New tendencies on repair and strengthening on masonry arch bridges

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ABSTRACT: The masonry arch bridges of the railway network are part of the historical heritage. To guarantee their stability, repair and strengthening works have been done over many years. Today, it is time to meditate about the effectiveness of those repairs done considering the knowledge recently acquired. This new knowledge has modified the repair techniques on bridges, being the new ones more respectful with their structural behaviour and with their aesthetical aspects.
The diagnosis of the damages lead to make an evolution in repair techniques: since many damages were classified as "caused by bad structural behaviour", many reinforcements were projected. Today, the diagnosis of many of those damages has changed and no reinforcements are required.
The consequences of these new tendencies are:

- More economical repairs.
- Respect to the original design and aspect of bridges.
- More effective repairs.
- Inclusion of durability as a project criterion.

1. FOREWORD

Masonry arch bridges are the oldest railway infrastructure elements. They were built between 1850 and 1940, being the most common type of bridge used on railway structures until that date.

Since 1940 the success of concrete as new construction material made that both design and building of masonry arch bridges became unused. Consequently, the specific techniques related to masonry were forgotten by the managers of the infrastructure, by the construction companies and the university teaching.

The abandon of masonry as a constructive material made that, when repairing these bridges, concrete-designed techniques (initially for purpose only with this material) were often used. During the last 50 years, reinforcements based on intrados concrete arches, shotcrete, etc became usual on masonry arch bridges.

Besides that, the behaviour of masonry as elemental material of an arch has also been forgotten. Concrete material behaviour is considered as normal on masonry, not taking into account the specificities of masonry material (anisotropy, composed material…). As a result of it, damages that could be considered as normal according to the behaviour of masonry arches, become object of repairs or strengthening.

From the point of view of the railway infrastructure administration, the previous considerations cause:

- Higher maintenance costs, because bridges with a correct structural behaviour are repaired and reinforced.

- Higher maintenance costs in the future, because some of the repairs or reinforcements projected can change the structural behaviour of the bridge, being able to reduce its ability to withstand railway loads and causing later damages.
- Reduction of the durability; even if masonry is a material with good durability conditions (in general), the use of repair techniques originally designed for concrete can sometimes change the masonry durability properties.

Once the problems of the masonry arch repairs made in the last years have been identified, the railway administrations have to make an effort to improve the way of inspecting these structures, write repair projects and carry them out, in order to make the repairs and reinforcements more effective and cheaper.

2. BASES OF THE NEW TENDENCIES ON MAINTENANCE

The need for changes in the masonry arch bridges maintenance comes from the detection by the railway administrations of recurrent damages on structures already repaired and the absence of guarantee of effectiveness of the reinforcements done. Because of these, since 2.001 66 studies of masonry material were carried out by ADIF on different bridges, with the aim of improve the knowledge about their behaviour. The studies consisted in both numerical studies concerning their ability to withstand the current railway axle loads and petrological analysis to obtain the durability properties of masonry material.

As a consequence of this investigation studies, ADIF proposed the new bases that currently are used in the masonry arch bridges maintenance. These bases are exposed as follows:

- Improvement of diagnosis in bridges inspections, because, frequently, the origin of an unnecessary repair or reinforcement comes from an incorrect result of the inspection or a misinterpretation of the results obtained that leads to a not entirely correct diagnosis of causes of the damages. The importance of the damages caused by durability processes of deterioration has been remarked because they are present most of the times on masonry arch bridges and, also were frequently considered to be caused by a bad structural behaviour of the structure. The phenomena that drive the process of deterioration have been studied, and a catalogue of typical damages has been developed to help the inspection process.
- Exhaustive study of the load carrying capacity of the bridge before designing reinforcements. Many of the reinforcements made are suspect to be unnecessary. The use of those techniques has been reduced in the last years after studying, among others, the effects of nature, disposition and dimensions of the bridge elements on the structural behaviour, and such implications on the load carrying capacity were not considered (i.e. height of haunching).
- Elaboration of protocols or methodologies of inspection (river beds, one of the weakest point of these bridges) and repair design (minipier reinforcements…), that allow both administration and construction companies to have a document to verify the work done (from the railway company part) and serve as a guide of how to execute it (from the construction company part).
- Recuperation of masonry construction techniques to repair bridges. It has been discovered that the best results of the repairs come from those considered "minor". Those interventions are related to repointing or reconstruction of damaged elements, whose cause is, almost every time, the presence of water. Many times, materials as Portland-type cement, steel and others have been used. The use, in repairs, of materials softer or similar to the existing ones on the bridge was proposed: hydraulic lime mortars. As expressed before, many of these techniques of repair come from the historical heritage maintenance field (restoration works).
- Verification of the evolution of the repair bridge. As many of these repair techniques had never been used by the railway bridges administrations, a systematic process of visiting and inspecting repaired bridges has been created. Their aim is to study the evolution of repaired bridges. Last year, 13 bridges were studied after the repair works, to control their evolution and to evaluate if the solution given was suitable to solve their problems or not.

- Establishment of a new scale of damages. The old scale consisted in four levels. The difference between one and another level was merely subjective, and because of that, in many cases, the same damages had different classification. A new scale has been proposed: C1-C2, C1 means damages that affect the structural stability and, consequently, the bridge has to be repaired. C2 means damages that do not affect the load-carrying capacity of the bridge, and thus its repair can be decided in each case. This new classification is somehow, more based on objective points of view.

These bases have been defined to improve the maintenance of masonry arches. The increased axle loads and/or speed of railway traffic observed in the last years, can affect their ability to withstand the loads. The final objective of maintenance is, in this case, to avoid their substitution and disappearance.

3. CONCLUSIONS: INSPECTION AND DIAGNOSIS

As a result of the great effort made since 2001, improvements in the bridge inspections have been achieved. The durability phenomena are today better understood by inspectors. It has been verified that a very high percentage of damages detected were due to durable facts and/or related with the presence of water. So the number of resistance damages have been reduced and so the theoretical need of reinforce the structures.

On this way, the development of the "damages leaflets", where indications to the inspector are given to check damages related with the one detected, have optimised the inspector's field work, because there is no need to return to the bridge to check if they exist or not.

Finally, it has to be noticed that the additional river bed inspection is at least as important as the proper bridge inspection. Because the early detection of pier and abutment undermining is extremely important, as it is very difficult to detect and this is a damage with a tendency to a very quick evolution towards collapse.

4. CONCLUSIONS: REPAIR EXAMPLE

The repair techniques employed in the repair of the bridge situated in kilometre 650/132 of the Madrid-Barcelona conventional railway line have been designed in the project taking into account the compatibility of the repair materials with the existing masonry. The reinforcement that has been carried out, was planned according to avoid changes into the structural behaviour of the bridge. The improvement of the load carrying capacity has been possible to be reached out without including external elements to the bridge: the result is an unchanged external appearance of the reinforced structure. Besides, it should be noticed that other aesthetic repairs have been carried out.

The repair of the bridge consisted of the following tasks:

- Cleaning of the structure by means of the projection of silicate of aluminium, a technique that is able to remove both superficial crystallized salts and lime crusts from brick and stone surface without causing erosion on masonry. The thickest crusts had to be removed by manual methods.
- Repointing of stone masonry (brick was not affected significantly by loss of mortar joint) with hydraulic lime mortar.
- Reinforcement of barrels by injection of lime mortar in the extrados of them at springing. The aim of this technique is the restitution or increase of the height of haunching, in many cases dissolved by water circulation. This reinforcement method allows the improvement of load carrying capacity without changing the structural behaviour of the bridge as other methods do (i.e., intrados concrete arches).
- Brick reconstruction using lime-coloured mortar.
- Execution of a metallic boardwalk.
- Protection of the piles base with reinforced concrete. The steel rods used were protected against corrosion.

The respect to the original design of the existing bridge was taken into account in the definition of the repair techniques

As general geometric data of the bridge:

- Number of spans: 8.
- Span: 9 m.
- Maximum height: 13 m

The repair budget was 442.000 euros, 55.250 euros per span. A similar bridge (with similar height and span characteristics) was repaired some years ago, using intrados concrete arches, being its budget of 85.000 euros per span (taking only into account the reinforcement tasks). For similar problems, the internal concrete arch solution can be 54 % more expensive. In addition to that, the external appearance of the bridge is considerably different from its original aspect.

Following some photographs concerning the repair process are shown:

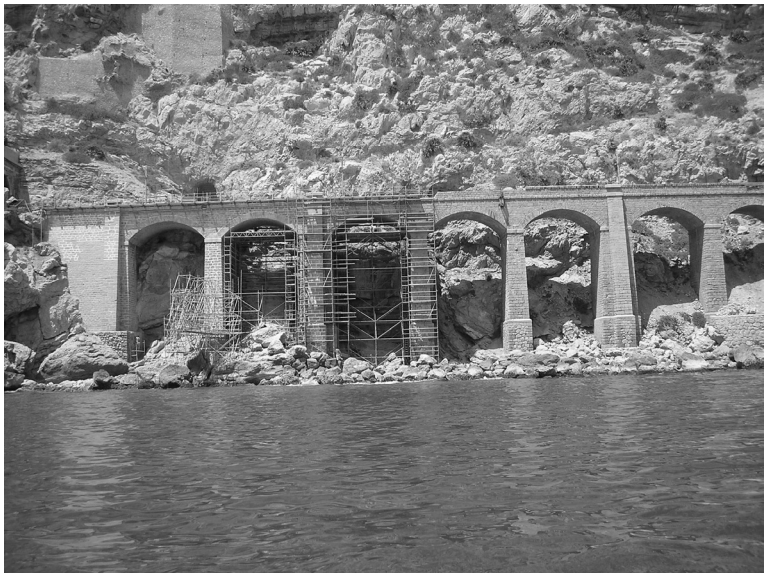

Photo 1: General view of the bridge.

Photo 2: injection of arch extrados.

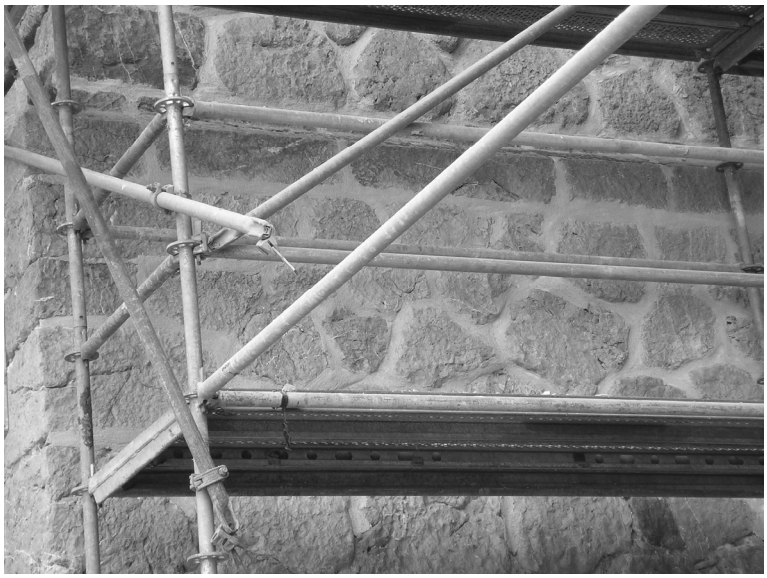

Photo 3: masonry repointing.

5. FINAL THOUGHTS

Many of the structures managed by railway administrations are part of the historical heritage of 19th century. This fact should be enough to consider making an effort to take care of them, trying at the same time to keep them on their best conditions. In addition, with the experience of ADIF after the changes carried out in the way of maintaining these structures, it has been verified that new techniques are not only more respectful with existing materials, but also more economical to the infrastructure manager. However, there is still a long way to complete this process of verification of the real effectiveness of the repairs carried out. That will be done both in a short and long term, regarding completion of different aspects. After that verification, hoping that the repairs will work in the way they have been planned, the process of amelioration of maintenance of masonry arches will be definitively achieved.

As it has been previously exposed, the final target of all of the introduced modifications is to preserve in good conditions (structural and aesthetic) the masonry arch bridges and, in addition, reduce their maintenance costs. The experiences carried out by ADIF show that, with a certain probability this is a right way to achieve both of these objectives.