Structural Evaluation and Rehabilitation Design of Puente Blanco in Quebradillas

Lismarie Vargas Andino
Master of Civil Engineering
Héctor J. Cruzado, PhD, PE
Department of Civil & Environmental Engineering and Land Surveying

Abstract

Puente Blanco is an arch bridge located in the municipality of Quebradillas, Puerto Rico. This reinforced concrete structure, which dates from 1922, was initially designed and built as a railroad bridge but was later renovated to be used by automobiles. Over the years, the structure has suffered severe damage due to exposure to coastal environment and lack of maintenance, causing the bridge to be closed to automobiles. Using a structural engineering program, a model of the bridge was developed to evaluate its design under current standards. Using the results, a rehabilitation that included reinforcement replacement and carbon fiber application was designed. The estimated cost of implementing the design is $3,771,651.24. If this rehabilitation is not implemented, the historic bridge is at risk of collapsing.

Historical Background

Figure 1
Original condition of the bridge

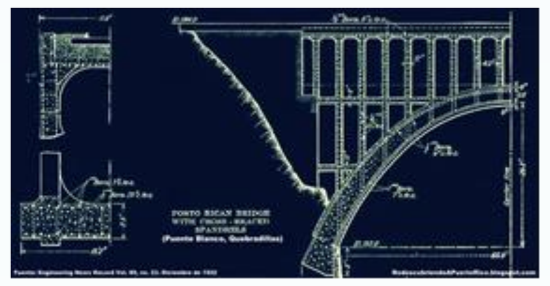

Figure 2
Structural blueprints

The strength of the concrete structures was limited by 1910 design specifications to 2,000 psi. The reinforcement of this era had a yield of 30 to 35 ksi for mild steel and 50 to 60 ksi for hard steel [1]. The reinforcement in the columns is composed of four 1-inch diameter vertical bars and 1/4-inch hoops every 12 inches, as shown in the original plans. The reinforcing steel bars in the structure consist of twisted iron, better known as a twisted square bar [3].

In 1984, Puente Blanco was listed in the National Register of Historic Places. In 1985, the bridge was renovated to widen the roadway to 23 feet for vehicular use by placing an 11-inch slab on top of ten beams, as shown in Figure 5. In 2008 the Department of Transportation and Public Works (DTOP) closed the bridge to vehicular traffic [4].

Puente Blanco was originally built as part of the railroad in Puerto Rico owned by the American Railroad Company. At its location, there had been a steel bridge that had spanned that section since 1907, but this had to be replaced because it was in poor condition. Puente Blanco was designed by Etienne Totti, a native of the municipality of Yauco, who served as chief engineer for the American Railroad Company. Construction of the arch bridge was completed in 1922 with a cost of $18,000. It supported the 84-ton weight of two locomotives crossing the bridge [1]. The original architecture of the bridge is presented in Figure 1.

A copy of the original bridge plan was obtained, from an old magazine article, as shown in Figure 2. It shows the structural details of the arch, the dimensions of the columns, the connections of the reinforcing bars to the arch, and a cross-section of the bridge. The arch bridge is 117 feet long with a depth of 26 feet.

Introduction

Puente Blanco is a spandrel concrete arch bridge which construction was completed in 1922 in Quebradillas, Puerto Rico. It is the only one of its class on the island. The original purpose of the bridge was to resist the load of railroad traffic [1]. The bridge crosses La Mala creek and is currently part of Panorámica Street, located near the north coast of Puerto Rico, as shown in Figure 3. Nowadays, the bridge is closed to automobile traffic due to the poor condition of the structural elements because of lack of maintenance and exposure to the coastal environment. If no action is taken, the bridge could eventually collapse.

The objective of this project is to present a design to structurally rehabilitate Puente Blanco, therefore preserving the historic structure. To accomplish this, the present condition of the bridge was inspected, and a computer model was developed to evaluate the structure using current standards.

This paper continues with the historical background of the bridge. Then, the findings of inspecting the bridge and field testing some of the elements are presented. This is followed by the analysis of the structure using a computer program, the design of the structural rehabilitation, and the cost estimate of implementing this design. Finally, the conclusions are presented.

Figure 3
Aerial view of bridge and surrounding area (Source: Google Maps)

Problem

Figure 4
Visual concept of the rehabilitated bridge

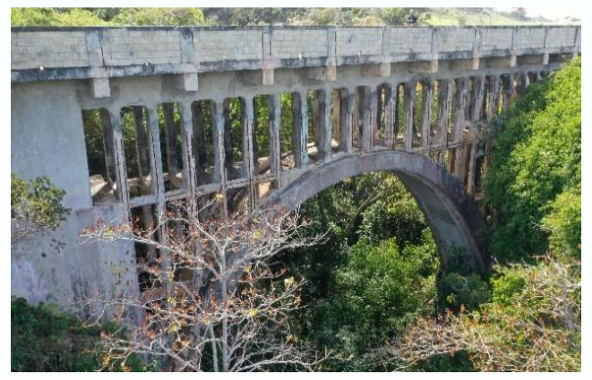

Figure 5
Visual concept of the rehabilitated bridge

Figure 6
Visual concept of the rehabilitated bridge

Figure 7
Visual concept of the rehabilitated bridge

Structural Analysis

For the structural analysis, a model was made using the computer program ETABS, as shown in Figure 9, with the main objective of comparing results and determining the appropriate use that could extend the useful life of the bridge. The following data was used in this analysis:

Figure 8
Windsor probe test

- Load combination and load factors in accordance with AASHTO [7].
- Live load of 85 psf, in accordance with the bridge being used by pedestrians and cyclists [7].
- Spectrum data for seismic analysis according to ATC Hazards by Location website.
- Soil type D - Stiff Soil (assumed).
- Dimensions of the beam, column, and arch elements according to their original condition.
- Compressive strength of concrete of 3,000 psi in the beams constructed for the 1985 renovation (assumed).
- Compressive strength of concrete of 5,500 psi in original columns and beams.
- Strength of Twisted Reinforcing Bars a yield strength of 50 ksi [8].

Results

Referring to Figure 10, as a result of the analysis, it was identified that the columns on the axes marked with a blue circle, require 4.75 in2 of additional reinforcement. Similarly, columns on axes not marked with blue circle, require 1.92 in2 of additional reinforcement.

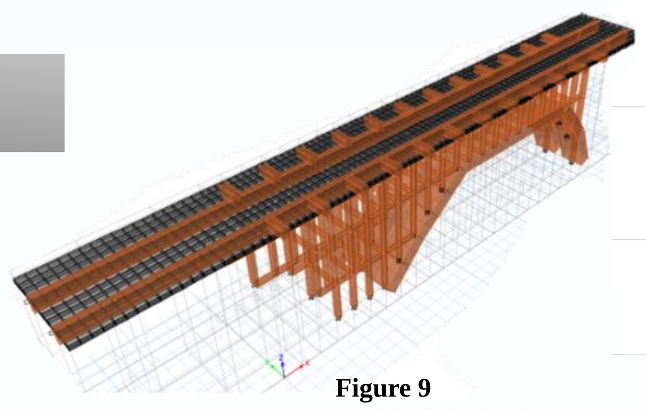

Figure 9
Computer model of the bridge

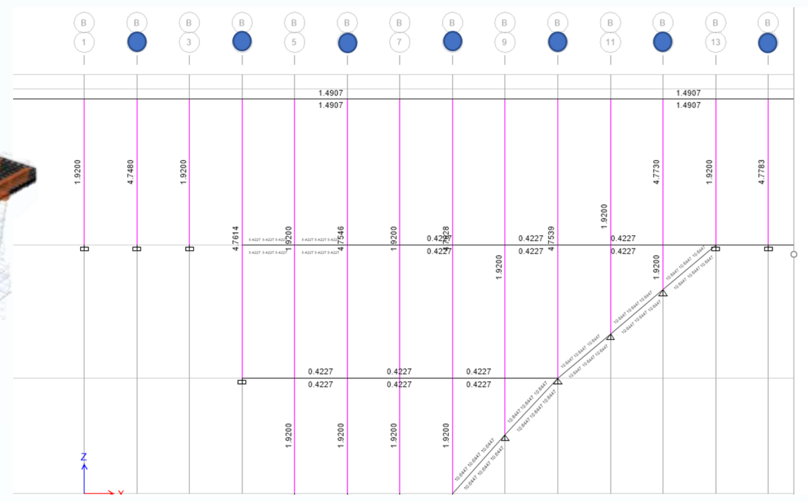

Figure 10
Structural model results with pedestrian

Rehabilitation Design

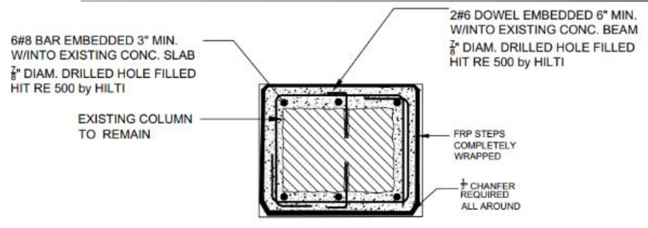

Figure 11
Column retrofit detail

Carbon fiber application

To retrofit the arches, girders, and columns, the installation of double carbon fiber is recommended, as shown in Figure 11. The addition of the fiber system is designed to provide the necessary additional reinforcement to the bridge. For its application, weak concrete and other loose particles must be removed and cracks must be repaired using epoxy injections.

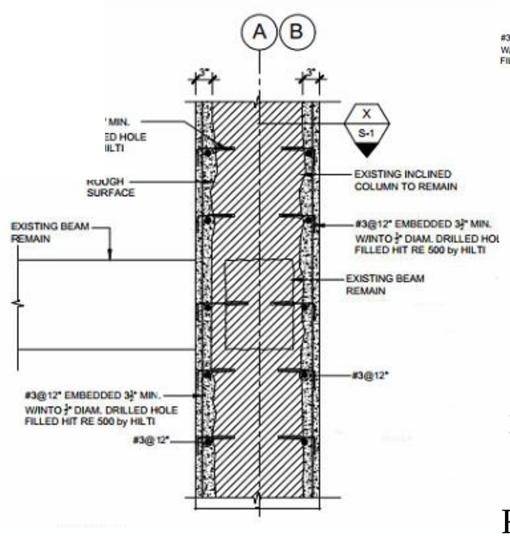

Figure 12
Column retrofit detail the lateral existing connection

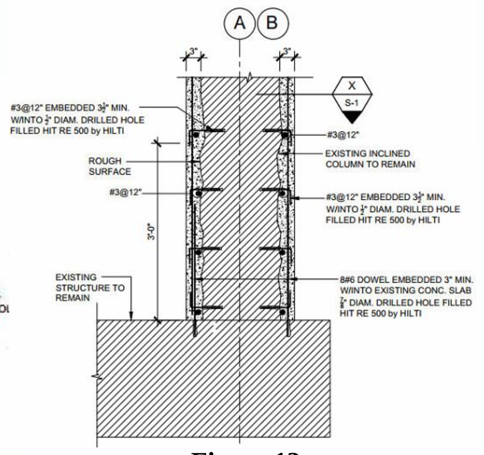

Figure 13
Lateral section of column retrofit detail

Inhibitor Application

For effective protection of Puente Blanco against the coastal environment, the application of high-tech corrosion inhibitors is recommended. This additive should be applied to the arches, beams, columns, and slabs.

Conclusions

Table 1 presents the cost estimate of performing the rehabilitation of the historic elements of the bridge as designed. As part of the work, removal of all loose concrete is required, so a partial demolition item is included. Also included is the new reinforcement to be replaced to support the loads presented. The highest figure in the cost estimate is the installation of the innovative carbon fiber system. It can be seen that all the work comes to about $3.8 million.

DESCRIPTION	TOTAL
Construction management	$ 265,200.00
Environmental control, health, and safety	$ 17,700.00
Preconstruction task	$ 40,366.00
Damage repairs	$ 1,687,295.80
Design/design management	$ 85,000.00
FRP Systems	$ 2,095,361.80
Miscellaneous	$ 838,144.72
TOTAL	**$ 3,771,651.24**

Table 1
Bridge rehabilitation cost estimate

Figure 14
Visual concept of the rehabilitated bridge

Puente Blanco is a historic concrete structure with severe damage and at risk of collapsing. Although it has been closed to automobiles, the structure is still in use and appreciated by pedestrian and cyclists. If the preservation of this structure is desired, action must be taken sooner than later. Figure 14 shows a visual concept of the final design, contemplating the proposed use of the bridge after it has been rehabilitated and is once again safe for visitors.

Acknowledgements

This project is dedicated to all the people who supported me at all times, Dr. Héctor Cruzado, all the staff at Graduate School and my co-workers at Engineered Advantage.

My greatest motivation who are my children Jeyli and José, my husband who was accompanying me on visits to the bridge and helping me with the children, my mother for support me and my father who in life always motivated me to study.

References

[1] L. Pumarada O'Neill, Los puentes históricos de Puerto Rico. Mayagüez: Centro De Investigación y Desarrollo Recinto de Mayagüez Universidad de Puerto Rico, 1991.National Park Service, (1984, February 23). National Register of Historic Places Inventory — Nomination Form: Puente Blanco. Available: https://npgallery.nps.gov/AssetDetail/NRIS/84003126

[2] National Park Service, (1984, February 23). National Register of Historic Places Inventory — Nomination Form: Puente Blanco. Available: https://npgallery.nps.gov/AssetDetail/NRIS/84003126

[3] "Engineering News Record; A Consolidation of Engineering News and Engineering Record." McGraw Hill Company Inc., New York, 1922, July-December.

[4] Cámara de Representantes de Puerto Rico, 1998, September 10. "Informe de la investigación Ordenada por la resolución de la Cámara 209", Available: http://www.tucamarapr.org/dnncamara/Documents/Measures/b8d8b6b4-4abd-4044-881e-510a00c0b815.pdf, May 30, 2017.

[5] ACI Committee 364, "Guide for evaluation of concrete structures prior to rehabilitation". Detroit, Mich.: American Concrete Institute, 1993.

[6] "Standard Test Method for Penetration Resistance of Hardened Concrete ASTM-C803 - 2018 edition".

[7] R. M. Barker and J. A. Puckett, Design of highway bridges: An LRFD approach. Hoboken: Wiley, 2013.

[8] A. Newman, "Structural renovation of buildings: methods, details, and design examples". New York: McGraw-Hill, 2001.