Visual Inspection and Determining Bridge Load Rating over the Torrential Rimac River in Lima, Peru

C Blas1, F Fernandez1 *and E Carrera1

1 Faculty of Engineering, Universidad Peruana de Ciencias Aplicadas, Prolongación Primavera, 2390, Lima, 15023

*Corresponding author: u201510159@upc.edu.pe

Abstract. Nowadays, the appropriate functioning of road infrastructure is a major concern that governments face. One of the structures most vulnerable to failure are bridges. In Peru, the hydrodynamics of torrential rivers, attributable to its geography, generates the collapse in the bridges by scour. Likewise, the increase in service overloads, compared to design loads (HS20), united with the fact that many bridges have more than 50 years in service, is another common factor that contributes to the bridge failures and should be considered in the evaluation of bridges. Therefore, this research aims to inspect, evaluate the load capacity in the superstructure of the Dueñas bridge using the LRFR methodology and propose improvements in the maintenance process. This bridge is made of prestressed concrete built in the 60's and over the torrential Rimac river in Lima, Peru. The findings, according to the field visit, indicate the main problems are scour in the intermediate pier and damage in the concrete in the structural elements. Additionally, the rating factor (RF) calculated in the beams do not exceed to unit which implies that they only need structural reinforcement. Finally, improvements were proposed for the prevention of failure in the beams and scour in the substructure.

1. Introduction

Road infrastructure assume an important role in countries, since it promotes social integration and sustained economy growth in modern cities. The successful performance of this transport infrastructure is still a major challenge for responsible governments around the world. One of the most important structures are the bridges, due to their purpose of connecting roads achieving the objective of road network. Bridges are highly vulnerable to failure caused by various factors, such as aggressive environmental effects and overloads, which have an impact on structural and functional deficiency, safety and integrity of the population [1].

Peru is a country that, for its geographical location, presents several natural phenomena which cause severe damage to bridges. The El Niño phenomenon is the most frequent cause of bridge failures in relation to rivers behavior: the scour. This consists of removal of materials or solid waste from the riverbed, which the main agent is water in the surroundings of the bridge substructure. It arises when appears local speeds greater than average speed of current produced by vortices in different directions in the substructure and is originated for two main reasons [2]. On the one hand, Peruvian geography facilitates the formation of torrential rivers through steep and narrow valleys at
high altitudes, causing changes in flow velocity and channel width [3]. On the other hand, the El Niño phenomenon represents a violent and unusual change in climate, allowing an increase in the discharges of rivers and streams due to the high intensity of rains with long durations between December and March, in addition to the lack of "Prevention culture" and insufficient river drainage [4]. For example, environmental conditions caused by the El Niño phenomenon in 2017 not only generated 1.9 million Peruvians affected, but also major losses and damage to the infrastructure of 601 bridges affected by scouring and would require USD 15 million to repair them or build them to 168 bridges [5].

Furthermore, other common factor that contributes to bridge failures is the union between the increase in service overloads, with respect to design loads (HS20) and that the bridges have more than 50 years in service. In urban areas with high population density such as Lima, structures are constantly affected by this combination of factors affecting their long-term capacity. For instance, in relation to the increase in the volume of the vehicle fleet, Ministry of Transport and Communications (MTC) shows that heavy and light vehicles increased by 12% between the years 2017-2018[6].

Therefore, this research aimed to inspect the actual condition of the elements and structurally evaluate the superstructure of the Dueñas Bridge over the Rimac river in Lima, Peru, as well as propose improvements to prevent failure in the beams and scour in the intermediate pier. In addition, this bridge has not suffered damage by seism during its service life; thus, the study does not consider seismic effect for this evaluation.

2. Materials and method

2.1. General description of Dueñas bridge
The bridge under study, as shown in figure 1, is located in the urban area of Lima, Peru and was built in the 60’s. It is made of prestressed concrete with a total length of 70 m, which is divided into two simply supported sections of 35 m supported by two abutments and a central pier. The height from the bottom edge of the footing to the top edge of the deck is 18 m.

![Figure 1. General view of Dueñas bridge.](image_url)

2.2. Inspections
MTC has a manual for inspection through standardized activities and procedures to determine the current physical and functional condition of the components in order to prevent deterioration. Generally, inspection is a task that involves two processes: visual and physical. In addition, they are classified three inspection types (initial, routine and special), which the first two are necessary for vehicle load capacity evaluation and, therefore, they will be used in the case study.
2.2.1. Initial Inspection. It’s the first inspection that allows the collection of information necessary for a database when the bridge is not registered in an inventory. It consists of collecting information through plans, files, history of the bridge, previous inspections or information regarding the bridge. This information will be recorded in an inventory by structure with relevant details found. MTC considers as a minimum to include the following information in the database: general data, basic information, geometric design characteristics, previous inspections, rehabilitation history and photographs.

2.2.2. Routine Inspection. This inspection is known as field inspection and carried out to detect timely deterioration, locate and repair them to prevent an increase in damage severity. This part implements the use of datasheets that include photographs of the damage, recommendations report for maintenance or if a special inspection is necessary. In particular, greater consideration should be taken of damage involved as: impact on user safety and functional or resistant characteristics degradation in the bridge components [7].

2.3. Load and Resistance Factor Rating evaluation of the superstructure

Primary focus of this section is the assessment of the safety of bridge for live loads (including overload) and fatigue. The LRFR method, provided by the Manual for Bridge Evaluation (MBE) in Chapter 6, is one of the last methods used based on the Load Resistance Factor Design (LRFD) philosophy. It is mainly used to determinate the safe live load carrying capacity in a newly designed or existing bridge structure. The factor (RF) is calculated using LRFR method from information obtained of bridge plans and supplemented with information collected from field inspections. The RF decides which structures have substandard load capacities that may require posting or other remedial action. The LRFR load rating equation is shown below [5]:

\[
RF = \frac{C - (\gamma_{DC})(DC) - (\gamma_{DW})(DW)}{(\gamma_{LL})(LL + IM)}
\]

where, for limit states of resistance,

\[
C = \phi_c \phi_s \phi R_n \quad (2)
\]

\[
\phi_c \phi_s \geq 0.85 \quad (3)
\]

The RF denotes the rating factor. C is the member's capacity or factored resistance. Rn represents the nominal strength of the member in the LRFD code and is calculated from the inspection condition. DC, DW and LL+IM denote the effects of load due to the weight of structural components and accessories, the weight of the wear surface and utilities, other permanent loads, live load plus dynamic allocation, respectively. \(\gamma_{DC}\), \(\gamma_{DW}\) and \(\gamma_{LL}\) are the corresponding load factors. \(\phi_c\), \(\phi_s\) and \(\phi\) are the condition factor, system factor, and strength factor respectively [8-9].

3. Results and Discussion

3.1. Initial inspection

The cross section has a total width of 20.6 m subdivided into 4 two-way lanes of 3.6 m in length each. The figure 2 shows the total cross section in which the six beams were named with a number. The figure 3 is represented as a semi-cross section where the thickness of the asphalt layer is 5 cm, sidewalk is 2.5 m wide and the steel railing is 1 m high. Regarding the beams, they are made of prestressed T-beam bridge decks whose dimensions are variable section whose maximum value is 0.40 m and 1.70 m in height.
3.2. Routine inspection

For this step, two maps of different views were developed in order to locate the damage to the structure during field inspection.

The first map, shown in figure 4, has five main problems. In the substructure, scour was found as the most prominent damage and advancing in the central pier. The actual scour height with respect to the level of the ground in 1965 is 2.63m (number 1). However, although there is no problem of scour in the abutments, this element is surrounded by garbage filling and toxic waste (number 4). The water of the Rimac river is contaminated with sewage from the invasion of houses on the river bank, mining and construction waste. In addition, the starling section is eroded (number 3) and vertical cracks were evident in the lower area of the pier (number 2). Finally, the T-beams and deck presents cracks in both directions, exposure of the steel in one of them as a result of the minimal coating used, and efflorescence due to high humidity (number 5).
The second damage map was made for the plan view which reflects four problems related to the users' safety according to figure 5. For example, numbers 2 and 3 affect the pedestrian because there are cracks in the sidewalks on both sides and rust is evident on the railings. For numbers 1 and 2, it not only affects drivers and vehicles, but also deteriorates the structure, since the pathology called "crocodile skin" and the poor condition of the expansion joints can alter the bases of the pavement.

Figure 4. Damage map for the overview of Dueñas bridge.
3.3. Rating factor (RF)

According to the MBE, they note that, if the RF at inventory level is less than 1.00, it needs to be evaluated at the operation level. Additionally, in Peru, bridge evaluation experts recommend that, if the RF value is greater than 1.00, the bridge is optimally state. If it varies between 0.65 and 1.00, you will need structural reinforcement and, if the RF value is less than 0.65, the bridge must be demolished.
The structural evaluation, based on the LRFR methodology, shows that the exterior T-beams are more critical than the interior T-beams because the external T-beams (1 and 6) support the pedestrian live load, in addition of the dead load distribution. This pedestrian live load is high due to the geometry of the sidewalk which has a width of 2.5 m. In table 1, all the parameters used to calculate the RF of the internal and external T-beams are presented according to equation (1) for the load combination Resistance I. Additionally, the RF is calculated for the inventory level and the operation level. For the inventory level, table 1 shows that none of the T-beams have enough capacity to withstand bending stresses. The flexural RF of the external T-beams are less than 1.00 in 30%, while the average of the internal T-beams is less in 23.5%. For the operation level, table 1 shows that no T-beam has enough capacity to withstand the bending stresses either, since on average the external T-beams are less than 1.00 by 9% and 1% for the internal T-beams. Therefore, all T-beams only require structural reinforcement.

**Table 1.** Parameters and RF values for the Dueñas bridge.

| T-Beam | 1 and 6 | 2 and 5 | 3 and 4 |
|--------|---------|---------|---------|
| RF(Inventory Level) | 0.71 | 0.77 | 0.76 |
| RF(Operation Level) | 0.92 | 0.99 | 0.98 |
| $DC$ (kN·m) | 3364 | 4001 | 4129 |
| $DW$ (kN·m) | 49 | 520 | 451 |
| $LL + IM$ (kN·m) | 5139 | 3923 | 3923 |
| $R_n$ (kN·m) | 11219 | 11631 | 11631 |
| $\phi$ | 1.00 | 1.00 | 1.00 |
| $\phi_c$ | 0.95 | 0.95 | 0.95 |
| $\phi_s$ | 1.00 | 1.00 | 1.00 |
| $\gamma_{DC}$ | 1.25 | 1.25 | 1.25 |
| $\gamma_{DW}$ | 1.50 | 1.50 | 1.50 |
| $\gamma_{LL}$ | 1.75 | 1.75 | 1.75 |
| $\gamma_{LL}$ (Operation Level) | 1.35 | 1.35 | 1.35 |

**4. Improvement proposal**

The proposals to improve the Dueñas bridge have been divided into two parts. The first part is proposed as a result of the routine inspection developed in section 3.2. Thus, as general measures of prevention of bridge failure, it is recommended the following:

- To avoid the reduction of the width of the river through an adequate urban planning, since there are housing constructions and litter on the banks of the river in order to prevent the increase of the average flow velocity (local scour) presented in the foundations.
- Elimination of the existing road under the bridge so as not to reduce the width of the river.
- Protection of concrete against acids and sulfates in river water.
- Application of fissure seals on concrete structural elements of the bridge.
- Construction of river defenses.

The second part is linked to the calculation results of superstructure structural evaluation carried out in section 3.3. Carbon fiber (Sika Carbodur S1012) is suggested to be applied to the beams (due to their low resistance capacity to current admissible loads) to improve the RF parameter. In figure 6, the location of the carbon fiber strips for the flex and shear reinforcement was rendered in 3D in Revit.

![Figure 6](image)

**Figure 6.** 3D view in Revit of the application of the carbon fibers bands in the beams.

For this purpose, in figure 7 (a), the cross-sectional view of the beam was represented in which the bands are placed on the center of the beams in all the bases whose dimensions are 0.30 m wide and a length of 30 m for the flexural reinforcement. Regarding to the longitudinal view, the placement of 6 bands of 0.10 m wide in the shape of “U” will be made every 0.20 m covered on each T-beam to ensure shear reinforcement shown in figure 7 (b).

![Figure 7](image)

**Figure 7.** (a) View of the cross section of the application of the fiber at the base of the beam. (b) Longitudinal view of the use of carbon fibers in the beam.

Finally, a flow chart was developed, as shown in figure 8, which summarizes all the procedures executed in this investigation. It starts from basic inspections (gathering general information), routine inspection (in field and office) and the improvement proposals.
5. Conclusions

In the present study, the visual inspection and superstructure evaluation, using LRFR method to the Dueñas bridge, was carried out with the objective of knowing the current physical and structural condition. It can be concluded that the Dueñas bridge presents grave problems in its current condition and does not have an inventory. Next, the most important findings and the improvement proposal to prevent the failure will be known:

- Before the visual inspection, it was necessary to collect information about the characteristics of the Dueñas bridge because the MTC has an inadequate database for bridges (a common characteristic in developing countries). The inventory has a fundamental role because it allows us to obtain information about any bridge. Also, it generates a broad vision on the evaluation and knowledge of previous inspections. Therefore, it is essential to have an updated inventory of the bridges in the construction and service life stage.

- The results of the evaluation using LRFR method indicate that the Dueñas bridge needs a structural reinforcement for all beams, since all RF values do not exceed 1.00. For this reason, it is recommended to apply carbon fiber to reinforce bending stresses and ensure shear force.

- During the routine inspection, damages were found associated to bridge and user safety. With regard to the bridge, the main problems are scour and damages in concrete caused by behavior of the torrential river, while, for users, there are defects in sidewalks, asphalt, and rusty metal railings. Consequently, it is important that the authorities have proper and opportune maintenance management to prevent bridge failures.
6. References

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