Dec. 6, 1955 A. LIPSKI 2,725,612

METHOD OF CONSTRUCTING PRESTRESSED REINFORCED CONCRETE BEAMS

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Fig. 1

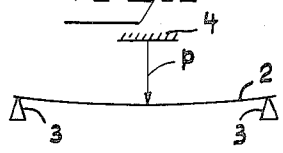


Fig. 2

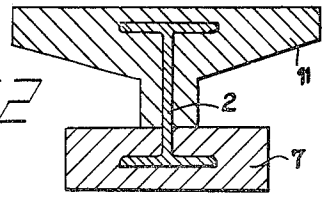


Fig. 3

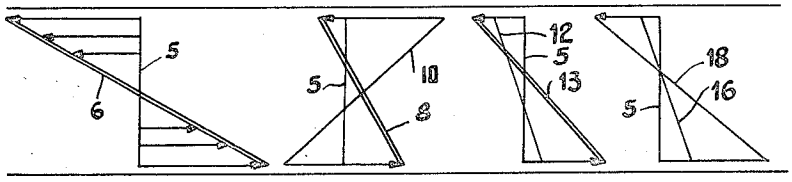


Fig. 4

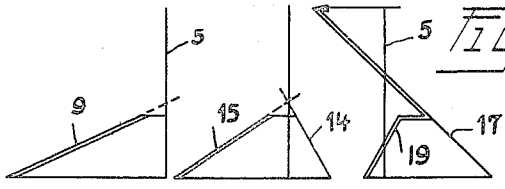


Fig. 5

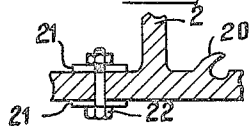


Fig. 7

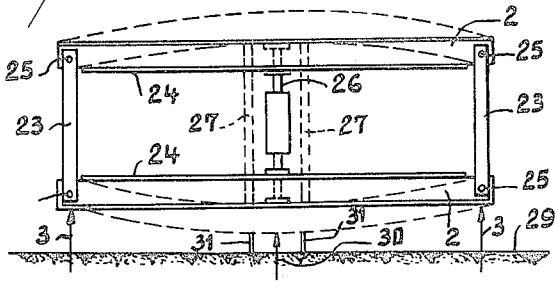


Fig. 6

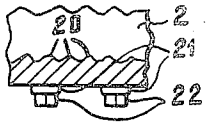


Fig. 8

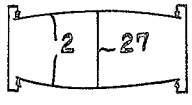


Fig. 9

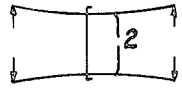


Fig. 10

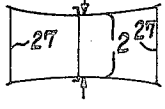


Fig. 11

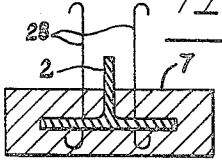
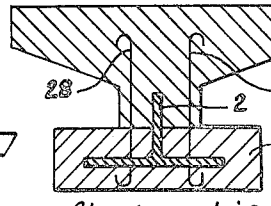


Fig. 12



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METHOD OF CONSTRUCTING PRESTRESSED REINFORCED CONCRETE BEAMS

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Fig. 13

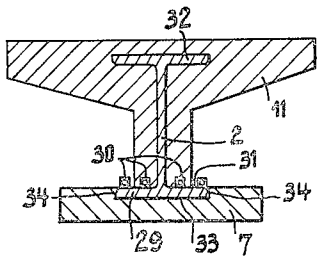


Fig. 14

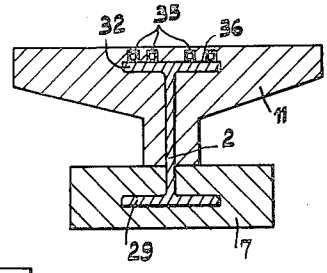


Fig. 15

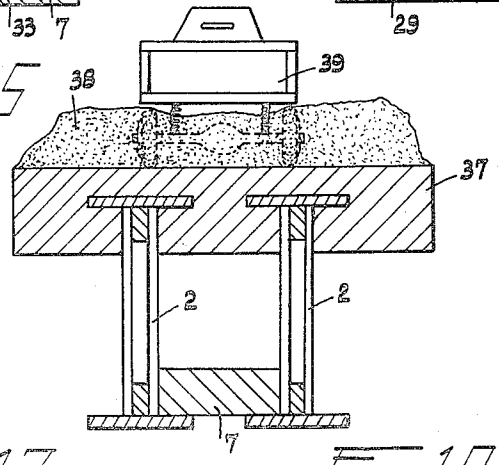


Fig. 17

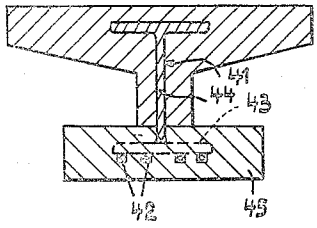


Fig. 18

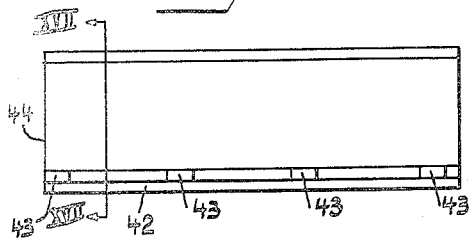


Fig. 16

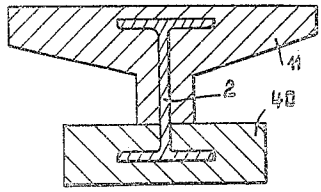
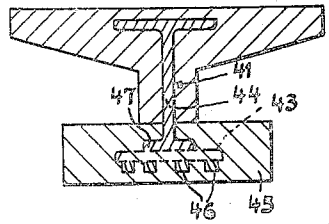


Fig. 19



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2,725,612

METHOD OF CONSTRUCTING PRESTRESSED REINFORCED CONCRETE BEAMS

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Application April 20, 1951, Serial No. 221,967

Claims priority, application Belgium April 24, 1950

11 Claims. (Cl. 25—154)

This invention relates to a method of constructing a beam consisting of a pre-stressed metal reinforcement covered with pre-compressed concrete.

Known methods of constructing pre-stressed concrete beams have as their object the artificial creation of stresses before the beam is placed under load, by means of tension exerted on wires or bars made of steels with high elastic limit. This tension is balanced by a corresponding compression in the concrete.

According to a first main alternative method, the tension is exerted before the concreting of the beam. In this case the tension must be temporarily balanced by a third body, for instance a very rigid mould or an installation with abutments. The concrete covers the pre-tensioned wires and adheres to them. After hardening, the wires are released and the concrete, by means of the forces of adhesion prevents them from shortening so as to return to their original length. The concrete is thereby placed in compression.

The second main alternative method consists in the application of tension to the wires by means bearing against the already existing hardened concrete beam. In this case it is necessary to reserve a space (sheaths for instance) for the wires, in which they are enabled to slide freely. In view of the fact that in this case there can be no adhesion, the wires have to be anchored at the ends by means of special devices and then protected against atmospheric action, usually by covering them or by injection of cement mortar into the sheaths through which they pass.

This invention relates to a method of constructing prestressed reinforced concrete beams which does not present the difficulties inherent in the above-mentioned methods.

In the method according to the invention a rigid metal reinforcement which even by itself constitutes a beam resistant to bending is bent in the direction in which it will bend under the stresses imposed on it in service, and the reinforcement bent in this manner is prevented from returning to its original position under the effect of its elasticity by the fact that concrete is made to adhere to at least part of those fibres of this reinforcement in which the stresses caused by loads imposed in service are tensions.

The bending of the rigid metal reinforcement need not necessarily be effected before the application to those fibres of this reinforcement in which the stresses caused by service loads are tensions, of concrete which prevents the bent reinforcement from returning to its initial position under the effect of its elasticity.

Instead of being prior to the application of the above-mentioned concrete the pre-deflection of the reinforcement may actually be concomitant with this application, or even subsequent to it, provided that the pre-deflection of the reinforcement is effected not later than the moment at which the concerte has become capable of resisting the return of this reinforcement to its initial position under the effect of its elasticity.

In one alternative form of the method, the above-

mentioned reinforcement is pre-deflected mechanically, at least a fraction of the part of the reinforcement subjected to tension as a result of the deflection is covered in concrete, the covered reinforcement is held bent during the hardening of the concrete, and the cause of the bending is removed after the concrete has hardened.

The preliminary bending of the reinforcement, which may advantageously consist of a rolled girder, may be effected very simply by the application of a force at a point on the reinforcement between the ends thereof which are held stationary, or conversely by the application of forces to the ends of the beam, an intermediate point thereof being held stationary.

The covering of at least a fraction of that part of the reinforcement which is subjected to tension, after bending, can be effected relatively easily in any suitable manner.

The use of girders or other rigid metal beams as reinforcements for ordinary reinforced concrete beams is known, and produces the known covered framework, the possibilities of which are however limited by the following considerations:

(1) Since it is not pre-compressed, the concrete cannot follow the stretched fibres of the metal without cracking, when their tensile stress is greater than about 1,200 kg./cm.^{2}. As a result, it is impossible to exploit the properties of special steels with high elastic limits, for instance the steel containing chromium and copper generally known as A52 steel, the working load on which is 2,400 kg./cm.^{2}, or even the properties of ordinary girders which can be placed under tensile stresses of 1,400 to 1,600 kg./cm.^{2}.

(2) Even if a stress of 1,200 kg./cm.^{2} in the reinforcement is not exceeded, it is hardly possible to ensure that cracks and separations will not appear in the stretched concrete, particularly under the action of repeated dynamical stresses, more especially because generally those concrete fibres which are most subject to such effects are also those where suitable concreting is most difficult (under the lower flanges of the girders).

The method according to the invention avoids these disadvantages and enables lighter, more economical and therefore superior (anti-crack) structures to be produced, through more efficient use of material.

Furthermore, it gives rise to the following advantages:

(1) It reduces the maximum absolute values of the forces of adhesion. Preliminary bending in fact creates forces of adhesion of opposite sign to those arising from the loads.

(2) It increases the rigidity of the whole by entirely or almost entirely preventing the existence of strongly stretched fibres of concrete, very often set in place under unfavourable conditions.

(3) It reduces the fatigue of the steels, on which the extreme stresses depending on live loads are brought closer together.

(4) It advantageously provides automatic testing of the strength of each reinforcement, accompanied in some cases by an increase in the elastic limit through cold working.

(5) It also subjects the pre-compressed concrete fibers to automatic testing when the preliminary bending stress on the reinforcement is removed.

(6) It also renders it possible automatically to regulate the counter-deflection of the beam by making a horizontal rectilinear mould for the covering concrete which is to be pre-compressed. As a result, the crust (the surface part which does not contain reinforcements) is thicker towards the extremities of the beam than towards the middle thereof, because of the deflection of the reinforcement which has been subjected to preliminary bending.

(7) It renders possible the production of a prestressing

force which is continuously variable along the axis of the beam.

The simplicity of the equipment necessary for carrying the method according to the invention into effect is still greater when for simultaneously subjecting the reinforcements of two beams to preliminary bending one of the reinforcements is used as a support for the preliminary bending of the other, the two reinforcements being disposed parallel to one another and bent in opposite senses in the same plane of bending, by varying the distances between the two reinforcements at certain points while at other points the reinforcements are held at a constant distance from one another.

It is particularly advantageous to produce deflection in the reinforcements of the two beams by moving the centres of the reinforcements apart while preventing their extremities from moving apart.

In this case, according to one alternative procedure, after connecting together the corresponding extremities of two reinforcements placed parallel to one another it is necessary only to place a screw jack between the centres of these reinforcements and move the centres apart. Then when the required deflection has been produced the centres are held apart from one another by one or two struts. After this the jack is removed and can then be used for another preliminary bending operation. When the concrete, with which the stretched parts of the bent reinforcements have in the meantime been covered, has hardened, the jack is temporarily replaced to enable the strut or struts to be removed, and the length of the jack is then gradually reduced until the two beams reach a state of balance due to the stressed condition of the reinforcement and of the concrete.

This latter interposition of the jack can moreover be dispensed with if struts of adjustable length are used, the length of which is gradually reduced when it has been decided to remove the cause of the preliminary bending.

In one alternative form of the method according to the invention it is proposed to pre-deflect the abovementioned reinforcement by creating, between at least part of those fibres of the reinforcement in which the stresses due to service loads are tensions and at least part of those fibres of the reinforcement in which the stresses due to service loads are compressions, a difference in temperature such that the former fibres are hotter than the latter.

The pre-deflection of the reinforcement is therefore caused by the application of heat energy instead of mechanical energy as provided in the alternative form described above.

The temperature difference to be created for effecting the pre-deflection of the reinforcement may be obtained by heating at least part of those fibres of the reinforcement in which the stresses due to service loads are tensions and/or by cooling at least part of those fibres of the reinforcement in which the stresses due to service loads are compressions.

In another alternative form of the method according to the invention, before the concrete is applied on those fibres of the reinforcement in which the stresses due to service loads are tensions, concrete is applied on at least part of those fibres of the reinforcement in which the stresses due to service loads are compressions and the weight of this latter concrete is made to act in such a way as to produce at least part of the desired pre-deflection of the reinforcement.

The pre-deflection of the reinforcement may be increased, before the application of concrete on those fibres of the reinforcement in which the stresses due to service loads are tensions, by making additional masses act temporarily on the structure consisting of this reinforcement and of the concrete already applied thereto on at least one part of those fibres in which the stresses due to service loads are compressions.

For instance in the case of principal beams under bridge roadways, resting on two supports, concrete may be made

to adhere to the upper flanges of the rigid reinforcements of these principal beams and form a roadway which may be loaded with earth brought and placed if necessary by trucks travelling on this roadway, after which operation concrete may be made to adhere to the lower flanges of the said reinforcements.

In this case, in contradistinction to the first alternative form described above, the placing of concrete in contact with that part of the reinforcement in which the stresses due to service loads are compressions is effected before the placing of concrete in contact with that part of the reinforcement in which the stresses due to service loads are tensions.

In another alternative form of the method according to the invention, the reinforcement is bent by making expanding concrete adhere only to fibres of this reinforcement in which the stresses due to service loads are tensions.

In this alternative form, for bending the reinforcement in the direction in which it will bend under the effect of service loads the internal energy of the expanding cement is used in place of at least part of the mechanical energy used in the first alternative form.

The beam according to the invention is characterised by the feature that it comprises on the one hand a rigid metal reinforcement which even by itself forms a beam resistant to bending which is pre-deflected in the direction in which it will bend under the effect of service loads and on the other hand pre-compressed concrete adhering to at least part of the said pre-deflected reinforcement.

This beam may advantageously be completed by non-pre-compressed concrete.

According to one alternative form, this pre-compressed concrete is made with expanding cement.

The invention lastly relates to a reinforced concrete beam, more especially a pre-stressed reinforced concrete beam obtained by the method according to the invention, the said beam comprising a rigid reinforcement which even by itself forms a beam resistant to bending.

Heretofore when a metal reinforcement of the abovementioned type has been covered in concrete great difficulty has been experienced in suitably applying the concrete against the lower surface of the bottom part of the reinforcement. This part actually always consists of a flat continuous flange extending over the entire length and the width of the reinforcement and for this reason there is difficulty in completely filling the space included between the lower surface of the bottom flange and the bottom of the mould with concrete.

In order to remove this disadvantage, in the beam according to the invention that flange of the said reinforcement in which the stresses due to service loads are tensions consists essentially of longitudinal elements held separate from and close to one another by being fixed to the web of the reinforcement through the intermediary of transverse members disposed at various points.

Other particular features and details of the invention will appear in the course of the description of the drawings accompanying this specification, which illustrate diagrammatically, and by way of example only, various stages in some alternative forms of the method according to the invention and various beams constructed by this method.

Figure 1 diagrammatically illustrates a first stage in the method according to the invention.

Figure 2 is a cross section through a beam constructed by the method according to the invention.

Figure 3 illustrates the laws of variation of normal stresses in a cross section of the reinforcement in various stages (considered separately and in superposition) of the construction of a beam according to the invention, and in use in acompleted structure.

Figure 4 illustrates the laws of variation of normal stresses in the cross-section of pre-compressed and non-pre-compressed concrete covering the reinforcement to which Figure 3 relates.

Figures 5 and 6 illustrate, in cross section and in longitudinal section respectively, part of the metal reinforcement shown in Figure 2, the adhesion between the reinforcement and the concrete having been increased by certain expedients.

Figure 7 is a diagrammatic view in elevation, illustrating the simultaneous application of the method according to the invention to two beams.

Figures 8 to 10 purely diagrammatically illustrate three alternative forms of the application of the method according to the invention to two beams simultaneously.

Figure 11 is a diagrammatic cross section showing an alternative form of the method according to the invention, at a stage following the obtaining of the pre-stressed concrete in the beam in the manner described with reference to Figure 2.

Figure 12 is a cross section of the beam finally obtained by the alternative method described with reference to Figure 11.

Figures 13 to 16 each illustrate a cross section of a beam constructed by the method according to the invention.

Figure 17 is a cross section, on line XVII—XVII of Figure 18, of another beam according to the invention.

Figure 18 is a side view of the metal reinforcement only of the beam according to Figure 17.

Figure 19 is a cross section, similar to Figure 17, of another beam according to the invention.

In these various figures, the same reference numerals indicate the same elements.

Figure 1 illustrates a beam 2 placed on two supports 3 and subjected to simple bending under the action of a force P applied at its centre. This force is exerted for instance by means of a screw-jack bearing against a fixed support 4.

The beam 2 illustrated in Figure 1 is assumed to be an I-shaped rolled girder such as that shown in Figure 2. This beam is obviously sufficiently rigid to be capable by itself of resisting bending. When this girder is bent, as illustrated in Figure 1, its state of stress, in the central section for instance, may be illustrated diagrammatically by lines 5 and 6 of Figure 3 in which the tensile stresses are illustrated to the right of the vertical line 5 and the compressive stresses to the left of this line.

The variation in stresses is therefore illustrated by an oblique line 6 with the line 5 as base line.

While the girder 2 is held in this state of stress, the concrete 7 (Figure 2) is applied to the greater part of that fraction of this girder which is subjected to tensile stresses. For this purpose, that part of the girder for instance is covered in concrete. The suitable application of this concrete, even under the lower flange of the girder, can be effected easily, more especially if use is made of vibration through the mould, through the concrete itself or even through the pre-deflected reinforcement.

The reinforcement is held in its bent position during the whole of the time taken by the hardening of the concrete 7. When this hardening is considered to be sufficient, the action of the force P shown in Figure 1 acting on the centre of the beam is made to cease. This force is not removed abruptly but is reduced gradually, for instance over a period of several minutes.

A beam is then obtained of which the metal reinforcement 2 and the concrete 7 are in states of stress illustrated by the diagrams included between the lines 5 and 8 in Figure 3 in the case of the metal reinforcement and by lines 5 and 9 in Figure 4 in the case of the concrete. It is obvious that the tendency of the girder to return to its state of zero stress which existed before it was bent as shown in Figure 1 is resisted by the concrete 7 covering the lower part of this girder. As a result of the adhesion of the concrete to the girder, after the removal of the force P, advantageous permanent states of stress remain both in the concrete and in the steel. The line 10 with the base 5 (Figure 3) illustrates the stresses in the metal due only to the operation of removing the force P. The superposition of these stresses on those illustrated by the line 6 gives the resultant stresses illustrated by the line 8, still with line 5 as base.

That part of the girder 2 which is still uncovered is then covered with fresh concrete 11 (Figure 2). At this stage the fresh concrete as yet makes no contribution to the strength of the beam, but the whole of the dead weight of this concrete acts as a load on the metal reinforcement 2 and the pre-compressed concrete. This dead weight creates in the metal reinforcement an additional state of stress which, if it were alone, would be represented by the diagram 12 in Figure 3. This diagram has to be superposed on the diagram 8 in order to obtain the state of stress in the reinforcement. This state of stress is represented by the diagram 13.

The state of stress in the pre-compressed concrete resulting from the dead weight of the non-stressed concrete is represented by the diagram 14 in Figure 4. The actual state of stress results from the superposition of the diagrams 9 and 14, producing the diagram 15.

When the upper concrete 11 has also hardened it can co-operate with the reinforcement 2 and the pre-compressed concrete 7 in providing resistance to stresses resulting from the incorporation of the beam in a completed structure.

The live load produces for instance states of stress in the reinforcement and in the concretes which are represented respectively by the diagram 16 in Figure 3 and the diagram 17 in Figure 4. The superposition of the diagrams 13 and 16 and that of the diagrams 15 and 17 produce respectively the diagrams 18 and 19.

In practice it is advantageous to subject the metal reinforcement, during the initial bending thereof, to a tensile stress greater than that to which it may be subjected during service.

It is also advantageous momentarily to subject the reinforcement, by bending it, to a tensile stress greater than its original elastic limit. The metal of the reinforcement is thereby subjected to cold working which increases its elastic limit.

If it is feared that the adhesion between the concrete 7 and the metal reinforcement 2 may be insufficient, the reinforcement is provided with projections which increase this adhesion.

Figure 5 illustrates projections 20 on the right-hand side of the bottom flange of the reinforcement which have been obtained by raising part of the metal constituting the flange. The left-hand side of this flange is provided with plate 21 held in place by bolts 22.

The projections 20 may alternatively consist of metal additions to the flange of the reinforcement.

Figure 7 diagrammatically illustrates the application of the method according to the invention to the simultaneous construction of two beams of which the metal reinforcements have their extremities connected together by means of ties 23 consisting for instance of strip iron. The flanges 24 of these two beams have been cut away at their extremities to facilitate the placing of the strip irons 23 which are attached temporarily to the webs of the girders 2 by means of bolts engaged in the holes 25 made in the strip irons 23 and the webs of the girders 2. While the extremities of the two beams are thus prevented from moving apart, the centres of these beams are moved apart by means of a jack 26 and they are held in this state by means of struts 27. If it is considered justifiable, the centres of the two girders are now simultaneously raised slightly by the further interposition of a jack 30 between the ground 29 and the lower girder, and the jack 30 is freed by means of struts 31. The object of this operation would be to correct the effect produced by the weight of the girders 2 and the struts 27 themselves and strictly to equalise the deflections or the bending moments of the two girders.

When it is decided to remove the bending force because the concrete has hardened sufficiently round the stretched parts of the girders, the jack 26 which was removed after the struts 27 had been set in place is replaced in order to facilitate the removal of the struts by a slight additional separation of the centres of the beams being manufactured. The length of the jack between the beams is then gradually reduced until the beams have assumed a shape in which they are in a state of balance.

If the struts 27 were of adjustable length, it would obviously be possible to dispense with the replacement of the jack 26 for allowing the beam to assume its new state of balance gradually, because it would be necessary only to reduce the length of the struts.

Figure 8 diagrammatically illustrates a construction according to an alternative form of this method in which the centres of the beams are held at a constant distance from one another while the extremities are moved closer together.

In the alternative form shown in Figure 9 the extremities are held at a constant distance from one another while the centres are moved apart.

In Figure 10, the extremities are held at a constant distance from one another while the centres are moved closer together.

Figure 11 illustrates an intermediate stage in the construction of a beam manufactured by the method according to the invention. After the concrete 7 has hardened and the force P has been removed, part of the reinforcement projecting from the concrete 7 is removed by cutting. After this removal, an additional quantity of concrete 11 is rendered rigid with the concrete 7, which is already under compression, by means of holding bars 28 so as to form for instance a beam of the kind illustrated in Figure 12.

Obviously, the beam subjected to pre-deflection may be a beam capable of being taken apart, of which the part which has not been covered with pre-compressed concrete is in this case removed without cutting and may be used again for the pre-deflection of other reinforcements.

Figure 13 illustrates a rigid metal girder 2 forming part of a beam which is assumed to be resting on two supports at its extremities. The lower flange 29 of this girder has been heated for instance by passing steam through tubes 30 which are in contact with its upper surface 31 while the upper flange 32 has been kept cold. Under the effect of this difference in thermal treatment the girder has become longer at its base than at its top part and consequently has bent so as to present a downwardly directed convexity. The reinforcement has thus bent in the direction in which it will bend under the effect of service stresses. These may comprise the dead weight of the beam, dead loads, varying loads, and sometimes live loads.

While heating of the lower flange 29 was continued, concrete 7 was applied against the lower surface 33 and the lateral surfaces 34 of this flange, that is to say against fibres in which the stresses due to service loads are tensions. Heating continued during the whole of the time during which the concrete was hardening. After hardening, heating ceased. Under the effect of the contraction of the lower part of the girder 2, the concrete 7 was compressed to the extent to which adhesion between the concrete and the flange 29 was sufficient.

The covering of the girder 2 was then completed by means of concrete 11.

In order to keep the upper part of the rigid metal girder 2 cool, if transmission of heat along the web of this girder is too great the flange 32 may be cooled or else transmission of heat from the lower to the upper part of the girder may be prevented by cooling the girder locally in the vicinity of the neutral axis.

Figure 14 illustrates another rigid metal girder 2 of which the upper flange 32 was cooled by passing through the tubes 35, in contact with the upper surface 36 of this flange, a refrigerant brine at a temperature substantially lower than the ambient temperature to which the lower flange 29 continued to be subjected.

Under the effect of this temperature difference between the upper and lower parts the girder 2 bent downwards, that is to say in the direction in which it will bend under the effect of service loads.

During this thermal treatment, concrete 7 was applied against the lower part of the beam 2, the lower flange 29 and part of the web being completely covered for instance. The thermal treatment did not cease until after the concrete 7 had hardened. The equalization of temperatures which resulted likewise had the effect of subjecting this concrete to compression to the extent to which its adhesion to the lower part of the girder 2 was sufficient. After this equilization of temperature that part of the girder 2 which had not yet been covered was covered with fresh concrete 11.

Figure 15 illustrates a beam of large dimensions comprising a metal lattice reinforcement consisting of two co-operating identical parts 2 which are to rest on two supports. After this reinforcement had been installed at the place at which the beam of which it is to form a part is to be in use, the upper flanges of this reinforcement, which flanges will be subjected to compression under the effect of service loads, were covered with concrete which at the same time formed a roadway 37. After this roadway 37 had hardened, earth 38 was tipped on to it. The roadway illustrated may be used as a road on which a truck 39, bringing the earth, may travel. Under the effect of the weight of this earth, of the concrete roadway 37 and of the metal reinforcement 2, this reinforcement bent in the direction in which it will bend under the effect of service loads, and the lower part thereof, subjected to tension as a result of the excess load, was then covered with concrete 7.

The weight of the concrete 37, with which the upper part of the beams 2 was covered before the concrete 7 was placed in position, obviously does not contribute to the pre-compression of this latter concrete, because it is not possible for the concrete 37 to be removed. But tensile stresses in the concrete 7 due to the weight of the concrete 37 and of the concrete 7 itself are avoided.

Figure 16 illustrates another beam according to the invention, comprising a metal reinforcement 2 of which the lower part, subjected to tensile stress when in service, was first of all covered in expanding concrete 40. It is to be noted that this concrete was applied only to that part of the reinforcement in which the stresses due to service loads are tensions. The swelling of this concrete during hardening produces at least part of the desired pre-deflection. After this concrete had hardened, concrete 11 made with nonexpanding cement was applied on the remainder of the metal reinforcement.

Figures 17 and 18 illustrate a beam comprising a rigid metal reinforcement 41 which has been covered in concrete. This reinforcement is capable by itself of resisting bending.

The lower flange of this reinforcement, that is to say the flange in which the stresses due to service loads are tensions when the beam of which it forms part is placed on two supports at its extremities, consists essentially of longitudinal tubes 42 held separate from and close to one another by being fixed to the web 44 of the reinforcement through the intermediary of transverse members 43 disposed at various points and fixed to this web, for instance by welding.

The lower flange of the metal reinforcement, consisting essentially of the tubes 42 and secondarily of the transverse members 43, can readily be covered completely with concrete 45. The use of tubes 42 enables the predeflection of the reinforcement to be effected readily through temperature difference between the upper and

lower flanges, since it is possible to circulate a hot fluid through these tubes.

If in place of tubes 42 bars 46 (Figure 19) are used to form the essential part of the lower flange of the metal reinforcement 41, these bars may be heated by being used as an electric resistance if it is desired to pre-deflect the reinforcement by this means. Figure 19 shows that the web 44 is provided with a narrow flange facilitating the attachment of the transverse members 43.

It is obvious that the invention is not limited exclusively to the embodiments illustrated and that many modifications can be made in the form, the disposition and the nature of some of the elements used in carrying the invention into effect, provided that these modifications do not conflict with the material contained in each of the following claims.

It is obvious for instance that the method according to the invention is not limited to simple beams on two supports but is also applicable to cantilevers, to continuous beams with numerous bays, to porticos and the like.

Furthermore the rigid reinforcement may for instance be rolled from one piece or composed of a latticework, with a solid or an open web, with pin connections or rigid joints.

What I claim is:

1. A method for constructing a beam with a rigid metal girder which itself forms a beam resistant to bending and with concrete, comprising supporting said rigid metal girder in such manner that its ends are free to move towards each other when the girder is bent, bending the girder in the direction in which it will bend under the effect of the service loads, restraining the so-bent girder from returning to its initial position under the effect of its elasticity by applying concrete to the portion of the girder in which the stresses caused by the bending forces are tensions and removing said bending forces after said concrete has set.

2. A method of constructing a beam with a rigid metal girder which itself forms a beam resistant to bending and with concrete, comprising arranging said girder and another identical girder with their mean plane parallel to the plane in which they will bend under the effect of the service loads in a common plane, the neutral axes of said girders being parallel to one another, supporting said rigid metal girders in such a manner that the ends of each girder are free to move towards each other when the girders are bent, mechanically bending said girders in such a manner that the two girders are bent in the direction in which they will bend under the action of the service loads by altering the distance between certain points of one girder and certain points of the other girder while other points of said two girders are held at a constant distance from one another by at least one member with which both girders are in contact, applying concrete only to the portion of said pre-bent girders in which the stresses due to the pre-bending forces are tensions, maintaining said girders in pre-bent position during the hardening of said concrete, and removing the mechanical cause of pre-bending of said girders after hardening of said concrete.

3. A method of constructing a beam with a rigid metal girder which itself forms a beam resistant to bending and with concrete, comprising arranging said girder and another identical girder with their mean plane which is parallel to the plane in which they will bend under the effect of the service loads in a common plane, the neutral axes of said girders being moreover parallel to one another, supporting said rigid metal girders in such manner that the ends of each girder are free to move towards each other if the girders are bent, bending said girders by moving apart the centers of the two girders by means of at least one jack while restraining the extremities of one girder from moving apart from the extremities of the other girder in such manner that the two girders are bent in the direction in which they will bend under the action of the service loads, holding these centers at the selected distance from one another by struts of adjustable length, removing the jack, applying concrete only to the portion of said pre-bent girders in which the stresses due to the pre-bending forces are tensions, and reducing the length of the struts when the concrete has hardened until the girders have assumed a shape in which they are in a state of equilibrium.

4. A method of constructing a beam with a rigid metal girder which itself forms a beam resistant to bending and with concrete, comprising supporting said rigid metal girder in such a manner that its ends are free to move towards each other if the girder is bent, temporarily mechanically bending the rigid metal girder in the direction in which it will bend under the effect of service loads by applying to it forces directed transversely to its axis, restraining the thus pre-bent girder from returning to its initial position under the effect of its elasticity by applying concrete only to the portion of the pre-bent girder which is put under tensile stress by the temporary pre-bending, removing said forces of pre-bending after hardening of the so applied concrete, and afterwards removing a fraction of the part of the girder which has not been covered with concrete during the pre-bending of the latter.

5. A method of constructing a beam with a rigid girder of steel with a high elastic limit, said girder forming itself a beam resistant to bending and with concrete, comprising supporting said rigid steel girder in such manner that its ends are free to move towards each other if the girder is bent, temporarily mechanically bending the rigid steel girder in the direction in which it will bend under the effect of the service loads by applying to it forces directed transversely to its axis, restraining the thus pre-bent girder from returning to its initial position under the effect of its elasticity by applying concrete only to the portion of the pre-bent girder which is put under tensile stress by the temporary pre-bending, and removing said forces of pre-bending after hardening of the so applied concrete.

6. A method of constructing a beam with a rigid metal girder which itself forms a beam resistant to bending and with concrete, comprising supporting said rigid metal girder in such manner that its ends are free to move towards each other if the girder is bent, temporarily mechanically bending the rigid metal girder in the direction in which it will bend under the effect of service loads by applying to it forces directed transversely to its axis and of such a value that the girder is subjected to a tensile stress greater than any such stress to which it will be subjected under the action of the service loads, restraining the thus pre-bent girder from returning to its initial position under the effect of its elasticity by applying concrete only to the portion of the pre-bent girder which is put under tensile stress by the temporary pre-bending, and removing said forces of pre-bending after hardening of the so applied concrete.

7. A method of constructing a beam with a rigid girder of steel with a high elastic limit, said girder forming even by itself, a beam resisting to bending and with concrete, comprising supporting said rigid steel girder in such manner that its ends are free to move towards each other when the girder is bent, temporarily mechanically bending the rigid steel girder in the direction in which it will bend under the effect of the service loads by applying to it forces directed transversely to its axis, these forces having a value such that the tensile stress produced in the girder are greater than the original leastic limit of the metal, restraining the thus pre-bent girder from returning to its initial position under the effect of its elasticity by applying concrete only to the portion of the pre-bent girder which is put under tensile stress by the temporary pre-bending, and removing said forces of pre-bending after hardening of the so applied concrete.

8. A method of constructing a beam with a rigid metal girder which itself forms a beam resistant to bending and with concrete, comprising supporting said rigid metal girder in such a manner that its ends are free to move towards each other when the girder is bent, creating between aat least a part of the girder in which the stresses due to service loads are tensions and at least a part of the girder in which the stresses due to service loads are compressions a difference in temperature such that the former part is sufficiently hotter than the latter in order to cause a pre-bending of the girder in the direction in which it will bend under the effect of the service loads, applying concrete on the so pre-bent girder only to a portion of the latter in which stresses due to service loads are tensions, maintaining the said difference of temperature during hardening of this concrete, and suppressing this difference of temperature after hardening of said concrete.

9. A method of constructing a beam with a rigid metal girder which itself forms a beam resistant to bending and with concrete, comprising supporting said rigid metal girder in such manner that its ends are free to move towards each other when the girder is bent, applying concrete first only to a portion of said girder in which the stresses due to the service loads will be compressions, in order to cause a pre-bending of the girder, making additional masses to act on the whole structure formed by said concrete and the girder after hardening of said concrete in order to cause a supplemental pre-bending of the girder, applying then concrete only to a portion of the so pre-bent girder in which the stresses due to the weight of the first concrete and of said additional masses are tensions, and removing said additional masses after the last concrete has hardened.

10. A method of constructing a beam with a rigid metal girder which itself resists bending and with concrete, comprising supporting said rigid metal girder in such manner that its ends are free to move towards each other when the girder is bent, applying concrete only on the portion of this girder in which the stresses due to service loads are compressions, applying, after hardening of said concrete, external forces in order to further bend the latter in the direction in which it will bend under service loads, applying concrete only to the portion of the so pre-bent girder in which the stresses due to the weight of the first concrete and to the external forces are tensions, and removing said external forces after hardening of this latter concrete.

11. A method of constructing a beam with a rigid metal girder which itself forms a beam resistant to bending and with concrete, comprising supporting said rigid metal girder in such manner that its ends are free to move towards each other when the girder is bent, applying external forces to the girders in a transverse direction to the axis of the latter, in such a manner that the girder is bent in the direction in which it will bend under the effect of the service loads, applying expansive concrete only to the portion of the girder in which the stresses caused by the external bending forces are tensions, and removing said external bending forces after hardening of said expensive concrete.

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