Structural Evaluation and Rehabilitation Design of Puente Blanco in Quebradillas

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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.*

Key terms *– historic bridge, steel reinforcement replacement*

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 (figure 1). 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.

Figure 1
Aerial view of bridge and surrounding area (Source: Google Maps)

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.

HISTORICAL BACKGROUND

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 [2] is shown in figure 2.

Figure 2
Original condition of the bridge

A copy of the original bridge plan was obtained, from an old magazine article (figure 3) [3]. 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 and 26 feet deep.

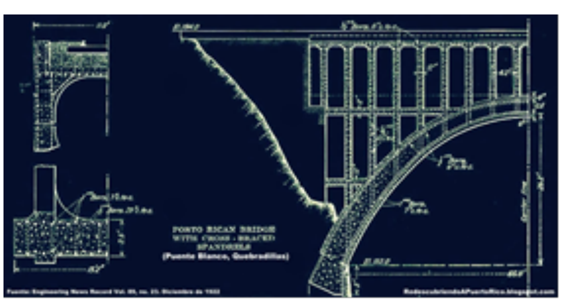

Figure 3
Structural blueprints

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 (figure 4). In 2008, the Department of Transportation and Public Works (DTOP) closed the bridge to vehicular traffic [4].

Figure 4
Bridge in its present condition

FIELD INSPECTION AND TESTING

From March through May 2022, visits were made to the bridge to inspect it and collect data. The surroundings of the bridge are of mixed use, as there are recreational, commercial, and residential areas. During the inspection visits, it was observed that, although the bridge continues to be closed to automobiles, it is used for recreational purposes by hikers and cyclists.

Measurements were taken of some elements of the bridge structure to subsequently make as-built drawings of the structure. The dimensions shown in Figure 5 were not found in the plans, they were measured on site.

Figure 5
Interior of bridge

Figure 6
View of north side of the bridge

It was noticed that the north side of the bridge, which is closest to the coast, is more deteriorated than the south side. The north side of the bridge has advanced stages of rebar corrosion, concrete cracking, and concrete spalling (figure 6). Meanwhile, the elements on the south side are not as deteriorated (figure 7).

Figure 7
View of south side of the bridge

As an example of the conditions found in the north side of the bridge, figure 8 shows contrast of the current condition of one of the columns with a red line indicating its original 16-in depth. It is estimated that this column has lost approximately 20 percent of its gross sectional area.

Figure 8
Example of north side column

Figure 9 shows the present condition underneath the bridge. It can be seen that some of the rebar of the arch has been exposed due to corrosion on the north side of the bridge.

Figure 9
The inferior side of the arch

In accordance with the Handbook of Nondestructive Testing of Concrete, the bridge was subjected to nondestructive testing for compressive strength [5]. A Windsor probe test was conducted on the bridge in accordance with ASTM C803 [6]. This is a special gun that inserts the probe into the concrete and the depth of penetration can be approximately related to the strength of the actual concrete. Three nondestructive tests were taken on a column on the north side (figure 10). This test required that the concrete not be plastered to obtain accurate results. The tests suggest that the concrete has a compressive strength of 5,500 psi.

Figure 10
Windsor probe test

STRUCTURAL ANALYSIS

For the structural analysis, a model was made using the computer program ETABS, as shown in figure 11, 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:

- Load combination and load factors in accordance with AASHTO [7].
- Live load of 85 psf, in accordance to 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].

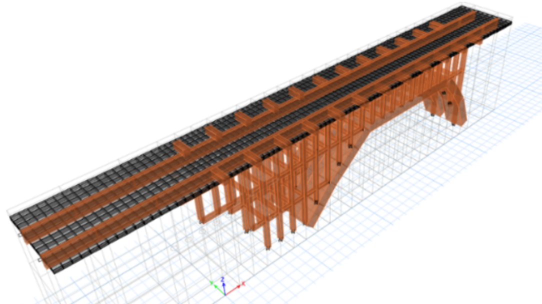

Figure 11
Computer model of the bridge

Figure 12 shows that, as a result of the analysis, it was identified that the columns on the axes marked with a blue circle, require 4.75 in^2 of additional reinforcement. Similarly, columns on axes not marked with blue circle, require 1.92 in^2 of additional reinforcement.

Rehabilitation Design

This section recommends strategies to repair the concrete focusing on restoring its structural strength, appearance, and durability.

Replacement of Reinforcement

The results of the structural analysis require increasing the ductility in the columns. To solve this, the installation of six No. 8 bars on the columns, as shown in figures 13 and 14.

For the beams that connect the north and south side columns, where loss of reinforcement was observed, four no. 8 with stirrups at 12 inches are required. Meanwhile, for damage beams that connect columns on the same side (north or south) of the bridge, the installation of four No. 6 rods with hoops every 6" is recommended.

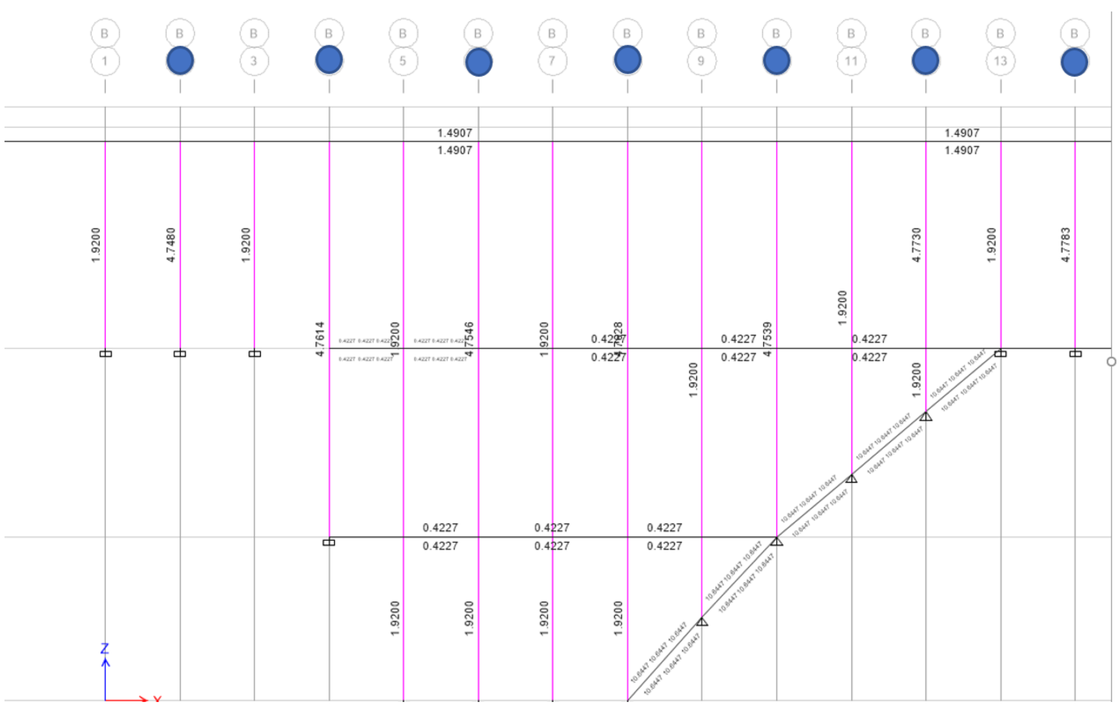

Figure 12
Structural model results with pedestrian and cyclist loads

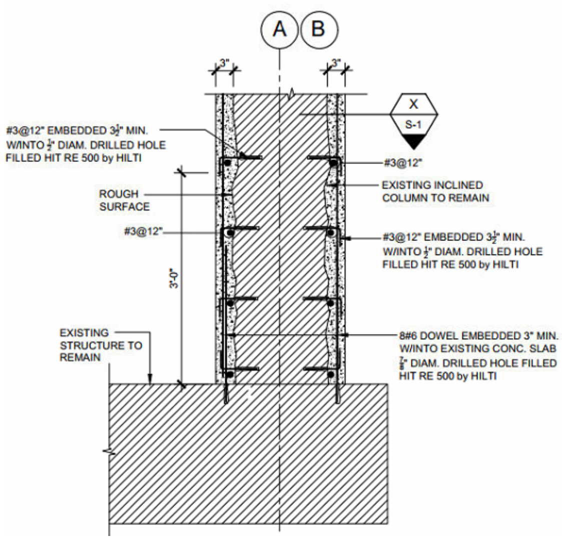

Figure 13
Lateral section of column retrofit detail

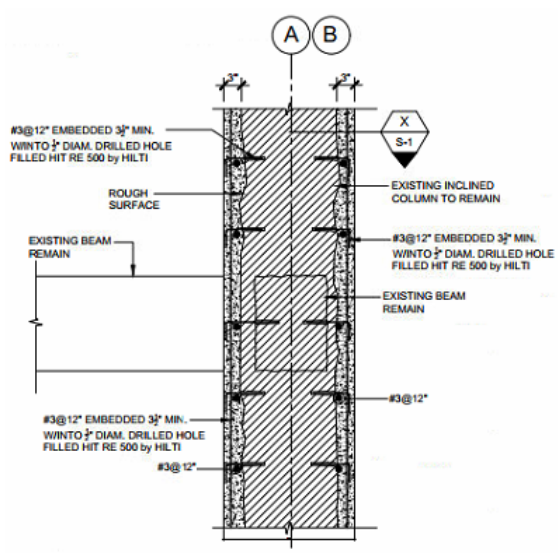

Figure 14
Column retrofit detail the lateral existing connection

Carbon Fiber Application

To retrofit the arches, girders, and columns, the installation of double carbon fiber is recommended, as shown in figure 15. 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.

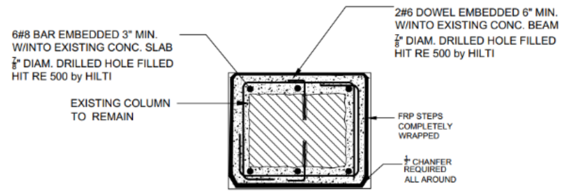

Figure 15
Column retrofit detail

The structural detail in figure 15 shows the installation of hoops to the existing concrete. This type of installation will be required for all elements requiring rebar replacement.

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.

Cost Estimate

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.

Table 1
Bridge rehabilitation cost estimate

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**

CONCLUSIONS

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 16 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.

Figure 16
Visual concept of the rehabilitated bridge

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