Pm: ratio of main reinforcement or ratio of main wire rope

Pf: hoop bar ratio or hoop wire rope ratio

FIG. **22** bears the test results concerning the yield strength of the columns. As a consequence of the test, the ultimate yield strength of the columns in the case of compressive force being given to the centers thereof is expressed by the following formula:

$PT = (s\sigma r \times sA + 0.85\ c\sigma B \times cA)\alpha$,

where,

$s\sigma r$, sA are yielding point stress or sectional area of the deformed bar or the wire rope respectively

$c\sigma B$, cA are maximum stress or sectional area of the concrete respectively and

α is function of the hoop ratio Pw (approx. 0.9 – 1.2).

In the above formula, if α is let to be 1, it will conform to the ultimate strength formula of the U.S. AC1 standards. In FIG. **22,** the dotted lines show the values obtained with α equal to 1.

From FIG. **22,** it is found that the extra coarselaid wire rope concrete increases in column yield strength in proportion to its increase in (i) main reinforcement ratio and (ii) hoop ratio.

It is due to the higher strength of the extra coarse-laid wire rope that the extra coarse-laid wire rope concrete is higher in ultimate yield strength P_T of the centrally compressed column than the deformed bar concrete, though the former is smaller than the latter both in main reinforcement ratio and hoop ratio. A diagonal hoop (seen in dotted lines in FIG. **23**) is effective for increasing the yield strength of the column. This is due to that the spiral hoop does not only bind the concrete for itself, but also binds the main reinforcement of the non-corner portions which are apt to swell outwardly, as well as increases the binding effect of the concrete. While, even with the same hoop ratio, it was found more effective to arrange smaller diameter hoops closely at narrower intervals than to arrange larger diameter hoops roughly at wider intervals. Further more effective is to arrange hoops parallel with one another.

For these reasons, in the WRRC structure according to the present invention, hoop wire ropes are provided

in spiral arrangement thus elevating the binding effect of the concrete.

Next, there are presented just for reference, some sample calculations by the fundamental equations specially derived for determining actual reinforcement employing the WRRC structure according to the invention:

"Fundamental Equations on Wire Rope Concrete Members." By Yuji Morohashi; Takashi Morohashi; M. Saeed Mirza

1. Introduction

Studies on the use of wire rope in structural concrete have concentrated on application of the technique to structural members in highway bridges and tall buildings.

Authors derived the fundamental equations for the ultimate flextural strength and other mechanical properties to determine the most economical wire reinforcement required.

The following describes the development of these fundamental equations and presents some sample culculations.

2. Notation

a: difference of strain at yield point
b: breadth
cCu: ultimate compressive strength of concrete
wCu: ultimate tensile strength of wire rope
d: depth
E: Young's modulus
cEc: compressive Young's modulus of concrete
cEt: tensile Young's modulus of concrete
wEc: compressive Young's modulus of wire rope
uEt: tensile Young's modulus of wire rope
$Fc^{kgl}cm^2$: flextural compressive strength of concrete
$Ft^{kgl}cm^2$: flextural tensile strength of concrete
j: distance of strength between compression and tension
ku: compressive stress block factor at the extreme concrete fiber (See FIG. **24**)
M: moment
Mc: flextural compressive moment
cM: moment of concrete resistance
wM: moment of wire rope resistance
n: Young's modular ratio

$$n = \frac{sE}{cE}$$

Pt: tensile area ratio of wire rope at the reinforced concrete
Ptb: balanced tensile area ratio of wire rope at the reinforced concrete
Pt: tensile area ratio of wire rope at the reinforced concrete
r: ratio at the wire rope reinforcement

$$r = \frac{Pc}{Pt}$$

Pc: compressive area ratio of wire rope at the reinforced concrete
Xnu: depth of neutral axis at the ultimate
Xnul: ratio of neutrol axis at the ultimate
Xnulb: balanced ratio of neutral axis at the ultimate
ϵ: strain
$c\epsilon cu$: strain at the ultimate compression of concrete
$c\epsilon cy$: strain at the yielding compression of concrete
$c\epsilon tu$: strain at the ultimate tension of concrete
$c\epsilon ty$: strain at the yielding tension of concrete
$w\epsilon cu$: strain at the ultimate compression of wire rope
$w\epsilon tu$: strain at the ultimate tension of wire rope
$w\epsilon ty$: strain at the yielding tension of wire rope
$w\epsilon y$: strain at the yield of wire rope
$(1/\rho)$: curvature
σ: stress
$c\sigma c$: compressive stress of concrete resistance
$w\sigma t$: tensile stress of wire rope resistance
$w\sigma tu$: ultimate tensile stress of wire rope resistance
$w\sigma y$: yielding stress of wire rope
$c\phi cu$: half-diameter of curvature at the ultimate compression of concrete
$w\phi ty$: half-diameter of curvature at the yielding tension of wire rope
μ: ductility factor
T: tensile strength
Tu: tensile strength of ultimate
K: parameter
s: suffix indicating wire rope
c: suffix indicating concrete
y: suffix indicating yielding
u: suffix indicating ultimate
ϕ: rotation strain

3. Assamptions

1. Plane section remain plane after loading (assumption of Bernoulli or Navier)

2. Maximum compressive strain at the extreme concrete fiber of slit tending to close at ultimate flexural moment is 0.003.

3. Stress-strain curve of wire rope is as shown in FIG. **27.**

4. Values of ku are taken as follows:

Fc kg/cm²	Ku	Fc kg/cm²	Ku
250	0.8	400	0.7
300	0.76	500	0.63

5. Concrete cover to wire rope on both tension and compression faces shall be as follows:

$dc = 0.1d$, $dt = 0.1D$

FIG. **25** shows the change of stress distribution with load increse up to the ultimate flexural moment.

FIG. **26** shows strain distribution.

FIG. **27** shows stress-strain curve of an extra coarse-laid wire rope, where *a* is a difference of strain at yield point (a case of compressive strain)

4. Derivation of Fundamental Equations

4.1—Ultimate flexural moment cut neglecting the tensile stress in concrete

$$Tu = cCu + wCu \quad (1)$$

$$Tu = wTu + cTu$$
$$w\sigma y = wEt(w\epsilon ty - a) \quad (2)$$

$$Tu = w\sigma y\ Pt\ bd \quad (3)$$

$$Tu = wEt(w\epsilon ty - a)\ Pt\ bd \quad (4)$$

$$cCu = Ku\ Fc\ Xnub \quad (5)$$

$$wCu = rPt\ w\sigma y\ bd \quad (6)$$

$$wCu = rPt\ wEt(w\epsilon ty - a)\ bd \quad (7)$$

Where

$$w\epsilon cu \geqq (w\epsilon ty - a)$$
$$M = Tuj \quad (8)$$

$$j = \frac{7}{8}d$$

$$M = 0.875\ wEt(w\epsilon ty - a)w\epsilon ty - a)Ptbd^2 \quad (9)$$

$$M = (cCu + wCu)j \quad (10)$$

$$M = 0.875\ bd^2\{Ku\ Xnul\ Fc + rPt\ wEt(w\epsilon ty - a)\} \quad (11)$$

Therefore the neutral axis ratio *Xnul* can be expressed as follows

$$Xnul = \frac{1}{KuFc}\left\{\frac{M}{0.875bd^2} - rPtwEt(w\epsilon ty - a)\right\} \quad (12)$$

Considering equations (9) and (10), the balanced neutral axis ratio will be given by equation (13) as

$$Xnulb = \frac{wEt(c\epsilon y - a)\ (1 - rPt)}{KuFc} \quad (13)$$

Balanced ratio of wire rope reinforcement can also be obtained from equations (9) and (10)

$$Pbt = \frac{Ku\ Xnul\ Fc}{wEt(w\epsilon ty - a)\ (1 - r)} \quad (14)$$

Replacing *Fc* in equation (11) by stress of resistance $c\sigma c$, can be expressed as equaton (15).

$$c\sigma c = \frac{\frac{M}{0.875\ bd^2} - rPt\ wEt(w\epsilon ty - a)}{Ku\ Xnul} \quad (15)$$

Equations (2) and (11) give

$$M = 0.875bd^2(Ku\ Xnul\ Fc + rPt\ w\sigma y) \quad (16)$$

Replacing $s\sigma y$ in equation (16) by $s\sigma t$, we obtain the following equation for $s\sigma t$

$$w\sigma t = \frac{\frac{M}{0.875bd^2} - Ku\ Xnul\ Fc}{rPt} \quad (17)$$

4.2–At ultimate flexural moment considering the concrete tensile stress

$$\phi = \frac{Ft}{(K\ \frac{d}{0.9} - Xnu)\ cEt}$$

$$\phi = \frac{Ft}{d\ \left(\frac{K}{0.9} - Xnul\right)\ cEt} \quad (18)$$

$$cEt = \frac{Fc}{c\epsilon tu} \quad (19)$$

$$\phi = \frac{Ft\ c\epsilon tu}{d\ \left(\frac{K}{0.9} - Xnul\right)\ Fc} \quad (20)$$

It is assumed that

$Fc = 10Ft$,

$$\phi = \frac{c\epsilon tu}{10d\ \left(\frac{k}{0.9} - Xnul\right)} \quad (21)$$

Ex. 1—Claculation of the rotation strain ϕ assuming $c\epsilon cu = 0.0006$ and $c\epsilon ty = 0.0011$

Let's suppose $Xnul = 0.3$, $d = 40$ K value varies in the interval off equation (FIG. 1) according to the following condition.

$$1 \geqq K \geqq 0.9\ Xnul \quad (22)$$

Let's take value of $K = 0.1$, then the value of ϕwill be given as fallows.

$$\phi = \frac{0.0006}{400\ \left(\frac{0.1}{0.9} - 0.3\right)} = \frac{5}{100{,}000cm}$$

4.3—K value at ultimate flexural moment neglecting the concrete tensile stress is given by the equation.

$$d\ \frac{k}{0.9} - Xnu = 0$$

$$\frac{k}{0.9} = Xnu$$

$$K = 0.9Xnul \quad (23)$$

Supposing that $d = 40$cm, then *Xnul* is 12cm, Therefore,

$$40 \times \frac{0.27}{0.9} - 12 = 0$$

4.4—Equations at ultimate flexural moment considering the concrete tensile stress are as follows

$$\frac{w\epsilon tu}{c\epsilon tu} = \frac{d - Xnu}{d\ \frac{k}{0.9} - Xnu} \quad (24)$$

$$= \frac{1 - Xnul}{\frac{k}{0.9} - Xnul}$$

$$\frac{w\epsilon ty}{c\epsilon tu} = \frac{0.9 - 0.9\ Xnul}{K - 0.9\ Xnul} \quad (25)$$

$$w\epsilon tu = c\epsilon tu\ \frac{0.9 - 0.9\ Xnul}{K - 0.9\ Xnul} \quad (26)$$

$$w\sigma tu = w\epsilon tu\ wEt \quad (27)$$

$$w\sigma tu = c\epsilon tu\ wEt\ \frac{0.9 - 0.9\ Xnul}{K - 0.9\ Xnul} \quad (28)$$

$$c\epsilon tu = \frac{Ft}{cEt}$$

Modular ratio

$$n = \frac{uEt}{cEt}$$

Therefore,

$$w\sigma tu = \frac{Ft\ wEt}{cEt}\left(\frac{0.9-0.9\ Xnul}{K-0.9\ Xnul}\right) \quad (29)$$

$$w\sigma tu = Ft\ n\ \frac{0.9-0.9\ Xnul}{K-09.\ Xnul} \quad (30)$$

Ex. 2—Calculation of ultimate flexural moment assuming that $Fc = 300$, $Ft = 30$, and $n = 18$, respectively.

The value of K varies in the interval of

$1 \geqq K \geqq 0.9\ Xnul$

If we assume $K = 0.3$, equation (30) become

$$w\sigma tu = \frac{0.9 - 0.27}{K - 0.27}\ nFt$$

$$w\sigma tu = \frac{0.63}{0.03} \times 18 \times 30 = 11.340\ \text{kg/cm}^2$$

Therefore, if a wire rope of size No. 6 × 7 (See FIG. **28**) is selected, it gives $w\sigma tu$

(17,798 kg/cm² ∴ OK)

4.5—The case in which the concrete tensile stress is nealy equal to zero

Ex. 3—Assuming $K = 0.28$, and substitute it into the equation

$$w\sigma tu = \frac{0.63}{0.01} \times 18 \times 30 = 37.020\ \text{kg/cm}^2$$

In this case, if we select the wire rope No. 3 × 9 (See FIG. **29**) it gives $w\sigma tu$

(37.068 kg/cm² ∴ OK)

4.6—The value of $x\sigma t$ is below its ultimate strength

In this case we obtain the value of $s\sigma t$ by selecting $K = 1$ under the condition of

$w\sigma t < w\sigma ty < w\sigma tu$

$$w\sigma t = Ft\ n\ \frac{0.9\ (1 - Xnl)}{1 - 0.9\ Xnl} \quad (31)$$

4.7—Ductility factor of wire rope concrete member is defined by the following equation

$$\mu = \frac{\frac{1}{cpcu}}{\frac{1}{wpty}} = \frac{wpty}{cpcu} \quad (32)$$

$\frac{1}{cpcu}$:

curvature of the section at ultimate flexural moment

$\frac{1}{wpty}$:

curvature of the section when the stress of wire rope in tension side reached the yield stress.

-continued

$$\frac{1}{cpcu} = \frac{c\epsilon cu + w\epsilon tu}{d} \quad (33)$$

$$\frac{1}{wptu} = \frac{c\epsilon cy - w\epsilon ty}{d} \quad (34)$$

$$\mu = \frac{c\epsilon cu - w\epsilon tu}{c\epsilon cy - w\epsilon ty} \quad (35)$$

5. Ductility of wire rope concrete member

5.1—Ductility factors of Tu, wCu, cM, wM, $c\sigma c$ and $w\sigma t$.

Each value of ductility factor can be obtained by substituting equation (35) into

equation (4) for Tu

$$Tu = wEt\left(\frac{c\epsilon cu + w\epsilon tu}{\mu} - c\epsilon cy - a\right) Pthd \quad (36)$$

equation (7) for wCu $wCu = rPtwEc \times$

$$\left(\frac{c\epsilon cu + w\epsilon tu}{\mu} - c\epsilon cy - a\right) bd \quad (37)$$

equation (9) for cM $cM = 0.875\ wEt \times$

$$\left(\frac{c\epsilon cu + w\epsilon tu}{\mu} - c\epsilon cy - a\right) Pthd^2 \quad (38)$$

equation (11) for wM $wM = 0.875\ bd^2 \times$

$$\{Ku\ Xnul\ Fc + rPtwEc\left(\frac{c\epsilon cu + w\epsilon tu}{\mu} - c\epsilon cy - a\right)\} \quad (39)$$

equation (15) for $c\sigma c$ $c\sigma c =$

$$\frac{\frac{M}{0.875bd^2} - rPtwE\left(\frac{c\epsilon cu + w\epsilon tu}{\mu} - c\epsilon cy - a\right)}{Ku\ Xnul} \quad (40)$$

equation (28) for $w\sigma t$ $w\sigma t = \frac{M}{0.875bd^2rPt} -$

$$\frac{Ku\ Xnul\ w\sigma tu\left(\frac{k}{0.9} - Xnul\right)\phi}{n\{(c\epsilon cy + w\epsilon ty)\ \mu - c\epsilon cy\}rPt} \quad (41)$$

5.2—The ductility factor for $Xnulb$ and Ptb can be obtained in the same manner as shown above, each value can be obtained by substituting the of equation (35) into

equation (13) for $Xnulb$ $Xnulb =$

$$\frac{wE\left(\frac{c\epsilon cu+w\epsilon tu}{\mu} - w\epsilon ty - a\right)\ 1-r\ \ Pt}{Ku\ Fc} \quad (42)$$

equation (14) for Ptb $Ptb =$

$$\frac{Ku\ Xnul\ Fc}{wE\left(\frac{c\epsilon cu+w\epsilon tu}{\mu} - c\epsilon cy - a\right)\ 1-r} \quad (43)$$

6. In Conclusion

Various design charts are now under preparation, and N values will be decided from the data from preliminary tests.

Next, described are actual examples of designs of the conventional deformed bar concrete structure (RC structure) (Case 1) and the WRRC structure (Case 2):

The buildings of both the structures Case 1 and Case 2 were designed under the same conditions, for comparison's sake. The outlines and conditions of the buildings to be constructed of such structures are as follows: FIGS. **30** and **31** are rough plan and sectional views of the building to be designed, respectively. This building is intended for a multi-story appartment house

having eight stories above and one floor under the ground, and also having a penthouse with two stories above. It is constructed to have an underground parking place, a restaurant on part of the first floor, dwellings on the second through the eight floors, a penthouse, a machinery room, an attic floor water tank, etc. The size of the reinforcing bar to be used in Case 1 is SD40 (JIS G 3112, 1964 see Page 14, Table 1 of this specification), and the size of the extra coarse-laid wire rope for Case 2 is WD120 (see Page 14, Table 1 of this specification), the concrete for both Cases having a 28 day post-mixing compressive strength of $28Fc = 270kg/cm^2$.

Cases 1 and 2 were designed under the above-mentioned same conditions. New description is made with respect to the typical column of the first floor (FIG. 32), and the beam of the second floor (FIG. 33). As seen from FIG. 32, the column of the first floor of the WRRC structure was reduced by 64% in sectional area ratio, and by 43% in steel ratio. Of course, similar results were obtained by the column of the second floor or above. As evident from FIG. 33, the beam of the present invention could be reduced by 61% in sectional area ratio, and 18% in steel ratio. Similar results were obtained by the beam of the third floor or above.

As a whole of the building, the column and the beam of the WRRC structure according to the invention were reduced by 35 – 55% and 20 – 40% in sectional area ratio, respectively. In steel ratio, they were reduced by 55 – 65% and 65 – 85%, respectively.

The building employing the present invention may advantageously be constructed in the following sequence:

First, a temporary work, an earthwork, and a foundation and foundation slub work are effected in the mentioned order. Following these series of works, a reinforcing work is executed which comprises the step of arranging wire ropes and hoop steel wires or wire gauze so as to form concrete moulds. Usually this work is done for columns, walls, beams, and slubs in said order. Then, concrete works in the order of columns, walls, beams, and slubs, to be followed by a waterproofing work, and a finish work in a conventional manner.

According to the WRRC structure, large simplification of the reinforcing work is feasible, as compared with the conventional RC structure, particularly in respect of the construction term. In addition, assembly of the columns and beams may be speeded up because of employment of the special connecting means as aforementioned.

As will be learned from the aforementioned structure of the present invention and the various test data, in place of steel frame, and reinforcing bars as mainly used in the conventional structures such as RC, SRC, SPC, PS, or dam structures, extra coarse-laid wire ropes are embedded in concrete columns and beams of the present invention, to be followed by mutually fastening of the wire ropes of the columns and beams at the intersecting points by means of special fasteners. Thus, in the columns and beams throughout the whole building are provided extra coarse-laid wire ropes mutually integrally connected together at their associated ends.

In conventional structures employing steel frames and/or reinforcing bars, compressive strength and bending stress are mainly undertaken by the concrete itself, and tensile strength and bending stress by the steel frames and/or reinforcing bars. Whilst, in the present invention, as evident from the above-mentioned test results, the extra coarse-laid wire ropes, used in lieu of steel frame or reinforcing bars, the adhesive power between the extra coarse-laid wire ropes and the concrete is outstandingly excellent relative to the steel frame or the reinforcing bar, by virtue of their specially configurated surfaces and unique properties, thus being free from their rubbing against the concrete. Further, as compared with the steel frame or reinforcing bars, the extra coarse-laid wire rope has higher restitution coefficient per se, enough to be more easily restituted into a pre-deformation state shortly after the load is released. For these reasons, the WRRC structure according to the present invention always acts in one body smoothly coping with all directional external forces applied to the structuree, thus exhibiting tenacity (or toughness). In addition, it may have a higher critical breaking stress, thus being excellent in mechanical strength. As mentioned before, the column and beam according to the invention, if they are given the same strength, may have reduced sectional areas by 35 – 55% and 20 – 40%, respectively. Therefore, more efficient use may be feasible of a given site or a dwelling space. As for the amount of steel (or material) required, large reduction may be possible, i.e., by 55 – 65% for columns, and by 65 – 85% for beams, which may lead to large curtailment of costs and considerable reduction in the weight of the whole structure.

Further, with the above-mentioned construction that the extra coarse-laid wire ropes arranged straight throughout the whole building or the like are all integrally joined together, the external forces applied to the structure are instantly transmitted from the force applied part of the wire rope to any other parts thereof or other wire ropes through the wire ropes to be thus dispersed. Thanks to the presence of air-gaps in the interior of the wire rope as unseen in steel frame of reinforcing bars, internal forces generated by external forces applied to the wire rope are absorbed into the air-gaps and consequently well damped. Therefore, partial destruction of the structure may be effectively avoided. Further, in the event of the building or the like employing the present structure being inclined, the whole building or the like is supported by the groups of extra coarse-laid wire ropes on the opposite side thereof to the direction of inclination, thus being prevented from falling down (In this moment, the concrete acts as a supporting rod). Thus, it is to be noted that the structure according to the invention is largely improved also in earthquake resistance. Also in the event of a fire, the heat energy may be more efficiently absorbed into the air-gaps existent in the extra coarse-laid wire ropes, in a similar manner. Thus, it has superior fire-resistance as well.

In addition, the extra coarse-laid wire ropes may be incorporated into the columns or beams of the structure in a more simple manner than the conventional steel framed structure, thus resulting in a shortened term of construction of the buildings or the like constructed according to the invention.

As stated in the foregoing, the WRRC structure according to the present invention is a novel organic structure which provides better resistance to earthquake, explosion, and fire, as compared with the conventional ones.

While a few particular embodiments have been described to the better understanding of the invention, it is to be understood that the present invention is appli-

cable to any other structure without departing from the scope of the appended claims.

What we claim is:

1. A reinforced concrete structural member adapted for buildings and the like, comprising:

a concrete column;

a plurality of extra coarse-laid wire ropes each comprising a plurality of strands each incorporating a plurality of wires laid helically in the same angular sense to provide a built-up lay, at least two strands each incorporating a plurality of wires, said at least two strands each being of at least as great diameter as the first-mentioned strands and being helically wound in two angularly opposite senses upon said built-up lay so as to cross one another at a phase angle of about 180°, the at least two strands being spaced to expose said lay exteriorly of the wire rope, between the at least two strands so the wire rope has a substantially greater diameter at the crossings of said at least two strands than where said lay is exposed exteriorly of the wire rope;

said extra coarse-laid wire ropes directly embedded in said concrete column in a three-dimensional array, in a fashion longitudinally vertically extending straight through the concrete column, but is an unstrained but unloosened stated, to reinforce the concrete column;

an open-work wrapping of steel wires or wire gauze or the like directly disposed about said array in a wrapped or wound fashion;

a concrete beam unitary with said concrete column;

a plurality of extra coarse-laid wire ropes having a structure the same as said first-mentioned extra coarse-laid wire ropes, directly embedded in said concrete beam near the upper and lower extent thereof, in a fashion longitudinally horizontally extending through the concrete beam, but under an unstrained but unloosened state, to reinforce the concrete beam;

an open-work wrapping of steel wires, or wire gauze, or the like directly disposed about said second-mentioned extra coarse-laid wire ropes;

the extra coarse-laid wire ropes of the column and beam crossing one another where the column and beam join one another; and

connecting means fastening the extra coarse-laid wire ropes of the column to the wire ropes of the beam where these wire ropes cross one another.

2. The reinforced concrete structural member as claimed in claim 1, wherein said connecting means essentially consists of a body of tubular shape formed with a plurality of through holes over the surface thereof in random arrangement, the extra coarse-laid wire ropes of the columns and beamd each having an end portion thereof inserted through at least two said through holes in random directions, in a fashion that the end portion has acute turns of such an extent as to permit the wire rope end portion to be urgingly and frictionally caughted by the mouth edge of the through holes.

3. The reinforced concrete structural member as claimed in claim 1, wherein said connecting means essentially consists of a body of spheric shape formed with a plurality of through holes over the surface thereof in random arrangement, the extra coarse-laid wire ropes of the columns and beams each having an end portion thereof inserted through at least two said through holes in random directions, in a fashion that the end portion has acute turns of such an extent as to permit the wire rope and portion to be urgingly and frictionally caughted by the mouth edge of the through holes.

4. A reinforced concrete structural member adapted for buildings and the like, comprising:

a concrete column;

a plurality of extra coarse-laid wire ropes each comprising a plurality of strands each incorporating a plurality of wires laid helically in the same angular sense to provide a built-up lay, and a plurality of transversely extending, axially regularly spaced metallic cross pieces incorporated in said lay and having both ends of each piece protruding substantially outwardly of said lay, and ball means secured on the protruding end of each cross piece, said extra coarse-laid wire ropes directly embedded in said concrete column in a three-dimensional array, in a fashion longitudinally vertically extending straight through the concrete column, but in an unstrained but unloosened state, to reinforce the concrete column;

an open-work wrapping of steel wires or wire gauze or the like directly disposed about said array in a wrapped or wound fashion;

a concrete beam unitary with said concrete column;

a plurality of extra coarse-laid wire ropes having a structure the same as said first-mentioned extra coarse-laid wire ropes, directly embedded in said concrete beam near the upper and lower extent thereof, in a fashion longitudinally horizontally extending through the concrete beam, but in an unstrained but unloosened state, to reinforce the concrete beam;

an open-work wrapping of steel wires, or wire gauze, or the like directly disposed about said second-mentioned extra coarse-laid wire ropes;

the extra coarse-laid wire ropes of the column and beam crossing one another where the column and beam join one another; and

connecting means fastening the extra coarse-laid wire ropes of the column to the wire ropes of the beam where these wire ropes cross one another.

5. The reinforced concrete structural member as claimed in claim 4, wherein said connecting means essentially consists of a body of tubular shape formed with a plurality of through holes over the surface thereof in random arrangement, the extra coarse-laid wire ropes of the columns and beams each having an end portion thereof inserted through at least two said through holes in random direction, in a fashion that the end portion has acute turns of such an extent as to permit the wire rope end portion to be urgingly and frictionally caughted by the mouth edge of the through holes.

6. The reinforced concrete structural member as claimed in claim 3, wherein said connecting means essentially consists of a body of spheric shape formed with a plurality of through holes over the surface thereof in random arrangement, the extra coarse-laid wire ropes of the columns and beams each having an end portion thereof inserted through at least two said through holes in random direction, in a fashion that the end portion has acute turns of such an extent as to permit the wire rope and portion to be urgingly and frictionally caughted by the mouth edge of the through holes.

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