

Jan. 25, 1966

U. FINSTERWALDER

3,230,560

SUSPENSION BRIDGE

Filed Jan. 28, 1963

4 Sheets-Sheet 1

FIG. 1

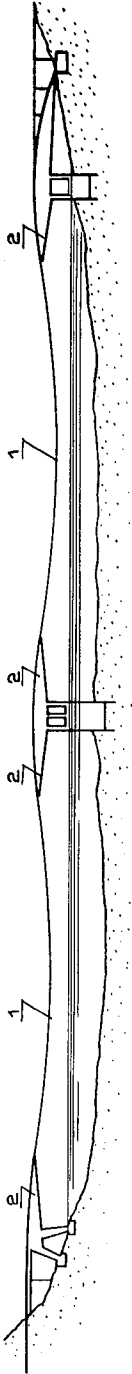


FIG. 2

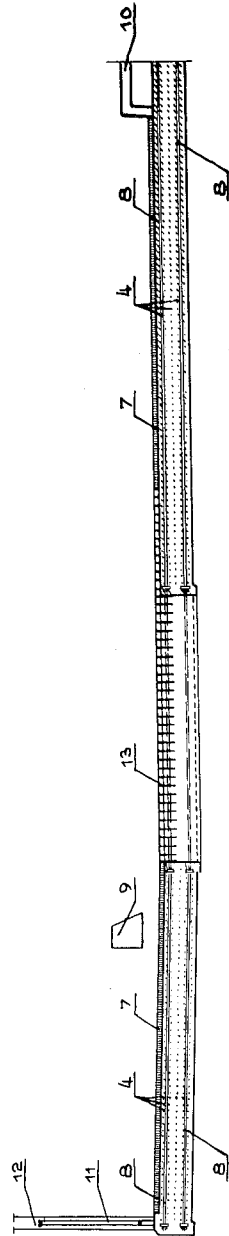
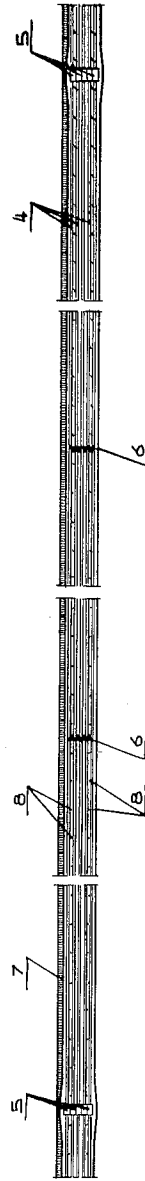


FIG. 3



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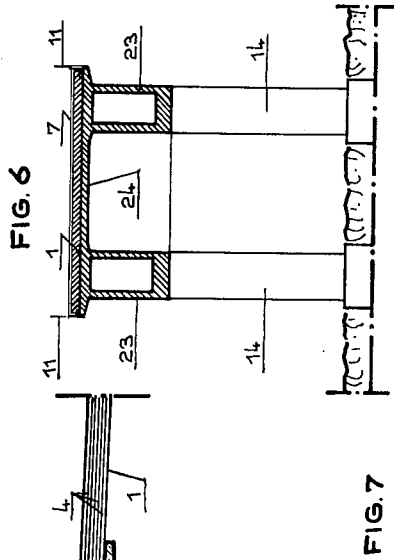
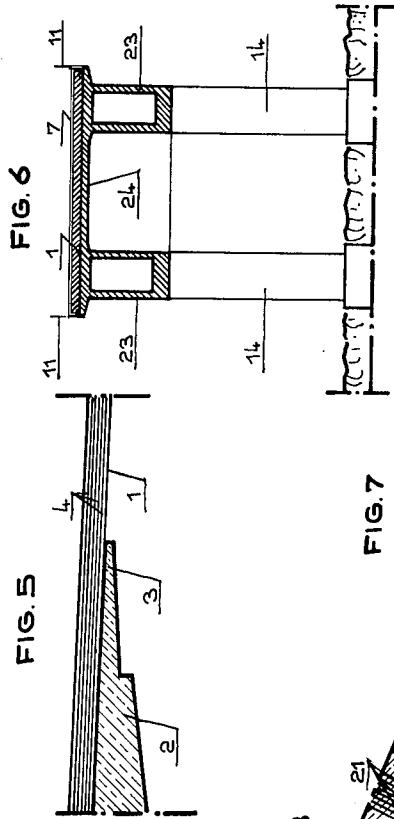
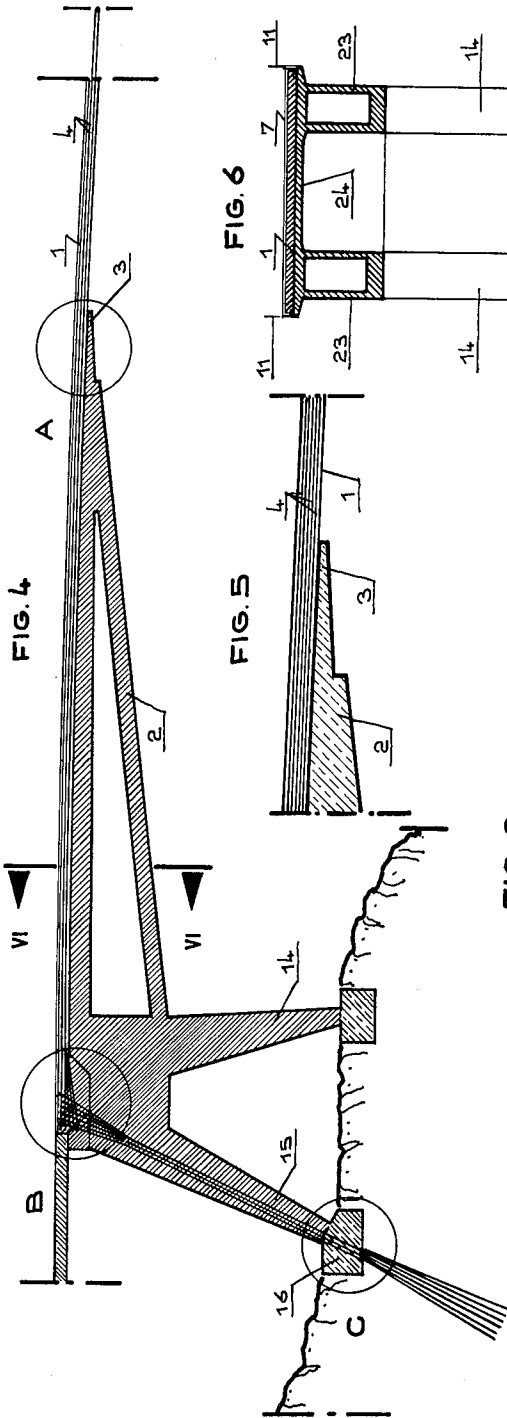
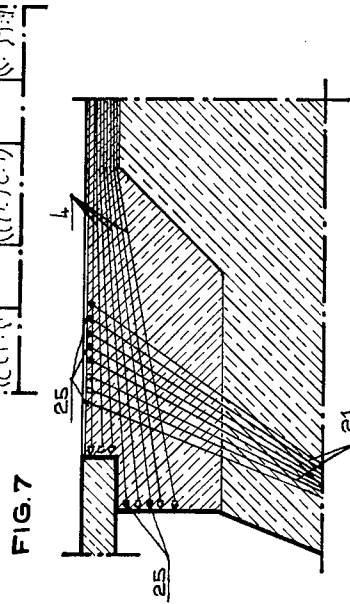
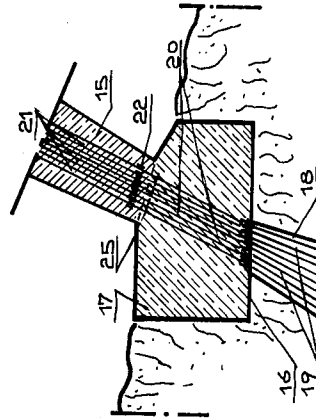


FIG. 8



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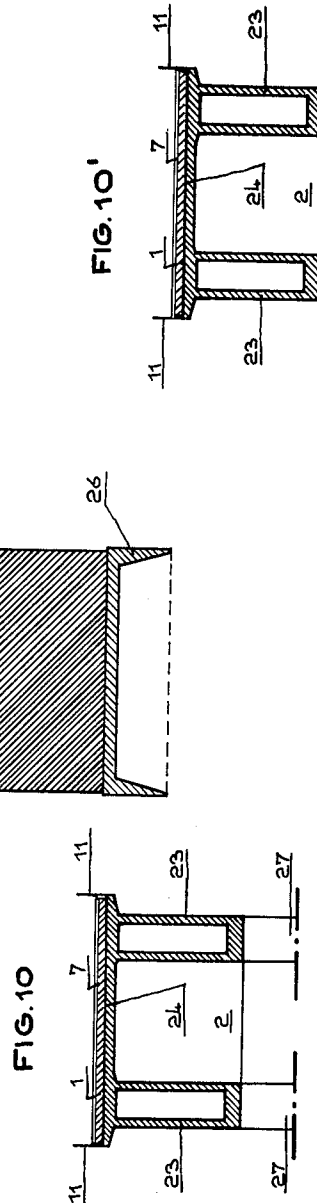
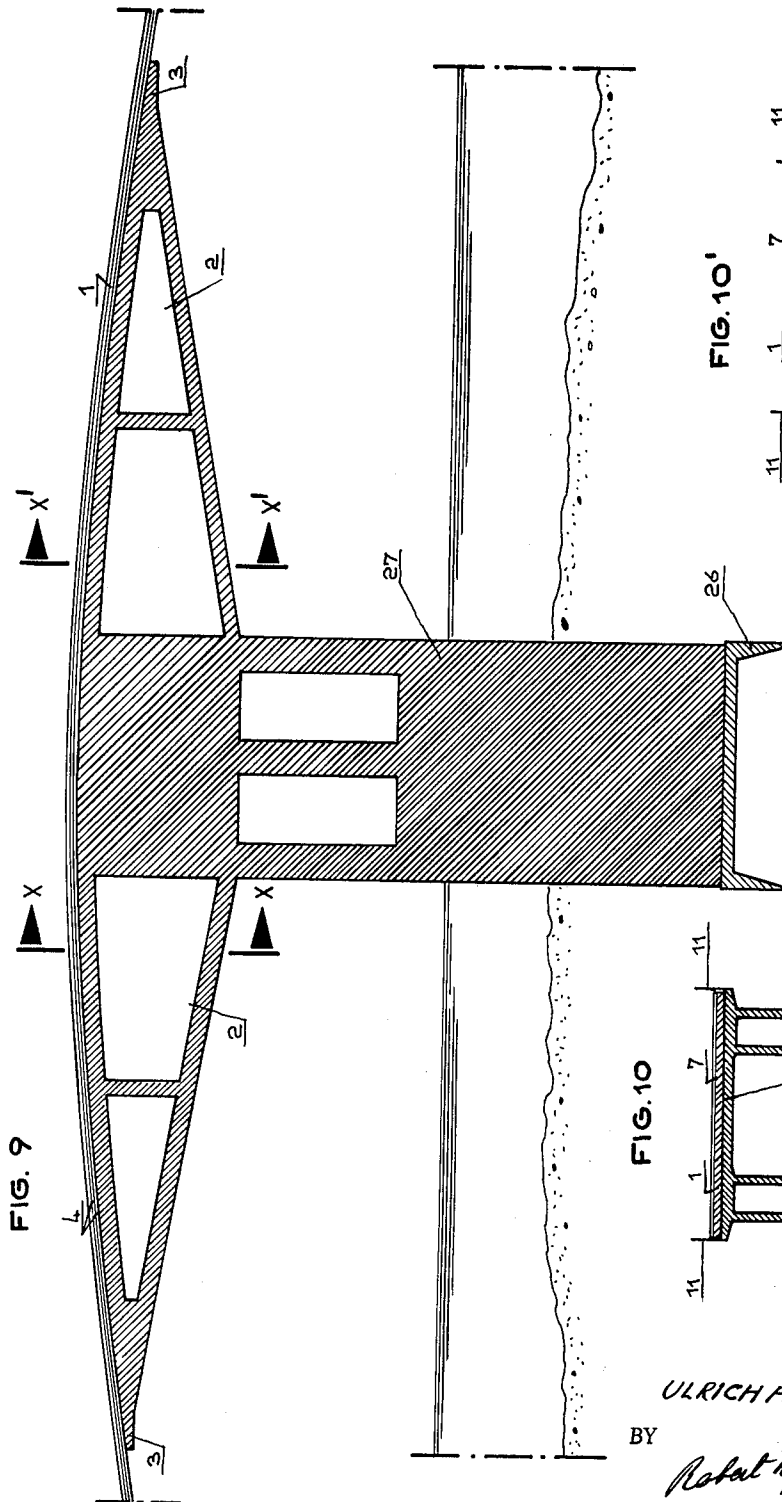
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SUSPENSION BRIDGE

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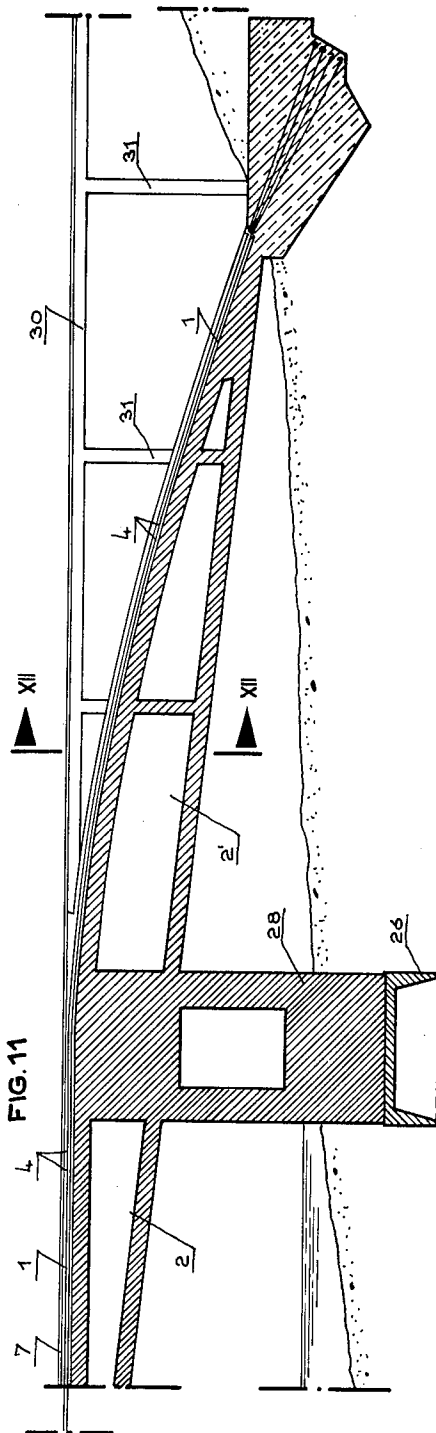


FIG. 13

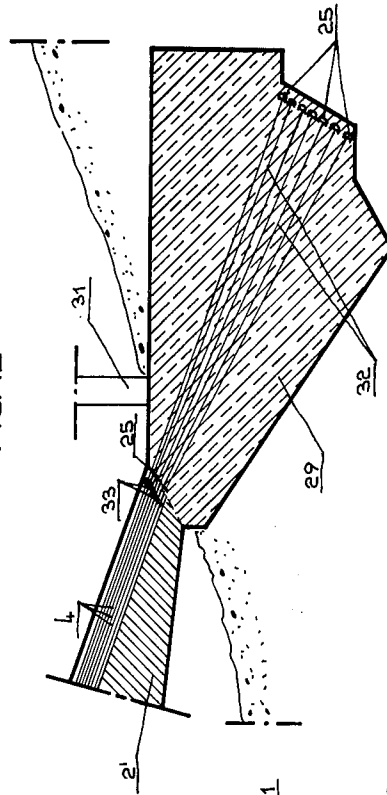
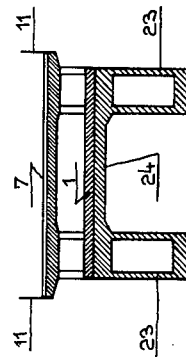


FIG. 12



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SUSPENSION BRIDGE

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Claims priority, application Germany, Dec. 27, 1957,

D 27,105

4 Claims. (Cl. 14—18)

The invention described herein relates to suspension bridges and is particularly concerned with suspension bridges made of reinforced concrete as disclosed in my earlier application Ser. No. 782,265, filed December 28, 1958, and now abandoned. In that earlier application I disclosed the general principles in accordance with which the new suspension bridge of my invention should be constructed and to that extent the present application is a continuation in part. Beyond the earlier disclosure this continuation in part describes specific structural features of my invention in greater detail than the parent case.

Suspension bridges generally consist of one or more carrying or suspension cables from which a roadway structure is suspended by means of hanger members. The cable or cables extend or are tensioned in any event over pylons or piers and are anchored at their ends in abutments or in the structure of the roadway or pavement. In general the wire cables are constructed in the form of fully locked cables.

The bridging of valleys and waterways by means of structures having freely hanging cables is old and suspension bridges of various types of construction are well known. For example in some areas cables made of lianas or similar plants have been used for the construction of hanging bridges on which the traffic may move directly or on branches that are disposed transversely over the cables. In the Chinese province of Szechwan a bridge of this type was built across the Min River which passes over a number of yokes and has a total length of 550 meters. The supporting structure of this bridge is constituted of suspension girders made of bamboo ropes or cables.

Thus, the concept of constructing such a simple and economical structure with materials conventionally used in bridge construction inexpensively and durably was near at hand. However, the development of this form of construction, which must necessarily meet the requirements of modern street traffic, was confronted with many difficulties and problems.

One proposal has been made to tension a sagging band of stressed concrete which bridges the span to such a degree of curvature that with respect to the rounding of the dips and the bumps it satisfies the projected location principles of modern speed highways in a manner that the band could be used directly as the bridge roadway. The realization of this proposal, however, encounters various difficulties that have thus far prevented the execution in actual practice.

It is known that stressed concrete structures can only be subjected to compression stresses up to 150 kg./cm.² and with tensional stresses up to 30 kg./cm.². In this tensional range of 180 kg./cm.² the stress fluctuations which develop as a result of traffic loads, temperature changes and the creeping and shrinking of the concrete must be absorbed. Due to the flat design of the tension band a temperature difference of +20° C. results in a fluctuation of stresses of from 100–120 kg./cm.², depending on the relationship of sag to the width of the span. The stress decrease caused by creepage of the concrete amounts to about 20–25% or approximately 50% of the initial stress owing to the high percentage of armoring. Inasmuch as the traffic load also causes a stress

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fluctuation of about 40 kg./cm.² the above tensional range of 180 kg./cm.² is sufficient to absorb the stresses only if the stress decrease due to shrinkage and creeping can be avoided or at least greatly reduced.

In this connection it has been proposed that the tension members should be loaded with ballast before the concrete is poured and to cast off the ballast during the pouring and the hardening of the concrete. One part of the ballast then serves to compensate for the weight of the concrete during pouring, another part for obtaining the desired compressive stress after the hardening of the concrete and a third part for maintaining the compressive stress during creeping. The casting off of the ballast causes the expanded tension members to contract so that the concrete is given the desired compressive stress. However, since the creeping of the concrete is known to continue for years, one part of the ballast has to stay in place, thereby limiting the usefulness of the bridge. Aside from the costs arising from the placing and the removal of the concrete, the impediment to traffic must be considered to be a shortcoming of this method.

It is an object of the invention to provide a means to overcome the foregoing difficulties and to make it possible to carry out in actual practice and in an economical and technologically satisfactory manner the concept of a sagging band on which the traffic can even travel directly.

In accordance with the invention a method is provided for constructing a suspension bridge of stressed concrete whereby stressed concrete plates are suspended between abutments and/or piers which are formed in the direction of their longitudinal axis along a catenary line and are constructed over their entire length or a part thereof as a roadway slab proper or as supporting structure therefor in that first the steel inserts constituting a large proportion such as 25% of the supporting cross section of the structure are placed, and after placing are tensioned until the desired sag is obtained and are then embedded in concrete while dispensing with the ballast.

In accordance with the invention this is based on the discovery that it is impractical with such a high percentage of armoring to prestress the concrete by shortening the steel inserts because a steel concrete structure without additional prestressing is simpler and it accomplishes the desired effect while avoiding the aforesaid shortcomings. It has been found that a steel concrete slab that is so heavily armored possesses expansion qualities that were unknown heretofore, without being subject to visible or even harmful rips so that the placing of ballast that is needed to effect the prestressing of the steel can be dispensed with.

While for normal armored structures the limitation of the tensional stresses to 30 kg./cm.², which corresponds to a tensional expansion of 0.1% with an E module of 300,000 kg./cm.² is deemed necessary in order to avoid ripping, it has been found that when the armoring of the concrete cross section amounts to 25%, the extensibility of the concrete amounts to about 0.5% as has been determined by pulsator tests with numerous changes of load. At the same time any rips occurring in the concrete are below the limit of visibility of the naked eye and only at 1% expansion rips will occur of about 0.1 mm., which as experience has shown, are harmless for a steel concrete structure. As compared to this proven expensibility of the concrete, the expansibility that is required with the freely sagging slab in accordance with the invention is only 0.5%, so that double safety is insured with the use of the 25% armored concrete cross section for a tension band even against rips that can be readily tolerated.

As compared to a sagging stressed concrete slab formed along a catenary line, the invention provides the advantage that the creeping is eliminated because in the slab of

steel concrete without prestressing there exists no permanent compression stress that would cause creeping. In addition, the need of loading on ballast is eliminated, so that a saving in costs is afforded as well as traffic hindrances are avoided which would result from the presence of ballast during the creeping and shrinking period.

In accordance with a further object of the invention the tension members of the stressed concrete plate or plates can be anchored in the abutments or anchorages which, in turn, are tensioned in the foundation of the structure by means of vertical or oblique tension members.

Structures are also possible where the stressed concrete plate or plates are carried at the shore end of the abutment in a decreasing curved stud structure for anchoring in the foundation, while the roadway continues in this area on top of this stud or support structure.

Finally, in order to accommodate movements of the stressed concrete plate caused by temperature variations, the cantilevers extending from the piers and from the abutments are so flexibly constructed at the tips that they can readily follow these movements.

Further features and advantageous qualities of the subject of the invention will become apparent from the following specification and from the illustrated embodiments of a suspension bridge in accordance with the invention as shown in the accompanying drawings, in which:

FIG. 1 shows schematically a suspension bridge in accordance with the invention over two areas where different possibilities of the abutment pier construction are illustrated;

FIG. 2 shows to an enlarged scale a partial cross-section up to the longitudinal axis of the bridge;

FIG. 3 is a partial longitudinal section through the steel concrete plate in accordance with the invention;

FIG. 4 is a longitudinal section through an abutment pier structure;

FIG. 5 shows the detail A of FIG. 4 to an enlarged scale;

FIG. 6 is a cross-section taken along line VI—VI of FIG. 4;

FIGS. 7 and 8 show to an enlarged scale the details B and C of FIG. 4;

FIG. 9 shows the center pier of a suspension bridge in accordance with the invention to an enlarged scale;

FIGS. 10 and 10' are cross-sections along lines X—X or X'—X';

FIG. 11 shows a different embodiment of an abutment pier;

FIG. 12 is a cross-section along line XII—VII of FIG. 11; and

FIG. 13 shows to an enlarged scale the anchoring block for the steel inserts or anchoring of the steel concrete plate.

The suspension bridge in accordance with the invention (FIG. 1) comprises a steel concrete plate 1 formed along a catenary curve upon which the roadway covering may be placed or which may be travelled on directly. The roadway plate 1 is undulatingly formed between the abutments and the center supports. No difficulties are presented by this form of construction to adjust the gradient and the radii of curvature of the roadway gradient to the requirements of modern street traffic. In order to obtain a relatively slow change in curvature at the abutments and at the piers, the roadway slab is supported there by a far reaching cantilever structure 2 which follows the gradient of the roadway. The cantilever arms 2 must be formed at the ends (FIG. 5) in such a manner that the roadway slab can be deformed in accordance with the sag resulting from load and temperature without the development of cracks. This is accomplished in that, for example, the end portions 3 of the cantilever arms by being tapered outwardly are made to be so thin as to be flexible, in order that they can follow the movements of the roadway slab 1. It is also possible, however, to achieve creeping support for the expanding band by forming the

ends of the cantilever arms along a curve of decreasing radius.

When the abutments and, as the case may be, center piers or pillars, have been installed, the tension members 4 are laid out in several layers above one another which serve as armoring for the freely sagging roadway slab 1 of steel concrete, and where they are of insufficient length, they are connected with suitable means such as sleeves 5. For this purpose at first two tension members are pulled by means of a boat to the next supporting structure. These two tension members are advantageously a part of the lower row of the armoring and are laid out of such a distance from one another that an auxiliary foot bridge (not shown) may be placed upon them. From this foot bridge the remaining tension members are installed between the supporting structures. They are held at the required spaced relationship by spacers 6. Thereupon the tension members are anchored at the abutments and, depending on the construction, they are tensioned from the other end or, as the case may be, also from both ends, for example by means of hydraulic presses. Such an anchoring arrangement is illustrated in FIG. 7 in connection with anchoring members 25, known per se. The tension load of each individual tension member is so computed for this purpose that the required sag or dip is attained.

After all tension members have been tensioned, then the concrete is poured beginning in the center of each field or area by laying sections in the direction toward the abutments or the intermediate piers. The required boarding or casing is fastened in a known manner onto the tension members 4 and is advanced in accordance with the progress of the construction. A partial cross-section through a finished steel concrete plate 1, which either forms the roadway itself or which may be provided with a special roadway covering 7, is shown in FIGS. 2 and 3.

The roadway slab may furthermore be reinforced or prestressed transversely of the roadway in a manner known per se by means of transverse reinforcing elements or tension members 8. The lateral limits of the roadway are defined by planks 9 or by a center beam 10. Along the border of the bridge a railing 11 is provided and, as the case may require, suitable masts for mounting lamps.

Simultaneously in order to save weight or also for aerodynamic reasons, parts of the concrete slab 1 may be recessed and the apertures covered by gratings 13.

The anchoring of the steel concrete plate 1 in accordance with FIG. 1 is shown to a larger scale in FIG. 4, where an abutment or anchoring is formed in rock formation. With such a foundation a type of trestle construction is advantageous, which divides the tension of the steel concrete plate or slab 1 into forces of tension and compression. Here the forward leg 14 which is inclined toward the center of the bridge and which is constructed in the form of a wall takes up the forces of compression, and the rear leg 15 takes up the tensional stresses. The latter must, therefore, be anchored in the rock. This is achieved in that first holes 18 are drilled into the rock from the level of the sole 16 of the foundation 17 before that is erected, and tension members 19 are inserted into the holes and embedded in concrete. Further tension members 20 are connected to these tension members 19 at the level of the sole of the foundation by means of sleeves. These members compensate for the arcuation between the tension members 19 and the tension members 21 of the leg 15. The tension members 20 or stays are inserted in the foundation 17 wherein they are longitudinally movable, and after hardening of the concrete they are stressed and the hollow spaces which remain are filled with grouting under pressure. At the upper end of the tension members 20 connection members 22 are provided for connecting the tension members 21 of the tension or pull stays 15 of the abutment. These are provided with surrounding tubes and embedded in the leg, and after the hardening of the concrete they are tensioned,

anchored by means of anchoring members 25, and the remaining hollow spaces are again filled with grouting in the same manner as in connection with tension members 29 of the foundation 17.

Towards the opening of the bridge a supporting configuration 2 is built onto the abutment trestle which cantilevers, and the upper side of which follows the gradient of the roadway. This configuration is preferably constituted of lateral box girders 23 and a slab 24 disposed on top, and it merges at the end with a slender or tapering and therefore flexible supporting portion 3. The construction of the cantilever arm 2 is advantageously effected in a known manner in freely built out sections.

If one or several center piers are provided, they are provided with foundations in the conventional manner corresponding to the local conditions by means of caissons 26, piles or other structural means. Also these center piers are provided with cantilever arms 2 which are formed and produced in the same manner as at the abutment.

FIG. 11 illustrates an abutment design for a foundation that is not suitable for anchoring by means of a traction anchor. The pier 28 erected by means of a caisson 26 or the like again has the cantilever arm 2 illustrated already in connection with FIG. 4, which extends in the direction of the bridge opening. The arm 2' on the shore side of the pier again consists of box girders 23 and slab 24 (FIG. 12) and is extended down against the ground with the tension members 4 of the roadway slab 1 anchored in an anchoring block 29 (FIG. 13). The under-structure 1, which in its normal part carries the roadway or forms it directly, no longer carries the roadway covering 7 in this area, but the roadway is continued on as an elevated road 30 while the trusses 31 on the arm 2' or on the anchoring block 29 are extended downwardly. In this connection it may be advantageous, owing to the small height above the terrain, to construct the arm 2 in sections, however not freely extended but upon casing scaffolding. The anchoring block 29 is made in a known manner with the tension members 32 embedded in concrete with anchorage 25 at which the tension members 4 of the tension band 1 are terminated by means of sleeves 33 prior to tensioning, which must be effected in this case from the other end.

Having now described my invention with reference to the embodiments illustrated in the drawings, I do not wish to be limited thereto, but what I desire to protect by Letters Patent of the United States of America is set forth in the appended claims:

1. In a suspension bridge of concrete, supporting structures including at least two abutments, anchoring means provided at the ends of the bridge at said abutments, said supporting structures each comprising an upright portion such as a pier and a curved horizontal supporting portion integral with said upright portion, presenting a convexly curved top surface and defining a cantilever arm having a free end, said arm tapering in thickness in the direction of said free end, and a continuous concrete plate having a convexly curved portion mounted on and following the curvature of said top surface and having a sagging portion extending between said abutments, said concrete plate being defined by tension members made of metal such as tensioned cables embedded in concrete, said cables having end portions anchored at said anchoring means and being tensioned to provide for a predetermined sag in said sagging portion

of said plate, said tension members constituting a large part, such as substantially 25% of the cross-sectional area of said plate, and said ends of said arms being flexible so they may follow the movements of said plate thereon caused by temperature expansion and contraction.

2. In a suspension bridge of a concrete, supporting structures including at least two abutments, anchoring means provided at the ends of the bridge at said abutments, said supporting structures each comprising an upright portion such as a pier and a curved horizontal supporting portion integral with said upright portion, presenting a convexly curved top surface and defining a cantilever arm having a free end, said arm tapering in thickness in the direction of said free end, and a continuous concrete plate having a convexly curved portion mounted on and following the curvature of said top surface and having a sagging portion extending between said abutments, said concrete plate being defined by tension members made of metal such as tensioned cables embedded in concrete, said cables having end portions anchored at said anchoring means and being tensioned to provide for a predetermined sag in said sagging portion of said plate, said tension members constituting a large part, such as substantially 25% of the cross-sectional area of said plate, and said convexly curved top surface providing progressive support to said plate as it expands with increasing temperature.

3. A suspension bridge comprising support means defining a catenary curve and having a roadway extending above and substantially parallel to said support means, said bridge comprising at least two abutment structures and a pier intermediate said abutment structures, said abutment structures and said pier having convexly curved top surfaces, said support means comprising tension members such as tensioned cables embedded in concrete to form a continuous plate defining a catenary curve, said plate being supported on and following the curvature of said top surfaces of said abutment structures and of said pier, said cables having their end portions anchored in the ground proximate said abutment structures, said abutment structures and pier having cantilever arms, each arm having a free end and tapering in thickness in the direction of the free end to present flexible end portions capable of following the movements of said plate caused by temperature expansion and contraction.

4. A suspension bridge in accordance with claim 3, where a separate wear surface is provided upon said concrete plate to define the roadway surface.

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