A scenographic solution for a Neapolitan bridge in the beginning of nineteenth century

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ABSTRACT: Object of the present study is the masonry bridge, still standing, built for King Ferdinand I of Bourbon, in 1818, by the court scenographer and architect Antonio Niccolini, in the Villa Floridiana Park in Naples. The original drawing, plan and front view, of Niccolini's design is kept in the Archive of the Saint Martin Museum in Naples. The bridge, made of Neapolitan tuff and bricks, with a single polycentric arch, spanning thirty metres, can be ascribed to the typology of lightened tympanum bridges, in which continuum masonry in the backfills is substituted by a system of vaults leaning upon the extrados of the underlying arch. The static behaviour of the bridge will be studied, basing upon a detailed survey and an accurate examination of the historical sources, also employing the graphical methods known at the age of its realization.

1 INTRODUCTION

1.1 Antonio Niccolini, scenographer and architect

Notices about the life and first education of the scenographer and architect Antonio Niccolini, born in Tuscany (at San Miniato in the district of Pisa), the 21 April 1772, can be deduced by his autobiography, "Memories of my life", written in 1847, now kept in the Neapolitan National Library, Mancini (1964).

After a brief apprenticeship made when he was still very young, in different subjects as geometry, arithmetic and architectonical drawing, Niccolini turned to painting. Meeting the Emilian set designer Francesco Fontanesi (1751-1795) let him discover theatre fascination and only twenty days beside his master were sufficient, according to him, to turn him in a scenographer, Mancini (1980). Already famous for works done in Livorno, Pisa and Florence, Niccolini, in 1807, was called in Naples as architect and set designer of the Royal Saint Charles Theatre, during the reign of Giuseppe Bonaparte, and there he stayed until his death in 1850.

Many information about his activity in Naples and specifically in the Royal Theatre can be inferred from the biography written by his friend Antonio Benci "Notices about Antonio Niccolini", Caruso (1987).

Even if Niccolini came in Naples in a particular historical period, when the great changes due to Napoleon had redrawn the set up of the European Courts, making his brother Giuseppe to take the place of the Bourbon king Ferdinand IV on the throne of the Neapolitan Reign, he continued to be appreciate as a scenographer and court architect, still after the Restoration. In fact, Niccolini held prestigious public appointments and had important jobs during the subsequent reigns of the Bourbon kings ascending the throne, Giannetti (1997).

His great ability as a scenographer can be noticed in his most famous realizations, as the wonderful Floridiana Park, also enriched by prestigious architectural works, or the precious flight of steps of the Capodimonte Royal Palace, and finally the great transformation works of the Royal Palace of Naples and the annex Royal Saint Charles Theatre. Niccolini theorized and

put in practice unity of architecture and scenography: settings seem have been used as a models catalogue suggesting architectures.

1.2 Floridiana Park

The bridge studied here is inside a private park which once was part of the Villa Floridiana Park, made by Niccolini from 1817, by appointment of the Bourbon King Ferdinand I, who gave it as a present to Lucia Migliaccio, his morganatic wife. Niccolini redrawn the park keeping as far as possible the standing trees and the structure of the ancient routes. The existing Villa of Saliceti was transformed in the Villa Floridiana, now housing the National Museum of pottery "Duke of Martina", and restored the little temple, built by the architect Francesco Maresca, (now Villa Lucia), to be used as Coffee-House. The complete design included also the building of an Egyptian door as scenographic entry to the bridge, a suspended flight of steps looking toward the see, a lions cavern and a tiger cage. The bridge was built to connect a previewed secondary access, which could be reached going over a deep valley existing inside the property.

Niccolini inserted in his park many details taken from the Gardens of Stowe, existing in Buckinghamshire, sixty miles from London, De Nicola (1906). Those gardens were considered a perfect model of English Gardens and in 1771 were owned by the Earl Richard Grenville. They were extensively described in a rare book by Thomas Whately, published in Paris in 1771, kept in the Royal Library, now part of the National Library of Naples. A great part of the architectonical and landscape elements present in the English gardens were reproduced by Niccolini as the labyrinth, the Doric temple, the caves and caverns, the dome upon columns, the open air theatre, and also the bridge. The English version of this element is a monumental neoclassical bridge, called "Palladian", while in Villa Floridiana Niccolini built a bridge of a completely different shape.

2 NICCOLINI'S MASONRY ARCH BRIDGE

2.1 Historical Survey

The great scenographic value of the bridge built by Niccolini in the Park of the Villa Floridiana is testified by pictures of nineteenth century painters, as Pitloo and Vervloet, Fig. 1.



Figure 1 : Painting by F. Vervloet, Saint Martin Museum.

The bridge was opened in 1818 and was considered a daring construction, as shown by the words of a contemporary chronicler, Giuseppe Francioni Vespoli, who, in 1825, defined it a "Bridge with a single arch of surprising and wonderful audacious imagination, which could be put beside the most beautiful Greek-Roman architectures, and be quoted between the finest productions of modern architecture", Francioni Vespoli (1825). Also the historian Napoleone Camillo Sasso, author of a famous history of the Neapolitan monuments and architects, reminded its constructive daring, writing that: "Niccolini, farsighted, for the final setting of the dried constructions, having left the bridge, without centrings, alone under its self-weight, ordered to complete it quickly, working night and day, so that the bridge was finished in few days"; Sasso re-

ported too that "the King, worried by the lightness of its shape, requested to check the bridge making a six cannons battery pass trough" and only after that, he crossed the bridge in his coach with the architect, Sasso (1858).

The valuable Niccolini's own hand drawing of the bridge, including the plan and the front view with the centrings, Fig. 2, is kept in the Saint Martin Museum in Naples. Even if the built bridge, Fig. 3, is quite similar to the designed one, nonetheless some differences are evident:

- the slope of the superior way is less accentuated;
- the arch shape is quite different at the reins;
- consequently the voids incidence on the filling of the tympanum is less;
- the realized arch doesn't show the relevant stucco ashlars, present in the drawing;
- the precious iron balustrade, anticipating liberty decors, took the place of the simple one inserted in the front view.



Figure 2 : Niccolini's own hand drawing, Saint Martin Museum.



Figure 3 : Bridge Photograph, Venditti (1961).

The deep analysis of the intrados shape of the built arch has shown that for its layout Niccolini employed a graphic construction he had already used, as quoted by Benci in his biography, to draw the stage arch of the Saint Charles Theatre. This procedure for tracing an arch profile, called by Niccolini "flat pointed arch", is, in the opinion of Benci, a transformation of the graphic construction of the "flat arch" due to Bernardo Buontalenti (Florence, 1536-1608). This famous architect for his tracing always used a rectangular parallelogram whose vertical side length was less than that of the horizontal one, Fig. 4a, while Niccolini thought to substitute a trapezium to the parallelogram, Fig. 4b, obtaining the tangent line at the keystone inclined instead of horizontal, and to modify the tracing of the curve, Fig. 5, so that also the tangent line at the base of the arch showed a slope different from the perpendicular one. "And it's sure that drawing arches in this way, all the arch lines converge at the point A, from which they depart, and where they all find support" is the final remark of Benci. Layout of Niccolini's arch intrados profile is shown on the left side of Fig. 6, on the front view of the existing bridge.

2 b

Figure 4 : Drawing construction of the "flat arch"



Figure 5 : Drawing construction of the "flat pointed arch".



Figure 6 : Bridge front view: on the left, intrados profile tracing; on the right the thrust line.

2.2 Sizes and materials

The in situ survey has allowed drawing completely the bridge, which has a single roadway, 35.00 m long, 4.90 m large, going trough a valley about 20.00 m deep, connecting the two parts of the Villa Lucia Park. The structure is constituted of a single arch, with free span of 29.10 m, 3.95 m large, maximum rise of 16.00 m, and keystone height of 1.30 m.

The diffuse lacking of plaster, which completely covers the masonry structures, allows the partial identification of the texture. The arch intrados profile is marked by the presence of two ribs, projecting 0.10 m, 0.95 m large and 0.50 m thick, made of large piperno elements, alternating to brick rows; these ribs bound the vault, which shows a brick intrados, 3.45 m large, Fig. 7a. The large sizes of the bricks, $0.35 \times 0.17 \times 0.05$ m, are quoted in the Military Engineers' rate book, dating 1831, as the dimensions of large flat tiles coming from the kiln of Ischia, Guerriero (1999). The tympanum is made of Neapolitan yellow tuff ashlars, with varying front shape, rectangular as well as square, placed with mortar joints in radial directions, near the ribs, and horizontally far from them. The tympanum is lightened by five holes on each side with shape varying from the round to the ogival one, and increasing size moving towards the piers. These openings are lined by brick covers, strongly linked to the tympanum masonry; the ribs also are linked to this masonry with the interposition of a toothed brick row, Fig. 7b. The piers, made of tuff, relay upon brick masonry bases and are completely covered by plaster with bush hammered ashlars work. The plank, built with a double layer of basalt stones, projects from the bearing structure of about 0.60 m, laying upon sixty corbels in calcareous stone.



Figure 7 : Photographs of constructive details.

The whole building is covered by plaster and enriched by stucco cornices and calcareous elements; over the keystone, adorned by a fine Bourbon lily, there are, on both sides of the roadway, parapets made of calcareous stone, with two different inscriptions in gilded bronze. Aside the parapets runs a beautiful wrought iron balustrade, enclosed by pillars in volcanic stone, surmounted by marble pinecones, marking the accesses to the bridge.

The bridge is in a quite good state, surface finishing partial decay excepted.

An original characteristic of the bridge is due to the acoustic properties of the vault intrados: the amplification of sounds produced by the shape of the arch gives rise to suggestive effects of sound diffusion, outcoming from Niccolini's great experience as a scenographer, as testified by his own writhing devoted to the sonority of theatres, Niccolini (1816).

3 THE STATICAL BEHAVIOUR OF THE BRIDGE

3.1 Neapolitan cultural background

When in 1734 Charles of Bourbon came in Naples, he encouraged the foundation of Military Academies, in which the study of mathematics and scientific subjects was considered essential. In spite of the economical and political instability due to the alternation of the Neapolitan Republic and thereafter Restoration, a lively cultural debate, concerning particularly the physical

and mathematical subjects, developed. It's important to underline that the main Architects, working in Naples in the first Bourbon period, as Luigi Vanvitelli (Naples, 1700 – Caserta, 1773) and Ferdinando Fuga (Florence, 1699 – Naples, 1782), took no part in this cultural debate, Buccaro (2003).

The political background changed with accession of Giuseppe Bonaparte, who, with the institution in 1806 of the Civil Buildings Council, following the French example, decreed the handing over of Public Works Authority from Municipality to this new organ. So new figures appeared, staff officers, who supported the Architects of the Royal House. Between these, Antonio Niccolini was a leading figure. In 1817 the Bourbon came back to Naples and the Council was exchanged by a Fortification Junta, which engaged the same technicists, already members of the Council, Buccaro (2004), and again they occupied leading roles with the Reign of Ferdinand II. This new class of public technical officers co-opted, in particular, experts of the Engineers Corp of Bridges and Roadways, instituted in 1808, who were incited by the new scientific spirit of the nineteenth century. Even if Niccolini, appointed of significant public jobs, worked with them, he appeared still linked to the cultural background of the eighteenth century.

The traditional school of apprenticeship and trade, based on the principles of perspective and drawing, mirrors itself in Niccolini's long career of architect, scenographer and painter. For this reasons, his education is affected by the culture of the Florence and Neapolitan Academies, also after its Statutory Reformation of 1809.

In the Neapolitan area, a great number of studies, concerning the buildings static, had been published, which, remaining faithful to classical models based on geometry, provided practical rules for sizing structures. In this context, a peculiar figure was Vincenzo Lamberti, (Naples, 1740-1790), author of two theoretical and practical treatises, "Vaults measurements"(1773) and "Static of buildings"(1781). Lamberti's aim was to give an useful instrument to professional architects, for dimensioning structural elements, with particular attention to typologies and materials of the Campania Region. In reference to bridges, an important treatise was the "Traité des pontes" (1714) by Henri Gautier, (Nimes, 1660- Paris, 1737), architect, engineer and inspector "Des Ponts & Chaussées". This book represented the first specific text on the subject. In those treatises, balance problems were still solved with the support of elementary means – lever, wedge, inclined plane – and the constructing material was still considered undeformable. However, the consciousness of a limited resistance required the necessity of detailed experimental campaigns, by which practical rules were derived.

An example of formula for arch sizing, widespread in contemporary literature, was devoted to evaluation of the thickness "e" to assign to the keystone with respect to the span, Corradi (1998):

- Perronet (1782) assumed e = k1 + k2 L with k1 = 0.325 and k2 = (1/24 1/144);
- Gauthey (1809) assumed e = 1/24 L with the following range 16 < L < 32;
- Dejardin (1845) assumed e = k1 + k2 L with k1 = 0.30 and k2 = 0.045;
- Dupuit (1870) adopted instead the formula $e = kL^{1/2}$ with k = 0.20.

The keystone thickness of Niccolini's bridge, equal to 1.20 m, for a span of 29.10 m, perfectly accords to the value assumed by Gauthey.

3.2 Structural behaviour

The studied bridge can be ascribed to the typology of arch masonry bridges with lightened tympanum, developed in nineteenth century. Niccolini can be considered a forerunner in the employment of this building technique, which involved many advantages: with a suitable disposition of the structural elements, the front walls thickness could be reduced, as those walls where no more loaded by the thrust of the bank; the load upon the whole structure was reduced; and also the load on the centrings decreased during the vault making, if it's taken in account that usually the backfills were already set at the height of the reins, to assure the stability of the vault, when the centrings were dismantled; masonry had a better protection from dampness, Torre (2003).

Two different tympanum lightening typologies can be envisaged basing upon the disposition of the lightening vaults: longitudinal lightening, made with barrel vaults parallel to the front planes of the bridge; transversal lightening, with the barrel vaults disposed perpendicular to the main arch. In the first building system, the vaults stay on masonry walls leaning upon the main vault extrados; so the front walls of the bridge are bearing structures. Consequently the impossibility of having large openings in the front walls allowed no masonry aeration. In the second disposition, lightening vaults are based on masonry walls perpendicular to the front walls, which consequently result unloaded of the thrusts and become simple closing walls, so that large openings can be cut, and aeration of the masonry is obtained.

Niccolini, in his own hand drawing, Fig. 2, wrights: "Openings created to lighten the building and to make it aired, so that it will be dried an practicable soon", recalling two of the positive characteristics of the constructive typology just described.

In the Campania Region other two examples of masonry arch bridges with lightened tympanum can be found, both built at the end of the nineteenth century:

- the bridge on Sele River, near Salerno (G. Fiocca 1871-1872), still standing, Fig. 8, called "Devil Bridge" or "Fiocca Bridge", designed with a single semi-elliptic arch, spanning 55.00 m, with a rise of 13.55 m. To reduce the load on the large depressed vault, the tympanum was lightened with ring-like vaults, made of tuff ashlars, hidden by the closing front walls, Sasso (1873);
- the Hannibal Bridge on Volturno River, near Capua, (G. Fiocca 1868-1870), designed with a single semi-elliptic arch, spanning 55.00 m, with a rise of 14.00 m, having lightened tympanum with ring-like vaults, hidden by the closing front walls, Sasso (1871).



Figure 8 : Devil Bridge on Sele River.

As the presence of transversal vaults let the loads upon the main vault be schematized by a set of applied forces, the thrust line can be traced with the graphical methods of the nineteenth century. So, even if it's not completely appropriate from an historical point of view, the Mery's construction has been used. The bearing structure can be envisaged in the vault, with varying thickness, whose extrados profile is the envelope of the tangent lines at the lower extremities of the lightening holes.

In Fig. 6, on the right, the thrust line is brought back. According to the assumptions of Mery's theory, the thrust line is constructed imposing that, at the keystone, the thrust passes trough the third upper mean, and at the impost, trough the third bottom mean. This disposition corresponds to the most unfavourable assumption. The maximum value of compressive stress, equal to 2.4 MPa, is evaluated in the cross-section corresponding to the first lightening hole, near the keystone. This value is lower than the typical compression collapse values, listed in the literature. Actually, in this section, the bridge structure is made, essentially, of brickwork; for this kind of masonry, considering the compressive strength of the bricks from Gaeta, equal to 9.5 MPa, Sasso (1873), and the bastard and pozzolanic mortar, type M4, the Italian law in force (Table A – D.M. Min. LL.PP. 20.11.1987) gives the limit compressive stress of 4 MPa. For Neapolitan yellow tuff, a mean stress of 3 MPa can be assumed.

Applying an appropriate numerical simulation, the consequence of lightening can be evaluated in reduction terms: total load, 21%, maximum value of stress, 4.7 %, and pull on the piers, 18.70%.

4 CONCLUSIONS

The bridge built by Niccolini, not well-known also in the Neapolitan area as it's located inside a private property, reveals an interesting forerunning of constructive solutions, subsequently adopted in the second half of nineteenth century.

Niccolini's work as an architect denotes a wide understanding of structural problems, as can be noticed also in other examples: in transforming the attic of the Real Palace Riding School in scene equipments depot, he, skilfully, changed the truss pattern to sustain the considerable loads due to the new function (Ceraldi, Russo Ermolli. and Tempone, 2006).

Even the change of the Buontalenti's construction of the "flat arch" in that of the "flat pointed arch", denotes a remarkable control of the force distribution pattern; it's clear that his static insight has allowed him to adopt innovative solutions. In fact, in the studied bridge, the research of a scenographic effect is closely linked with technical solutions, particularly effective from a static point of view, as the assumption of the resistant vault profile in accordance with the supposed distribution of loads, depending on the shape and the location of the lightening holes.

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