Restoring and reconstructing masonry bridges: researches in Campania (Italy)

S. Casiello, A. Pane, V. Russo and E. Vassallo
Dept. of History of Architecture and Restoration, University of Naples Federico II, Naples, Italy

ABSTRACT: Recurring to significant case-studies, the paper analyzes construction and consolidation methods employed in bridges from Roman age till XX century in Campania, pointing out the importance of a deep documentation in absence of any information available in site. Following a chronological sequence, the study concerns the Roman bridge of Capua, restored during past centuries and mostly rebuilt with ‘modern’ technologies and ‘ancient’ shapes after the second world war. Besides this case, the accurate analysis of the construction techniques of a ‘bridge system’, built in nineteenth century with the specific installation of brick-kilns for the railroad plan between Avellino and Rocchetta Sant’Antonio, contributes to emphasize not only architectural but also environmental significance that masonry bridges have still today on the territory.

1 CONSERVATION OF BRIDGES: KNOWLEDGE AND METHODOLOGICAL ISSUES

1.1 Theoretical and operative aspects

Here we are going to afford a problem, which has been common to several European countries, as well as to Italy since the end of Seventies. That is to say recognize values and environmental meanings that bridges hold in territorial reality as an expression of «industrial archaeology». On 1978 Borsi writes, referring to the whole heritage of industrial archaeology, including bridges: «We have no right in choosing the suppression of present heritage for posterity. The sense of history have nothing to do with erudite snobbishness, amateurish curiosities and so on. The State duty is to preserve the integrity of cultural heritage apart from choices and values judgments (…)» (Borsi 1978). A first distinction about bridges has to be done in typology, concerning to the ones existing in urban centers and the ones risen as a consequence of modern development of means of transportation and of industries in a territory that bridges themselves modified. Before analyzing the problems related to the conservation of bridges still existing inside our cities, it is important to confirm that the solutions to be adopted for the transmission to the future of the whole cultural heritage come from several considerations and have to be afforded case by case. Ponte Vecchio in Florence, for instance, in case of war destruction, would never been rebuilt as it was. Actually this bridge is – as Roberto Pane wrote – «the unreproduceable result of accidental and picturesque stratifications; it’s more a nature work than a artwork, and we have to consider it like one of many Etruscan villages rising over the hills of Lazio and Toscana, almost shapes made by the rock itself where they posed their roots» (Pane 1987).

Then, the cases hereby presented show both the typologies just quoted. In each one of them, historical knowledge is the basis of the individuation of values and meanings that legitimate the instance of preservation of the heritage that bridges represent. A specialist scholar in bridges, meant as architectural works that have to be preserved, notices that part of this heritage, «expression at the highest level of knowledge, taste, technical resources of their times, foundations and irreplaceable testimonies of regions and communities» (Re 1996), has been lost or has been altered with unsuitable adaptations it has been subjected to. Moreover, many historical bridges still existing are reconstructions made necessary because of war destructions and sometimes suggested by the exigency of restoration of the urban or natural environment and only in few cases because of their architectonical importance. This is the case of the Santa Trinita Bridge in Florence, work of Ammannati, that, according to Roberto Pane, could have been rebuilt with an internal structure in reinforced concrete covered with stone. After a diffuse theoretical debate, the bridge has been completely rebuilt in stone. Unlike the Florentine example, the 'Roman bridge' in Capua, as furthermore explained, has been rebuilt with the recourse to 'innovative' materials and techniques as the use of reinforced concrete demonstrates; moreover, the context has so much influenced the sense of the composition and the architectural language that, finally, the reconstructed bridge is deeply different from the original one.

Masonry bridges are being valued again in recent years, as Vittorio Nascé emphasizes (Nascè 2005). In fact, they represent both the values of a still functioning infrastructure and historic, artistic and environmental evidence. Further to the techniques that are represented and to the large benefits that they offer in comparison with metallic and reinforced concrete ones, we are especially interested in the significance of masonry bridges as a cultural heritage to be preserved. Some of them, as in the case of the construction of the Avellino-Rocchetta S. Antonio railway, required the establishment of specific brick-kilns, turned into decline as soon as the construction of the bridge was completed. The research carried out about these bridges is included in that tradition of studies that concur to reach a «deepened knowledge about structural composition and materials of each work, extending to their historical context and to the criteria that ruled plan and construction» (Nascé 2005).

2 TRADITION AND MODERNITY: THE 'ROMAN BRIDGE' IN CAPUA

2.1 The building and water: construction techniques and restorations

The necessity to cross the river respecting the already determined direction of Via Appia constitutes, in the history of the 'Roman bridge' on Volturno river, as much significant a factor in relation to the urban settlement as influencing the stability of the structure. Its establishment only afterwards a deep fluvial bight with the consequential increase of flow speed especially close to east piers will turn out to be among the main 'intrinsic' causes of the bridge structural problems. The role played by the building over the centuries, moreover, will pass over its function of connection between two riversides in order to constitute a relevant point of access into the urban centre: two pseudo-octagonal towers will be erected near the west bridgehead (about 1276) respecting the will of Frederick the second and pointing out the entrance to the reign of Sicily. Among these last ones, a gate of the town will be constructed, accompanied by a triumphal arch with decorations (Filangieri and Pane 1994, p. 138-146). Described buildings will be incorporated (1557) in Capua fortifications, among them 'bastione Cavaliere' will obstruct, particularly, the visibility of the towers and, indirectly, that of the bridge.

The knowledge concerning the roman structures of the bridge is particularly uncertain because of its destruction occurred in 1943. Refererring to archival sources, besides meagre descriptions, it is possible to assume that the building, dating to II b.C. (Trimarchi 1981, p. 53), was characterized by a humpbacked profile and by the sequence of six arches, each of them with a free span, in correspondence to the abutments, of 5,80 metres and, proceeding from west to east, of 18 metres, of 10,90 metres, of 12,60 metres and, finally, of 10,80 metres. Each one of the round arches, connected with solid spandrel walls, was constituted by 'peperino' or limestone (Galliazzo 1994) ashlars. Corresponding vaults were constructed, likewise, with 'peperino' ashlars, probably arranged in independent rings and mutually linked by lead cramps (Trimarchi 1981) and mortar. Vaulted parts were based on piers 4,70 metres wide and about 11,50 metres long; referring only to local historians' hypothesis (Trimarchi 1981), it is possible to consider the structure of the piers as formed by an internal nucleus in *opus caementicium*, externally covered by a pseudoisodom work. Piers were upriver reinforced by triangular cutwaters, covered by stone slabs on the upper part. There is no evidence about the roman foundations of the bridge, constituted, according to Sasso, of a masonry *platea* leaning on sand

(Sasso 1879, p. 2). The bridge, because of its problematic location too, is restored, probably, in Augustan and Adrian age (Mecchia 2001, p. 97), in IX century and, moreover, during the reigns of Ruggiero (1134) and Frederick the second (1247). Other "accomodationi" are made in 1695 (ASNa, Sommaria, Bandorum, vol. 37) and in 1756, as already explained in previous studies (Di Resta 1985, p. 84, fig. 84). During this year, the structure is subjected to a strengthening intervention of the vaults, made by means of semicircular centres overhanging onto the river. The reconstruction of the roman bridge geometry, rather than the knowledge of its constructive techniques, has been based also upon a drawing of 1805 (Fig. 1) (Di Resta 1983, fig. 5), where a plan, a longitudinal section and an upstream elevation of the bridge is outlined. The drawing gives information about the spans of the arches and shows the existence of an infill in the last arch on the east side. Moreover, the drawing puts in evidence the different springs of the roman vaults and the presence of a particularly marked local erosion closeness to the second pier from the left. This last issue, strictly connected to the relation between the bridge and the river course, will engage technicians from the second half of XIX century and it will be solved, partially, only with the reconstruction of the building. The last quarter of the century is particularly characterized by a succession of proposals in which the issue of the pier and the adjacent vaults has been dealt without any 'archaeological' attention but rather with a destructive approach. For instance, engineers of the Corp of *Genio Civile* suggest the demolition of the eroded pier since 1873 and the substitution of the adjacent vaults with only one masonry vault or, alternatively, with an iron truss (ASCe, Amm. prov., Ponti, serie 3, f. 11728). The masonry vault design, studied by Sasso with reference to Méry method (Sasso 1879), is taken on again in 1898 because of its satisfactory "aesthetical" values; specimens are executed in the left abutment towards Capua in order to prove the resistance of materials by laboratory tests, considering the increase of stresses determined by the new vault. Since the above described projects had no avail, a reinforcement of the «corrupted» pier, already damaged in 1874, is unsuccessfully attempted. The cracking pattern, connected to the separation of downstream arches from the structure of the vaults, and the presence of a diagonal crack in the fifth vault from west lead, moreover, to an extensive substruction work done in between 1890 and 1893 (ASCe, Amm. Prov., Ponti, serie 3, f. 11730). This operation drives to the substitution of the peperino ashlars in vaults and spandrel walls with red bricks tied up with Portland cement mortar. The fifth vault instability, probably due to a rotation of the eroded pier, has been solved by putting a double couple of iron tie-beams transversally to the bridge.

During the above mentioned years, the ability to operate on elevating masonries does not correspond to an availability of knowledge and means to operate under water; in fact, the difficulty to dry around the structure and to deep the bulkhead, because of the antique 'platea' ruins, causes the failure of the 1874 works. The same kind of operation is conducted with different results in 1928-1930, with a diver's help and with very thorough bulkheads (ASCe, Genio Civile, cat. 10, f. 1800 and ivi, f. 2579). The peculiar erosion of the second pier from the left will concern, as unpublished coeval surveys demonstrate, the total length of the pier and its depth for about three meters. This last condition causes a widespread loss of material and, therefore, an incipient instability of the contiguous vaults. Successive building yards will allow the repair of the pier and its underpinning through Portland cement, pozzolana and calcareous gravel casts, fighting, on several occasions, against the destructive effects of the Volturno's flooding. The progress of operative instruments will permit to solve, within 1930, an intrinsic problem of the bridge; the solution, hardly pursued in the past decades, will guarantee the stability of the ancient building but it will result absolutely unsafe to the hardness of the war.

2.2. The reconstruction of the bridge: the test of time

On September 9th 1943 an air bombing completely destroys the Volturno roman bridge, leaving behind only the piers foundations and the west abutment. Since 1955 the Genio Civile, in charge of all the public works, rebuilds the 'roman bridge' using reinforced concrete covered with travertine. The new bridge (Fig. 2), when compared with the ancient one, maintains the principal dimensions, the same orientation and location, but it assumes a different structural and architectonical plan. Moreover, it tries, in connection with the total environmental system that contains it, to combine, in the new structure, elements taken from the XIX century constructive tradition and some others referred to the demolished roman bridge itself.

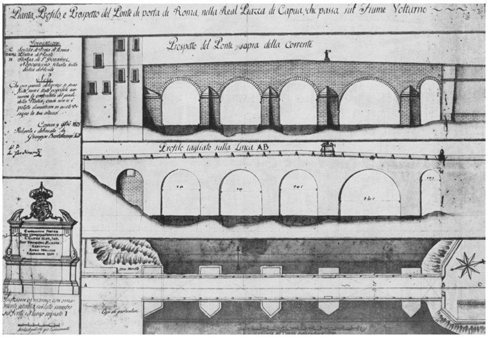


Figure 1 (left): Capua, the 'Roman bridge'. Plan, longitudinal section and elevation (G. Bartolomaji, 1805) (Istituto Storico di Cultura dell'Arma del Genio, Rome).
Figure 2 (right): Capua, the 'Roman bridge'. View from the east riverside (2007).

Unpublished photographic files, coming from the *Archivio di Stato* in Caserta (Genio Civile, Museo) show phases of the rebuilding yard. They constitute the principal reference to investigate new structure of the bridge. As the images show, the current bridge structure is composed of a sequence of reinforced concrete arches; each of them is constituted, lengthwise, of four partition walls joined by two extrados and intrados reinforced concrete slabs (Croce 1955). Finally, four concrete columns, resting on each pier, hold up the roadway. The pictures let us see the centering and the wooden formworks under construction, the placement of the piers, the slabs and the longitudinal arches irons bars and the piers foundations building yard. The choice to use reinforced concrete structure, by that time commonly employed, finds its explanation in economical contingencies, in the potential improvement from the performance viewpoint that this kind of structure promised; in this specific case, the major agility of a concrete construction will allow to modify the bridge geometry. As compared to the ancient bridge the arches number, actually, is reduced from five to three of equal dimensions to which is jointed the fourth narrower one, close to the west river side. The comparison between the historical drawings and surveys highlights how the modern bridge has kept the first and second arches span on east side. This latter, which corresponds to the ancient major arch, has probably influenced the length of the two new arches. As a consequence, the first and second arch from right probably use, only in the deepest parts, the old roman foundations, while the third and fourth arches, at the present time, lean on a new pier built in between the ruins of the two abolished ones. The decision to abolish a pier has most likely been determined by the impelling necessity to solve the erosion problems of the second pier from east. Along with the innovative elements introduced in the construction of the new bridge there are, in order to facilitate the water outflow in case of river flood, two lightened flow windows that cut transversally the bridge spandrel walls. In an ideal continuity with the destroyed pre-existence the humpbacked bridge profile is proposed again, being a typical element of the pre-nineteenth century bridges characterized by unequal arches (Torre 2003). The new piers design recovers the original geometry triangular plan of the cutwaters, covered with superior cut stone cups. The travertine semicylindric hump is taken, in a simpler shape, from the old stone parapet characterized by a mixtilinear section. Finally, the choice to cover both frontwalls using travertine, recovering Frederick the second towers' stony surface, exhibits the clear intention to adapt the new fabric to the old one and to stratified environment to which it is connected. Without deceiving the observer, the bridge openly declares its own structural technique in the arches intrados where the wooden formwork texture, imprinted in the concrete, is clearly visible.

The fabric, today, is overall in a good state of structures and materials. Nevertheless, the effects of the interaction between the concrete building and the external face are quite evident: rust drippings reveal the iron bars and the travertine anchor pins oxidation. As far as the reinforced concrete structure is concerned, it shows signs of an even erosion of the concrete. This phenomenon seems particularly alarming by external corners of the arches where the iron bars resurface, exposing themselves to the corrosive effects of the atmospheric agents. The cover, adopted to defend the concrete nucleus, shows the signs of a superficial degradation: the weathering of the bridge to the wind action, to meteoric and fluvial water turns out in a differentiated degradation of the two travertine surfaces. The upstream side presents black crustes and a diffuse rain-wash phenomenon as well as biological patina near the free water surface in shade zones. The downstream side seems resenting positively of the less exposed position, maintaining an aspect generally close to the original one. Considering the situation of the bridge, a broader reflection has to be made about the actual state of this kind of structures that, largely employed over the last century, faces the time test in a condition of constant interaction with natural elements. In this regard it would be interesting to analyse the resistance of the second pier from the left and of its foundation in order to verify the efficacy of the post-war planning solution.

3 THE MASONRY BRIDGES OF AVELLINO-ROCCHETTA RAILWAY

3.1 The spread of masonry bridges in the Italian railways after 1860

The systematic researches about bridges in Italy carried out in the last years, have drawn attention to an actual rediscovery of masonry technology between the end of XIX and the beginning of XX century. Marked by significant technical and structural refining since first half of XIX, masonry bridges seem face, for some decades, the progressive diffusion of the steel girders (Nascè 2005). First of all, the reasons of this renewed attention are traced back to the strong railway network development, that shows an exceptional increase in Italy since 1860, growing to 6000 km of national rail in ten years (Maggi 2003).

It's just within railway engineering that the renewed attention for masonry bridges efficacy develops, especially in presence of high viaducts with slender piers, whose stability could be assured only by the remarkable load of the masonry structures. The turning to the many spans masonry viaducts ductility seems more streamlined than any other constructive systems even to follow curvilinear course, that occurs frequent along the articulate plans of first railway lines.

Some important developments about building techniques, datable on the half of XIX century, also contribute to the masonry bridge's success, considerably reducing the building costs. Between these, we have to quote the introduction of water lime mortar, that allows to limit the production time from four to one year, leading to use bricks instead of more expensive freestone also in big span bridges (Nascè 2005).

3.2 The bridges of Avellino-Rocchetta and the Hoffmann brick-kiln in Manocalzati

Some masonry bridges of Avellino-Rocchetta line are the witnesses of this time of masonry renewed employ, among many railway works carried out in Italy. This line has been built since 1888 within the network of complementary railways crossing the Appennine range. As a result of decades of proposal and debates starting from 1868, the Avellino-Ponte S. Venere railway (from the name of site located right to the West from Rocchetta S. Antonio rail station) was included, as a third category line, in the July 29th 1879 law, dedicated to the rearrangement of italian railway network (de Majo 2006). Anyway the works will start after more than a decade, during which several opposite opinions will compare about the plan, with the presence of engineer Giulio Cesare Melisurgo and the great expert on the problems of Southern Italy Giustino Fortunato, who wrote many publications on «Ofantine» railways.

In these years the corps of railway engineers consolidates in Italy, constituted at the end of XIX century of about a thousand technicians, independent by then from the original training of «Ponti e strade». Those are the technicians who face the difficult task of planning, carrying out and managing railway lines (Merger 1999). The railway engineers are asked for the attentive study of routes, caring about technical requirements – like the turning of major relief – but also involved in political pressures that drive to cross particular regions and towns, in the general purpose of reducing building costs in the interest of companies. Therefore, nearly all new lines plans are discussed on several options, as the Avellino-Rocchetta case confirm. The quoted railway is built by Società per le Strade Ferrate del Mediterraneo, who at the end of XIX century can count in his staff some great railway engineers, such as Cesare Bermani e Mattia Massa, both coming from experiences made in Northern Italy (Merger 1999).

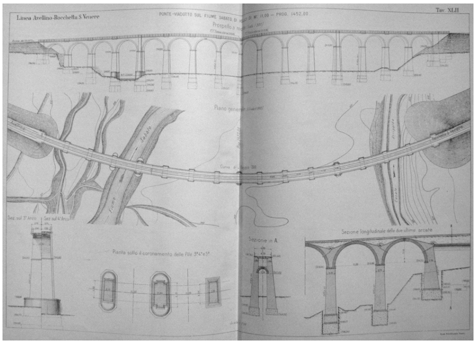


Figure 3 (left): The Sabato river viaduct near Avellino rail station (photo A. Pane 2005).
Figure 4 (right): The Sabato river viaduct, plan from Società per le Strade Ferrate del Mediterraneo, 1898.

The Avellino-Ponte S. Venere is definitively approved at the end of 1885, on a plan made by Società per le Strade Ferrate Meridionali, but soon the project is submitted to the quoted Società per le Strade Ferrate del Mediterraneo, which starts the works in 1888 – after drawing an executive plan – ending the last section in October 1895, two years before deadline. Among the three valleys of Sabato, Calore and Ofanto river, extended for almost 120 km, the route faces a rugged land with galleries, bridges and viaducts, most of them to be built in masonry according to the plan. The nature of soils appear prevailingly argillaceous and schistose, with rare limestone, marl and sandstone outcrops, while alluviums characterizes the Ofanto valley (Società Italiana per le Strade Ferrate del Mediterraneo 1898).

The need of bricks supplying for the several masonry bridges provided by the plan and the presence of «blue clay» along the route, leads to establish some Hoffmann brick-kilns since the beginning of the works. Dedicated to the first section of the railway between Avellino and Paternopoli completed in October 1893, the ruins of first brick-kiln still survive at the border of municipal district of Manocalzati (Corvigno and Famiglietti 2005). Therefore, railway works start a tiny industrial development in Avellino's county, that will not survive after railway opening. In fact, after the assignment of «Mediterranee» railways the project undergoes several changes directed to cost restriction, such as the replacement of many masonry viaducts with cheaper steel girders, rising considerable criticism about work management (Fortunato 1898).

More than fifteen structures above 50 m length realized in masonry stand out anyway within the main fifty-eight bridges and viaducts, among which the major is the big viaduct crossing Sabato river with curvilinear movement of 225m total length. The viaduct, characterized by sixteen spans of 11 m length, is placed immediately outside Avellino rail station and close to the Hoffmann brick-kiln in Manocalzati raising also an important landscape value (Fig. 3-4).

Among the bridges included in the Avellino-Paternopoli section, where the use of bricks manufactured by Manocalzati's brick-kiln is ascertained, another remarkable work is the oblique bridge crossing Calore river near S. Mango (km 24-376), formed by five arches of 12 m span with 104 m of total length. The bridge is characterized by an helicoidal vault brickwork due to its oblique course in relation to the piers, and has coffer-dam foundations, tested in Italy since 1860 (Jorini 1905), and well-built piers with cutwaters, crowning and caps (Fig. 5).

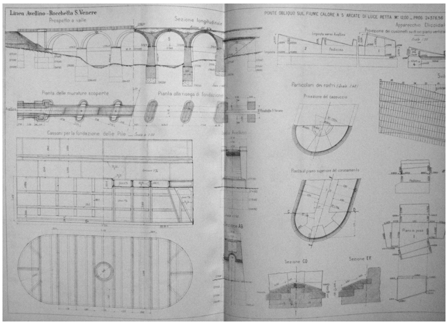
At last both the structures show a very diffuse typology in railway works, where the choice of round arches with less than 15 m span come from the problem of horizontal drift bred at the top of the pier when the train is braking and when it loads only one of the two vaults led on the same pier (Nascè 2005). To the same reasons the presence can be traced of three piers-abutments placed every four spans in the long viaduct crossing Sabato river.

3.3 War damages, reconstructions and present questions about preservation

The military actions conducted during the Second World War in the land of Avellino-Rocchetta line, especially from September 13th to October 2nd 1943, produce remarkable damages to the railway, not much in the superstructure but mainly extended to its artworks, where at least five major masonry bridges stand out (ASFS, b. 3490, report dated March 19th 1947). Since September 1944 the procedures for reopening of the line are started, witnessed by a rich correspondence between the Servizio Lavori e Costruzioni of Italian Railways in Rome and the Compartimento of Naples. Some hints about the materials to be used in the works of reconstruction come out among earliest documents, showing the intent of re-employment of existing elements in accordance with the serious logistic and economic troubles of that time. The request is to use bricks coming from brick-kilns in Casalvelino for the first three bridges and brick supplies stored near Nusco rail station for the viaduct placed at 44+747 km, up to recommend the use of ordinary mortar for the general cases (ASFS, b. 3490, letter of September 7th 1944). The works quickly proceed since the first months of 1945 authorized by the Allied Commission, with further precepts about the increase of vault thickness (ASFS, b. 3490, letter of February 26th 1945), reaching the definitive reopening of the whole line in April 1946.

There are several reconstructions or integrations carried out employing masonry in respect of the original building techniques. Just after the Montella rail station, at 44+747 km, the reconstruction of the whole three span of 12 m length viaduct has a prominent position among them. The works lead to rebuild foundations, piers, vaults, buttresses, mantles and fillings, those last made of dry heap of stone (Fig. 6). A specific subject in this sphere concerns the elements in freestone, like the crowning – sometimes built in reinforced concrete for the hard finding of large size elements – and the piers. Even for those elements the Allied Commission suggests the use of bricks, contesting because of its slow installation the use of so called «bolognini», although they were preferred from Italian Railways company in respect of the original structure's connotation (ASFS, b. 3490, letters of June 16th and September 12th 1945).

In last decades most of Avellino-Rocchetta masonry bridges are survived thanks to their loading flexibility, which allowed the remarkable increase of trains weight unlike the steel bridges. In fact, the present load limit of 16 tons per axle imposed to the whole railway line, which forces the use of old rail car «Aln 668» still today, is just due to the load limit of steel bridges and not masonry ones.



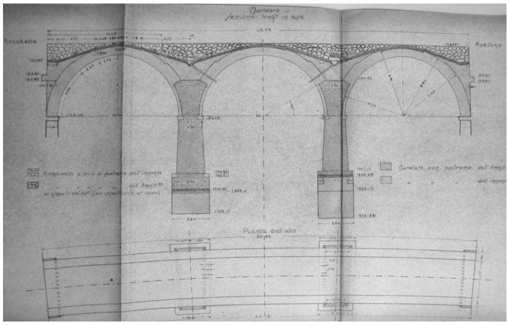


Figure 5 (left): The oblique bridge crossing Calore river, plan 1898.
Figure 6 (right): The three span viaduct near Montella, reconstruction plan, 1947 (ASFS, b. 3490).

Last reflections are concerned to the present problems involving the conservation of the Avellino-Rocchetta masonry bridges. First of all, it should be pointed out that the primary question is about preservation of the railway itself, since it seems almost disused by now: no more than two trains are passing per day and very few users take them.

Anyway the bridges themselves, in particular some of them which hadn't specific restoration interventions after the Second World War, show troublesome decay phenomena today. While hydraulic compatibility conditions seems to be fairly good, also in virtue of the mild stream's flow, the problems related to the draining of meteoric waters are quite serious. A specific feature of railway bridges, as known, has always been in fact the complete water permeability of the ballast, turning to an effective internal draining system, associated to a good watertight vault mantle (Torre 2003). At present days, however, these elements show evident problems of maintenance and functionality, producing efflorescence, spots, biological patina and self-vegetation. The quoted Sabato viaduct is a representative case for this phenomena, combined with extended zones of brick's erosion for the whole height of the piers (Fig 5).

The specific conservation questions of the bridges, extended to their structures and materials, shall not be separated in any case from a general project turned to the whole Avellino-Rocchetta line's destiny, avoiding its abandonment. An interesting path – experienced for many secondary Italians lines in last years, especially in the North – is the complete or limited reconversion of the railway for tourism purpose, using historical trains for environmental and landscape trips, of which the old Val d'Orcia railway is the first example. This kind of proposal seems moving in the circle of «compatible use» of historical infrastructures, and appears preferable in comparison to bicycle or pedestrian paths installation, which preserve only the railway course, deleting its technology and definitively its history.

4. CONCLUSIONS

The comparative study of the Avellino-Rocchetta masonry bridges and of the Capua reinforced concrete bridge highlights how the restoration of this kind of structures has to be strongly related to their constructional conception. Once recognized architectural and historical-cultural values, the conservation plan has to measure itself, therefore, with the signs of the historical building yard both operating on structures realized with "traditional" techniques and, at the same time, when the object is built with "modern" materials; analogous principles – reparability, distinguishing ability, compatibility and minimal impact – have to be followed in both situations. The integration of historic and structural engineering knowledge can reach an «integrated preservation» of this particular heritage, composed by manufactures that have to be preserved, for their cultural values, also with a different role from the original.

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Abbreviations: ASFS = Archivio Storico delle Ferrovie dello Stato (Roma), Fondo Sezione Lavori e Costruzioni; ASNa = Archivio di Stato di Napoli; ASCe = Archivio di Stato di Caserta.

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