

# The Chiani Suspension Bridge: A Complete Overhaul

**Marco Petrangeli**  
Professor  
University of Pescara  
Pescara, Italy  
*marco@integer.it*



**Marcello Petrangeli**  
Structural Engineer  
Integra S.r.l.  
Rome, Italy  
*promo@integer.it*



## Summary

The paper presents the total rehabilitation of the Chiani suspension bridge in Algeria. The bridge, designed by the French engineer Arnodin at the end of the last century span 105 metres using a mixed cable supporting system with a stayed deck portion near the towers. The bridge was designed and built before the similar Sidi M'Cid one in Constantine.

The authors have been asked to engineer a complete overhaul of the bridge, a beautiful structure completely abandoned and closed to traffic because of its severe state of degradation. The works included the complete substitution of the suspension system, widening of the superstructure with new pedestrian walkways moved out of the parapet girders and a new concrete deck to allow unrestricted vehicular transit.

An innovative suspension system with resin encased strands has been used for the main cables, stays and hangers replacement in lieu of ropes and steel bars. New saddles, made of welded plates following a concept originally developed for the 3rd generation suspension bridges, have been placed over the existing ones with the two systems working in parallel during the load transfer.

**Keywords:** Suspension bridge, cable substitution, deck widening, strands, saddle, clamps.

## The Chiani bridge rehabilitation main features

Various existing small to medium span suspension bridges built in the late 19th and early 20th century are now in need of strengthening and repair. Very often it is now time to replace the main suspension cables that given their reduced diameter and lack of proper protection are more prone to corrosion compared to those used for major suspension bridges.

The Chiani bridge was supported by two cables, each one made of 6 ropes. Clamps and hangers were closely spaced at 1.25 metres centre holding I-type cross beams supporting the deck. Twenty metres each side of the towers the deck was supported by 6 plus 6 stays (ropes). The deck stays are anchored to two stiffening I-beams that run beneath the stayed portion of the deck. The opposite horizontal force components of the stays are balanced by 2 traction ropes running below the deck along the suspended part and connecting the above-said I-beams. The saddles originally could slide on rollers; this mechanism, although showing extensive sign of deterioration, must have been still effective at the time of rehabilitation judging from the perfect condition of the stiff masonry towers. All the elements of the suspension system showed severe signs of deterioration. Stays had quite a few broken wires hanging loose, cables were still locked but close inspection after their removal showed corrosion had reached the inner wires with localised pitting phenomena.

The metallic part of the superstructure was made of two parapet stiffening girders and transverse I

beams spaced at 1.25m centre supported by the hangers. Both elements showed extensive but still superficial corrosion. The running surface of the deck was made of wooden planks in a very poor state, falling apart and leaving wide gaps so that the bridge was officially closed to traffic although still providing factual crossing for pedestrian, small motorbikes and herds along the two steel clad kerbs running besides the two parapet girders.

In order to open the bridge to vehicular traffic it was decided to cast a concrete slab on top of the transverse beams in between the two parapet girders. While providing a firm surface for vehicular traffic the slab would also strengthen significantly the bending and axial behaviour of the superstructure. Thickness of the slab has been kept to a minimum (14 cm) so as to reduce its weight. The slab was cast onto corrugated steel sheeting for increased punching and bending resistance. Still, the new concrete slab made for an hundred percent increase of the deck self weight with



respect to the original configuration.

In order to allow for vehicular traffic to run onto the new deck, two other aspects had to be addressed, namely: transverse beams had to be strengthened and kerbs displaced to make place for a single lane carriageway in between the parapet girders. Strengthening of the transverse beams was obtained by welding additional plates onto the bottom flanges and stud connectors on the top ones so as to obtain composite action with the concrete slab.

Sidewalks were moved outside of

the parapet girders. This displacement required the transverse beams to be extended with additional steel plates bolted onto their webs so as to support the new sidewalks positioned in between the parapet girders and the new hangers. The hangers had also to be displaced half a metre outwards thus swinging the suspension cables from the slightly inward original position. Additional plates were also welded onto the upper chords of the parapet truss girders increasing the upper chord lateral and torsional stiffness and the girders buckling resistance.

The new saddles are composed from an assemblage of smaller components made of rolled and welded plates instead of being a single casting. The old saddles have been encased in a steel box, cement grouted once the old cables and stays were removed. The new saddles are placed on top of these encasings on Steel-Teflon bearing pads that allow longitudinal displacements.

Main suspension cables are made of epoxy coated prestressing strand arranged in 3 ropes of 13 strands on each side. Clamps, kept at their original spacing, are made of two parallelepiped castings bolted together. Hangers are made of two strands each fixed to the camps with standard mono-strand prestressing anchorages. Between hangers and transverse beams, high strength treated bars are interposed to allow for easier and finer final tensioning.

The new suspension cables and stays are anchored in cast-in-situ reinforced concrete blocks connected to the existing anchorages. These anchorages were made of concrete cast inside pits bored in the rocky ground. The pits were large enough to make room for the new reinforced concrete castings. The additional weight of the new casting, provided sufficient strength for the increased weight of the suspension bridge.

# The Chiani suspension Bridge: a complete overhaul

**Marco Petrangeli**  
Professor  
University of Pescara  
Pescara, Italy  
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**Marcello Petrangeli**  
Structural Engineer  
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## Summary

The paper presents the total rehabilitation of the Chiani suspension bridge in Algeria. The bridge, designed by the French engineer Arnodin at the beginning of the last century span 105 metres using a mixed cable supporting system with a stayed deck portion near the towers. The bridge was designed and built before the similar Sidi M'Cit one in Constantine, Algeria.

The authors have been asked to engineer a complete overhaul of the bridge, a beautiful structure completely abandoned and closed to traffic because of its severe state of degradation. The works included the complete substitution of the suspension system, the widening of the superstructure with new pedestrian sidewalks moved out of the parapet girders and a new concrete deck to allow for unrestricted vehicular transit.

An innovative suspension system with resin encased strands has been used for the main cables, stays and hangers replacement in lieu of ropes and steel bars. New saddles, made of welded plates following a concept originally developed for the 3rd generation suspension bridges, have been placed over the existing ones with the two systems working in parallel during the load transfer.

**Keywords:** Suspension bridge, cable substitution, deck widening, strands, saddle, clamps.

## 1. Introduction

Various existing small to medium span suspension bridges built in the late 19th and early 20th century are now in need of strengthening and repair [1][2][3][4]. Very often it is now time to replace the main suspension cables that given their reduced diameter and lack of proper protection are more prone to corrosion compared to those used for major suspension bridges.

Replacement of the suspension system is not a simple task though. Large displacements, deformations and elastic energy are stored into these elements making it difficult to perform the release and replacement of the various components, especially the suspension cables.

The Chiani Bridge (Fig. 1) is a small suspension bridge designed by the French engineer F. Arnodin at the beginning of the last century. The bridge spans over the Chiani river at the outskirts of the homonymous village, located near Annaba in north-eastern Algeria. The bridge was built few years before two similar ones were erected by the same engineer in Constantine, the Sidi M'Cit [5] and the Perregaux bridges.

The structure uses a mixed system (popular among French engineers during that period [6] and adopted few decades later by Dischinger) with both suspension cables and stays. The main suspension cables and the back stays are anchored into 4 concrete pits excavated into the rocky

ground.

The bridge showed extensive signs of corrosion in the suspension and stay cables and in the deck stiffening girders and transverse beams. The deck running surface, originally provided by wooden planks resting on the steel transverse beams was completely rotten leaving for the pedestrian crossing only two steel plated narrow kerbs adjacent to the parapet truss girders.

## 2. The bridge suspension system

The Chiani bridge was supported by two cables, each one made of 6 ropes of 75mm diameter. These ropes run horizontally adjacent and so rested over the saddles at pier tops and at the anchorages. Each suspension rope was individually clamped with steel bars to small steel profiles connected to the hangers made of 33mm dia. rods. Clamps and hangers were closely spaced at 1.25 metres centre holding I-type cross beams supporting the deck. Twenty metres each side of the towers the deck was supported by 6 plus 6 stays made of 35mm dia. ropes. These 6 stays were made of 3 ropes looping around 3 pulleys at the saddles. Their force was balanced by a single back stay



each tower made of a 42mm dia. rope. The deck stays are anchored to two stiffening I-beams that run beneath the stayed portion of the deck. The opposite horizontal force components of the stays are balanced by 2 traction ropes running below the deck along the suspended part and connecting the above-said I-beams. This configuration allows the deck to swing longitudinally since the above said horizontal force stay components are self-equilibrated and the deck does not push against the abutments (towers).

The saddles originally could slide on rollers; this mechanism, although showing extensive sign of deterioration, must have been still effective at the time of rehabilitation judging from the perfect condition of the stiff masonry towers.

All the elements of the suspension system showed severe signs of deterioration. Stays had quite a few broken wires hanging loose, cables were still locked but close inspection after their removal showed corrosion had reached the inner wires with localised pitting phenomena.

*Fig. 1 – The bridge during the deck rehabilitation*

## 3. The deck widening and strengthening

The metallic part of the existing deck was made of two parapet stiffening girders and transverse I beams, spaced at 1.25 metre interval, directly supported by the hangers. Both elements showed extensive but still superficial corrosion. The running surface of the deck was made of wooden

planks in a very poor state, falling apart and leaving wide openings so that the bridge was officially closed to traffic although still providing factual crossing for pedestrian, small motorbikes and herds along the two steel clad kerbs running besides the two parapet girders.

In order to open the bridge to vehicular traffic it was decided to cast a concrete slab on top of the transverse beams in between the two parapet girders. While providing a firm surface for vehicular traffic the slab would also strengthen significantly the bending and axial behaviour of the superstructure. Thickness of the slab has been kept to a minimum (14 cm) so as to reduce its weight. The slab was cast onto corrugated steel sheeting for increased punching and bending resistance. Still, the new concrete slab made for one hundred percent increase of the deck self weight with respect to the original configuration.

In order to allow for vehicular traffic to run onto the new deck, two other aspects had to be addressed, namely: transverse beams had to be strengthened and kerbs displaced (Fig. 2) to make place for a single lane carriageway in between the parapet girders (see also [7]). Strengthening of the transverse beams was obtained by welding additional plates onto the bottom flanges and stud connectors on the top ones so as to obtain composite action with the concrete slab. Sidewalks were moved outside of the parapet girders. This displacement required the transverse beams to be extended with additional steel plates bolted onto their webs so as to support the new pedestrian corridors positioned in between the parapet girders and the new hangers. The hangers had also to be displaced half a metre outwards thus swinging the suspension cables from the slightly inward original position, to their new, 3° outwards, position.

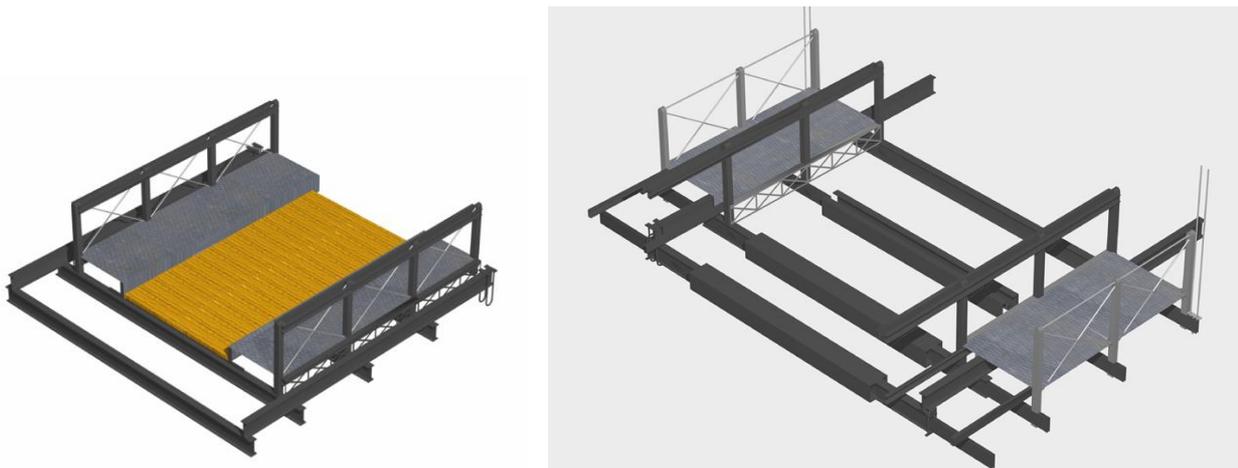


Fig. 2 – Deck 3D view. Before (left) and after widening

Since deck concreting displaced the section centroid downwards, while strengthening the transverse beams, additional plates were also welded onto the upper chords of the parapet truss girders increasing the upper chord lateral and torsional stiffness and the girders buckling resistance.

#### 4. The new suspension system

Two options were available for the suspension system replacement.

The first option was to replace the main suspension cables and stays one by one retaining the existing saddles. This approach was used for the partial replacement of the Cidi M Cid suspension cables in Constantine [5]. For the Chiani Bridge it would have had few drawbacks though: the works are slow and cumbersome with a maximum of two suspension cables at the time to be replaced followed by the stays and the hangers; the existing saddles would have to be retrofitted, especially the rollers beneath them. This latter aspect would have been particularly difficult to address since access to the bottom of the existing saddles would have required their lifting, that is to

say, lifting of the entire deck. The second option was to build an entire new system, independent of



the existing one, made with state of the art materials and technologies. This second option was retained because it was more efficient, durable and economic with respect to the former. The only problem with this second solution being the challenging operations required for transferring the load from the old system onto the new one, with the two systems working in parallel before the old one could be completely unloaded and removed (see also [8]).

*Fig. 3 - The new saddles*

The key elements of the new system are the new saddles (Fig. 3). These element were designed



following a philosophy developed for larger bridges by William Brown (1928-2005) were the saddles are an assemblage of smaller components made of rolled and welded plates instead of being made of a single casting. The old saddles have been encased in a steel box, cement grouted once the old cables and stays were removed. The new saddles are placed on top of these encasings on Steel-Teflon bearing pads that allow longitudinal displacements.

*Fig. 4 - The new cables, clamps and hangers*

Main suspension cables are made of epoxy coated prestressing strand arranged in 3 ropes of 13 strands on each side. Clamps, kept at their original spacing, are made of two parallelepiped castings bolted together. Hangers are made of two strands each fixed to the camps with standard mono-strand prestressing anchorages. Between hangers and transverse beams, high strength treated bars are interposed to allow for easier and finer final tensioning.

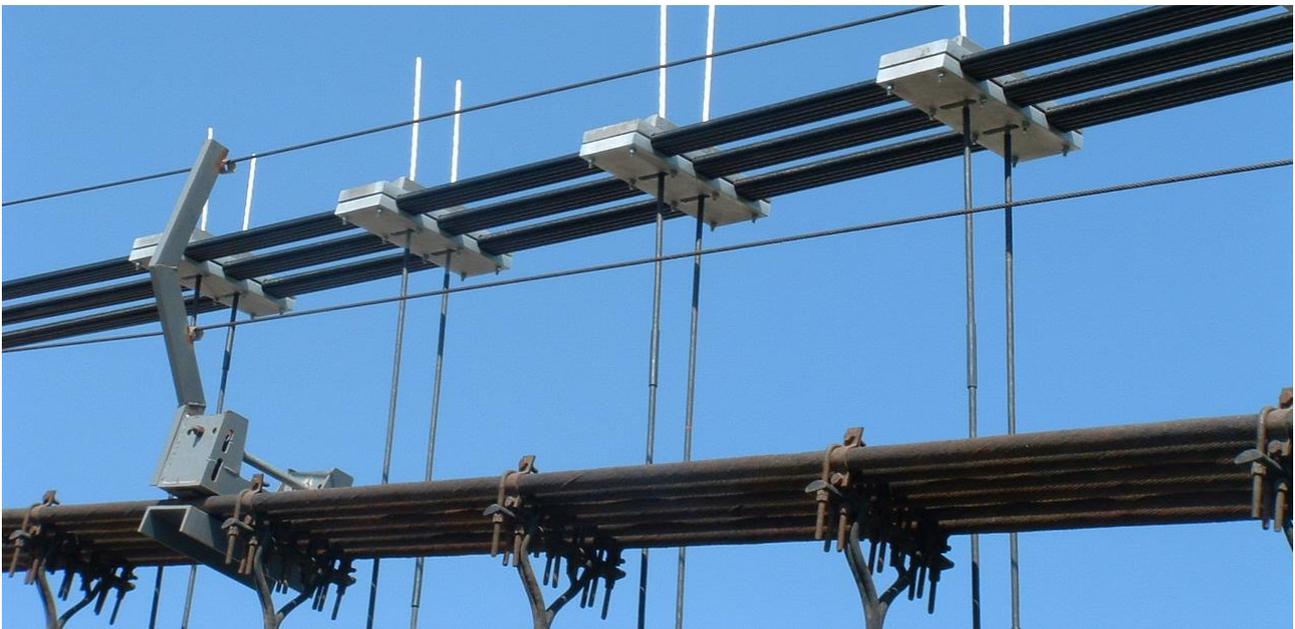
A number of tests were carried out in Italy to assess the clamps capability to resist the tangential

force component of the hangers pull that increases toward the towers up to 25% of the vertical force. The tests showed a surprisingly good capability of the clamps to resist tangential forces. Short term resistance was, on average, 50% of the clamping force (8 D12mm bolts each clamp). No significant reduction of this resistance could be detected for long term load application although some loss can be expected after prolonged exposure to the Algerian sun. Still, the design maximum tangential force for the clamps (5 kN) is less than 10% of the resistance (50 kN) found in the laboratory on a prototype, clamping only 1 cable out of 3 with 4 bolts, instead of 2 cables and 8 bolts of the actual clamp. All the suspension system components were therefore made in Italy and shipped to Algeria together with the epoxy coated prestressing strands.

The new suspension cables and stays were anchored in cast-in-situ reinforced concrete blocks connected to the existing anchorages. These anchorages were made of concrete cast inside pits bored in the rocky ground. Cables were deviated and anchored vertically. The pits were large enough to make room for the new reinforced concrete castings. The additional weight of the new casting, firmly connected to the existing anchorages with reinforcing bars drilled and grouted into it, provided sufficient strength for the increased weight of the suspension bridge.

## 5. The work phasing

The works commenced with the complete removal of the wooden deck planks and sandblasting of the existing steel deck components. The steel deck was then reinforced by welding the additional plates and widened by bolting extensions to each transverse beam (Fig. 1). A total of 2.5 kN/m of structural steel was added to the superstructure during this stage. Corrosion protection was then applied to the whole of the structure.



*Fig. 5 – The two suspension systems before the load transfer*

Works on the tower and existing saddles followed, with temporary steel platforms erected on top of the towers, encasing of the old saddles and erection of the new ones. In order to keep the encasings of the old saddles within acceptable weight (plate thickness), the encasings were tailored so as to transfer the load to the old saddles along multiple contact lines. Upon removal of the old cables and stays, grouting of the four encasings provided additional strength and solidity to these bases supporting the new saddles.

Replacement of the suspension system followed. The new cables were spun across one strand at the time (78 strands) using the catwalks erected on the existing cables. The free standing position of the new cables was, at midspan, 3.5 metre circa above the deck and therefore 3 metres higher than the old cables (Fig. 5). This choice allowed, after loading the new cables, to leave a minimum 2.2 metre clearance at midspan along the pedestrian walkways.

A first tensioning of the new system was then carried out with the new hangers shortened to a given length so as to take over roughly 50% of the deck weight. This operation was rather unusual since the stay technology and equipment used for the new suspension system are designed for stiffer configurations and higher loads. Tensioning started from the midspan hangers, shortened by 50cm circa, with a tensioning force of few kilonewtons. Tensioning then moved symmetrically towards the towers with the main cables gaining tension and stiffness thus simplifying the tensioning operations. Because this first tensioning took place after a prolonged summer stop due to environmental and minor technical adjustments, significant errors were committed when shortening (tensioning) the hangers to the predefined length. A plot of this error is shown in Fig. 6. Hanger length was topographically measured after first tensioning. Since tension in the hangers was negligible, topographically measured length was a fair estimate of the actual unstretched one.

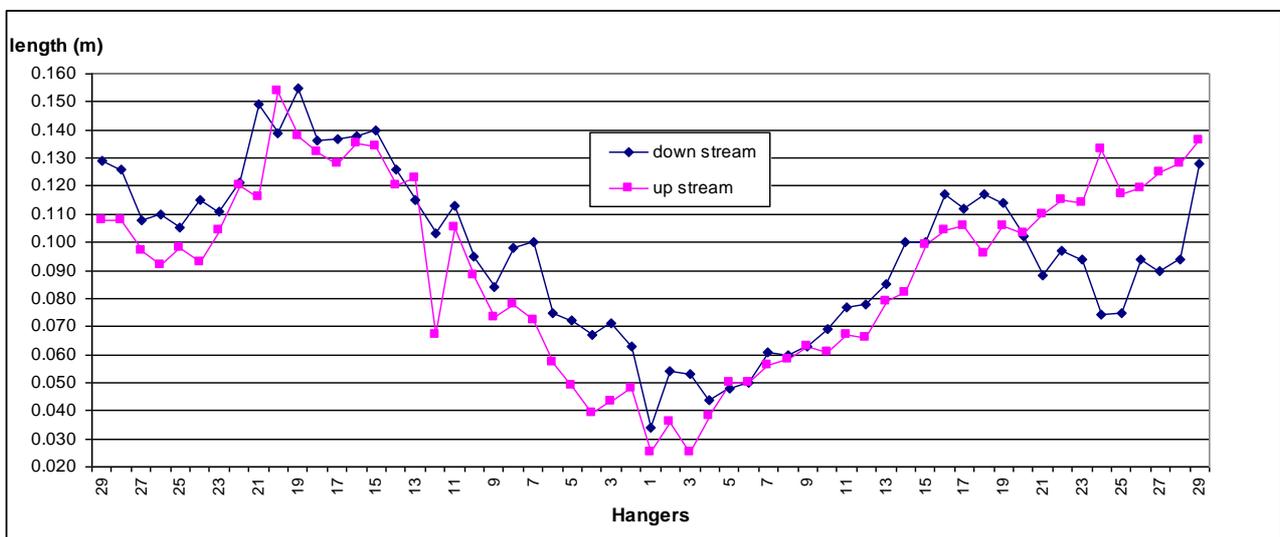


Fig. 6 – Hanger's length difference between design and measured after first tensioning

Error in hanger tensioning could be easily verified by manually checking the tension in the hangers. According to the above graph, few hangers were almost slack, other significantly stiffer than the others. Nonetheless, the bridge deck proved to be sufficiently strong and flexible to withstand the uneven load distribution resulting after the first hanger tensioning. Given the very light deck configuration and strength reserve of both deck and hangers, it was therefore decided to proceed with the next phase leaving the correction of the first tensioning to a later stage.

Next phase was the complete unloading of the old suspension system. Old hangers were released one by one leaving the deck hanging from the new cables. The old suspension ropes, standing under self weight only were temporarily clamped, sawn at midspan and removed from both sides. The operation required the ropes to glide inside the old saddles grooves, previously greased to reduce friction.

Finally, the second tensioning of the new hangers could be performed, before concreting of the new deck slab. Because concreting of the deck would increase the deck weight by 100%, the second tensioning had to significantly raise the deck to make up for the subsequent sagging of it. While doing this, the following other issues were to be tackled:

- correct 1<sup>st</sup> phase tensioning errors and adjust for other tolerances in the initial cable set up

- allow for the third and final tensioning to be performed from the bottom rods only
- adjust rod lengths so as to obtain a constant height of the anchorage plates between hangers and roads after final tensioning.

After the second tensioning, strand anchorages up in the clamps were pushed to lock, the strands cut to measure and the anchorages greased and closed with their metallic cap. After second tensioning, the error between design and measured value reduced significantly as shown in Fig. 7. Following the second tensioning, stays were replaced, two at a time, with the new ones made of the same strands used for the main suspension cables. Contrary to hanger tensioning, carried out under geometry (length) control, stays have been tensioned to predefined force values.

With the suspension system fully replaced, concreting of the deck slab was performed. The slab was cast over corrugated steel sheeting discontinuous over the transverse beams where stud connectors were welded to obtain composite action with the concrete deck slab. The concrete top surface slab was then immediately waterproofed with acrylic painting. During this phase, 80% of the deck weight increment was applied to the bridge, with the deck camber of 700mm after second tensioning reducing to 350mm. Because of the cables tension increment, saddles displaced 10cm circa towards central span partially recovering the initial set back imposed during cables erection.

After deck concreting the third hangers tensioning and the second stays tensioning took place. Once again, hangers tensioning was carried out with a displacement controlled procedure whereas stays with a force controlled one. Finishing works then followed, with a 30mm bituminous wearing course cast on the deck slab and the walkway external railing fixed to the hangers.

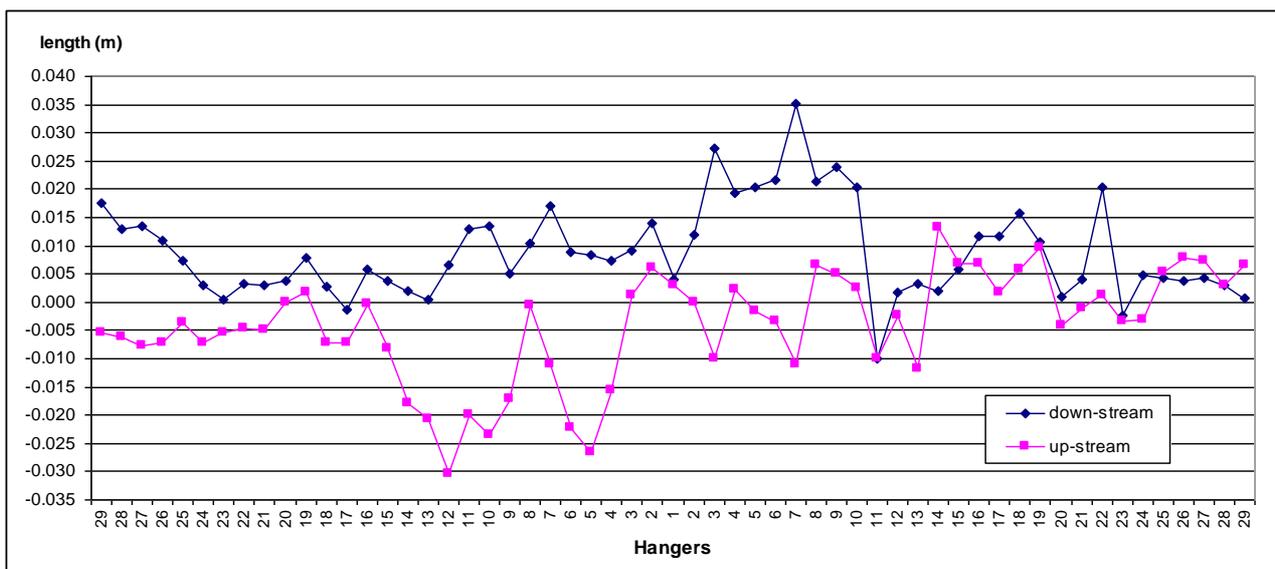


Fig. 7 – Hanger’s length difference between design and measured after second tensioning

## 6. Conclusions

Rehabilitation and strengthening of small to medium span suspension bridges built in the late 19<sup>th</sup> and early 20<sup>th</sup> centuries around the globe is finding growing interest from the structural engineering community as these bridges are now in need of extensive repairs and upgrade. On the basis of the author’s field experience, the following recommendations can be made:

- Small suspension ropes used in these bridges are economically and efficiently replaced by cables made of prestressing tendons. Epoxy encased strands increase life span but also allow for efficient clamping.

- Replacing of the existing suspension system can be carried out with the two systems (old and new) in parallel, provided the two are cinematically independent at the towers.
- The suspension system replacement must be conducted under a displacement controlled procedure. Any procedure based on force specification is likely to be translated, on site, into displacement (elongation). This simple truth is often ignored in the design of contemporary small to medium cable (stay) supported bridges. With a stiff girder and a reduced number of cables (stay) a force controlled procedure may still work but with a flexible deck and a large number of supporting cables, as the case under consideration, displacement control is always simpler and safer, especially in developing countries where topographic stations are more popular than pressure gauges.
- Hanger spacing and number is better kept as in the original configuration for aesthetic and structural reasons. Increasing hanger spacing and reducing their number modifies the mechanical behaviour of the steel stiffening girder. Again, prestressing strands and stay technology can be used for the hangers as they are cheaper, easier to erect and adjust.
- Concreting of the deck is often a simple and efficient system to strengthen the bridge provided the towers and the foundations have enough strength reserves. Additional weight can be



accounted for when designing the new suspension system thus obtaining a stiffer structure (via the increased tension in the cables) but also a tougher and more ductile response of the deck under the increased live loading of today traffic.

- New saddles at towers can be easily made of welded and rolled plates instead of cumbersome and expensive castings.

Fig. 8 – The new Chiani suspension bridge

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