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F. EMPERGER
REINFORCED CONCRETE
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2,255,022

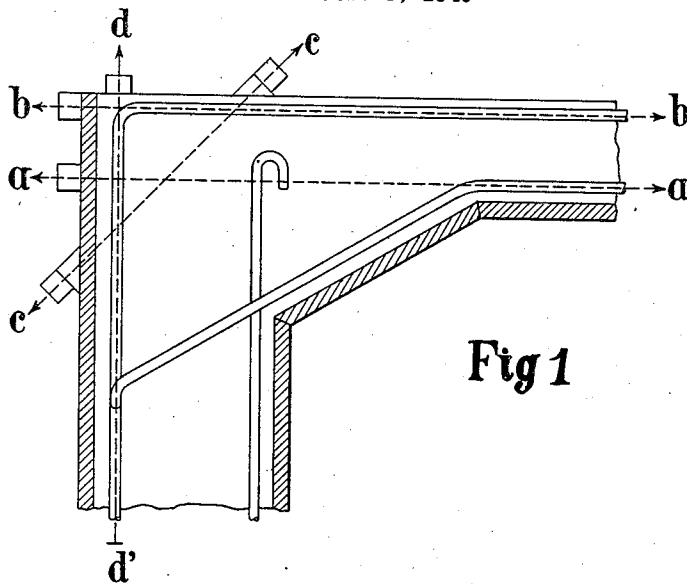


Fig 1

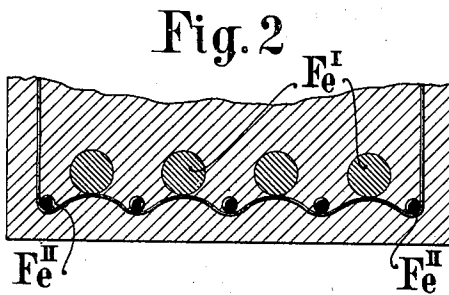


Fig. 2

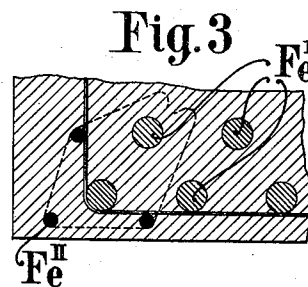


Fig. 3

Fig. 4

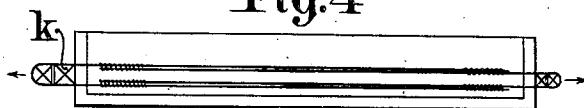
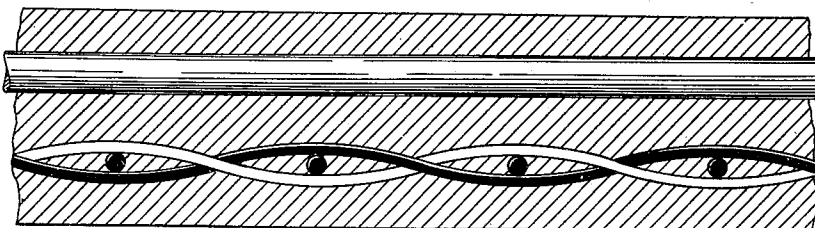


Fig. 5



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REINFORCED CONCRETE

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The invention refers to objects or structures of reinforced concrete, such as girders, arches, frames, beams, and parts thereof.

The concrete of structures of such type is subject to cracks in zones where tensile stresses occur under load, and it has been suggested to prevent formation of such cracks and to increase the strength of the structure by preliminary or prestressing all the reinforcements which therefore had to be made of high quality steel. Considerable difficulties were met however, in manufacturing such concrete bodies or structures either in a plant or in situ, i. e. at the place where they were to be used, in that uniformly prestressing a great number of reinforcements requires complicated apparatus and great care in their use, and the great number of relatively thin reinforcements of high quality steel considerably increased the cost.

Taking a cylindrical reinforcement embedded in concrete, it has been shown (cf. O. Graf "Beton und Eisen," 1910, p. 177 and "Handbuch für Eisenbetonbau," 4th ed., first vol., p. 40) that the increase in plasticity of the concrete by reinforcement is very small, and the less the thicker the layer or body of concrete covering the reinforcement is. The maximum plastic or elastic deformation of a layer of 2 mm. thickness around the cylindrical reinforcement has been found to be 0.4% at most before rupture occurs, and if the thickness of the covering cylindrical layer or body amounted to 30 mm., the maximum elongation without rupture has been found to be only 0.2%. Taking a steel the elongation of which amounts to 0.2% at a stress of 400 kg./sq. cm., the covering layer of 30 mm. thickness will yield and form cracks if that stress of 400 kg./sq. cm. is exceeded.

Taking however a higher quality steel the elongation of which amounts to 1.4% at a stress of 2800 kg./sq. cm., experiments made by the inventor have shown that a relatively thin cover of concrete will be sufficiently plastic so as to crack only at the yield point of that high quality steel.

It has been suggested therefore to use high quality steel for reinforcements of concrete and to arrange them in such numbers and proximity to each other, furthermore to prestress them uniformly to such an extent that due to the bond of the set and shrunk concrete with the individual reinforcements, crack formation was prevented under predetermined maximum load. The compressive stresses exerted by the prestressed reinforcements through the bond upon

the concrete were so high that they counterbalanced the tensile stresses exerted upon the concrete by the predetermined maximum load.

It has been found however that crack formation is not dangerous as long as cracks, when formed, are prevented from widening in continuous use and under recurrent load, and substantially close when the load is moved.

Hence it follows that the reinforcements should be prestressed only to such an extent that the compressive stresses exerted by them upon the concrete bonded with them suffice to substantially close the cracks under dead load.

Even if prestressing is limited in this way, or highly prestressed reinforcements are arranged in such distance from each other that the compressive stresses produced by them in the concrete bonded with them suffice to substantially close cracks produced by the live load, their number is still great and the difficulties as to uniformly prestressing them as well as their high cost persist.

It is therefore an object of the invention to reduce the cost of manufacturing in a plant or in situ of objects or structures of reinforced concrete the hair line cracking of which is reduced by prestressing those reinforcements.

It is another object of the invention to increase the strength and reduce the crack formation of objects or structures of reinforced concrete in which the reinforcements are prestressed.

It is still another object of the invention to secure more uniform prestressing of those reinforcements.

It is still another object of the invention to reduce the amount of high quality steel used in reinforced concrete the reinforcements of which are prestressed.

It is still a further object of the invention to prolong the life of objects or structures of reinforced concrete by reducing the width of cracks formed under predetermined maximum live load and causing the cracks to substantially close under dead load by the use of prestressed reinforcements.

It is still a further object of the invention to prevent hair line cracking in reinforced concrete structures.

It is still another object of the invention to improve the property, in particular the tensile strength of the concrete used in reinforced concrete structures.

According to the invention main reinforcements or rods are used and disposed in the usual

manner, and in addition thereto prestressed other preferably rod-like reinforcements. While the main reinforcements preferably consist of ordinary steel as heretofore used for reinforcements, the additional reinforcements consist of a higher quality steel, i. e. a steel of superior tensile strength and yield point than the steel used for the main reinforcements. The number of additional reinforcements will be considerably smaller than that of higher quality steel reinforcements heretofore used in reinforced concrete objects in which all the reinforcements consisted of higher quality steel which had been prestressed.

Furthermore, uniform prestressing of the relatively small number of additional reinforcements can more easily be effected than prestressing of all the reinforcements of high quality steel. It is also possible to cut these additional reinforcements so as to cover only regions or zones in which tensile stresses under maximum load occur which might cause dangerously wide, or gaping cracks. In particular, the cut pieces of the additional reinforcements can be arranged in any desired manner and relative configuration so as to follow e. g. a curved or polygonal structure and its axis.

The objects and nature of the invention will be more clearly understood when the specification proceeds with reference to the drawing in which Fig. 1 shows more schematically in a section taken in the direction of the reinforcing bars or rods the arrangement of main reinforcements and prestressed additional reinforcements in a corner of a reinforced concrete frame or arch; Figs. 2 and 3 show each a cross section through the web of a T-girder, the prestressed additional reinforcements being arranged in the lower portion or the corners of the web in which hair line cracks are most likely to form; Fig. 4 shows more schematically a method and means for preliminary or prestressing the additional bars or rods positioned in a form for molding a reinforced concrete beam; and Fig. 5 shows a cross section taken along a main reinforcement through a piece of concrete in which twisted or plaited, prestressed additional bars or wires are used to form a lattice work or netting.

Referring to Fig. 1, the corner portion of the mold or form in which the reinforced concrete structure forming a frame or arch is to be made is shown in cross section. Bent and otherwise suitably shaped main reinforcements or bars preferably of ordinary steel are shown therein in elevation. The position of additional preferably rod-like reinforcements of high quality steel which are to be prestressed is shown in dotted lines. Thus, additional reinforcements should be arranged in the horizontal planes shown in dotted lines *a-a* near the bottom and *b-b* near the top of the girder or beam forming the upper part of the frame or arch. Other additional reinforcements should be arranged in the plane *d-d'* in the upright forming the lateral part of the frame or arch. Additional reinforcements may also be arranged in the plane *c-c* across the corner, the additional reinforcements thus shown resulting in a polygonal arrangement composed of groups of additional reinforcements arranged in different planes. Removable abutments on the mold can be provided for prestressing the additional reinforcements, as indicated in Fig. 1; the prestressed reinforcements may also be anchored in the foundation, or

wherever it is suitable. After the main reinforcements or rods have been placed in the mold or form and the additional preferably rod-like reinforcements uniformly prestressed, the concrete is poured or pressed into the mold, tightly around all those reinforcements, and allowed to set and shrink, whereby a tight and firm bond between the concrete and all the reinforcements is effected.

After the prestressed additional reinforcements have thus been firmly bonded with the concrete so that the prestress applied to them is maintained in them by that bond, the removable means, if any, for prestressing them relative to the form or mold, as well as the latter, can be removed.

The main reinforcements preferably consist of rods of ordinary steel as heretofore used for this purpose and have in any case a lower yield point and tensile strength than the additional reinforcements.

The total area of the cross sections of the main reinforcements is F_e^I (also designated with A_e^I); the total area of cross sections of the additional reinforcements is F_e^{II} (also designated with A_e^{II}).

The total area of all the reinforcements, main and additional, $F_e = F_e^I + F_e^{II}$.

The main reinforcements have a yield point of f_y^I which is considerably lower than the yield point f_y^{II} of the additional reinforcements. Calling the average yield point of the two kinds of steel used for the main and additional reinforcements f_y^{III} , prestressing of the additional reinforcements should be effected to such an extent at the maximum that desired safety, and preferably double safety is obtained with respect to that average yield point f_y^{III} .

Although the additional reinforcements also add to the overall strength of the reinforced structure and their presence and cross sections, etc., are to be duly taken into consideration in calculating the structure, it should be understood that the prestressing of the additional reinforcements in the main serves to reduce the width of the hair line cracks if and when they occur under predetermined maximum or permissible load, or to prevent their coming into existence.

As stated above, prestressing of reinforcements embedded in and thereby bonded with the set and shrunk concrete results in compressive stresses within the body of the concrete surrounding each individual prestressed reinforcement, the absolute amounts of those compressive stresses forming a maximum close to the reinforcement and quite rapidly decreasing with the distance from that prestressed reinforcement.

Referring to Fig. 2 it will be appreciated therefore that the compressive stresses imparted to the concrete body or layer surrounding each individual additional reinforcement indicated by F_e^{II} will reach an adjacent main reinforcement indicated by cross hatching and reference character F_e^I , it being understood that the number of those additional reinforcements and their distance from the main reinforcements be such that this result can be obtained. Therefore, if in the concrete of that cross section tensile stresses are produced by a live load, they will be counteracted by those compressive stresses, and if the tensile stresses thus imparted to that cross section are greater than the compressive stresses and therefore eventually result in hair line cracks, the width of the latter will be considerably smaller than it would be if no prestressed additional reinforcements were present. Hence it follows

that by the use of main reinforcements and a relatively small number of additional prestressed reinforcements of a steel of higher quality than the main reinforcements, furthermore by arranging the prestressed additional reinforcements in suitable proximity to the main reinforcements so that the compressive stresses are transmitted up to the main reinforcements, and finally by arranging the prestressed additional reinforcements in regions of the cross section and in suitable relation to a surface most endangered by tensile stresses caused therein by the load, the formation of hair line cracks of dangerous or undesirable size and width can successfully be prevented. The number of additional reinforcements and the extent of their prestressing can easily be calculated or ascertained by a few experiments in each individual case, and the maximum preliminary stress put on the additional reinforcements should be such that an average double safety or any other desired or prescribed safety of the structure is secured.

It will furthermore be appreciated from the showings of Figs. 2, 3 and 5 that the cross section of the individual rod-like main reinforcements is advantageously considerably larger than that of the additional rod-like reinforcements and consequently the total area F_{eI} will very considerably exceed the total area F_{eII} .

The load, dead as well as live, will therefore be carried in the main by the main reinforcements. As to the prevention of dangerous crack formation, or reduction of the size of the cracks formed under live load, to a desired extent, the prestressing of the additional reinforcements comes decisively into play.

Besides the number of individual additional reinforcements, also their tensile strength and yield point has to be taken into consideration.

Corners of reinforced concrete structures are particularly subject to hair line cracking and should be reinforced in the way to be derived from Fig. 3 without further comment.

Though anybody skilled in the art is capable of applying the invention in practice, it should be mentioned that according to tests carried out by the inventor, high quality steels can be successfully used for additional reinforcements having a safe tensile strength of 1000 to 1200 kg./sq. cm., this value to be taken as a basis for calculation of their permissible prestressing.

Most surprisingly, the tensile strength of the concrete, as small as it may be, can also be taken into consideration in calculating the structure according to the invention. With normal concrete of present time manufacture about 20 to 30 kg./sq. cm. tensile strength can be assumed for a concrete mass undergoing bending by the live or dead load. Due to the compressive stresses imparted to the concrete according to the invention, tensile strengths up to 50 and 75 kg./sq. cm. can safely be made a basis for calculation; in other words, if tensile stresses imparted to the most stressed zone of a structure by the dead and live load do not exceed 50 to 75 kg. per sq. cm., the concrete will neither loosen from the reinforcements, nor crack. Now, in calculating the structure, its cross section has to be taken into consideration in which the largest tensile stress occurs under predetermined maximum load. It is common to consider in such case only the total tensile strength of the reinforcements positioned in the stressed area of that cross section. If however the tensile stress

per sq. cm. in that area does not exceed 50 to 75 kg., the tensile strength of the concrete in that area can be taken into consideration in addition to that of the total tensile strength of the reinforcements, main and additional, arranged in that area. If however calculation shows that the tensile stresses in the last mentioned area exceed that maximum value per unit of area, crack formation will occur, and consequently the old rule of basing the calculation only on the total tensile strength of all the reinforcements positioned in that stressed area of the cross section should be applied.

Heretofore hair line cracking was permitted and by and by the cracks extended from the outer surface of the stressed portion of the structure to its neutral axis. They gaped widely and thus admitted moisture into the interior of the structure which corroded the reinforcements and weakened the concrete. By arranging additional reinforcements according to the invention, particularly in the endangered zones of the most stressed cross section and near its outer surface, such dangerously gaping cracks can either be prevented or their width under predetermined load be reduced. It is a preferred feature of the invention to measure the degree of prestress on the additional reinforcements, furthermore to choose their number and distance from the main reinforcements so that under dead load the compressive forces produced by the prestressed additional reinforcements suffice to substantially close the cracks when formed under predetermined maximum live load.

Since the compressive stresses produced in the body of the concrete closely surrounding the prestressed additional reinforcements quasi improve the properties of that concrete in the way described above, it is even possible to use for the purposes of the invention concrete of lower quality than heretofore used for structures of same dimensions, purposes and loads. On the other hand, with that improvement in quality of the concrete according to the invention, reinforced concrete can be used for purposes heretofore unknown or only to be served by more complicated and expensive structures.

The degree of prestressing of the additional reinforcements depends upon the result to be obtained and particularly the maximum loads to be carried. In many structures and particularly those in which the live load is relatively small compared with the dead load, a low degree of prestressing suffices, and in such cases also the quality of steel used for the additional reinforcements need not considerably exceed that used for the main reinforcements. Since the individual additional reinforcements are of considerably smaller cross section than the individual main reinforcements, wires can be used for the former. Due to the manufacture of wires, their tensile strength and yield point is usually higher than those properties of the bars from which the wires have been drawn. Therefore, if relatively low degrees of prestress are to be applied, it suffices sometimes to use for the main reinforcements thicker rods and for the additional reinforcements drawn wires of substantially the same steel quality.

As pointed out above, all the reinforcements are placed in the mold or form, and prestresses are applied before the concrete is poured into the mold or form. However, it is within the realm of the invention to place all the reinforcements in the mold and to apply the prestressing after the

concrete has been placed in the mold, it being understood that such prestressing has to be performed before the concrete starts to set.

Any means and method for prestressing the additional reinforcements can be applied.

Fig. 4 illustrates schematically the manufacture of a beam or girder in situ or in the plant. Only the additional reinforcements are shown, placed in the mold, and wires attached to the ends of these reinforcements and passed through the front walls of the mold to form a loop. At least within one of these loops a wedge *k* is positioned so that by driving it in, any desired degree of prestress can be applied to the additional reinforcements. After the concrete has been poured into the mold and finally set, the wedge or wedges are removed, the loops cut off, the mold is removed, and any still projecting ends of the pulling wires cut off. Instead of wedges, any other means for accurately effecting prestressing can be used, such as tensometers or expansion meters; also winches and screws can be used stressing the loop in Fig. 4, and by counting the number of revolutions of the screw the accurate stress desired can be applied.

In order to improve the bond between the concrete and the prestressed additional reinforcements, any means known in the art can be used. In particular, the additional reinforcements substantially arranged in the direction of the tensile stresses produced in the concrete by the load may be made of two or more twisted or plaited wires, as shown in Fig. 5, where the upper transverse wire illustrates a main reinforcement and the two plaited wires below an additional prestressed reinforcement. By arranging transverse wires passing the loops of the plaits as shown in Fig. 5, a lattice work or netting of additional reinforcement can be obtained. The transverse wires can be rigidly connected with the plaits, for instance by welding. Such transverse wires at the end of the plaits can then be formed into loops and used for prestressing the plaits in a method as described with reference to Fig. 4.

It will be appreciated from the above that by the invention many outstanding advantages are obtained as to saving of expensive high quality steel, more uniformity and ease of prestressing the relatively small number of additional reinforcements, improvement of the properties of the concrete used, preventing the formation or reducing the size and particularly avoiding dangerous widths of cracks, and prolonging the life of the final structure.

It should be understood that the invention is not limited to any exemplification or illustration herein shown, but to be derived in its broadest aspect from the appended claims.

I claim:

1. A beam, girder or frame structure, or part thereof, substantially consisting of concrete reinforced in the region of tension by rod-like reinforcements of steel and other rod-like reinforcements of superior tensile strength than and supplementing said first mentioned reinforcements, said other reinforcements arranged such distances from said first mentioned reinforcements and being prestressed so that the compressive stresses produced in the body of the concrete bonded with an individual other reinforcement extend to an adjacent main reinforcement.

2. A beam, girder or frame structure, or part thereof, substantially consisting of concrete re-

inforced in the region of tension by rod-like reinforcements of steel and other rod-like reinforcements of superior tensile strength than and supplementing said first mentioned reinforcements, said other reinforcements arranged such distances from said first mentioned reinforcement and a surface under tension of the structure and being prestressed so that the compressive stresses produced in the body of the concrete bonded with an individual other reinforcement extend to an adjacent first mentioned reinforcement and said surface, thereby substantially reducing or preventing hair line cracking of the concrete.

3. A beam, girder or frame structure, or part thereof, substantially consisting of concrete reinforced in the region of tension by rod-like main reinforcements of steel and other rod-like reinforcements of superior tensile strength than and supplementing said main reinforcements, said other reinforcements being sufficiently prestressed and arranged such distances from a surface under tension of the structure subject to hair line cracking under live load so as to keep, by the compressive stresses produced in the concrete by said prestressed other reinforcements, within a predetermined limit the width of such cracks when formed under predetermined maximum live load and to substantially close those cracks when the live load is removed.

4. A beam, girder or frame structure, or part thereof, substantially consisting of concrete reinforced in the region of tension by rod-like main reinforcements of steel and other rod-like reinforcements of superior tensile strength than said main reinforcements, said other reinforcements being prestressed and arranged such distances from said main reinforcements as to substantially improve by the thus produced compressive stresses in the concrete the tensile strength of the concrete bonded with them and supplement said main reinforcements.

5. A beam, girder or frame structure, or part thereof, substantially consisting of concrete reinforced in the region of tension by rod-like main reinforcements of steel and other rod-like reinforcements of superior tensile strength than said main reinforcements, said other reinforcements being prestressed and arranged such distances from said main reinforcements and a surface under tension of the structure so as to improve by the thus produced compressive stresses in the concrete the tensile strength of the concrete bonded with them, supplement said main reinforcements and substantially reduce or prevent hair line cracking of the concrete.

6. A beam, girder or frame structure, or part thereof, substantially consisting of concrete reinforced in the region of tension by main rods of steel and other rod-like reinforcements of superior tensile strength than and supplementing said main rods, said other reinforcements exemplified by steel wires being of considerably smaller cross section than said main rods, said other reinforcements being prestressed and arranged such distances from said main rods and a surface under tension of the structure so as to substantially reduce or prevent hair line cracking of the concrete by the compressive stresses produced in the concrete bonded with said prestressed other reinforcements.

7. A beam, girder or frame structure, or part thereof, substantially consisting of concrete reinforced in the region of tension by main rods of steel and other rod-like reinforcements of superior tensile strength than and supplement-

ing said main rods, said other reinforcements being of substantially smaller cross section than said main rods and combined in networks as exemplified by plaited strands extending substantially in the direction of tensile stresses produced in the concrete under load and wires interlaced with said strands, said wires extending in a substantially vertical direction to said strands, said other reinforcements being sufficiently prestressed

and arranged such distances from said main rods and a surface under tension of the structure as to substantially reduce or prevent hair line cracking of the concrete by the compressive stresses thus produced in the concrete and substantially extending to said adjacent main reinforcements and surface.

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