Rescuing the Sidi Rached Bridge

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Summary

The Sidi Rached Bridge, built in the early 20th century, crosses the deep Rhumel canyon in the centre of Constantine, Algeria. The bridge is a famous city landmark and one of the main cultural heritage of Algeria as well as the largest masonry structure of this type in Africa. The 8 spans on the right bank have been suffering for over 50 years, from intermitting slope instability. The problem has been addressed and temporarily solved few times now. All the attempts tried to anchors the pier foundations to the bedrock while reducing the cause of soil instability with drainages. During the '70, the downhill displacement of the abutment spiked and the structure had to be disconnected severing the first arcade and replacing it with a simply supported buffer steel girder. After 30 years of relative calm, the landslide peaked again in 2008 causing severe damage to al the piers on the right bank and the near collapse of one arch. A new campaign of assessment, reconstruction and strengthening has therefore been undertaken. Using high precision topographic readings and 3D finite element model of the bridge the mechanics of what is taking place in the structure has been fully understood. The paper presents the results of the study and the first interventions taken while monitoring, studies and works proceed on this historical monument that still provides a vital crossing in the hearth to one of the most populous cities of North Africa.

Keywords: masonry bridges; slope instability; numerical modelling; external post-tensioning.

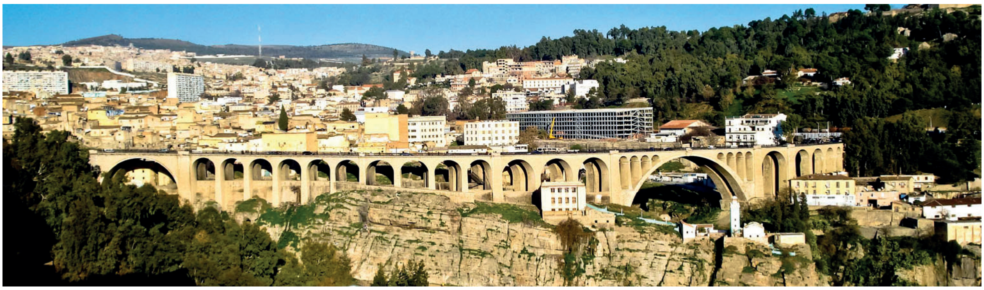

Fig.1 : The Sidi Rached Bridge seen from upstream (right bank on the right)

1. The bridge

The Sidi Rached bridge is a stone masonry arch bridge made of 27 arcades. The typical arcade has a clear span of 9 metre roughly. There are another 4 arches with 16 metres span, one with 30 metre span and the main arcade crossing the Rhumel with a 68 metre clear span. The stone facing of the structure is made of a very tough limestone rock. Pier foundations are built into the bedrock except for the first 8 piers on the right bank where the bedrock is 15 to 5 metres deep below ground level. The bridge does not present any sign of ageing except for the damage on the approach spans caused by the slope instability on the right bank. Traffic is intense but heavy axel loads not particularly

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frequent as the bridge leads to the very city centre. Climate is forgiving and water scarce. Icing-de-icing phenomena very rare. In spite of standing in a seismic area, no major earthquake happened since the construction of the bridge. Although slope instability was known from the construction time, serious damages only developed in the '60. A series of interventions were then carried out on the bridge. The major and possibly more successful of them has been severing of the first arcade to allow for the abutment to slide without pushing against the rest of the viaduct. Also a drainage pit was bored in front of the abutment with radial drains fanning out from it into the pelites. Stability of the first 8 piers was also tackled casting a network of reinforced concrete beams that connected the foundations of these piers and propped them downhill against the surfacing limestone. In 2008 the bridge started to bulge with very wide cracks opening at the pier bases. The damage extended to the 4^{th} arcade with crushing and spalling of the stone masonry of one arch.

2. The numerical simulations

Although quite simple with hindsight, the kinematics and mechanics of the damage was not clear at all to the various experts that visited the bridge. A 3D finite element model of the bridge was set up. The model clearly shows that when a push is applied from the abutment the approach spans on the right side of the Rhumel river (the ones depicted in the F.E. model above) buckle and sway outwards. Very wide flexural cracks forms at the pier bases. The measured outward sway of the deck is 20cm circa. Crack opening at the pier base up to 20mm, consistent with a rigid body kinematics. At the centre of the curve, a plastic hinge developed in the deck with crushing of the inside (downstream) arch.

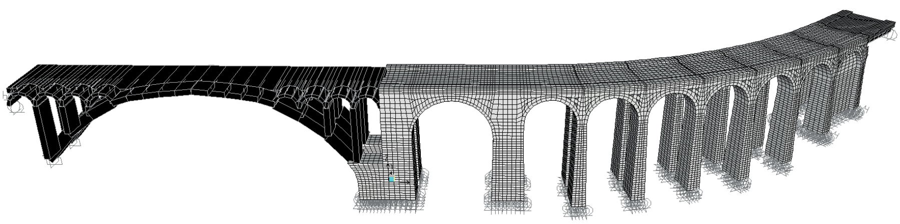

Fig.2 : The Finite Element model of the bridge right bank and main arcade

3. The repair works

The repair works have been phased so as to address the short term safety issues (propping) and the long term rehabilitation of the structure while keeping in mind the city traffic constraints. Given the size of the landslide no quick fix can be found and therefore repair works on the bridge will have to adjust to the timing required for the slope stabilization. Unfortunately, there is no guarantee that the latter can be achieved before the bridge is completely wrecked. The Constantine's Public Work Authority dismissed an early proposal to demolish the last few spans of the bridge and replace them with a new structure capable of withstanding, absorbing or avoiding the downhill slide of that part of the slope. This was a bold decision, driven by cultural and heritage concerns but certainly very risky under a structural point of view.

The first interventions have been the temporary propping of the crushed arch in order to allow the transit of the bridge. Second intervention, in summer 2011, has been the replacement of the old buffer deck that was jammed and pushing against the bridge with a new one, shorter, lighter and with enlarged gaps to allow for differential displacement of the abutment. Currently, micropiles are being driven into the sandstone to try stabilize the foundation of the first four arcades. Drainages work will follows soon and a rigid structured bored between the abutment and the rest of the bridge to disconnect the uphill portion of the slope to the downhill one. Once the soil instability will be tackled and the bridge will show no sign of further deformation, the collapsed arch between Pier 4 and 5 will have to be demolished and reconstructed. Based on the numerical analyses, the bridge is still carrying a compression force in the deck of 900 tons. Demolishing that arch while unloading the bridge that twill set back and recover from the swayed and rocked position will be a very delicate operation to perform.