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Review

Innovative bolted junction with high ductility for circular tubular element

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ABSTRACT

This paper deals with the design of an innovative type of bolted junction that shows a high plastic range in the load displacement. The schematization studied and reported in this paper is generally valid for steel structures and can be applied where high ductility is required (for example structures subjected to earthquakes) or statically indeterminate structures. In this case due to the high ductility of the junction there is a redistribution of stress/load in the elements. For this implementation the bolted junction was studied and applied to the arches of a bridge (designed by the University of Brescia). The developed junction described in this paper will solve the problems described above and permit an adjustment of the arch length until a balanced configuration is reached. The design procedure includes a preliminary analytical computation using the most important buckling theories; subsequently it is carried out a numerical analysis which results are validated executing several experimental analyses on a scale model. The final scope is the design of an innovative junction for tubular elements with circular section which permits the modification of the post-buckling curve in order to increase the ductility of the entire junction. The geometric solution studied was verified numerically and experimentally tested on a scale model. The results show a meaningful increase in elastic plastic performance of the junction. Indicatively this innovative geometry increases the elastic plastic behavior on the experimental geometry approximately 2 times when compared with the junction of the tubular elements without the designed junction.

Contents

1. Introduction

One of the most serious problems in civil and mechanical engineering is the buckling phenomenon [1–5], that happens when the axial compressive loads are mostly lower than the mechanical strength of

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the material used, leading at the end to catastrophic failures. Generally one of the problems in the design of bridges is the buckling of the elements which compose the arches as they are subjected to compression, therefore it is important to avoid the phenomenon of instability [6,7] through appropriate constructive solutions which increase the compliance of the elements: for example developing particular solutions of the junction between the tubular elements.

The buckling phenomenon can manifest in different forms [8–12]: first is the global or Eulerian instability, which occurs in the presence of slender beams, with a high ratio between length and section dimensions; a second type is the local buckling, which occurs in beams which have a low ratio between length and size of the section [13–15]. The parameter which determines the onset of this type of instability generally is the thickness of the section which, if below a specific threshold, causes the curling of the sheet metal: this kind of buckling strongly depends on the geometrical imperfections of the structure. They can be generated by different phenomena and they are also related to the manufacturing process of the component [16–22]. The geometric imperfections in the components play a fundamental role in the design: for example a bridge, whose thorough evaluation and implementation in the FEM software allows a correct estimation force–displacement diagram of the component [23].

The designed bridge (Fig. 1) is an arch composed of four supporting arches on which are connected all the rods that support the roadway; each of these arches is connected to the ground with a bolted junction and this component is properly designed in order to avoid buckling phenomena of the structure. The schedule followed in the work comprehends the definition of the geometry of the tube composing the arches, the introduction of the imperfections, the numerical analyses and the comparison with the experimental results; in case of different behavior of the junction than the expected one, the geometry is modified in the numerical program in order to obtain the optimal one.

This junction must have compliance characteristics in order to allow a deformation able to compensate any possible difference in length due to manufacturing defects, thermal effects, etc.; its global stiffness has also to be lower than the one of the tubular arch and this means that the maximum load necessary to reach the plastic limit of the junction must be lower than the critical buckling load of the arch. For this geometry, it is more dangerous the local buckling caused by the small thickness of the pipe whereas the global instability is reached with much higher stress values, due to the reticular structure of the arches.

The final geometry of the device, reported in Fig. 2, is composed by a circular ring having an outer diameter smaller than the inside diameter of the tube; on the external side of the ring are welded eight rectangular blocks and on the other side the ring is welded on eight triangular brackets staggered with respect to the blocks: this particularity allows to have plastic deformations on the ring until reaching the correct length. The main tube has a lateral hole which is necessary to apply the correct tightening of the bolts and for coating a resin in order to prevent and minimize the corrosion phenomena that would lead to premature failure of the structure [24,25]. After these operations, the lateral hole is closed with a plate bolted to the tube in order to open for the subsequent maintenance of the arches of the bridge.

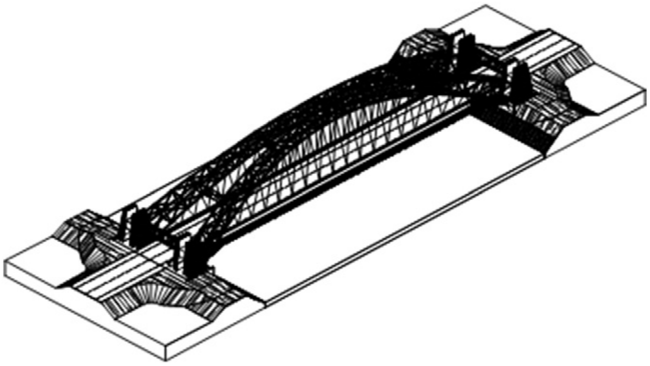

Fig. 1. Perspective view of the bridge (total length = 80 m).

2. Materials and methods

2.1. Definition of the materials and the specimens

The first step consists in the definition of the material used for the tubes, S235JR (UNI EN 10025) structural steel and in order to determine its behavior in the elastic and plastic range they are carried out some tensile tests executed on the INSTRON machine (Fig. 3).

The second step consists in the definition of the geometry of the tube used to make the subsequent experimental tests. A single element of the arches of the bridge has originally the following dimensions: length L = 8000 mm, external radius R = 250 mm, and thickness t = 12.5 mm; with these dimensions, especially the length, it is impossible to make experimental tests with the instrumentation available, therefore it is necessary to consider scaled specimens and the main constraints for their realization are:

- the inner radius must have a minimum value that allows to insert and weld the triangular brackets, thus not less than 125 mm;
- the total length has to permit the realization of the tests, the bench test allows a maximum length of 3000 mm;
- the maximum load must be lower than the highest value reachable with the provided machine, equal to 1200 kN.

Determining the dimensions of the specimen is also important in order to maintain the characteristic ratios of the original tubes [1–3]:

$$\frac{L}{R} = \frac{8000}{250} = 32 \quad \frac{R}{t} = \frac{250}{12.5} = 20\,.$$

Considering a length of L = 2000 mm it is not possible to maintain a radius with a value equal to a quarter of the original one because it would bring to a smaller diameter than the minimum required; the chosen diameter and thickness, considering the maximum load of the machine (equal to 1200 kN), of the tubes available on the market are respectively equal to R = 136.5 mm and t = 4.2 mm.

Using the ECCS standards [14], with this geometry the tube comes to elastic instability if

$$\alpha\sigma_{cr} < \frac{\sigma_y}{2} \text{ and } \sigma_f = \sigma_y\left[1-0.4123\left(\frac{\sigma_y}{\alpha\cdot\sigma_{cr}}\right)^{0.6}\right] \qquad (1)$$

where:

$\sigma_y = 275$ MPa is the value of the minimum yield stress of S275JR (UNI EN 10025) steel;
$\sigma_{cr} = 2507.47$ MPa is the elastic critical buckling load not considering the defects and following the Timoshenko theory [1];
α is a coefficient computable with the following formula: $\alpha = \frac{0.83}{1+0.01\cdot R/t} = 0.639$ and
σ_f is the critical buckling load.

With these values Eq. (1) becomes: $0.639 \cdot 2507.47 = 1602.3 > 275 \cdot 0.5 = 137.5$, and $\sigma_f = 235.62$ MPa and so the tube is also subjected to elasto-plastic instability.