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Wheeling Suspension Bridge, USA — Case Study

Le pont suspendu de Wheeling, USA — Etude de cas

Wheeling Hängebrücke, USA — eine Fallstudie

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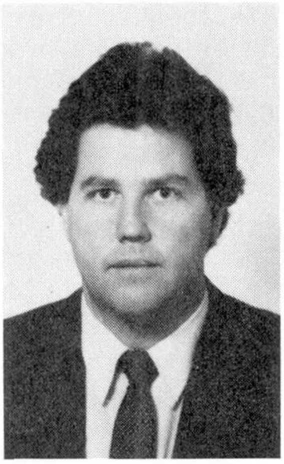


Raymond McCabe, born in New York in 1952. After receiving his Civil Engineering Degree at City College of New York, he joined the consulting firm of Howard Needles Tammen and Bergendoff. Since 1978 he has been involved in the design of medium and long span bridges.

SUMMARY
This paper reports on all aspects of the inspection, condition and rehabilitation of the Wheeling Suspension Bridge, WV, USA, one of the worlds oldest existing suspension bridges.

RESUME
Cet article présente en détail l'inspection, l'état réel et la rénovation du pont suspendu de Wheeling, USA, actuellement un des plus anciens ponts suspendus du monde.

ZUSAMMENFASSUNG
Dieses Manuskript erklärt im Detail die Inspektion, den Zustand und die Renovation der Wheeling-Hängebrücke, eine der ältesten, existierenden Hängebrücken der Welt.

INTRODUCTION

Spanning the Ohio River at Wheeling, West Virginia, is the historical Wheeling Suspension Bridge. The structure is one of the world's oldest existing suspension bridges and was the first bridge built with a span length exceeding 300 meters. In 1969, the American Society of Civil Engineers designated the bridge as a National Historic Civil Engineering Landmark, and in 1975, the National Park Service designated the bridge as a National Historic Landmark. It was designed by Charles Ellet, a civil engineer, who acquired much of his knowledge and experience in suspension bridges while studying in Europe. The suspension bridge was completed at an estimated cost of $250,000 and first opened to traffic on August 1, 1850. It is interesting to note the structure's original design live loads. According to Ellet, the bridge was designed for 2640 kN of live load or that represented by 16 six-horse wagons and 500 people occupying the bridge at one time. Other representations were that of 700 head of cattle or an army of 4,000 men.

On the afternoon of May 17, 1854, violent winds caused excessive vertical oscillations of the bridge which resulted in the cables breaking loose from their anchorages and the deck dropping into the river. This collapse provided engineers with quite a lesson on bridge aerodynamics.

The structure was rebuilt by Mr. Ellet using much of the original material and was reopened in 1856. In 1872 a system of radiating stay cables from the tower top to the deck was installed to stiffen the structure in accordance with a scheme designed by the famous Roeblings. Since that time, a number of repairs and modifications have been made. The last major modification was in 1956, when the entire timber floor was replaced by open steel grating supported on steel floorbeams.

GENERAL DESCRIPTION OF BRIDGE

The present day bridge has a main span of 307 meters between centers of masonry towers. The bridge roadway is 6.1 meters wide accommodating two lanes of automobile traffic and there are two-1.2 meter sidewalks. A general elevation and typical deck cross section of the bridge are given in Figure 1.

There are four main suspension cables supporting the bridge, two along each side. Each cable is approximately 19 centimeters in diameter and consists of 2200 wrought iron wires laid parallel. Each wire has a diameter of 3.5 millimeters. To exclude moisture and maintain compactness, each cable is tightly wrapped with 2 mm wire. The specifications under which the iron wire was furnished were not available. Tensile tests were therefore performed which indicated the wire to have an average breaking strength of 5780 N. This correspondends to an ultimate tensile stress of 600 N/mm^2 quite remarkable for its time.

The longitudinal stiffening trusses of the bridge are of timber construction. They are classic Howe trusses with counters in every panel. The diagonals are capable of resisting compression only. The chords and diagonals are fabricated from structural timber and the verticals are wrought iron rods. The truss depth is 1.9 meters which is only 1/160 of the span length. The combination of timber construction with small depth results in a rather small stiffness for a span over 300 meters long. The trusses are braced laterally by curved steel members extending out from the floorbeams.

The radiating stay cables are wire ropes which extend from the tower top to various points along the bottom chord of the stiffening truss. They have diameters varying from 25 millimeters to 44 millimeters and are clamped to the cable hangers at each intersection. There is a system of lateral sway cables consisting of wire ropes which are connected to the floorbeams and main cables and are anchored into the river banks with partially buried masonry deadmen.

The cable hangers are 2.9 millimeter diameter rods and are connected to the floorbeams at each panel point.

The deck system is composed of open steel grating supported by wide flange floorbeams spaced at 2.44 meter centers.

BRIDGE INSPECTION

The bridge inspection was conducted during July and August of 1978 and a supplemental cable inspection was made during January and February of 1979. The inspection consisted of an in-depth visual observation of all parts of the structure. A longitudinally moving scaffold was rigged beneath the superstructure so that the entire underside of the deck could be inspected. Due to the lack of a cable walkway, a hydraulically operated aerial lift platform was used to inspect the main cables.

The main cables were unwrapped and wedged open in thirteen different locations to observe the condition of the parallel wires. Cable bands were removed and inspected at four locations. The cables were inspected inside all four anchorages.

BRIDGE CONDITION

In general, the wire wrapping of the cables was found to be excessively corroded, loose and broken away in many locations, all of which allow deterioration of the underlying wires. Broken and severely corroded cable wires were discovered at a number of locations of which the most severe are described below.

The outer cable at Panel Point 16 South had approximately 50 broken wires and an additional 85 wires with up to 50 percent loss of section. The inner cable at Panel Point 123 North had 15 broken wires and approximately two hundred wires with excessive section loss. In the northeast anchorage, the inner cable wires were found to be seriously corroded. The corrosion was the result of water leaking through the anchorage ceiling. We estimated that 125 wires were broken or seriously corroded at this location.

In general, the cable hangers exhibited minor corrosion. As shown in Figure 1, one hanger from each cable is connected to the floorbeam at every panel point. At a number of panel point locations, one of the hangers was slack and carrying no load while the adjacent hanger was carrying the full load.

Many of the radiating stay cables were excessively slack and exhibited considerable corrosion. As previously mentioned, these stay cables are clamped to the cable hangers at each intersection. At many locations these clamps have become loose and worn. This has resulted in a constant rubbing action between the two members. Over a time span of many years, the rubbing action has created excessive section loss to both the cable hanger and stay cable.

The timber stiffening trusses were found to be in the advanced stages of decay. The upper and lower chords were considerably rotted throughout 90 percent of their length. More than fifty percent of the timber diagonals were loose and a number of chord splices were found to have failed.

The floorbeams, laterals and bridge grating were in generally good condition with only minor corrosion. The most significant areas of corrosion were at the two ends of the bridge. At these locations, salts and other debris which are carried onto the bridge by automobiles, pass through the open grating and collect on the flanges of the floorbeams.

BRIDGE REHABILITATION

Of prime importance in developing rehabilitation plans was to maintain as much as possible the historical appearance of the structure. The following paragraphs discuss the major items involved in the repair.

The wire wrapping will be completely removed and the cables rewrapped using a neoprene elastomeric wrapping system. This system consists of a first coat of liquid neoprene applied to the cleaned surface of the cable. Next a double thickness of 1.6 mm uncured neoprene is wrapped spirally around the cable with a 50% of overlap. Following this, two coats of Hypalon paint are applied to the neoprene sheet. After careful study, we found the system to be less costly, lighter, and to require less maintenance than the conventional wire wrapping. Another important reason for our recommendation of this system of cable wrapping was that due to the close proximity of the main cables at each side of the bridge, the proper installation of wire wrapping using a wrapping machine would be impossible. Installation of a wrapping system of this type has been performed satisfactorily on a number of bridges.

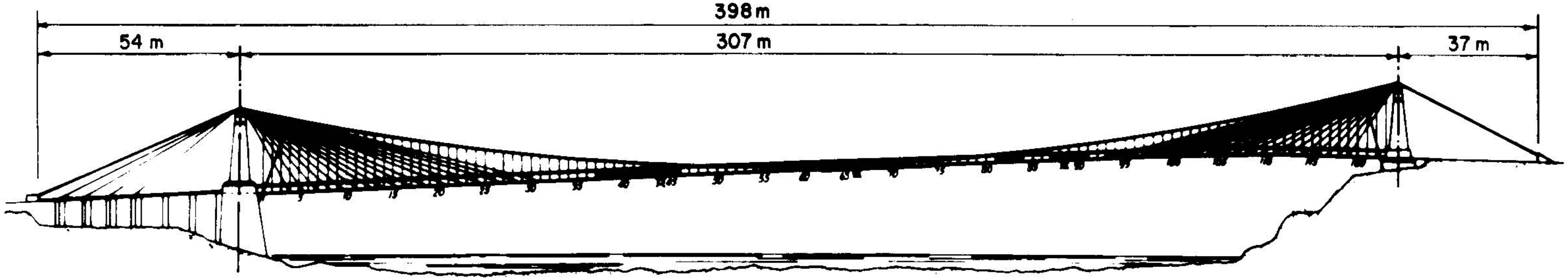
At those locations where broken or severely corroded cable wires occur, new wires will be spliced in. Two methods of splicing were investigated. First, a threaded coupling system was studied. Sample threaded couplers were fabricated and tested at West Virginia University using original bridge wire. The tests showed that the wires failed at an average load of only 60 percent of the ultimate wire strength. In every test the wire failed within the threaded length. Another drawback of this system was that the torque due to the threading process was causing the wire to delaminate. In addition, it would be tremendously difficult to thread the wires in the field. This system was therefore not considered acceptable. We next investigated a swaged type coupling. Couplings of this type have been used in the original construction of many suspension bridges including the Second Delaware Memorial Bridge and the Newport Bridge. This coupling is manufactured by CCL Systems of Leeds, England. Tests performed using these swaged couplers on the original bridge wire showed that the coupler could develop the ultimate wire strength. We found this system to be satisfactory and have therefore recommended it for the wire repair. Prior to performing any wire repairs, the timber trusses, representing fifteen percent of the total dead load on the cables, will be removed.

The cable hangers and stay cables with excessive section loss will be replaced. New clamps will be installed to connect the stay cables to the hangers. The timber trusses will be completely replaced using a dense graded select structural Douglas fir. The timber will be treated using a pentachlorophenol treatment. The chord splices will be made using modern split ring connectors. The stay cable connections to the bottom chord will be made using a steel anchorage plate connected to the chord with special shear plate connectors. All of the steelwork will be blast cleaned and painted using a three coat system.

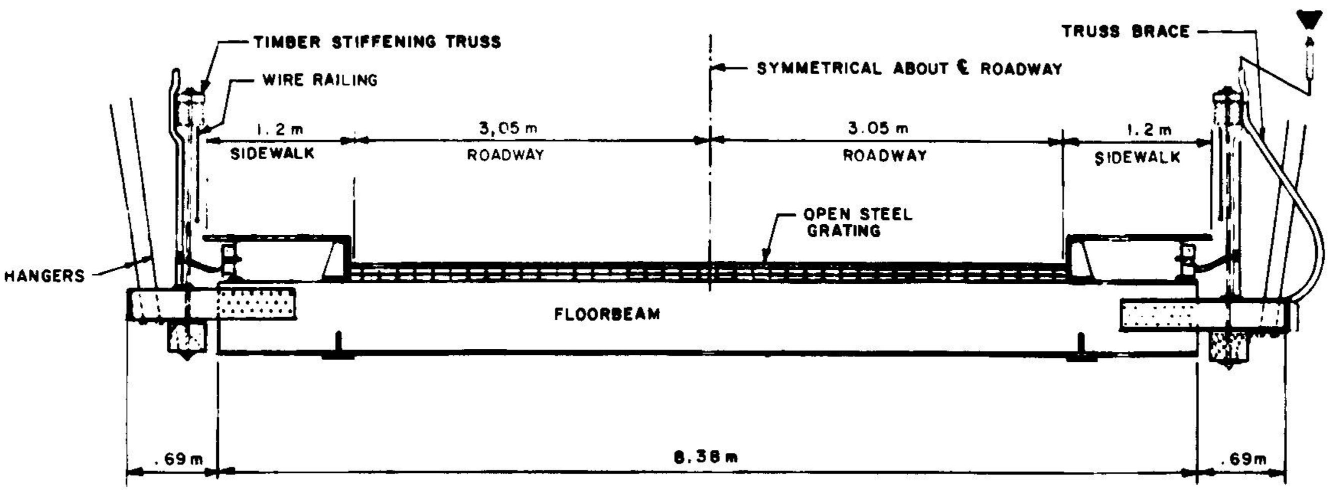
STRUCTURAL ANALYSIS

In order to prepare design plans and specifications for the rehabilitation of the Wheeling Suspension Bridge, an accurate analysis of the structure was essential. The analysis of the bridge presents a problem quite different from that of the typical suspension bridge. The highly indeterminate effect of the stay cables must be included in the analysis. Moreover, the non-linear behavior of suspension bridges is well known and is considered in design. Preliminary linear analysis of the Wheeling Bridge showed the deformations to be large enough to cause significant change in the geometry of the structure. Therefore, a non-linear analysis was required to solve for equilibrium in the deformed position under applied loads. In a typical cable stayed bridge, the horizontal components of the cable forces produce compression in the deck. However, for the Wheeling Bridge these horizontal cable forces produce tension in the stiffening truss. In addition, the stay cables in a typical cable stayed structure have a very large initial dead load tension and therefore remain in tension for all conditions of live load. The stay cables in the Wheeling Bridge have only a minimal dead load tension. As a result, various positions of live load will cause some stay cables to become slack. Therefore, an iterative analysis had to be performed neglecting those stay cables which become slack in the final solution.

The repair contract ($2.6 million) is presently underway and is scheduled for completion in early 1983. Were it not for the structure's great historical significance, the cost of the repairs could not be justified. Upon completion of the repairs, the bridge will be capable of carrying passenger vehicles only.



ELEVATION



TYPICAL DECK CROSS SECTION

WHEELING SUSPENSION BRIDGE
FIGURE 1