Aluminium Structures in Refurbishment: the case of the "Real Ferdinando" bridge on the Garigliano river

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Summary

Starting from the experience of retrofitting of old suspension bridges in France by means of aluminium structures, a similar solution has been proposed and used in the structural restoration of the "Real Ferdinando" bridge on the Garigliano river near Naples, which was the first suspension bridge built in Italy in 1832. The historical background, the structural restoration criteria, as well as the design and the execution of this bridge are described in this paper.

Introduction

The use of aluminium alloys is today an emerging activity which competes with steel in many specific fields of structural engineering [1]. A new field of particular interest is the one of structural restoration, where aluminium and its alloys represent a new material whose properties can be exploited in very promising way. An interesting experience has been done in the restoration of old suspension bridges in France during the seventies [2]. These structures, built during the 19th century, were made of wooden deck, masonry piers, steel girders and steel suspension cables. Their bad condition required structural consolidation operations, also in view of re–using these bridges in a new improved road planning. After a national competition, in which both steel and aluminium solutions were presented, the French Road Authorities accepted to use an aluminium deck in the retrofitting project of three bridges (the Montmerle and the Trevoux bridges on the Saône river; the Groslée bridge on the Rhône river). They were completed within 1975.

In the Montmerle bridge (two 80 m bays) the use of aluminium both for the two longitudinal truss beams with bolted connections and for the deck structures led to the possibility of increasing the weight of the road vehicles, while preserving both the existing cables and piers without significant strengthening (*Fig. 1*). In the retrofit of the Groslée bridge (a single 174 m bay) the new deck structure is made of three longitudinal aluminium truss girders, connected to a light reinforced concrete slab (*Fig. 2).*

At the end of the eighties, a structural restoration project of the oldest Italian suspension bridge, the "Real Ferdinando" bridge on the Garigliano river (1832), has been proposed in the context of a wider rehabilitation program of that area, which wanted to re-use it for a pedestrian connection [3]. This bridge was designed by Luigi Giura in 1828 (*Fig. 3*) and erected in 1831-32 under the supervision of the King Ferdinando II. During World War 2 the deck of the bridge was completely destroyed and it was in a bad condition for many years.

Considering the positive french experience, it was clear that an aluminium solution would be very appropriate for the planned purpose. But it was necessary to develop a comprehensive comparison between the more classical steel solution and the aluminium one in order to convince the public Authorities [4]. A long procedure of about ten years followed after the first approach to the problem [5]. In 1998 the erection of the new aluminium bridge has been successfully completed [6].

The original design

The structural scheme of the suspension bridge is characterised by a deck of 5.80 m wide with a span of 85 m (*Fig. 4*). The suspension system consists of two couples of chains, each chain has a rectangular cross-section made of puddled iron, which are connected together by means of cylindrical pins.

Fig. 1: The Montmerle bridge on the Saône river (France)

Fig. 2: The Grosléee bridge on the Rhône river (France)

The vertical suspension ties, 1.36 m spaced, are connected to the pins of the chain. They inferiorly hang the longitudinal iron girders with rectangular cross-section, which support the wooden deck made of transversal oak beams, 1.36 m spaced as the vertical ties,completed by a wooden deck planking.

Fig. 3: A painting of the "Real Ferdinando" bridge on the Garigliano river (Filangieri's Museum, Naples)

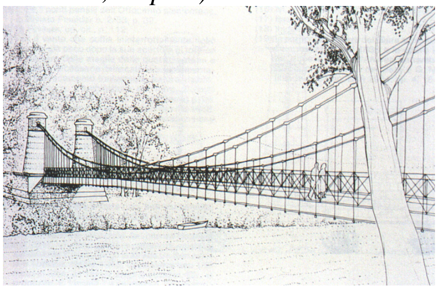


Fig. 4: The graphical reconstruction of the original "Real Ferdinando" bridge

The capital of the pier is in "Egyptian style".

The four masonry piers are conceived in "Egyptian style" with floreal top capitals.

The supporting devices of the suspension chains are located inside the capitals. These special devices work like a pendulum, allowing the chain to have horizontal displacements in the plan of the bridge and transferring to the pier vertical actions only. This was a very clever and forerunner idea of the designer.

The retaining chains are anchored in a massive block of stone masonry at a depth of 6 m and at a distance of 24 m from each pier, where the sphinxes indicate the point of anchorage.

The analysis of the existing original material gave the possibility to identify many important data of the design process. The total dead load of the bridge structure, including chains, ties and deck, can be evaluated at about 260 kg/m^2 and the structure has been checked for a live load of 240 kg/m^2.

For the total load of 500 kg/m^2 distributed along the span, the value of the axial force in the chains is 500 tons, which corresponds to a stress of about 15 kg/mm^2 in the material. This value seems to be too high for the puddled iron, also considering that the assumed amount of live load is very low in comparison with actual loading conditions.

From the complete structural analysis, the followings aspects can be identified:

- the structural scheme has a stable performance under vertical loads, provided that they are symmetrically distributed;
- the deformability of the bridge is very high and produces a mechanism effect, when the live load is not symmetrically distributed (this result has been confirmed by the chronicles of those time telling that a local peasant observed a raising of half meter at the edge of the deck when a carriage entered the bridge from the opposite edge);
- due to the total absence of horizontal bracings, the bridge is not able to resist any kind of lateral forces, like wind and earthquake, so that too large horizontal displacements can arise;
- the considered live loads are inferior even to the ones which today are requested for a simple foot bridge.

These remarks confirm the general consideration that the old structures of the 19^{th} Century were mainly designed to resist vertical and symmetrical loading conditions, but unsymmetrical and horizontal loading conditions were ignored, also because of the absence of adequate calculation methods, which have been set-up only during the second half of the 20^{th} Century.

In addition no consideration was given to deformability problems, which were neglected because of lack of sensitivity. In fact, on one hand we have to remember that the suspension bridge is the descendant of the liane bridge of the primitive people, and on the other hand deformability checks belong to the modern philosophy of structural design, which only in the last decades introduced the so-called "serviceability limit state".

The structural restoration criteria

The structural restoration of the "Real Ferdinando" bridge has been based on the choice to rebuild the missing deck and to substitute the suspension system, in order to obtain a pedestrian bridge connecting the two parts of the new archaeological area created around the Garigliano river.

The design of the new bridge structure has been done following three basic criteria:

1. to keep the same image of the original bridge in rebuilding the new deck with the suspension system;
2. to provide the deck with a sufficient stiffness, both in vertical and horizontal directions, which was completely absent in the old bridge;
3. to identify a solution based on contemporary technologies and modern materials.

On the basis of the first criterion, it has been decided:

- to preserve the existing masonry piers by means of appropriate consolidation operations;
- to keep the same number of chains (two for each side);
- to keep the same distance among the suspension ties;
- to maintain the same width of the deck between the railings;
- to use a structural system for the deck as close as possible similar to the original one.

On the basis of the second criterion, the longitudinal girders had to be sized in order to guarantee adequate vertical flexural stiffness, and integrated by horizontal cross-bracings in order to provide lateral stiffness in line with modern codification.

According to the third criterion, the technologies of the puddled iron and of the wooden deck have to be substituted by equivalent ones, which today can be identified in a wide family of the modern metallic materials.

Fig. 5: The new "Real Ferdinando" bridge after erection

In particular, the use of the following materials has been examined:

• high strength steels, i.e. spiroidal wires for cables, substituting the iron chains;

• low carbon steel for the deck structure and the suspension ties;

• aluminium alloys, as an alternative to steels for the deck structure, taking advantage of their lightness and corrosion resistance.

The new bridge

The deck of the bridge is made of aluminium alloy (type 7020 T6 for longitudinal girders and 6060 T6 for transversal beams).

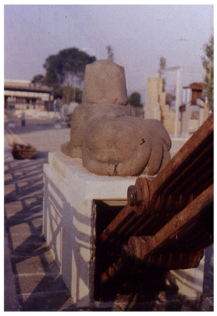
The two longitudinal girders have a structural scheme of a Vierendeel beam, made of two horizontal chords connected by vertical members having the same spacing as the suspension ties (*Fig. 5*). The vertical members of each girder are split into two elements in order to receive inside the transversal beams, whose ends are connected to the suspension ties (*Fig. 6*). The masonry piers have been consolidated by substituting the damaged stones with new ones *(Fig. 7)*.The horizontal bracing system is made of X-bracing, which are located in the mid layer of the bottom chord of the Vierendeel beam (*Fig. 8*), according to a mesh equivalent to two or three spacings of the transversal beams.

Figs. 6 and 7: Details of the mesh of the Vierendeel type girder and of the masonry piers

Fig. 8: Lateral support of the girders and horizontal cross-bracings

The deck is covered in the central part by a wooden floor limited at both sides by a seating bench separating the lateral fiddley opening *(Fig. 9).* Also the four sphinxes have been cleaned and restored *(Fig. 10).* The anchorage system has been revised and the suspension supports on the top of the piers have been substituted with modern devices. The old pendulum system designed by Luigi Giura has been removed and located beside the bridge in a kind of museum, where also the remaining parts of the old chains are displayed to the visitors *(Fig. 11).*

Fig. 9: The deck of the new bridge



Figs.10 and 11: The sphinx and the old pendulum system

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