Narrowing of the Rimac River due to Anthropogenic Causes - Partial Engineering Solutions

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ABSTRACT

This paper describes and pin points the factors that led to the formation of an urban canyon in Lima, Peru. The streambed of the Rimac River deepened approximately 20 m downstream of the Army Bridge. As the river formed the canyon, several structures located downstream, such as the Dueñas Bridge, were affected. Remedial measures that locally controlled the erosion of the streambed are presented. Solutions are considered partial because it is thought that restoration of the river prior to the formation of the canyon is impractical and very costly. Recently occurred events and announcements related to new interventions in the Rimac River are also discussed.

INTRODUCTION

Lima, the capital of Peru, is by far its most populated city. The Rimac River flows in the East – West direction. The historical center, or Downtown, is located slightly south the Left bank. The Rimac neighborhood (nowadays the Rimac district) was located north of the Rimac River. By the beginning of the 20th century at least 3 bridges connected Downtown with the Rimac Neighborhood.

Explosive growth from the 1950s, mainly from immigration from the highlands of Peru until present led to a total population of 8 million as of 2010. Severe droughts occurring in a number of events affected the crops and pastures of Andean peasants who migrated to Lima in search of better opportunities to improve their standard of living. Table 1 compares population growth in Lima and Peru.

As the population grew explosively, new settlements and developments took place north of the Rimac River and West of the Rimac district. To connect these new neighborhoods with the left bank of the river, new bridges were built.

Table 1. Comparison of population growth in Lima and population growth in Peru.

	Lima		Peru	
Year	Population (Thousands)	Annual Growth Rate (%)	Population (Thousands)	Annual Growth Rate (%)
1940	645	-	6208	-
1961	1845	5.1	9907	2.3
1972	3303	5.4	13538	2.9
1981	4608	3.8	17005	2.6
1993	6345	2.7	22048	2.2
2007	8482	2.1	27412	1.6

In 2001, the first two authors of this paper and another professional were called upon to conduct remedial works to retrofit the Dueñas Bridge whose structures were undermined. The bridge had been built in 1966. During the course of this investigation it was found that deepening of the river was not localized, but had occurred in a large reach whose length is measuring approximately 4.6 km. The formation of the canyon started downstream of the "El Ejercito Bridge (Army Bridge, in English).

Several research studies were reviewed and a number of possible causes for the deepening of the river have been mentioned (Laredo, 1992), namely: (i) Construction of bridges since colonial times, (ii) Construction of the Panamerican Highway By Pass, (iii) Construction of the Lima-Callao and Lima- La Oroya Railroad (iv) Continuous incorporation of sediments intentionally dumped by garbage trucks (v) Erosion control/ structures built by illegal occupants of the river banks.

This paper presents a timeline of the most important interventions in the reach of study and also engineering solutions that mitigated the effect of scour in the canyon reach of the river. The effects of the structures that affected the morphology of the Rimac River and those that prevent further undermining of crossing structures is discussed. In addition, the response of the population to river changes is also commented.

DESCRIPTION OF THE STUDY AREA

The Rimac River basin, with a total area of 3 398 km^2, is divided in a wet basin and a dry basin. Practically all of the rainfall contributing to the surface flow is collected above the 1000 m elevation, in the so called "wet basin". A hydrological station, R-2 or Chosica, is located approximately 30 km E of Lima and registers the flows that are used for the design of river structures. The collection area at R-2 is 2370 km^2. Climate ranges between hyperarid in the lower reaches to semi-arid in the upper reaches. Vegetation is very scarce o spare in the entire basin.

The river is, in general, very steep. The average slope is 3.23 %. In the lower reaches (between Chosica and the Pacific Ocean), the average slope is 1.7 %. The river is braided in the area of study, which reflects the high sediment content and the steep slope.

The first El Ejercito Bridge (Army Bridge), which was a metallic structure, was completed by the end of 1936 to allow communication between Downtown Lima and the recently occupied Northern Sector. Table 2 shows the division of the study area in subreaches, which allows explaining the relative position of the structures mentioned in this paper.

Table 2. Sub reaches of the study area described in the upstream direction.

Nº	Reach	Brief Description
1	500 m downstream of the Dueñas Bridge to 200 m upstream of the Dueñas Bridge	This sector was intervened in 2001, when undermining of the foundation of the Dueñas Bridge almost caused its collapse.
2	Dueñas Bridge – El Ejercito (Army) Bridge	The river has formed a deep urban canyon. Approximate width at the base is 9.5 m. The length of this reach is 2.6 km.
3	Army Bridge - Trujillo Bridge (Stone Bridge)	In this section the river width varies between 25 m and 78 m. However, the river is not very deep. The railroad fill is closer to the Stone Bridge. This reach is 1.6 km long.
4	Stone Bridge (Trujillo Bridge) – Acho Bull ring (Balta Bridge)	The river width varies between 41 and 150 m. This reach is 0.7 km long.
5	Acho Bull Ring (Balta Bridge) - San Cristobal Mountain	The San Cristobal mountain has acted as a geologic control. The Rimac River flows at its foothills. This reach is 1.1 km long.

GEOLOGY OF LIMA METROPOLITAN AREA (LMA)

Most of Lima Metropolitan Area (LMA) is located on old floodplains of the Rimac River. The large alluvial fan is formed by material transported by the Rimac River. Conglomerate, mainly formed by cobbles and boulders in a sandy matrix with some fines, is the predominant material. The depth of the alluvial material deposits have been estimated at 200 to 400 m. Some layers are superimposed by deposits of the Chillon River, which also flows in the East-West direction north of the Rimac River. Most of the area is flat, although some small hills are found. Its vertices are Vitarte, Morro Solar and the Bocanegra Farm. The alluvial fan has been eroded away by wave action along the coastline, forming cliffs whose height increases in the South direction. On this alluvial area, the Rimac River has changed its alignment in different geological eras, depositing what is now the foundation of LMA (INGEMET, 1988). The cliffs rise to 70 m in the SE direction.

HUMAN INTERVENTION IN THE RIMAC RIVER

The Rimac River has sustained a number of changes, mainly due to the city needs. The timeline for these changes follows. Old maps and paintings, old aerial photographs, and other historical documents have been analyzed to pin point the time when deepening of the Rimac River that led to the formation of a canyon took place.

One of the first structures built on the Rimac River was the Stone Bridge or Trujillo Bridge. According to historical records, it was finished in 1610 and measured 112 m or according to literature consulted "500 geometric feet". It consisted of a stone multiple-arch bridge that crossed the streambed and part of the floodplains of the river near Downtown to connect it with the Rimac neighborhood.

During the year 1870 the first railroad in South America was built. It connected Lima with the harbor of Callao. According to Regal (1965), the fill on which the railroad was built, occupied part of the Rimac River streambed just outside of the old Walls that surrounded Lima. The railroad passed underneath the arch of the Stone Bridge located on the left bank of the river. The railroad fill, therefore, occupied part of the left floodplains and streambed of the Rimac River.

According to the report by LNH (1997), the fall just downstream the El Ejercito Bridge was approximately 4 m when the Army Bridge was built. In 1997, the height of the fall was approximately 16 m, because the streambed had deepened forming an urban canyon with very steep cliffs with heights of approximately 20 m.

A map made at the beginning of the 20th century (Basurco, 1904) shows that reach of the river comprising sectors 1 and 2 (See Table 2) was much wider than the river upstream. Aerial photographs taken in 1944 (see Figure 1) show that the recently built "El Ejercito" Bridge (Army Bridge) had induced deepening of the river downstream of the structure. This occurred several decades after the railroad fill had partially occupied the streambed of the Rimac River and two decades before the Pan American Highway By Pass had been built. Documented evidence shows that narrowing of the Rimac River occurred after the construction of the Army Bridge, which was completed by the end of 1936.

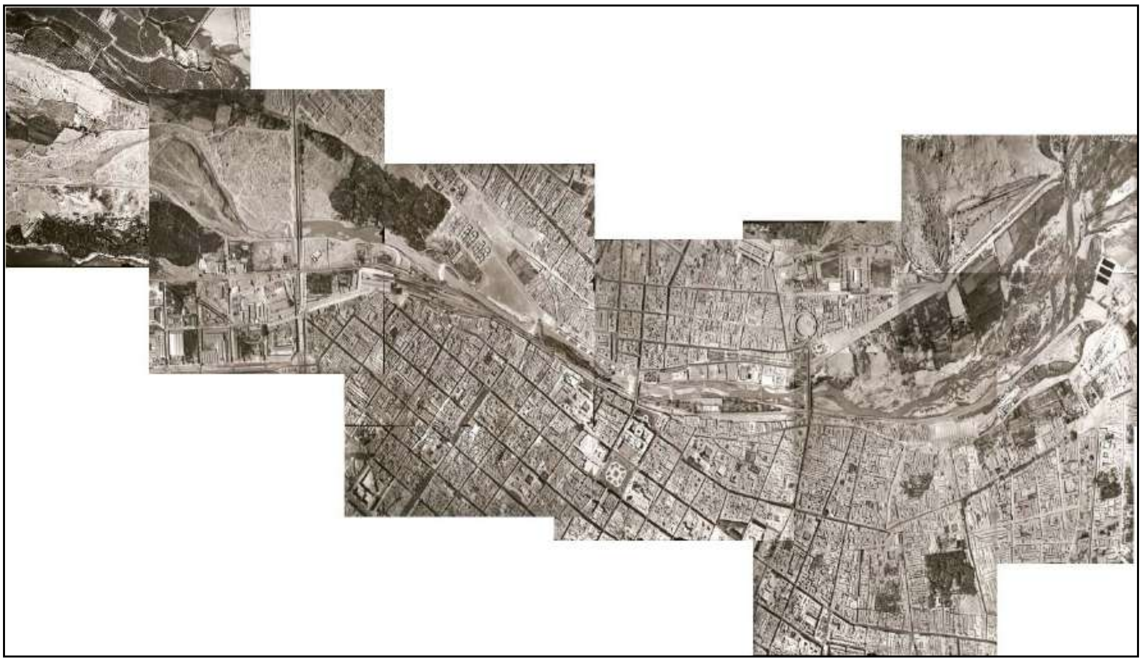

Figure 1. Composition of aerial photographs taken in 1944. The river flows right to left. Notice the width of the river and the floodplains on the left side of the picture.

As the river became narrower and deeper, old floodplains were abandoned. This encouraged new illegal settlers to occupy the banks of the Rimac River. The cliffs are almost vertical as seen in Figure 2. Several houses have fallen because the cliffs are highly unstable. In addition, in more than one occasion, sewage from the houses directly discharging into the river had eroded away the foundation of the houses, causing the precarious structure to fall into the river. Precarious erosion control structures, such as rock deflectors, have been observed. In addition, settlers encourage garbage trucks dump sediments into the Rimac River, which somehow reduces erosion on the river almost vertical cliffs.

In 1968, the construction of the Pan American Highway By Pass narrowed the Rimac River near Downtown. Concrete walls were used as river training works to protect the road against flooding and erosion. The Stone Bridge and the Balta Bridge were partially demolished. Figure 3 shows the Pan-American Highway By Pass occupying part of the streambed and the right floodplains of the Rimac River. Also concrete walls one meter wide were placed as river grade controlling structures downstream of the Stone Bridge. Supposedly, they are also used to encourage infiltration into Lima’s aquifer. However, no data related to aquifer recharge has been collected.

Figure 2. Urban canyon downstream of the Army Bridge.

Figure 3. Construction of the Pan-American Highway By Pass narrowed the Rimac River. Notice the railroad fill on the left bank of the river. The photograph was taken looking in the upstream direction.

PARTIAL ENGINEERING SOLUTIONS

As the Rimac River morphology changed, and the occupation of land took place in its former floodplains, restoration to its conditions previous to 1936 was impractical.

As time passed by, the waterfall height increased from 4 m to 16 m (LNH, 1997). The National Hydraulics Laboratory, a National University of Engineering research center, conducted studies to stabilize the river bed downstream of the Army Bridge.

In 1998, high discharges related to a very intense ENSO led to conduct temporary remedial works downstream of the Army Bridge. These remedial works consisted of dumping large rocks on the bed stream of the Rimac River. The solutions by LNH are yet to be implemented.

In 2001, Inversiones Metropolitanas (INVERMET, an infrastructure investment city agency) was concerned because one of its inspectors found that the foundation of what he believed was the right abutment of a bridge had undergone severe scour, endangering the structure.

A review of photographs taken shortly after the construction of the bridge was finished, revealed that, in reality; the bridge originally had two openings in 1966 and the river width was approximately 45 m. The bridge deck laid on a central pier and two abutments. In time, deepening of the river caused that all of the flow to pass underneath the left opening. Further deepening of the river scoured the foundation of the central pier. Figure 4 shows the condition of the Dueñas Bridge in October 2001, when inspection by the first two authors of this report took place.

Special grouting injections were used to stabilize the central pier. The hydraulic works consisted of using a broken rock ramp with a 1.33 % slope upstream of the centerline of the bridge and 3.65 % slope downstream of the centerline of the bridge. The average width of the river bed is 9.5 m. Hand placed rock walls protected the almost vertical banks of the canyon upstream of the bridge. Downstream of the bridge, riprap was accommodated to a 2H: 1 V slope where possible. D_{50} was 1.30 m. No geotextile was placed underneath the two-layer protection because the bed was mainly composed by cobbles. A paper discussing this case study was presented in Hydrology Days 2004 (Kuroiwa et al, 2004). Peak discharge between 2001 and 2009 was 142.1 m^3/s. The rock ramp has been stable for the last 9 years and although it was thought as a temporary solution, it has become a permanent structure. Use of dumped rock contributed to the dissipation of energy downstream of the bridge, where slope is very high. Protection of the bridge, the streambed and the banks has encouraged the illegal occupation of the right bank of the river, upstream of the bridge.

Figure 4. Scour under the Duenas Bridge. Notice the grade control structure built in 1977 that was completely destroyed in 2001.

Figure 5. View of the rock ramp during a flood in March 2003.

RECENT DEVELOPMENTS

In 2009, one of the piers of the Balta Bridge collapsed on March 13, 2009, at 11 am (El Comercio, 2009). Scour underneath the pier caused settlement of the structure. This bridge is located in a sector that has been narrowed by the construction of the Pan American Highway By Pass. This bridge was closed by the National Police and has been declared unused. This bridge was built between 1870 and 1872 and is considered of historical interest.

In 2010 (Andina, 2010) the former mayor of Lima, Luis Castañeda, announced that the Linea Amarilla (Yellow Line, in English) project had been awarded. This project consists of a Toll Expressway that will connect Lima with Callao, where the harbor and Peru's main airport is located. According to official information, a tunnel underneath the Rimac River will allow traffic in the downtown area to travel west.

By the time this article was about to be concluded, Augusto Ortiz de Zevallos, a renowned urban planner and advisor to the recently elected mayor announced that the width of the Rimac River was going to be reduced to 45 m in order to gain 60 m for reforestation of the river banks and to incorporate city recreational areas. (Andina, 2011) This is an attempt to beautify Downtown Lima and make it friendly to its citizens and visitors. However, further narrowing of the Rimac may cause further deepening of the river in sectors that have not been affected. In addition, narrowing of the Rimac River may have already caused the collapse of the Balta Bridge, a historic bridge built in the 19^{th} century, and other crossing structures may also be damaged in the future.

CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

This paper presents the results of an investigation whose main purpose was to identify the main cause of the formation of a canyon downstream of the Army Bridge and to assess the effectiveness of a grade control structure built underneath an undermined bridge. The main conclusions follow:

Narrowing and the formation of the Rimac River urban canyon has been the consequence of human activities.

Although the Rimac River has undergone a number of modifications since the 17^{th} century, the main cause of the formation of the Rimac River urban canyon is the construction of the Army Bridge in 1936. Aerial photographs, taken in 1944, show the recently built bridge and the early incision process downstream of the Army Bridge.

The use of a rock ramp has stabilized the foundation of the Dueñas Bridge, located at the downstream of the study area. This solution has not produced an adversely hydraulic effect.

River protection works in urban areas tend to encourage people to settle near the banks of the rivers, even if the banks are unstable.

New constructions threaten to further modify the morphology of the Rimac River, endangering its crossing structures. Some of them are of historical value and need to be protected against large floods.

RECOMMENDATIONS

Both the Yellow Line Project and the River Bank treatment need to conduct coordinated hydraulic and geomorphologic studies to assess the effects of the construction of the tunnel underneath the Rimac River and further narrowing of the river. These studies should consider retrofitting of the Balta Bridge and protection of other existing bridges along the Rimac River.

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