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(54) Title: LONG SPAN SUSPENSION BRIDGES - DECK GEOMETRY

Figure 2

(57) Abstract: A suspension bridge, with a deck (3) and a suspension system (4) supporting the deck throughout its span and in which the deck at its mid-span region (8) has a region of upward curvature along the span, followed by a substantially steady gradient, which is then followed by a region of downward curvature towards the end of the span such that the elevation of the deck at its mid-span is at a practical minimum.
LONG SPAN SUSPENSION BRIDGES - DECK GEOMETRY

This invention relates to suspension bridges, especially those with extremely long spans of over 3000 metres.

INTRODUCTION

Suspension bridges invariably have decks with their highest elevation around the mid-span position; this is convenient for taller ships sailing down the middle of the river. Simple geometry indicates that the height of the towers must be at least equal to the elevation of the bridge deck at mid span plus the sag of the cables. As the span of the bridge increases, it follows that the heights of the towers also increases, and for extremely long span bridges the towers may need to be several hundred metres high.

The invention described here suggests a design of the bridge such that the elevation of the deck at its mid-span is at a practical minimum hence the elevation of the lowest part of the suspension cables is also at its practical minimum. In this way, for a given cable sag, it would be possible to reduce the tower height by perhaps 65 metres.

With the middle of the cables and deck close to the water beneath the deck, the extremely long span with which this invention is concerned, will be such as to allow the deck to sweep up from its low point at the mid-span region and to clear the tops of the highest ocean-going vessels which now would need to navigate close to the edges of the span, rather than close to the middle of the span as is currently the situation with all of today's long span suspension bridges.

Furthermore, with the mid-span position at a very low elevation, it becomes practical to provide physical interaction between the deck and the water beneath it. This presents possibilities of counteracting the effects of wind-induced lateral forces or damping out oscillations of the deck or cables.

SUMMARY OF THIS INVENTION

A suspension bridge over a navigable waterway, comprising a continuous cable means whose ends are attached to ground anchors and which passes over the tops of two towers located at the respective ends of the span of the bridge, and which supports the deck via hangers at intervals along the span, and has a region of upward curvature away from the mid-span region followed first by a region of substantially steady gradient and then by a further region of downward curvature.
DESCRIPTION OF THE DRAWINGS

Figure 1 shows a side view of a typical suspension bridge deck with the highest point of the deck at a position around the middle of the span.

Figure 2 shows a side view of a suspension bridge with the lowest point of the deck at the middle of the span, with high points of the deck near the respective ends of the span.

Figure 3 shows a side view of a suspension bridge with the lowest point of the deck at a position around the middle of the span, with the highest point at a position near one edge of the span.

Figure 4 shows a cross section of a typical deck with an attached underwater feature at mid-span which provides additional torsional damping of the deck.

Figure 5 shows a cross section of the deck with an attached neutral buoyancy underwater feature at mid-span which provides additional torsional damping of the deck.

Figure 6 shows a cross section of a deck attached to which is a pair of lateral stays anchored to the sea bed.

Figure 7 shows a cross section of a deck attached to which is a pair of lateral stays anchored to the sea bed via intermediate pontoons.

Figure 8 shows a cross section of a typical bridge deck mechanically coupled at its mid-span to a pair of outboard buoyancy elements.

Figure 9 shows a lateral propeller-operated thrust device installed beneath the deck at or around the mid-span position.

Figure 10 shows the mid-span region of a single centre-line cable supporting the bridge deck and attached to the mid-point of the deck at its centre-line.

Figure 11 shows the mid-span region of a single centre-line cable supporting the bridge deck by vertical centre-line hangers and located above the deck.

Figure 12 shows a single centre-line suspension cable bifurcated in the mid-span region and attached to the sides of the deck around its mid-span position.

Figure 13 shows a single centre-line suspension cable bifurcated in the mid-span region and located above the deck, supporting the sides of the deck via hangers.
EMBODIMENTS OF THE INVENTION

The embodiments of this invention are hereinafter described with reference to the accompanying drawings and are the subject of the claims in the schedule hereof.

Figure 1 shows the side view of a conventional suspension bridge with its towers [1] and [2] supporting the deck [3] by means of the suspension cables [4] via hangers (not shown). The water level under the bridge is shown at [5] while the edge portions of the ground below the water are shown at [6] and [7], and the respective side spans [12] and [13] are connected to ground anchors (not shown). It will be noted that the highest point of the deck above the water is at [8], under the middle of the deck, with the elevation of the deck progressively reducing towards the ends of the span. The required under-deck clearance [8] is determined by the maximum height of the ships that may need to pass under the bridge deck. To accommodate large ocean-going liners, cruise ships, oil tankers etc, this clearance height needs to be around 75 metres. Two such ships [9] and [10] are shown passing beneath the central area of the deck.

With this invention, it is possible to reduce the heights of the towers by reducing the clearance under the middle of the deck, hence reducing the height of the suspension cables and lengths of the hangers throughout the span. Figure 2 shows a suspension bridge otherwise similar to that of Figure 1, with a modified profile [3]. This enables the reduction of the under-deck clearance at mid-span [8] to a minimum.

For example the mid-span clearance may be perhaps 10 metres, which in this example would allow the whole cable assembly [4] to be reduced in elevation by perhaps 65 metres, thus allowing for the heights of the towers [1] and [2] to be reduced by a similar amount. This would result in a significant reduction in the cost, size and mass of the towers and their foundations, and a reduction in lateral wind loads on the towers and cables.

In order to allow the said shipping to pass under the bridge, there needs to be an increase in deck elevation towards the ends of the span. Figure 2 shows a symmetrical arrangement with the increased deck elevation at both ends of the span so that large ships [9] and [10] can pass underneath the deck near the respective ends of the span.

As an alternative embodiment of this invention, Figure 3 shows an arrangement with the maximum deck elevation near one end only of the span. This enables large ships [9] and [10] to pass beneath this area of the deck. The embodiment puts no
constraint in respect of the under-deck clearance below the other end of the span [11], which may be constrained to ascend or descend from the mid-span region or remain substantially horizontal from the mid-span region.

Clearly the viability of such an arrangement will depend on adequate water depth towards the end(s) of the span and the ability of the traffic on the deck to traverse the gradient between the middle of the deck to the highest point of the deck.

With the deck profile according to this invention close to the water surface below the mid-span region of the deck, there is the possibility of some form of water-contact or water-immersed device to be introduced so as to stabilise the deck in one way or another. Examples of such water-contact features are described below.

Figure 4 shows a cross section of a typical bridge deck [1] at its mid-span position. (This single deck section is shown for clarity, although the embodiments of this invention would apply equally to more complex deck types). This area of the deck is close to the water in accordance with this invention. This enables a structure to be attached to the underside of the deck such that its lower part is immersed in the water [2], with the lower part of the structure [3] supported by the deck via rigid structural elements [4] and [5]. The lower part of the structure [3] is subject to forces resulting from rotational movement of the deck with respect to the water in such a way as to provide torsional damping to the deck. This would help to damp out oscillatory motion of the deck that may result from a tendency towards flutter at high wind speeds, or to the general effects of turbulence on the deck and cables.

Figure 5 shows an underwater structure similar to that shown in Figure 4, again able to provide torsional damping to the bridge deck, but now including a buoyancy element [7] and a counterbalance mass [6]. This arrangement would give the under-deck structure substantially neutral buoyancy, and with self-righting characteristics to facilitate the attachment and detachment of the structure to the deck.

Figure 6 shows a cross section of the bridge deck [1] at its mid-span, with laterally disposed tensile elements [8] and [9] anchored to the sea-bed [10] at locations [11] and [12] respectively. The purpose of these tensile elements is to restrain the lateral displacement of the bridge deck under conditions of high cross-winds. Each tensile element may consist of a single or a multiple set of cables.
Figure 7 shows an arrangement of lateral constraints broadly similar to those shown in Figure 6. However intervening buoyant elements, or pontoons as they will now be termed, are now introduced at either side of the deck. The bridge deck is linked via tensile elements [8] and [9] to these two respective pontoons [13] and [14], which in turn are anchored to the sea bed at [11] and [12] via two further tensile elements [15] and [16]. The pontoons reduce the undesirable down-force on the bridge deck resulting from the mass and tension of the lateral restraining elements, and also help to warn shipping about the presence of underwater cables.

Figure 8 shows a simplified arrangement of outboard pontoons [3] and [4] attached to the deck [1] at its mid-span position, via intervening support structures [5] and [6] acting in compression. Tensile restraints [7], [8] and [9] link the deck to the pontoon [3], while similar tensile restraints [10], [11] and [12] link the deck to the pontoon [4]. As the sea level will generally be subject to tidal and other variations, and the elevation of the deck around its mid span position will also vary due the effects of traffic loads and thermal expansion of the cables, it will be necessary to introduce the means to compensate for the variation of the clearance elevation of the deck [1] above the surface of the water [2]. The mechanism required to achieve this compensation is shown simply as the two tensile elements [9] and [12] which are parts of the said tensile restraints. These elements could be simple damper strut assemblies with a long time constant characteristic which would make the elements operate as rigid struts for short time constant motions, but which would be able to adjust their length in long term conditions due to tidal and other effects. Alternatively these tensile elements could be actuators controlled by sensors to detect and compensate for departure from the nominal deck clearance elevation above the water, or to enable the retraction of the pontoon assembly for maintenance action.

Figure 9 shows a further embodiment of the water-immersed feature, with a water-immersed device which is able to provide a lateral force to the deck by means of propellers. The deck [1] with its attached cables [3] and [4] support the under-water device by means of structural elements [4] and [5]. The said under-water device includes a pair of propellers [6] and [7] which are driven by a central mechanical propulsion unit [8] which contains the necessary motor, gearbox and bearings to enable the propellers to operate. The operation of the propellers would be controlled by the sensed lateral deflection of the deck and cables and would be enabled under conditions
of high wind. It may be an attractive alternative to the use of lateral tensile restraints shown in Figures [6] and [7].

There is likely to be some benefit in adopting an unconventional suspension system for extremely long span bridges relevant to this invention. This would involve replacing the conventional 'H' shaped towers, with its twin cables, by 'A' shaped towers which now support only a single suspension cable either along the complete length of the span, or at least over much of the outer regions of the span. The benefit of such arrangements relates to the structural triangulation of the deck and its inclined hangers which would be expected to increase the torsional stiffness of the deck, cable and hanger assembly, with a consequent improvement in both flutter alleviation at high wind speeds, and the tendency of the deck to tilt under asymmetric loading conditions. This embodiment, along with the underwater damping arrangement, would be expected to have such a beneficial impact on deck flutter at high wind speed as to enable the retention of a simple conventional single deck, rather than the alternative arrangement of relatively complicated two or more laterally disposed deck sections, which is the generally accepted method of alleviating flutter in very long span bridges.

Figures 9 and 10 each show the central region of a bridge deck [1] where the single suspension cable [3] supports the mid-span region of the deck by means of vertical hangers [5]. Outside this mid-span region the deck is supported along its sides by means of inclined hangers [4]. In figure 9 the cable is attached to the deck at its mid-span centre-line position, whereas in Figure 10, the centre-line cable is located above the deck.

Figures 11 and 12 each show the deck [1] supported by a single cable [3] outside the central region of the deck, supported by inclined hangers [4]. In its mid-span region, the suspension cable is bifurcated into two cables [6] and [7], and over this region the deck is supported along its edges by means of hangers [5] connected to the respective bifurcated cables. Figure 11 shows an arrangement where the bifurcated cables are attached to the sides of the deck, whereas in Figure 12 the bifurcated cables are located above the sides of the deck.

As a point of clarification, the word 'cable' may include an arrangement of two or more immediately adjacent and mutually attached sub-cables which together perform the functions of a single cable.
CLAIMS

1. A suspension bridge over a navigable waterway, comprising a continuous cable means whose ends are attached to ground anchors and which passes over the tops of two towers located at the respective ends of the span of the bridge, and which supports the deck via hangers at intervals along the span, and has a region of upward curvature away from the mid-span region followed first by a region of substantially steady gradient and then by a further region of downward curvature.

2. A suspension bridge as claimed in Claims 1, in which a water-immersed means is attached to the deck in the region of its mid-span position.

3. A suspension bridge as claimed in Claim 2, in which the water-immersed means includes a damping device which provides a damping moment on the deck about its longitudinal axis as the deck rotates about its said longitudinal axis.

4. A suspension bridge as claimed in Claim 3, in which the said water-immersed means includes a buoyancy element that provides buoyancy and self-righting characteristics when detached from the deck.

5. A suspension bridge as claimed in Claim 2, where laterally disposed tensile restraints are connected from the bridge deck and anchored to the river or sea bed at either sides of the bridge deck.

6. A suspension bridge as claimed in Claim 5, where the said lateral tensile restraints are anchored to the river or sea bed via a pair of pontoons laterally disposed one at each side of the bridge deck.

7. A suspension bridge as claimed in Claim 2, in which the deck is mechanically attached to a pair of outboard pontoons.

8. A suspension bridge as claimed in Claim 7, in which the mechanical attachment to a pair of outboard pontoons includes an actuator that enables the vertical adjustment of the position of the pontoon assembly.
9. A suspension bridge as claimed in Claim 7, in which the mechanical attachment to a pair of outboard pontoons includes a damping means that automatically adjusts itself to accommodate long term variations in the span.

10. A suspension bridge as claimed in Claim 2, in which the deck is attached to an underwater propeller-operated lateral propulsion unit in the region of the mid-span position.

11. A suspension bridge as claimed in Claim 1, in which the cable means consists of a single cable attached to the centre-line of the deck at its mid-span position and which supports the deck elsewhere by means of hangers at intervals along the span.

12. A suspension bridge as claimed in Claim 1, in which the cable means consists of a single cable located above the centre-line of the deck which supports the deck by means of hangers at intervals along the span.

13. A suspension bridge as claimed in Claim 1, in which the cable means consists of a single cable over the outer regions of the span which is bifurcated to form two cables over the central region of the span, and where the bifurcated cables are attached to the sides of the deck at around the mid-span region and which support the deck elsewhere by means of hangers at intervals along the span.

14. A suspension bridge as claimed in Claim 1, in which the cable means consists of a single cable over the outer regions of the span which is bifurcated to form two cables over the central region of the span, and which supports the deck by means of hangers at intervals along the span.
INTERNATIONAL SEARCH REPORT

A. CLASSIFICATION OF SUBJECT MATTER

INV. E01D11/02

ADD.

According to International Patent Classification (IPC) and/or both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

E01D

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

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Further documents are listed in the continuation of Box C. See patent family annex.

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Date of the actual completion of the international search

27 April 2017

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