Repair and improvement of Buonopane bridge in Ischia

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ABSTRACT: The paper describes interventions performed for repair and strengthening of Buonopane bridge in Ischia island. The bridge was built in the second half of XVIII century, in place of the existing wooden bridge, which in turn was built in the second half of XV century.

Masonry of the bridge partly cracked due to aging: the mortar lost its cohesion and some ashlars were ejected, wide cracks developed in a pier and in the below cantilever made of lava stone, longitudinal and transverse cracks grew in the ring of the middle arch. Ischia is a seismic area and interventions have been performed with reference to Italian seismic codes, taking into account that we are dealing with an historical bridge. Techniques and products employed have been traditional one: special sulphate-proof mortar injected at low pressure in the masonry, steel tie bars fixed to the masonry by steel plates.

1. INTRODUCTION

Assessment of bridges, design, realization of repair and improvement interventions is an issue of the first importance not only for the specific aspects of scientific and technological research but also for the financial burden that bridge maintenance entails.

The problems are very complex because existing bridges differ in structural materials, in construction age, in types and in condition rating.

The most frequent bridge building materials have been stone, wood, reinforced concrete, prestressed r.c. and steel. Existing stone bridges are centuries-old and many of them are historical buildings.

The causes of defects are material aging, environment pollution, poor maintenance, wrong repair works, change of live loads because design loads did not include actual ones due to the different type of traffic.

Any repair has to take into account not only defects and damages identified, but also the main features of the bridge, the intervention costs and operation difficulties. The management of existing historical bridges might be tackled by means of a specific Bridge Management System, as like as for all existing bridges and viaducts.

The most important problems are connected with understanding of the structural behaviour of masonry arch bridges. In fact studies and researches on masonry arch bridges had been dropped with the use of reinforced concrete and steel as bridge building materials.

In the last few decades researches on structural behaviour of masonry arch had flourished again as a consequence of the necessity to appraisal historical masonry arch structures and masonry structures in seismic countries. New methods for the analysis and design of the masonry arch have been developed (Heyman 1982, Page 1993, Parag 1993, Franciosi 1986, Frunzio 1998).
At the moment, paradoxically, we had to solve twofold complex issue: to understand behaviour of these structures and to determine the type of maintenance and rehabilitation interventions, as a consequence of the damage that affects materials and the change in external loads (traffic loads, seismic loads).

Many masonry arch bridges are excellent reminders of the architectural heritage and therefore techniques and products for repair and maintenance should be compatible with historical features of these structures. Moreover chemical and physical properties of the repair materials should be compatible with properties of the existing ones. For instance it is unwise to use hard engineering bricks to repair a bridge built of much softer bricks. Care should be taken that the repair technique does not itself cause further damage to the bridge.

It must be pointed out that is very important to provide a reliable judgment on the durability of maintenance and rehabilitation materials and on the long term effectiveness of the measures employed. In fact the useful information obtained from experience-based tests are restricted to those which are in use for decades and in many cases the monitoring period is fairly brief in comparison with the age of the bridges.

The development of methods for the structural analysis, more sophisticated in comparison with ones available when these bridges were built, enables the designer to investigate deeper their behaviour. Nevertheless these new methods have not been tested by means of realization of masonry arch bridges like as the more traditional theories and, therefore, their use to understand structural behaviour of existing old masonry arch bridges may not provide reliable judgements.

Besides that it is very complex, if not really impossible, to assess mechanical properties of actual materials for all bridge’s members. The properties of the masonry differ notably from member to member of a bridge and often in the same member because they have been damaged and repaired many times during their life, and often repair works are not well documented.

A lot of recent studies carried out on appraisal of r.c., prestressed r.c. and steel bridges is available, comparatively studies on behaviour of masonry arch bridges are fewer and, when they are, concern valuable historical bridges (Roca 1995, Zák 1995).

The inspections and the investigations entail a certain cost that has to be in any case justified; therefore only in specific cases, when interventions actually have to be performed on valuable historical bridges, a very deep analysis of the bridge can be performed by means of exhaustive measurements, tests and deep investigations.

In Italy for this type of bridges like as for historical buildings, according to the code requirements, a specific structural analysis does not need. The ideas that inspire the interventions on these constructions are the improvement of static conditions. According to this feature the original static scheme has to be kept and only the measures that improve mechanical behaviour of masonry and repair local defects are allowed.

To such purpose it is useful to rediscover the traditional techniques employed in the past time when these types of bridges were built and studies and researches on masonry arch were widely developed.

The Bridge Management Systems (BMS) actually developed for masonry bridges in some countries is an useful tool since it gives the operator information on the most experienced products and techniques employed in repair and improvement of masonry arch bridges, by means of data-base created on the basis of performed interventions (Parag 1993).

The first Author of this paper is involved recently in researches and studies on these subjects (Contaldo 1995, 2000) and the aim of the present paper is also to divulge information on an actual intervention. Thus the knowledge of the interventions performed could be utilized by all operators for a twofold purpose: to excite research and comparison and to create data-base for future uses.

The paper deal with the repair and improvement interventions performed by ANAS, Italian Road Agency, on an historical masonry bridge.
2. BUONOPANE BRIDGE

Ischia island is a well known resort and includes seven communes, which are connected by means of the national road number 270. This road reaches the two main harbours that are in Casamicciola and Ischia communes, from where the connections by sea sail. A lot of tourist visits always the island and so the national road is very important internal connection in the island.

The bridge we are dealing with is in Barano commune, at Km. 7+100 section of road, and passes over the Buonopane narrow valley and so it is an important infrastructure for the internal communication.

As a result of damages occurred, traffic on the bridge was restricted both by one-way running and by no thoroughfare of vehicles more than 13.5 tons heavy.

2.1 History of bridge

Barano, where is Buonopane bridge, is well known since antiquity, during Greek colonization and later during Roman age, for its famous thermal waters, for grape growing and for wine flourishing trade. When the Kingdom of Naples was under the Angevin dynasty rule wine trade flourished with France.

The existence of the Nitrodi famous thermal waters, well known since antiquity, was the main reason for the construction of a carriage-road which passed over the narrow valley in Moropane place, the ancient name of the locality called Buonopane today. The early reference of the construction of a wooden bridge in this site is in 1472 dated historical document.

In the reign of Ferdinando, during the Aragonese age, following Angevin age, Ischia island received the very longed for title of “Most Faithful”. As a consequence the island had to pay no more tribute to Pozzuoli, a commune on the continent, but had to charge duty on native people in order to provide funds for financial requirements.

One of the first interventions was the arrangement of the harbour in Ischia commune in order to make safer the docking for ships and so to promote the commercial enterprise between the communes of Ischia island and between Ischia and the continent.

In 1770 Barano commune decided the construction of a masonry bridge in lieu of the existing crumbling wooden bridge. The work was justified not only because it made continuous the road connecting all the communes, but also because it could increase the tourism towards Nitrodi thermal waters.

The work of construction of the bridge was lengthy since it was very difficult to collect funds only by means of taxing native people, which was very poor.

In 1883 a disastrous earthquake caused enormous damages in all the island with the nearly total destruction of Casamicciola, one of the most important town in the island and of the local English garrison which had 600 dead.

The Government of the Italian Kingdom charged the provincial administration of Naples to do a set of reconstruction works including the restoration of the carriage-road connecting the communes of the island and the completion of Buonopane bridge, which was performed in a brief period.

The actual layout of the road is the original one and the bridge had well performed for all this period.

2.1 Bridges features

Buonopane bridge is made of a chaotic tuff masonry, partially cracked and degraded. The bridge consists of three arches, the side arches have a length of 2.10 m. and the middle one has a length of 5.40 m.; the global length is 20.00 m. The width is 5.10 m. at the roadway, while it is 4.20 m at the piers, so that spandrel wall rest on cantilevers made of lava stone (Photo n. 1).

The bridge was built, as above mentioned, on a narrow valley, which is 18.00 m. deep in the lowest point and which was filled with rubble with the time, as measured during investigations on foundation masonry; therefore the bridge rises about 7.00 m. today.
Recently the Administration of Barano planned the restoration of the place where is Buonapane bridge and the Nitrodi thermal waters. The design has been accepted by the BAAS, Italian Authority for Architectural and Historical Heritage.

3. STRUCTURAL DEFECTS

Materials aging is the main cause of structural degradation of the bridge. Defects identified as a results of inspections carried out on the bridge are:

1. General degradation of mortar (Photo n. 2), from which the loss of masonry closeness results; as a consequence some ashlars have been ejected (Photo n. 3) and the above masonry caved in;
2. Subvertical crack in the masonry of the pier with the failure of the above cantilever (Photo n. 4); crack starts from the cantilever and extends alongside the abutment until the ring of the middle arch up to the crown (Photo n. 5);
3. Disjunction of some ashlars from the arch on the entrance to the cellar, placed under the embankment towards Barano (Photo n. 6).
Photo 3: Ashlars ejected

Photo 4: Subvertical crack on stone cantilever
4. PLANNED INTERVENTIONS

The planned intervention takes into account the historical feature of the bridge and thus it has been developed according to the "Recommendations relating to interventions on historical monuments of special typology in seismic areas" drafted in 1986 and "Directive for setting up and carrying out restoration programmes involving earthquake resistant improvement and maintenance work in architectural complexes of historical and artistic importance in seismic areas" drafted in 1989 by the Committee of the Ministry for Cultural and Environmental Heritage.

These instructions provide precise guidelines on the consolidation of foundations, walling, columns, arches vaults and other structures.
In these documents “the aseismic improvement” is so defined:

“The realization of one or more works referred to individual structural member of a building in order to achieve an higher degree of security, without, however, any substantial modification of its overall structural behaviour.”

This implies that no structural verification needs in the case of improvement; instead when the building is seismically upgraded a deep structural analysis must be performed.

The maintenance of the monuments must improve their resistance to earthquake and it must be carried out with those traditional materials and construction techniques that have enabled them to withstand the test of the time for so long. Normal seismic standards for new constructions are unsuitable for historical heritage and, therefore, historical constructions cannot be upgraded seismically.

Techniques and products employed in maintenance and improvement of Buonopane bridge have been traditional one: special sulphate-proof mortar injected at low pressure in the masonry, steel tie bars fixed by steel plates on the masonry.

Later on the interventions planned in order to eliminate the above defects are described

4.1 General degradation of masonry as a consequence of mortar’s cohesion loss.

The masonry is made of ashlars of tuff, a volcanic stone, arranged in a chaotic manner and bound by a mortar that lost its cohesion. For this reason it has been planned to improve bond between stone ashlars by means of a cement mortar injected into holes drilled into the masonry so that the mortar fills the cavity caused by the degradation of the original mortar.

This technique is well known and the sequence of operation schedules the washing of the masonry in order to remove all dusty residue of original mortar and in order to saturate the stone so that it does not absorb the water required for chemical reactions of the mortar that will be injected later on.

The components of the mortar are sulphate resistant and the hardening of the mortar is gradual. The joints between ashlars are sealed thoroughly and mortar is injected at low pressure, from the lower part in order to fill all cavities.

The operation is described in photo n. 7, where you can see the grid of tie bars.

Photo n. 7: Grid of tie bars
4.2 Subvertical crack in the pier and in the ring of middle arch.

Several causes of this damage have been identified:

- The original roadway was limited by two parapets high nearly 0.40 m. on the extrados of pavement. Afterwards the extrados of pavement has been lifted up to the top of parapets in order to widen roadway of 0.80 m. Therefore traffic loads increased on a portion of the bridge which was not loaded originally and particularly on spandrel walls which rest on trachytic stone cantilevers where cracks appeared.
- Crack affects the curved portion of the bridge on which effects of external loads are higher.
- The inspections performed onto the roadway have pointed out the presence of two pipes which lie near the parapet at depth of 0.50 m.. It is plan that these pipes had been installed by means of a deep excavation in bridge masonry causing the reduction of the tooth of spandrel wall.

The loss of tooth has been removed by means of tie bars inserted into holes drilled in the masonry. Tie bars are prestressed and connected to the masonry by mortar injected in the holes and fixed to the spandrel wall by steel plates. Road base has been removed and replaced by a reinforced concrete slab, which distributes and spreads traffic loads.

4.3 Crack in arch on the entrance to the cellar

The defect is a consequence of settlement of the retaining wall of the car parking near the bridge. The interventions performed are injections of mortar and tie bars inserted in holes drilled in the masonry; moreover underpinning piles have been executed under both abutments.

4.4 Foundations

The understanding of type and depth of existing foundations has been performed in two phases. During the investigations performed to plan the repair design, tests on foundations showed the presence of an arch under the middle span of the bridge, hidden by rubble that obstructs today the narrow valley on which the bridge passes. The first design hypothesis deduced that the piers and abutments of the bridge rested on masonry built on the bed rock, while in the middle span
there was an opening for the flow of the water. So it was planned to execute deep reinforced injection in order to improve tooth between the foundation masonry and the above ones.

During the works a cavity was identified in the masonry under side arches, so that it was deduced that the foundation masonry has the same arrangement as the above one. So the intervention on foundations had been performed modifying the geometric arrangement of reinforced deep injection (fig 1).

Beginning from the roadway extrados, masonry has been drilled by means of 120 mm. bore subvertical holes in which 90 mm. bore steel pipes have been inserted and injected with mortar of the same type used for masonry improvement. This intervention produces no modification in structural behaviour of foundations.

5. CONCLUSIONS

The paper deal with the repair and improvement of the Buonopane bridge in Ischia island. It is an historical bridge that showed degradation defects due to material aging and to incorrect repair works performed in the past.

This specific case bears out that it is necessary to seek all information on construction technique, mechanical, physical and chemical properties of materials, analysis methods used in design of structure. Investigations and tests must be performed during both design phase and construction phase. It is important that materials, techniques for structural repair and improvement are compatible with those employed when the structure was made. It is better to use products and techniques whose behaviour with time is well known and documented.

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