Sept. 12, 1939. E. FREYSSINET 2,172,703

METHOD OF CONSTRUCTING REINFORCED CONCRETE MONOLITHIC STRUCTURES

Filed Jan. 8, 1936 2 Sheets-Sheet 1

Fig: 1

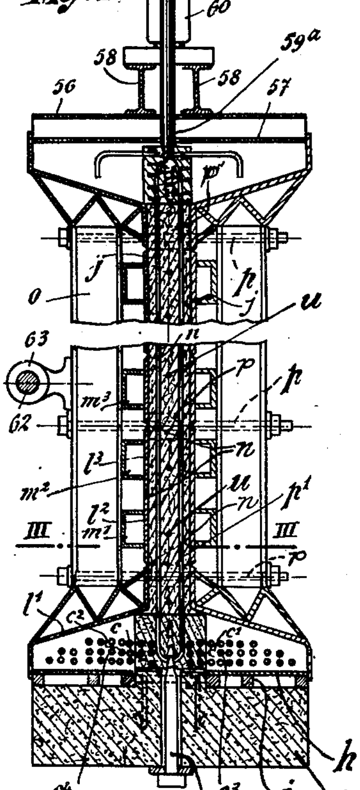


Fig: 2

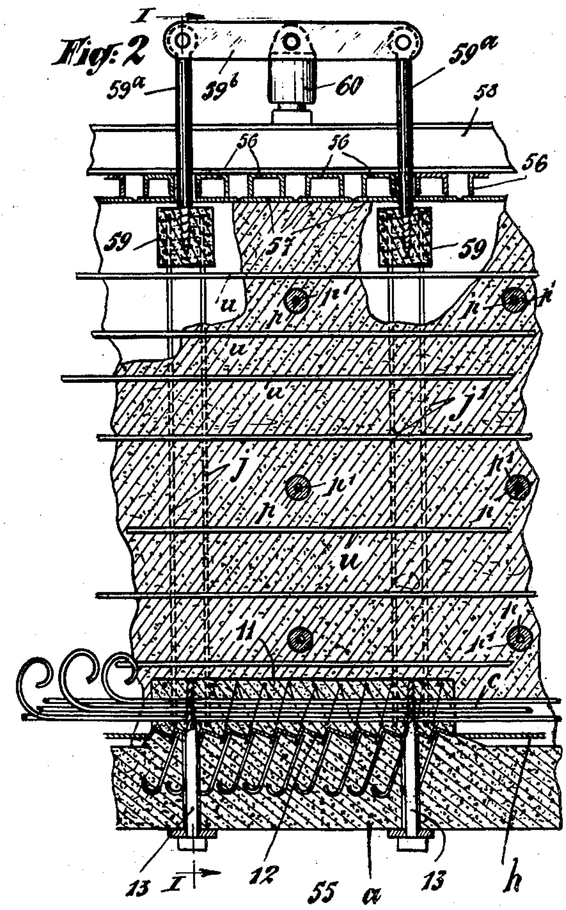


Fig: 3

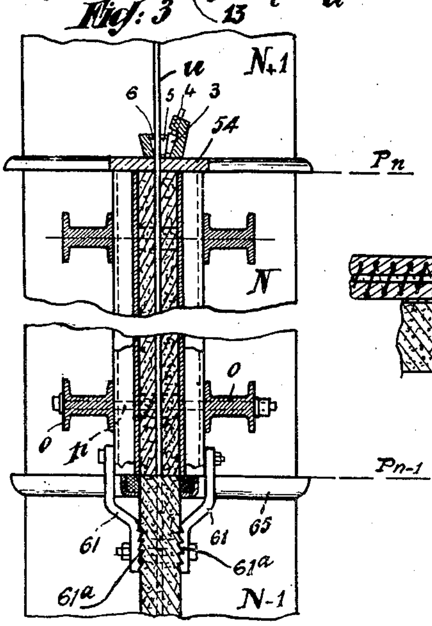


Fig: 5

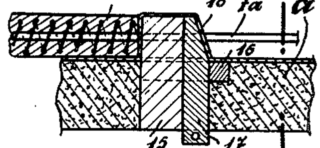
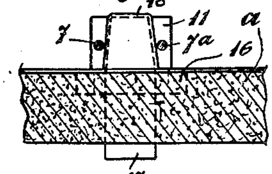


Fig: 6



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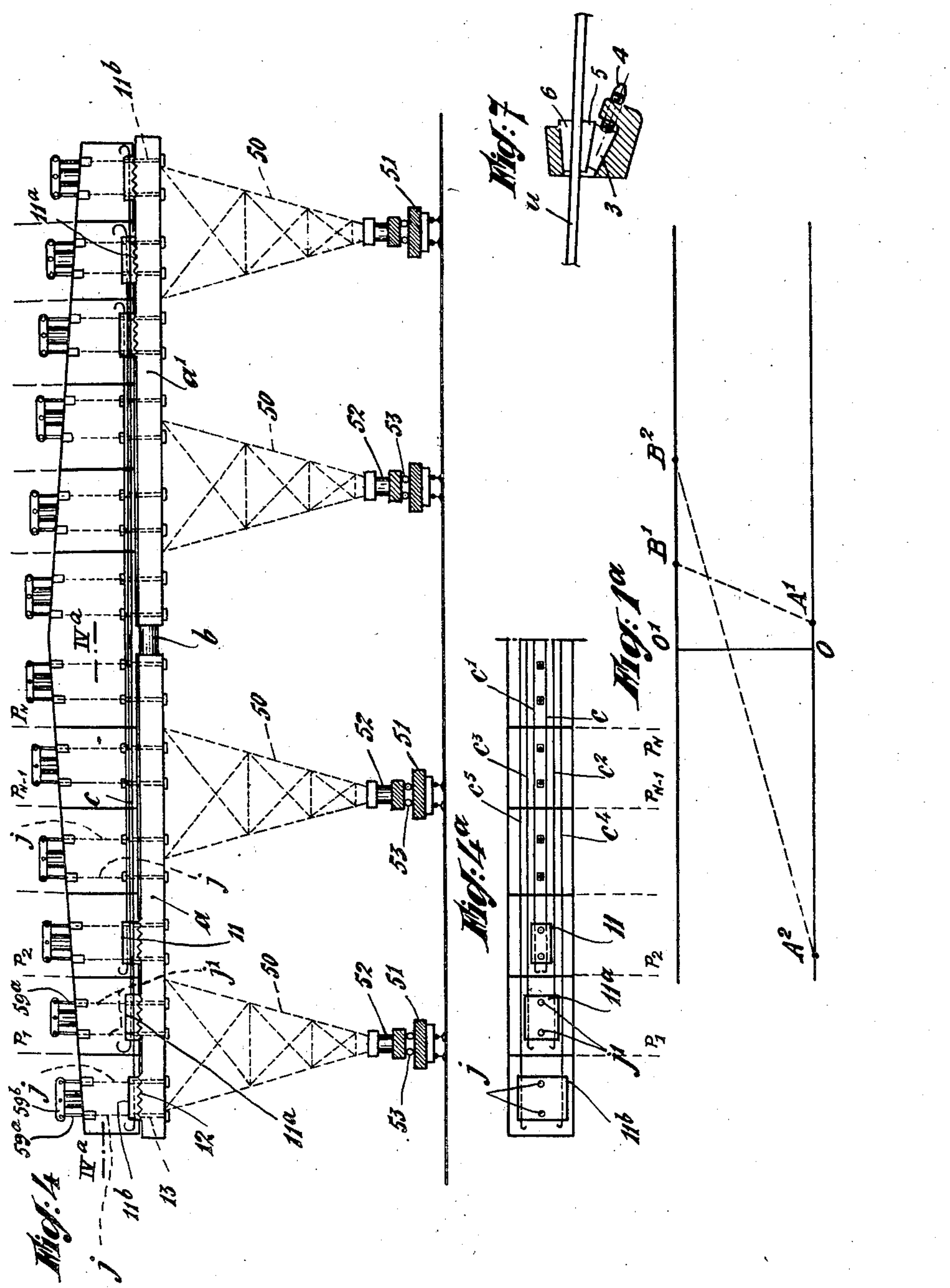
METHOD OF CONSTRUCTING REINFORCED CONCRETE MONOLITHIC STRUCTURES

Filed Jan. 8, 1936 2 Sheets-Sheet 2



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UNITED STATES PATENT OFFICE

2,172,703

METHOD OF CONSTRUCTING REINFORCED CONCRETE MONOLITHIC STRUCTURES

Eugène Freyssinet, Neuilly-sur-Seine, France

Application January 8, 1936, Serial No. 58,183
In France January 11, 1935

8 Claims. (Cl. 25—154)

In my former patents and publications, I have shown that it is possible to considerably increase the qualities of reinforced concrete by employing reinforcements, made of steel having a high elastic limit, subjected to preliminary tensions sufficiently high in order that they may remain tensioned so as to produce, in the concrete mass, systems of permanent stresses which advantageously modify those resulting from the efforts to which the piece is subjected when in service. I thus obtain pieces which have exceptional qualities from the point of view of strength and cost.

These methods require the use of plants the weight, the cost, and the difficulty of transportation and operation of which increase with the size of the elements to be manufactured and which, for certain sizes, cannot be transported. Accordingly, the method above referred to was hardly ever applied to the construction of monolithic structures up to the present time.

The method according to the present invention makes it possible to apply this method, which is based upon the provision of pre-stresses imposed to the materials, to reinforced concrete structures of any size whatever, having all the properties of monolithic structures made on the spot, by means of a plant which is little expensive and easy to transport and operate.

In order to build a structure with the method according to the present invention, I determine, as if I intended to make a monolithic structure, by applying the principles concerning the strength of materials, the shape and size of the structure and its reinforcements and the elastic state that should be imparted thereto prior to the pouring of the concrete that must embed said reinforcements, in order to obtain, prior to the setting of the concrete and to the various deformations that said concrete is to undergo, the system of stresses that is most favorable to the obtainment of a strong finished construction.

This elastic state includes tensions, ranging between zero and the elastic limit of the metal, to be applied either from one reinforcement to another one, or along a given reinforcement.

This being done, I divide the mass of concrete of the structure into elements of such a size that they correspond to moulds capable of being handled without undue difficulty, and generally made of parts capable of being reemployed many times. These elements of the structure shall be manufactured separately or successively, the reinforcements remaining uninterrupted and extending through suitable apertures of the framings corresponding to the surfaces of contact of adjoining elements, hereinafter called "intersurfaces".

These intersurfaces must be traced in such manner that, in the finished structure in service, the elastic efforts which shall be directed at right angles thereto, shall always be compressive efforts, excepted in the case of very small efforts. This can always be obtained by providing a suitable distribution of tensioned reinforcements extending through these intersurfaces.

Prior to pouring the concrete of a first element, the reinforcements that extend therethrough are placed, at least over the length corresponding to said element, into the desired elastic state, previously determined as above explained.

In the most general case, this shall be obtained according to the United States patent applications, Ser. No. 395,297 filed September 26, 1929, Ser. No. 714,724, filed March 8, 1934, Ser. No. 709,878, filed February 5, 1934, Ser. No. 734,861 filed July 12, 1934, Ser. No. 734,863, filed July 12, 1934, by catching each reinforcement bar or group of reinforcement bars by means of temporary anchorings consisting of clips or the equivalent, subjected to the action of jacks so as to elongate the reinforcements, said jacks bearing upon members for the transmission of efforts, generally disposed on the outside of the piece to be manufactured.

After having waited for a sufficient hardening of the concrete of the first element, I dispose the reinforcements corresponding to the second element so as to impart the desired tensions thereto at least over the length corresponding to said second element.

For the reinforcements of this second element that are not rigid with the first one, I proceed as above explained concerning said first element. For the reinforcements that are common to the first and second elements, it is necessary to modify the intensity of the efforts that were applied, up to then, to these last mentioned reinforcements, by modifying the conditions of working of the anchorings and jacks. As a rule, this involves the creation of local efforts between the reinforcements and the concrete of the second element, and, furthermore, the application, to the whole of this element, of a force opposed to the resultant of the supplements of efforts applied to the various reinforcements that extend therethrough. This involves the provision of suitable connection devices forming fixed abutments between the tensioning jacks or the like and the concrete of the first element.

Generally speaking, the local stresses thus imparted to the concrete of the first element, prior to pouring the concrete of the second, shall be very high. They imply resistances of the concrete which are rarely obtained in ordinary practice and only after a very long period of time, required for setting and hardening.

In most industrial applications, the necessity of allowing a considerable time to elapse between the moulding operations of an element and the operations of adjusting the tensions prior to the moulding of the next element would render the method useless. But it is known that the hardening of concrete can be accelerated through various operations the effects of which can be amplified by associating them in a predetermined order, so as to permit of reducing the delays as much as it is necessary for the applications that are considered. The favorable effect of vibrations has been known for a long time. I have found that, by associating in a suitable manner and under certain conditions a compression with the vibration, the results that are obtained are considerably improved, as well from the point of view of the rapidity of hardening as from that of the final quality of the concrete. Concretes treated in this way can be heated without precautions or risks, even at temperatures higher than 100° C., which permits of obtaining, in a period of time of less than two hours, with ordinary Portland normal concretes, resistances of several hundreds of kilogrammes per square centimeter which, after final hardening may exceed 1000 kgs. per sq. cm. It is thus possible to obtain the desired hardening of the concrete in a very short time.

The method according to the present invention includes carrying out the operations of moulding the successive elements in such manner that concrete is, in most cases, vibrated, compressed, and heated. In exceptional cases, in which rapidity of working is not a very necessary condition, heating, and even compression, may be dispensed with.

The general method above described affords, in all cases, a solution of the problem, but, in the various specific cases that are met with, it is nearly always possible to simplify it, due to the fact that the particular conditions of a given application generally permit the simultaneous, or even conjugated, execution of operations which are distinct a priori. In nearly all applications of the invention, the operations of placing under tension, or increasing the tension of, certain reinforcements and compressing the concrete can, at least partly, be conjugated in such manner that one results from the other. It suffices, for this purpose, to maintain the walls of the mould against the pressure exerted by the concrete in said mould, by connecting the reinforcements to these walls, which becomes particularly easy when these reinforcements normally extend through these walls and beyond them (case of the framing of an intersurface between two successive elements). It is then possible, by making use of the resistance of the reinforcements for resisting a hydraulic thrust of the concrete, created through any suitable means, to tension the reinforcements to a rate which can easily be calculated and adjusted. Or alternately, I may place the reinforcements under tension through the action of special jacks, acting on the wall of the mould, which otherwise is free, and thus obtain compression of the concrete. In both cases, the efforts necessary for creating tensile stresses in the element that is considered are transmitted to the preceding element, in which are sealed the reinforcements thus tensioned, first temporarily through the hydraulic forces transmitted by the compressed fresh concrete and the action of which shall be facilitated by maintaining an intensive vibration state therein, then, in a final manner, through the same concrete, once it has hardened.

In both cases, the transmission of the efforts imposed to the first element by the action on these reinforcements needs not be made to the jacks through special connecting devices, which can therefore be wholly or partly dispensed with.

Another simplification may be effected whenever it is possible to incorporate a reinforcement in the first element without preliminary tension. This permits of avoiding the necessity of a temporary anchoring for this reinforcement.

Generally speaking, any reinforcement has close to its end, a part in which there is no fatigue, or very little fatigue, which is not advantageous to tension, and which forms an anchoring; the simplification just above mentioned can therefore be applied frequently. It is even possible, in some cases to repeat it at both ends of a reinforcement and thus to avoid the use of any system or metallic clamp.

The modification of the state of tension of the reinforcements between the execution of two successive elements may correspond to only a portion of the reinforcements. It may also happen that a given state of tensioning is common to several successive elements. Of course, this makes it possible to dispense with one or several operations of adjusting the tensile stresses.

Several applications of the invention will be hereinafter described, but it should be well understood that they are merely intended to set forth the principles of the invention by showing their application to various specific cases. These examples are not in any way limitative.

Figs. 1 to 4 relate to the construction of a roof for a large span shed by means of beams having a vertical web and two treads.

Fig. 1 is a transverse sectional view of a moulding device for one of these beams, according to the invention;

Fig. 1a is an explanatory diagram;

Fig. 2 is a partial longitudinal section corresponding to Fig. 1; the concrete filling the mould being broken away at various places to show the internal parts of the mould;

Fig. 3 is a horizontal section on the line III—III of Fig. 1;

Fig. 4 is a diagrammatical view in vertical elevation of the whole of a moulding plant according to the present invention.

Fig. 4a is a partial horizontal section on the line IVa—IVa of Fig. 4, showing the fixation of the reinforcements to the base of the mould.

Figs. 5 and 6 are a sectional elevation of an abutment member, and a transverse section thereof, respectively;

Fig. 7 is a section of a device for engaging and holding a reinforcing rod.

The reinforcement system of the beam consists of a series of horizontal bars c, c^1, c^2, c^3 . . . grouped in the lower portion, uniformly distributed horizontal bars u, and vertical bars j, j^1. All these bars might be made of steel, for instance of a breaking strength of 100 kgs. per sq. mm. and of an elastic limit of 80 kgs. per sq. mm., obtained by preliminary drawing. Furthermore, the system includes reinforcements, made of steel of any grade whatever, disposed transversely to the first mentioned ones so as to improve their anchoring by a concrete hooping effect. The reinforcements of hard steel shall be tensioned in such manner that, taking into account all the stresses imparted to the beam, as well bending as shearing stresses, and all the deformations of the concrete (deformations due to shrinkage, elastic and plastic deformations) there remains in the concrete, at any point, permanent compressions.

It is clear that, in this way, I eliminate any possibility of cracking of the beam. It is then possible to have rates of shearing stresses of the same order of magnitude as the compression stresses, that is to say much higher than the maximums usually accepted. On the other hand, the maximum compressive stresses are considerably lower than in ordinary reinforced concrete. As a matter of fact, the diagram of these stresses (Fig. 1a) is a line such as A^1B^1. For ordinary reinforced concrete, this diagram would be a line A^2B^2, in which O^1B^2 represents the deformation of concrete and OA^2 the deformation of steel.

In order to make the beam in question, I first determine, according to the general method, the concrete elements to be successively poured. In this case, these elements may be divided into four groups:

1. elements embedding both portions of the reinforcements c of the same length, close to their ends, and portions of the reinforcements j that penetrate thereinto (see for instance element 11, Fig. 2);

2. elements embedding only portions of reinforcements j close to the upper ends of these reinforcements (for instance elements 59, Fig. 2);

3. elements embedding only portions of reinforcements j close to their lower ends;

4. elements limited by equidistant vertical planes . . . P_{N-1}, P_N . . ., etc. . . . (Fig. 3), constituting the whole of the remainder of the beam.

The concrete elements of the first group have decreasing widths in such manner as to leave a free passage for those of the reinforcements c which do not correspond thereto (see elements 11, 11a, 11b, in Fig. 4a).

I might, for the construction of the structure, apply the general method above set forth, but the work may be considerably simplified by noting that the reinforcements extending through the first three groups of elements or sections are not to be tensioned and that these elements have no common surface. It is therefore possible to make them separately, and even in advance, for those, for instance belonging to groups 2 and 3, the unitary volume of which is not too important and which can, therefore, be set in position after casting of the concrete.

It should also be noted that the reinforcements c common to all the elements of the fourth group through which they extend can be tensioned simultaneously without any difficulty.

For this purpose, the whole of the reinforcements is disposed on a member which forms the bottom of the mould for the whole beam. This member is constituted by a strong beam made of two elements a and a^1 carried by suitable frames such as 50 (Fig. 4) on bases 51 which permit of placing them successively under each of the beams to be built.

The two beam elements a, a^1 must be capable of being fixed or displaced vertically some centimeters by means of jacks 52 for permitting removal from the mould and they must be capable of having small movements in the direction of their length, owing to the provision of rollers 53, under the action of jacks b which permit of moving their ends apart with a power equal to the total maximum tension to be given to the whole of the main reinforcements c, c^1, c^2.

This being done, the elements of the three first groups are poured and the elements of the first group, such as 11 (Fig. 2) are temporarily secured to the bottom of the mould which is for instance obtained by means of ridges 12 provided on the upper face of said bottom and of screw spikes 13 extending into the moulded elements through the bottom of the mould (see also Figs. 4 and 4a).

I may also employ abutment members such as those shown in elevational view in Fig. 5 and in transverse section in Fig. 6. In these figures, 15 designates a piece of high resistance engaged through a hole provided in the bottom of mould a. Between this piece 15 and the part 16 through which it bears upon the mould bottom a, I preferably engage an element 17 the removal of which, when the concrete of the piece moulded on bottom a has set and hardened, is intended to create an empty space which facilitates the separation from the mould. The whole is covered with an envelope 18 intended to render the unmoulding easier, said envelope being made of a matter easy to deform, to destroy, or to remove by sliding, such as rubber, plaster, cardboard, fabric, felt, wood, or metal sheet.

I secure, through analogous means, the elements of the third group with the bottom of the mould. Full hardening of the elements of the three first groups shall be made as rapid as necessary by vibrating concrete or vibrating and compressing it; or again by vibrating, compressing and heating it, for instance by devising the ridges 12 of the bottom of the mould, and eventually screws 13, in such manner that they can be heated through a steam circulation.

The two parts a and a^1 of the bottom of the mould are then forced apart by means of hydraulic jacks b (Fig. 4). In this way all the bars c, c^1, c^2 etc. . . . are simultaneously tensioned.

Prior to setting the reinforcements in position I have disposed on the mould bottoms, under the elements of the first group, metal sheets h held apart from the mould bottoms by projections i or bars or recesses provided in the concrete surface of the mould, both in order to avoid that the mass and rigidity of the mould bottoms may deaden the vibrations of the concrete and in order to permit of said concrete being heated by steam flowing between metal sheet h and the mould bottom. Finally, this arrangement facilitates the separation between the moulded concrete and the mould.

I then set in position the framing of an element of the fourth group, said framing having the length of said element, which may be relatively small. This framing may be constituted as shown, by way of example, by Figs. 1 to 3. It includes sheet metal elements l^1, l^2, l^3 . . . and sectional elements m^1, m^2, m^3, assembled together by longitudinal welds and constituting tubular elements the lines of contact n of which are adjusted in such manner as to prevent the passage of solid material but to permit water to leak therethrough. These elements are assembled on sectional irons o in such manner as to form half-sheets associated two by two through rods p extending across the web of the beam through flexible rubber tubes p^1 (see Fig. 1), which permit of easily extracting said rods after hardening of the concrete.

This mould being arranged in position, for instance in order to make the element N of the fourth group at the end of the element N—1 already made (Fig. 3), the vertical framing elements **54** separating it from the space for the next element N+1 is set in position, the preceding element N—1 closing, on the other side, the end of the mould. These vertical framings **54** are fixed to the horizontal reinforcements *u*, determined in such manner that, at the desired rate of tension of said reinforcements, they maintain said framing elements against the hydraulic pressure of the concrete, I may make use for this purpose, of device acting as stops for framings **54** and adapted to be fixed to the reinforcements (for instance a system of wedges such as that shown at the upper part of Fig. 3 and visible, on a larger scale, in Fig. 7; wedge **3** being blocked by a screw **4**, wedges **5** and **6**, the apex angle of which is small, cannot be disengaged and keep bar *u* in position, the unscrewing of screw **2** releases the system).

The vertical framing elements **54** are provided with holes for the passage of the reinforcements and which may be fitted with packing members for preventing leakage of concrete.

The upper part, or top, of the framing, which constitutes the lid of the mould, is for instance made of U-shaped irons **56**, arranged in transverse position, welded to metal sheets **57** and upon which longitudinal I-shaped irons **58** are bearing. The whole is maintained by big screws **59***a* screwed in the elements **59**. These screws are connected, for instance through equalizing bars **59***b*, with jacks **60** bearing upon I-shaped sectional irons **58**. Of course, when the parts are set in position for receiving concrete, elements **59** are at a distance from bars **56**, so as to permit relative movement with respect thereto.

Orifices, provided for instance in the upper part of the framing, permit of filling the mould with concrete.

The concrete in the mould is vibrated for instance by means of shafts **62** having unbalanced masses and revolving at high speed in bearings **63** fixed to the lateral mould elements (Fig. 1).

After having filled the mould with concrete, the orifices for this operation are closed and jacks **60**, which act upon the upper part of the framing, are operated. I may also act, by means of jacks or nuts, on the rods *p* that connect together the two halves of the mould, on the right and left side of the beam. It is clear that concrete is thus perfectly compressed in all of its parts. The compression of concrete produces the tensioning of the vertical reinforcements j, j^1 . . . and of the horizontal reinforcements *u* through movable framing elements **57** and **54**.

If it is desired to quickly remove the framing elements from the concrete, steam is sent in contact with the concrete, by causing said steam to flow for instance through the channels of sectional irons m^1, m^2, m^3; . . . and **56**, or through other channels for instance the hollow spaces existing between metal sheet *h* and the bottom of the mould, as above explained.

Once the element N of the beam has been made, the mould may be displaced toward the next element N+1 through carriages rolling upon a track supported by the mould bottom a, a^1. In the case of beams of variable height, it shall suffice to add to or remove from the lateral moulds an element of constant width. In a likewise manner, it is possible to vary the thickness of the webs or of the treads by merely changing the relative portions of the parts.

If the mould is of the same length as the element to be moulded, the liquidtightness at the connection with the preceding element N—1 precedingly moulded will be ensured by means of a deformable element **65** which does not oppose the compression of the concrete. This element **65** may consist of a metallic gutter provided with a rubber packing member (Fig. 3).

The mould may be connected to the parts already moulded through suitable organs such as **61** (Fig. 3) permitting deformations, these organs being fixed to the concrete already hardened by making use of holes provided in the web, or of ridges **61***a* moulded in the wall of the concrete piece and against which the organs to be fixed are kept applied. It is possible, in this case, to make use of the mould for tensioning the horizontal reinforcements beyond what is possible when making use for the pressure exerted by the concrete on the separation framing element **54** of the successive concrete elements.

It is possible to make of pre-stressed concrete the portions of the structure that connect to a beam the precedingly constructed beams.

For this purpose, it suffices to set in position, prior to pouring the concrete of the beams, the reinforcements of these portions of the structure that are at right angles to the beams and penetrate thereinto. After the beams have been finished, these reinforcements shall easily be tensioned by means of hydraulic jacks, suitably distributed, acting between the treads of the beams, and then concrete shall be poured.

It is unnecessary to prove the general character of the invention by giving a great number of examples. Any structure, however complicated it may be, can be obtained through the application of the general methods above described. But it will be possible to find simplifications applicable to the various particular cases.

The invention is all the more advantageous as it is the case of structures subjected to stresses to which it is particularly difficult to resist with ordinary methods of constructions, such as exceptionally high fatigues, especially high shearing stresses or violently alternated stresses.

The method according to the present invention is of course applicable to all kinds of structures, other than beams, for instance cylinders or prisms of any shape or dispositon, the method permitting the sinking, as well as the construction of the structure, tubes and hollow or solid columns for drilling, piles driven in any suitable manner, subterraneous or submarine structures, such for instance as inverts, side-walls of a canal-lock, etc., which have to withstand high bending or shearing stresses and may have, in length, width, and thickness, any dimensions, columns and pipes of any kind. The method is all the more advantageous as it permits of obtaining pieces the resistance of which to compression, tension, bending stresses and torsion is enormous, the cost of these pieces being very low due to the high resistance of the concretes that are obtained and to the low cost of the hard steel wires that form the reinforcements.

Having thus fully described my invention, what I claim as new and desire to protect by Letters Patent is:

1. A method of making a monolithic structure of reinforced concrete, which comprises, arranging at least a portion of the reinforcements in predetermined position, arranging mould parts limiting at least one element of the concrete structure and imparting predetermined tensions to at least the portion of said reinforcements that

corresponds to said element, pouring concrete into the space limited by said mould parts, allowing said concrete to set and harden, then arranging mould parts limiting one other element of the concrete structure, adjacent to the first mentioned one and imparting predetermined tensions to at least the portion of the reinforcements that corresponds to said last mentioned element, pouring concrete into the space corresponding to this last mentioned element, allowing this concrete to set and harden, and so on, until the whole structure is finished, the tensions imparted to the reinforcements being always such that the mutual reactions of the respective elements thus formed successively, over the surfaces along which they are assembled together, are essentially compressions tending to apply said elements against one another.

2. A method according to claim 1 which further includes vibrating the concrete of the successive elements so as to facilitate and accelerate the hardening thereof.

3. A method according to claim 1 which further includes vibrating and compressing the concrete of the successive elements so as to improve and accelerate the hardening thereof.

4. A method according to claim 1 which further includes vibrating, compressing and heating the concrete of the successive elements so as to improve and accelerate the hardening thereof.

5. A method according to claim 1 which further comprises fixing at least some of the reinforcements extending through an element to one of the corresponding mould parts, and compressing the concrete of said last mentioned element by reducing the volume limited by said corresponding mould parts, whereby tensioning of said last mentioned reinforcements is simultaneously obtained.

6. A method according to claim 1 which further comprises fixing at least some of the reinforcements extending through an element to one of the corresponding mould parts, and compressing the concrete of said last mentioned element by displacing another of said correponding mould parts, whereby tensioning of said last mentioned reinforcements is simultaneusly obtained.

7. A method according to claim 1 which further comprises, providing a mould part common to a plurality of concrete elements, securing hardened concrete elements, with reinforcements embedded therein, to said last mentioned mould part, and tensioning said last mentioned reinforcements between said last mentioned mould part and said last mentioned concrete elements.

8. A method according to claim 1 for the manufacture of a structure including a plurality of elements having reinforcements extending through all these last mentioned elements and intended to be tensioned at the same rate over their whole length, which method further comprises, simultaneously tensioning the whole length of said last mentioned reinforcements, prior to successively making these last mentioned concrete elements.

EUGÈNE FREYSSINET.