

Nov. 2, 1943.

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2,333,136

STRUCTURAL SPAN

Filed Aug. 3, 1940

3 Sheets-Sheet 1

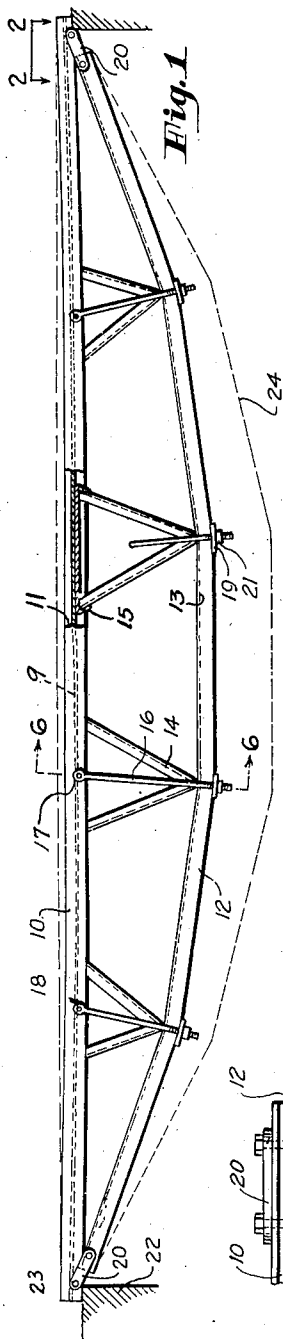


Fig. 1

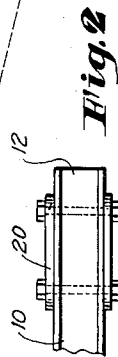


Fig. 2

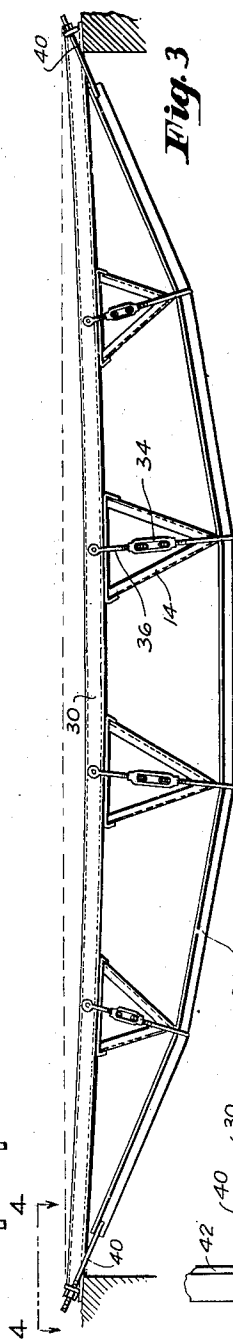


Fig. 3

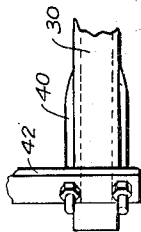


Fig. 4

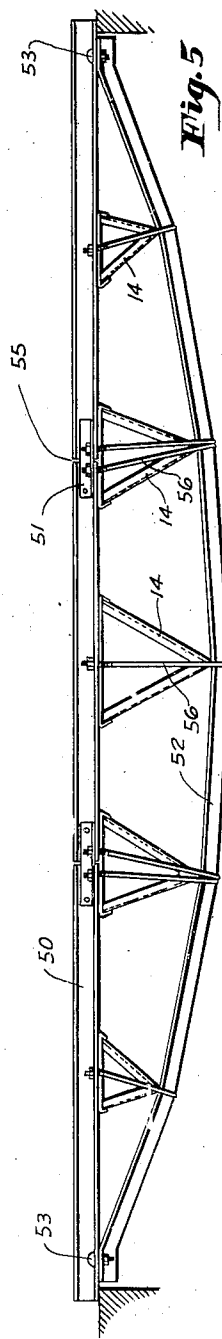


Fig. 5

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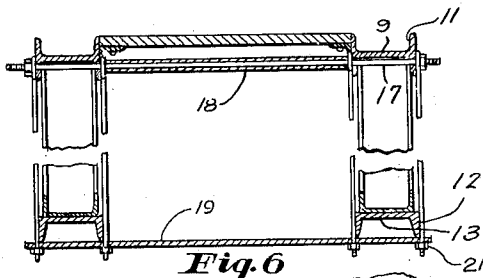


Fig. 6

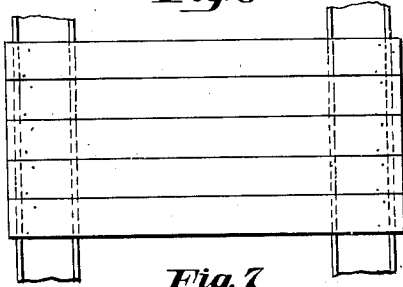


Fig. 7

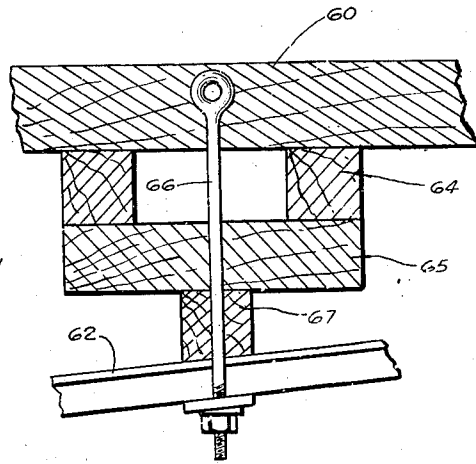


Fig. 8

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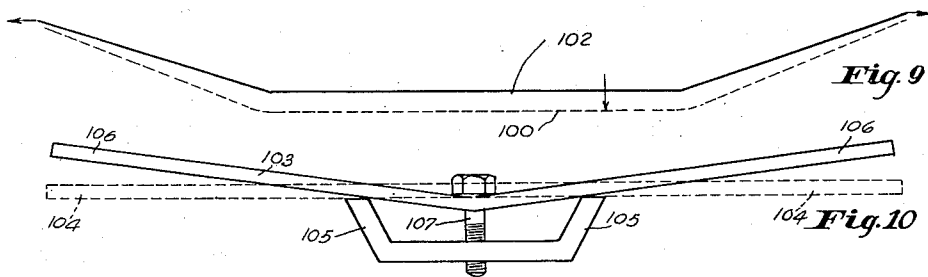
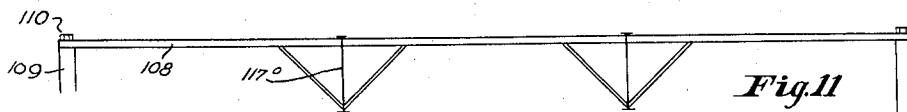
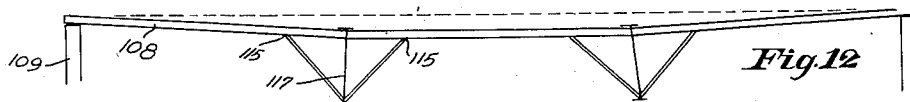
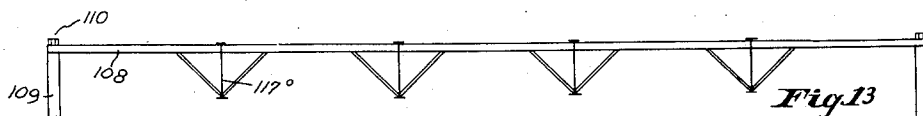
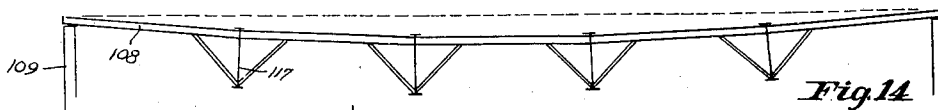
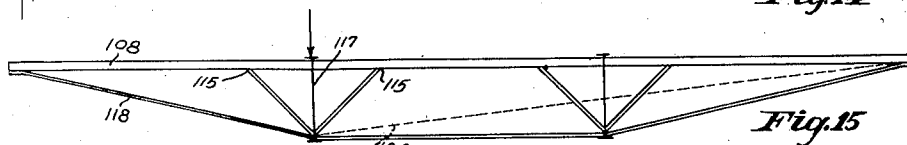
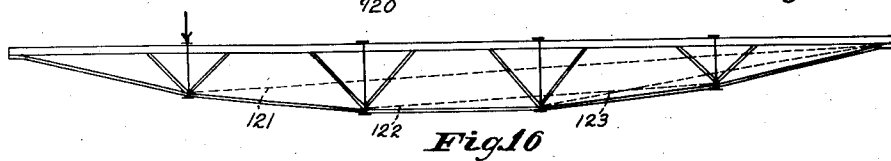
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3 Sheets-Sheet 3



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2,333,136

STRUCTURAL SPAN

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Application August 3, 1940, Serial No. 350,364

18 Claims. (Cl. 189—37)

This invention relates to improvements in structural spans.

More specifically it relates to a type of structure which I have chosen to designate as a "limited-catenary-span," in order to distinguish it from the customary trussed type of structure, which the invention is intended to replace where lightness and compactness of structure are desirable.

It is an underlying principle of the invention that the load shall be carried, primarily, by a tension member which has the characteristics of a limited-catenary. This is particularly true when the invention is applied to the construction of a girder. In such, the end portions of the tension member are anchored to the end portions of a compression member, with struts between these members holding them apart. In a preferred form of the invention I use four struts; thus the load is transferred from the compression member to the tension member at four positions intermediate of the ends of the span.

The chief accomplishment of the invention, however, is the stabilization of this type of structure. That is, the invention provides a relationship between simple elements of structure effective to prevent troublesome undulations from developing as a load moves from one end of the span to the other.

Bridge builders are familiar with the undulations which arise when one walks across a foot-bridge of the suspension type. The chief phenomenon here is illustrated by a rope or chain suspended between two supports with substantial sag: if a load is applied at one position on the chain other portions of the chain will rise. If for example the chain be depressed at approximately one-fifth of the distance between supports from one end support, then, that portion of the chain which is about the same distance from the other support will rise through a very considerable distance.

It is a leading object and feature of the present invention to provide accentuated regional prestressing in either or both of the two load-carrying members at the vicinities of the struts, with forces resulting therefrom, viz, the resilient force thereof, opposing this "rise" so effectively as substantially to eliminate it.

In the above phrase "accentuated regional prestressing" the word "accentuated" is used to signify augmented stressing of specified regions of the members, irrespective of dead loading stresses or other stresses which may be in those members.

The invention provides a number of structural

features which contribute to the achievement of this result. Some of these features may be used singly to attain a degree of freedom from undulation which is entirely satisfactory for certain uses to which the structure of the invention may be applied; or, combinations of two or more of these features may be made to supplement each other in such manner as to produce an extremely light structure with exceptional freedom from undulation and vibration, when compared with its load-carrying capacity. This lightness of structure as compared with its load-carrying capacity can be made little short of phenomenal, if heat treated metals having a high elastic limit are used. The longer the span the more phenomenal will this comparison appear; and even in cases where longer spans than are now feasible with a heavy, massive, trussed structure are contemplated, the simpler and lighter structure of the invention will find an extended field of application.

A distinctive feature of the invention is that the limited-catenary tension member not only carries the load, but is constructed and arranged to be a vital factor in stabilizing the span.

In a girder construction the tension member is curved only at the struts; the remaining portions of its length being substantially straight, as contrasted with the varying and gradual changes in curvature in a catenary curve.

These positive limitations imposed on the curvature of the tension member make the term "limited-catenary" appropriately descriptive of the type of structure which the invention provides.

Theoretically, also, the word catenary is especially appropriate here, because, for optimum load-carrying capacity combined with lightness of structure, the points at which the tension member presses against the struts should fall approximately on a catenary curve passing through the anchorage points of the tension member to the compression member. That is, if the total load carried by the tension member could be simulated by a heavy chain supported at the anchorage points of the tension member, then the points at the bottom of the struts should approximately coincide with the axis of the chain at the respective longitudinal positions of the struts.

However, the invention has a wide range of application where this optimum theoretical height of struts need not be rigidly adhered to, if other stabilizing characteristics of the invention are present.

It is a further distinctive feature of the invention to provide the limited-catenary tension member with a distributed cross-sectional area adapted to resist bending, and to fabricate this member so that, in its free untensioned state, as before assembly, it will have a more acute curvature at those portions which will be drawn against the struts in the process of assembly, than will be the curvature of said portions after assembly. Thereby, within the tension member at the vicinity of each strut, accentuated regional pre-stressing will be produced. The resilient force of this accentuated regional pre-stressing of the tension member at any particular strut will be an inherent loading within the span, tending to prevent "rise," when a load is applied to the span at some distance along its length such as would tend to produce "rise" at that strut.

A further feature is to arrange this distributed cross-sectional area so that the tension member will be of greater cross-sectional area in that side which is toward the struts than in that side which is more remote. For example, a T section or a channel section may be used, with the top of the T or the web of the channel against the struts. This special distribution of cross-sectional area is desirable, because, in deflecting the tension member to produce the force, referred to above, the lower part of the tension member is placed under compression strain which must be balanced by tension strain in its upper part. This tension strain is additional to the direct load carrying tension strain in the tension member.

Another feature of the invention is to provide struts in the form of a V, with the ends of the arms at the open end of the V pressing against the compression member, and the point of the V pressing against the tension member; tie rods extending from the compression member, at the middle portion of the V, to the tension member, at the point of the V; and, preferably, adjustable means, such as nuts on the tie rods to apply tension to the tie rods. By this feature a very effective restraint against "rise," or upward movement of the span at the position of a strut, is produced. In this particular structure there are resulting tendencies to deflect the span, at the regions of the struts, in the direction from the compression member toward the tension member, and this tendency is resisted by the tension member. Thus, again, a downward force or inherent loading is produced within the span which loading must be sustained by increase of tension in the tension member.

This distinctive construction in which accentuated regional prestressing results in regional inherent loading, as a factor contributing toward the stabilizing of a self-contained suspension span, has practical applications of far reaching value. The relations of the forces here involved are illustrated in the accompanying diagrams.

The structure of the present invention, being light in type and being stabilized against undulations by simple elements, without reversals of stress, provides a total structure which is extremely light, and which has a wide field of practical applications, including bridges of many kinds, and other structures. The great length of span which the invention makes possible invites the bridging of deep chasms, without the need and expense of building intermediate piers. The lightness makes for portability; and this favors bridges and girders for uses of all sorts, tem-

porary or permanent, as, for example, in construction or in aid of construction in roads, and, as regards the latter, in the portable aspect, for reaching lumbering, quarrying, and the like temporary works, and especially in military affairs; and also in naval affairs and otherwise on ship-board where light weight is important. Other utilities arise prominently from its characteristic of being a self-contained suspension span. When utilized as a road bridge for motor vehicles the parallel compression members may each be provided with a distributed cross-sectional area having a channel-like top surface adapted to be a vehicle track.

As the invention may be used for a variety of practical purposes, the accompanying drawings illustrate several embodiments; but it will be understood that the invention is not limited to these, and that in construction these are in-structive rather than definitive.

It is intended that the patent shall cover, by suitable expression in the appended claims, whatever features of patentable novelty are in the disclosure here made.

In the accompanying drawings, which illustrate embodiments of the invention,

Figure 1 is a side elevation of a girder, in which the compression member may also serve as a vehicle track, and therefore is especially adaptable for light bridge construction, and may be made in a portable type;

Figure 2 is a top plan of an end portion of the girder of Figure 1, on a larger scale;

Figure 3 is a side elevation of a girder illustrating an arrangement which is optimum for minimum weight of material, and for stability, including shape and arrangement, considered primarily from the standpoint of load-carrying capacity;

Figure 4 is a top plan of an end portion of the girder of Figure 3 on a larger scale;

Figure 5 is a side elevation of another girder, illustrating applicability of the invention where compression members are placed endwise in succession to produce a length of span greater than can conveniently be made in one integral length, as for example exceeding the standard commercial length of 60 or 90 feet;

Figure 6 is an end elevation, in section as on line 6-6 of Figure 1, on a larger scale, illustrating a roadway of two such girders, in which the compression members constitute vehicle tracks spaced and tied together, with bridging material intervening as for a foot or horse path;

Figure 7 is a plan of the same, except that the planking is differently arranged, being set across the whole width, instead of merely between the girders; and

Figure 8 is a side elevation of a fragment, showing the V-strut which appears in Figures 1 and 3 as it might be built up of timber;

Figures 9-16 are diagrams for illustrating the theory of the invention.

Referring to the drawings the main features in the girder of Figure 1 are a compression member 10, a tension member 12, and intervening struts 14 and tie rods 16. The compression member 10 there represented is that known structurally as an H-form wide flange beam. Placed on its side, with flanges vertical, the web 9 is horizontal and may form a vehicle track guarded by the flanges 11. The tension member 12 is a channel bar placed with the web 13 of the channel upward toward the compression member.

The ends of the tension member and of the compression member are secured together so that there can be no endwise motion of the one relative to the other. In Figure 1 this connection is made by a pair of links 20 on either side of the two members. Bolts at one end of the links 20 extend through them and through the compression member, and at the other end of the links 20 extend through them and through the tension member. The compression member extends beyond the links, as at 23 to rest on an abutment 22; and the whole can hang on the abutments at either end, as a self contained suspension unit.

A series of struts 14, which as illustrated in Figure 1 are four in number, intervene between the compression member and the tension member and hold these two member apart from each other throughout the major portion of the length of the span. These struts are preferably in the form of a V which may conveniently be formed of channel iron bent into V-shape, the flanges being nicked to permit of the bending, with the point of the V pressing against the tension member, and the ends of the arms of the V pressing against the compression member and preferably secured together by a suitable local tie as by a flat bar 15 hooked around the two ends of the V. This construction makes each strut a complete unit which may be handled conveniently in the assembling, and makes it unnecessary to attach the ends of the arms to the compression member. The V-part of this structure cooperates with the tie rods 16 to restrict rise.

The tie rods 16 extend from the compression member, at the middle of the top of the V, to the tension member at the point of the V. These tie rods may conveniently be eye bolts, through the eyes of which at the top are bolts or cross ties 17 which pass crosswise of the span through flanges of the compression member as seen in Figures 1-6; and if there are two parallel girders these may reach integrally through the two and may carry spacing tubes 18 for fixing the position of those girders side by side, as seen in Figure 6.

The tie rods 16 extend downward to plates or spacing bars 19, seen also in Figure 6, with nuts 21 on the rods below the plates which are themselves below the flanges of the channel bar which constitutes the tension member 12. These plates may extend across to a parallel girder if there be such, and may constitute spacing bars for the bottoms of the tension members, as in Figure 6. The arms of each V have unequal length, for tipping the axis of the V so that the tie rod can be approximately radial to the curve of the tension member at the point of the V.

The tension member 12 is fabricated so that in its free untensioned state, before assembly, it has a more acute curvature or bend than it has in the assembly, at those portions which are to be drawn against the struts in the process of assembling. In Figure 1 the dotted line 24 is intended to indicate the contour which the tension member 12 had before it was assembled into the position seen in Figure 1. In the assembling the forcing of the ends of the tension member 12 farther apart, by applying tensioning pull at its ends, will make its curvature less acute at the regions of said bends; and the drawing of those regions upward into assembled position will produce accentuated regional pre-stressing within that member 12 at the vicinity of each strut. The resilient force of this accentuated

regional pre-stressing will tend to deflect the tension member downward at the vicinity of each strut, thus providing an inherent loading within the span, available to resist "rise" at a strut when a live load is applied to the span at some distance along its length such as would tend to produce "rise" at that strut.

In Figure 1, where no method of changing the length of the tension member relative to the compression member is shown, the requisite state of tension in the tension member, and the resulting compression strain in the lower part of the curved regions of that member, required to produce the stabilizing feature, are attained by following a special method of assembling. In lighter structures, if the parts are assembled upside down, the weight of the tension member plus such force as may be conveniently applied, will flatten the curvature of the tension member sufficiently to permit the insertion of the last bolt through the link 20. In heavier structures a similar deformation can be obtained with aid of screw jacks or convenient clamps for drawing the tension member up into place for bolting through the link. Next the middle struts 14 may be placed in position. Then the end struts 14 can be slipped into position by placing their upper ends in the channel of the compression member and slipping them lengthwise of the span into position. The bottom plates 19 may then be placed in position, and the nuts 21 on the tie rod 16 drawn up to apply substantial tension to the tie rods. This applying of tension to tie rods tends to pull down into the V that portion of the compression member which is between the arms of the V, and so produces a deflection which results in accentuated regional pre-stressing of the compression member at the vicinity of the arm ends of each V-strut. The resilient force of this accentuated regional pre-stressing will be an inherent loading within the span, imposed on the tension member at the vicinity of each of the struts, which offers resistance effective against upward movement at any particular strut, when a load is applied at some other position along the span which tends to cause upward movement at that strut.

In Figure 1 there is also seen a slight downward curvature of the entire length of the compression member. This places the whole structure in a stable position, in which the whole is hanging from the abutments, being thus a self-contained suspension span. The slight downward curvature seen in Figure 1 adds a stabilizing feature as will be explained more fully in connection with Figure 3 where the downward curvature is greater.

Two parallel girders, of the type shown in Figure 1, tied together at an appropriate distance apart to serve as vehicle tracks, as seen in Figure 6, may form a complete bridge span, and thus constitute an entire motor vehicle bridge of extremely light weight as compared with present types of structure. Such a bridge is portable for sundry places where temporary or emergency or other crossings are wanted, as well as being suitable for a permanent structure, and is economical of costs of manufacture and for being set. The lightness of the girders makes it possible to build single spans of much greater length than is possible with heavier girders.

In Figure 3 the girder portrayed is of the same general type as that in Figure 1, but the compression member 30 is a rectangular tube. The tension member 32 has a T cross section, with

the top of the T against the struts 14. The V-struts 14 which hold apart the tension and compression members may be similar to those of Figure 1, and tie rods 36 similar in position and function to 16 in Figure 1, with any suitable means such as turnbuckles 34 used for applying tension to tie rods.

Figure 4 shows, in plan, the region at either end where the compression and tension members are connected together and are held against relative lengthwise movement. In the particular connection illustrated a rod bent into U-form 40 passes through a hole in the stem of the T-tension member 32. The threaded ends of the U extend through a plate 42, beyond which there are nuts for adjusting the length of the tension member relative to the compression member. The plate 42 is inclined and rests against the end of the compression member 30.

The rectangular cross-section of the compression member 30 is optimum for a column under endwise compression. If lateral stability is of primary importance the rectangular tube 30 may be substantially square in cross-section. The T cross-section of the tension member 32 approximates the optimum for such a member when accentuated regional pre-stressing is desired at the vicinity of the V-struts to create downward forces which are loadings inherent within the span at the vicinities of the V-struts. This inherent loading resists rise at any particular strut when a live load is applied to the span at some distance along its length such as would tend to produce "rise" at that strut. This inherent loading is built up by pre-forming the member 32, as in the case of the member 12 in Figure 1, so that in its state of rest, before assembly, its curvatures, at the regions which are to be drawn against the struts, are more acute than they will be when it has been drawn against those struts. When the nuts on the U-bolts 40 are tightened the tension member 32 is shortened and drawn against the struts 14. Accentuated regional pre-stressing is thus produced at the vicinities of the struts. This produces a compression strain in the lower end-part of the stem of the T; and a coordinating tension strain in the upper part of the T. This co-ordinating tension is added to the load-carrying tension in the upper part of the tension member.

The beam characteristics of the curved regions of such a tension member, which resist bending to provide the inherent loading, require, for an optimum use of material, a vertical distribution of that material. Preferably, also, such a tension member should have a greater cross-sectional area in its upper part than in its lower part. The T cross-section provides a distributed cross-sectional area embodying both of these features.

A rectangular cross-section having a depth distribution of material greater than its width increases resistance to bending, i. e. stiffness, as compared with the same amount of material equi-laterally located about a center, as in a round rod. However, due to the fact that the main tension load must be sustained by the upper part of such a rectangular section, the neutral plane would be well below its vertical center; therefore its effective beam depth would be reduced. Since stiffness varies as the cube of the depth, this would greatly reduce the stiffness as compared with the total structural depth of such a rectangular section. The flange at the top of a T cross-section will sustain this triple or quad-

ruple tension loading and still maintain the neutral plane well above the vertical center of the stem of the T. Furthermore, the flange at the top of the T provides lateral stiffness for the stem so that its depth may be 8 to 10 times its width, as compared with a depth to width ratio of 4 to 6 for a rectangular cross-section alone. The neutral plane within a T cross-section being proportionately higher within this greater depth provides increased stiffness, i. e. enhanced resistance to rise, for a given quantity of material used.

The V-struts in Figure 3 are similar to those in Figure 1. The ties, extending from the compression member between the arm ends of the V to the tension member at the point of the V, may have any suitable means for increasing their tension, turnbuckles 34 being shown. Tightening these applies another increment of inherent loading within the span at the vicinities of the struts, and this loading adds another increment to the load which must be carried by the tension member.

The provision for tightening the tie permits of the making of precise adjustment of the length of each tie rod 16, 26 or 56, to attain whatever inherent loading is desired, as, for resisting "rise." The diagrams herewith illustrating the theory of the invention will make clear the relations of forces involved in restricting "rise."

As the invention is directed toward the preventing of rise, the optimum of stability will not be attained if the compression member is forced during assembly into a position from which it inherently tends to rise.

The natural sag of an I-beam placed on its side as in Figure 1 will ordinarily, in the length used, be as great as or greater than that which the compression member is desired to have in its assembled position. It even may happen that the compression member, 10, 30 or 50, is not stiff enough to carry its own weight, without excessive sag. This is especially likely to happen when the compression member is a series of separate lengths butted end to end as in Figure 5. The compression member may have preliminary regional bends, similar in position and for the purpose described with reference to the tension member. In all of these cases those portions of both the compression member and the tension member which are at the vicinities of the struts are forced upward during assembly and remain in those raised positions.

Also, in the construction illustrated in Figure 3, there is a deeper downward curvature in the compression member than that shown in Figure 1. In consequence of this there is greater lateral stability, but this sag should not be greater than about what is indicated in the drawings relative to the sag of the tension member, if optimum load-carrying capacity is a vital consideration.

In Figure 5 the compression member 50 consists of a succession of separate lengths of structural beams, those shown being of the H-section broad flange type. These lengths are butted end to end, three being shown, with angle-iron side plates 31 providing against lateral displacement. The tension member 52 may be of T-section pre-formed and assembled as in the other cases. In this figure the connection represented between tension and compression members is a cross bolt passing through the lower flange 53, one at each side of the web of the T. The V-struts 14 are placed, one at each junction of sections in the compression member, and one approximately in

the middle of each such section. Each tie rod 56 is in the form of a U-bend extending around the bottom of the tension rod 52 and extending up through the lower flange at each side of the compression member, with adjusting nuts above that to apply tension. At the points where the compression member sections are connected, the ties also pass through the angle plates 51, and the nuts are above the plates. If desirable for adjusting the length of the assembled compression member relative to the tension member, shims 55 may be placed between the ends of the sections of the compression member.

In Figure 5 the compression member is represented as being straight. This compression member in combination with the V-struts and their tie rods provide effective resistance against "rise" at the vicinities of the struts.

The V-struts are not necessarily of the particular type illustrated in Figures 1, 3 and 5. They may be built up in many different forms, so long as the load is carried by two contact points against the compression member, at a substantial distance apart, and that load is transferred to a common point in the strut and thence to the tension member. Figure 8 illustrates how such a strut may be made of timbers. The compression member 60 and the tension member 62 are kept apart by a cross-laid structure. This comprises two cross blocks 64 which immediately underlie the compression member, and may extend across the bridge to a parallel girder; a lengthwise block 65, underlying those two blocks 64; and a crosswise block 67, under the middle of the last and resting on the tension member 62. The tie 66 at the middle of this V is of that type shown at 16 in Figure 1, and serves the same general purpose. When the tie rods 66 are under tension a very substantial resistance is produced by each, against "rise" in its section of a completed girder, when a load is applied at some other place on the girder at a substantial distance.

Fundamental characteristics of the theory of the invention are illustrated in Figures 9 to 16 inclusive.

In Figure 9 the line 100 represents the lengthwise contour of a tension member when untensioned as in its free state before assembly. The line 102 represents its contour in assembled and tensioned position, after its curved regions have been made less acute by pulling on its ends and elongating it so as to have its assembled contour. The degree of accentuated pre-stressing is greater at the curved regions of a tension member, where its curvature changes from that in 100 to 102, by pulling at its ends, than if the curved portions were merely pushed upward from one position to the other. The change in curvature is confined principally to the curved regions in 102 and is not distributed in other parts of its length.

Figures 10-14 elucidate the coaction of the compression member and the V-strut with the vertical tie rod which extends from the compression member to the point of the V.

Figure 10 illustrates the underlying principle of the V-form strut and its tie which the invention utilizes in combination with the compression member to produce inherent loading. If a straight bar whose ends are at 104, 104 be placed across two supports 105, 105 at a distance apart, to simulate the arm ends of a V-form strut, and then the middle portion of the bar be drawn down between the two supports by a bolt 107, the ends

will rise as indicated in the full line positions 106 shown in Figure 10.

If now these ends be depressed from their positions 106 to their original positions 104, while the V-supports 105 are held against downward movement, a downward, depressing, pressure will be applied at the supports 105. If the ends of the bar had been held at their original positions 104, while the bolt 107 was being screwed down as before, the same downward depressing, pressure would have been developed at the supports 105.

In consequence of the downward pressure which results on the arm ends, 105, 105, when a tie 107 is tightened and the bar ends are held down to positions 104, the whole of this supporting structure 105 is pressed downward. When this support terminates in a V-point at its bottom, such downward pressure can be restrained at that point. If it is not restrained the structure 105 will move downward making a sag in the compression member.

Figures 11 and 12 show the application of this principle in a simple arrangement of the invention where two V-struts are used, the compression member 108 only being shown, as resting on supports 109 at either end. Figure 11 shows the unstressed state. By tightening the tie rods 117 the compression member may be made to sag, with its middle portion lower than its ends as indicated in Figure 12, being bent as in Figure 10, at two V-strut regions which have moved downward while its ends have remained at their original level on supports 109. If a tension member be placed beneath the point ends of the V-struts, and be secured at its ends to the compression member before the ties are tightened, so that it holds the V-struts against moving downward relative to the ends of the compression member, then the tightening of the ties will produce a regional pre-stressing of the compression member 108; and the resulting resilient force of this pre-stressing tends to force the V-ends of the struts against the tension member, and thus applies inherent loadings to the tension member at the vicinities of the struts.

Figures 13 and 14 show that this same principle is valid for a greater number of V-struts than two, four being shown.

If, instead of having a tension member present to prevent downward movement of the V-struts, the ends of a compression member 108 be held against movement upward from the supports 109, as indicated by cap screws 110 in Figures 11 and 13, and the platform of a weighing scale be set beneath any particular V-strut, to substitute for the tension member in resisting the downward movement, then the magnitude of this downward force or inherent loading at that particular strut can be measured, by tightening the ties and recording the weight which the scales show.

By this procedure tests may be made to obtain data relating to the comparative value of the number and relative position in various arrangements of V-struts.

In Figure 15, with a load applied at the left hand V-strut, the broken line 120 indicates the direction of pull toward the remote end of the span which is the index line that the contour of the tension member tends to approach.

In Figure 16, the upper broken line 121 likewise indicates the direction of pull toward the remote end of the span, with the load again at the left hand strut. The other two broken lines 122, 123 in Figure 16 indicate the direction of

pull, assuming each V-strut to be restrained successively, or serially, against "rise."

It follows that if each V-strut is effectively restrained against "rise" individually, then the inherent loading required to prevent "rise" at any particular strut is greatly reduced in magnitude as compared with the magnitude of the loading which would be required to restrain "rise," if struts which do not apply inherent loading, are used.

Considered theoretically this fundamental concept of stabilization through the use of an inherent loading to restrain "rise" centers the attention of a designer on the desirability of increasing the load-carrying capacity of the tension member in order to sustain regional inherent loading, and thus to stabilize the span; as contrasted with the customary concept that resistance to longitudinal shear must be provided to stabilize a self-contained span. In an I-beam the web of the I provides this resistance to longitudinal shear. In trussed structures diagonal braces are relied upon to resist this longitudinal shear. Also, these braces are usually subject to strain, first in one direction and then reversely in the opposite direction, which, in resilient materials, produces an amplitude of movement resulting in vibrations and undulations unless a massive structure is used.

In the structure of the invention however, increasing or decreasing the tension intermittently in the tension member, to stabilize the span, does not reverse the strain in that member; and therefore the amplitude of any movement due to the addition or subtraction of a unit of stabilizing strain is less by one-half than if there were a reversal of strain of equal magnitude.

In the above illustrations the term "rise" is used to indicate the tendency toward straightening of curvature. This is the tendency of those curved regions which are not in the vicinity of a live loading to become straightened in response to live loading, in other words, to reduce the curvatures in said curved regions when the tension is increased, irrespective of the direction in which that straightening tends to move these curved regions of the tension member. In the specific instances used for illustration, a chain or a horizontal girder, this direction, of tendency to move, is upward, and the term "rise" which is appropriate to that is herein conveniently extended into use for the generic case. The specific idea here in mind is the providing of a structure which will resist straightening of curved regions of the tension member at the vicinity of any particular strut when the tension of that member is increased by loads applied elsewhere.

In practical designing and construction of girders there will usually be an even number of struts; and where stability combined with lightness is desired there are advantages in making the height of the struts in the middle pair of the order of 5% to 7% of the length of the span. If the height is less than 3%, a desired resistance to bending of the span as a whole will not be obtained; and if the height is more than 8 or 9%, thus making the weight of the struts disproportionately heavier, and the curvature of the tension member greater, more resistance is required to prevent that straightening of the tension member which must be restrained if freedom from undulation is attained.

In relatively short spans where simplicity of structure combined with extreme stability is desirable, practical advantages are had by having

the V-struts, four in number, those toward either end having approximately three-fourths of the height of the middle.

In general, an optimum spacing of V-struts along the compression member is more than once, and less than three times, the spacing between arm ends of the V-struts. With this spacing the portions of the compression member which are between struts will be adapted to carry, without undue flexure, loads comparable with loads which the span as a whole is adapted to carry.

I claim as my invention:

1. Stabilizing means for a structural span comprising, in combination, a compression member and a tension member; each of said members extending in a lengthwise direction of said span and each having a depth distribution of material adapted to resist bending; said members being at their end portions held together and against relative lengthwise movement; said tension member, at at least one region between each held end and the lengthwise center of the span, being curved convexly outward from said compression member; and there being a strut at each said region holding said tension member at a spaced distance from said compression member; said combination being an assembly in which there is accentuated regional pre-stressing, which pre-stressing produces, at the vicinity of each of said struts, a downward resilient force in the compression member and a downward resilient force in the tension member, and each of these resilient forces applies downward inherent loading to said span at its respective struts, when the span is free from live loading; thereby restricting rise at the vicinity of one of said struts when live loading is applied to said span at the vicinity of another of said struts.

2. A limited-catenary-span comprising, in combination, a compression member and a tension member, the end portions of these members being held together and against relative lengthwise movement; and struts between said members holding them apart from each other throughout the major portion of their lengths; said tension member having a distributed cross-sectional area adapted to resist bending and being curved convexly outward from said compression member in those regions of its length which are at the vicinities of the struts; said combination being an assembly in which there is accentuated regional pre-stressing in said tension member at the vicinities of the struts; the resulting resilient forces of said pre-stressing applying downward inherent loadings to the span at said regions while the span is free from live loadings.

3. A limited-catenary-span as in claim 2, in which the said distributed cross-sectional area of the tension member is greater in its top tension-carrying part than in its bottom compression-carrying part.

4. A limited-catenary-span as in claim 2, in which the said distributed cross-sectional area of the tension member is in substantially T-form, with the flange of the T upward.

5. Stabilizing means for a structural span comprising, in combination, a load-carrying tension member extending in a lengthwise direction of said span; there being means holding the ends of said tension member in fixed positions; said tension member having a distributed cross-sectional area adapted to resist bending and being curved convexly downward at at least two regions between its held ends; said tension member being

under a tension load, lengthwise of said span, such that the lower part of each of its said curved regions is under compression while the span is free from live loading, thereby providing a downward inherent loading at each of said curved regions.

6. Stabilizing means as in claim 5 in which the said distributed cross-sectional area of the tension member is greater in its top tension-carrying part than in its bottom compression-carrying part.

7. Stabilizing means as in claim 5, in which the said distributed cross-sectional area of the tension member is in substantially T-form, with the flange of the T upward.

8. A limited-catenary-span comprising, in combination, a compression and a tension member, the end portions of these members being held together and against relative lengthwise movement; and struts between said members holding them apart from each other throughout the major portion of their lengths; said struts each comprising a structure of substantially V-form with the arm ends of the V pressing against said compression member; and tying means for applying, intermediate of said arms, a tension load between the compression member and the point-end of the V; whereby undulations are restricted as concentrated loadings are intermittently applied to said span.

9. A limited-catenary-span, as in claim 8, in which the distance along the compression member, between the adjacent arm-ends of consecutive struts is more than once and less than thrice the distance between the arm-ends of either of these struts.

10. A limited-catenary-span comprising, in combination, a compression member and a tension member, the end portions of these members being held together and against relative lengthwise movement; struts between said members holding them apart from each other throughout the major portion of their lengths; said struts each comprising a structure of substantially V-form with the arm-ends of the V pressing against the compression member, and the point end of the V pressing against the tension member; and tying means holding said members together and for applying, intermediate of said arm-ends, a tension load between the compression member and the point-end of the V; and a tie holding the arm-ends of the V against spreading, whereby the V becomes a unit independent of the compression member.

11. A girder having a limited-catenary-span comprising in combination, a compression member and a tension member, the end portions of these members being held together and against relative lengthwise movement; and struts between said members holding them apart from each other throughout the major portion of their lengths; said struts being of substantially V-form with arm ends pressing against the compression member, and the point end of the V pressing against the tension member; tie rods extending from the compression member at the middle portion of the V to beneath the tension member at the region where said struts press against it; and adjustable means for applying tension to said tie rods.

12. A limited-catenary-span comprising, in combination, a compression member and a tension member, the end portions of these members being held together and against relative length-

wise movement; and struts between said members holding them apart from each other throughout the major portion of their lengths; said compression member having a distributed cross-sectional area forming a top surface adapted to be a vehicle track; said struts each comprising a structure of substantially V-form with the arm-ends of the V pressing against the compression member, and the point-end of the V pressing against the tension member; and tying means holding said members together and for applying, intermediate of said arm-ends, a tension load between the compression member and the point-end of the V.

13. A vehicle bridge comprising a pair of limited-catenary-spans, as in claim 12, in which the spans are girders and there are cross ties holding the girders at a fixed vehicle-tread distance apart.

14. A vehicle bridge comprising a pair of limited-catenary-spans, as in claim 12, in which the spans are girders and there are cross ties holding the girders at a fixed vehicle-tread distance apart; and means secured to the said compression members adapted to support bridging material between said members.

15. Stabilizing means for a structural span comprising, in combination, two load-carrying members extending in a lengthwise direction of said span; said members being held against separation from each other; struts interposed between said members holding them apart from each other; said struts each comprising a structure of substantially V-form, with the arm-ends of the V pressing against one of said members; the distance along that member between the adjacent arm-ends of consecutive struts being greater than the distance between the arm-ends of either of these struts; and tying means for applying, intermediate of said arm-ends, a tension load between said member and the point-end of the V.

16. Stabilizing means for a structural span comprising, in combination, two load carrying members extending in a lengthwise direction of said span; said members being held against separation from each other; struts interposed between said members holding them apart from each other; said struts each comprising a structure of substantially V-form, with the arm-ends of the V pressing against one of said members; and tying means for applying, intermediate of said arm-ends, a tension load between said member and the point-end of the V; said combination comprising at least two of such V-form struts which cooperate with each other, to restrict undulations within said span, characterized by decreasing said tension load at either of said V-form struts, as concentrated loadings are intermittently applied to said span at the region of that strut, and by increasing said tension load at the other of said V-form struts.

17. A limited-catenary-span comprising, in combination, a compression and a tension member, the end portions of these members being held together and against relative lengthwise movement; and struts between said members holding them apart from each other throughout the major portion of their lengths; said struts each comprising a structure of substantially V-form with the arm-ends of the V pressing against said compression member; and adjustable tying means for applying, intermediate of said arm-ends, a tension load between the compression member and the point-end of the V, whereby said tension load

may be adjusted to apply an inherent loading greater than that required to prevent "rise" at any particular strut when a live load of predetermined magnitude is applied, at that position along said span which will produce the greatest tendency to "rise" at said particular strut.

18. Stabilizing means for a structural span comprising, in combination, two load-carrying members extending in a lengthwise direction of said span; said members being held against separation from each other; struts interposed between said members holding them apart from each other; said struts each comprising a structure of substantially V-form, with the arm-ends of the V pressing against one of said members; the distance along that member between the adjacent arm-ends of consecutive struts being greater than

the distance between the arm-ends of either of these struts; and tying means for applying, intermediate of said arm-ends, a tension load between said member and the point-end of the V; said combination comprising at least two of such V-form struts which coordinate each other within said combination so that, as concentrated loadings are intermittently applied to said span at the region of either of these V-form struts, tending to deflect the span in the direction from the arm-ends of the V toward the point-end of the V, the span tends to deflect in the opposite direction at the other of said V-form struts, whereby increasing tension load in the tying means at said last mentioned V-form strut restricts deflection of the span in said opposite direction.

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