Structural Assessment of ASSHTO Girder Bridge Overpass after Traffic Impact to Exterior Girder

Juan Rubén Collazo Cariño
Master of Engineering in Civil Engineering
Dr. Manuel Coll Borgo
Civil & Environmental Engineering Department
Polytechnic University of Puerto Rico

Abstract *– Bridges are essential structural components to a country to connect important cities, villages to develop the economic and social of the people. The objective of the investigation was to evaluate the bridge located in overpass under normal conditions and the immediate solution was to close the traffic lane next to the exterior girder and install a temporary concrete barrier to avoid traffic in the area affected due to the impact received in exterior girder. The evaluation of the bridge was made for inventory rating and operating rating in each girder. The bending moment and shear force was computed for inventory rating and operating rating. The bottom bending stress was made for inventory rating only. The rating calculations mentioned were realized under conditions and traffic lane closed with the temporary concrete barrier to be compared which girders were affected with loads redistribution.*

Key Terms *– AASTHO Girder Bridge Overpass, Loads Redistribution**,** Rating Factors**,** Structural Assessment*.

INTRODUCTION

Bridges are a structural edification designed and built with the main objective to provide transportation system over physical obstacle. The physical obstacle which is known as underpass, it could be human-made such as highways, rail lines, and canals or natural such as water courses and ravines. Civic populations see the bridge as a link between neighborhoods and a way to provide fire and police protection and access to hospitals. In business community the bridge is seen as opening up markets and expanding commerce.

A bridge is an important element in transportation system for three reasons: strength, benefit/cost analysis, and safety. Strength is always a foremost consideration to prevent deterioration or failure in the future once the bridge is in service. Benefit/Cost Analysis considers the costs of the design limit states required by the codes, detailing, construction, materials, workmanship, government permissions associated with the benefit usage of the structure. Safety is the state of condition to protect life of the public who transit through bridge.

The structural design of the bridges are divided in superstructures elements and substructures elements. The structural assessment was focused on superstructures elements in which will be described in the problem definition. The superstructure elements comprise all components of a bridge above the supports such as parapet, wearing surface, structural concrete deck and prestressed concrete girders.

Parapet is a concrete barrier placed on the outside face of the bridges and the middle of the bridges. The wearing surface is a portion of the bridges deck cross section in which resists traffic wear. In some instances, the wearing surface is made of bituminous material installed on bridges, while in some other cases it is an integral part of bridges concrete deck. The structural concrete deck is the physical extension of the roadway across the obstruction to be bridged. The main function of the structural concrete deck is to distribute loads transversely throughout the cross section of the bridges.

Prestressed concrete girders are reinforced concrete in which internal stresses have been introduced to reduce potential tensile stresses in the concrete resulting from loads [1]. This procedure overcomes the natural weakness in tension which the concrete cannot handle. To overcome the natural weakness in tension which the concrete cannot handle, tendons generally of high tensile steel cable or rods are used to provide a clamping load which produces a compressive stress that balances the tensile stress that the concrete compression does not withstand due to experience bending load. Furthermore, these girders are known as primary members who distribute loads longitudinally and are usually designed principally to withstand flexure and shear.

Bridge evaluations are performed for varied purposes using different live load models and evaluation criteria. Evaluation live load models are comprised of the design live load rating, legal loads rating, and permit loads rating. The structural assessment was looked at design live load rating. Design load rating is a first-level assessment of bridges based on the HL-93 loading and LRFD design standards, using dimensions and properties of the bridge in its present as-inspected condition [2]. It is a measure of performance of existing bridges to current LRFD bridge design standards. Under this check, bridges are screened for the strength limit state at the LFRD design level of reliability. The rating also considers all applicable LRFD serviceability limit state.

Rating Factor is defined as an analysis of a structure to compute the maximum allowable loads that can be carried across the bridges. This rating analysis is divided in inventory rating and operating rating. These ratings were applied to assess each girder. Bridges that pass the design load check greater than one would have satisfactory load rating of acceptance [3] [4].

Inventory Rating corresponds to the customary design level of capacity which can safely utilize a bridge for an indefinite period of time. This rating reflects the existing bridge and material conditions with regard corrosion, loss of section and other deficiencies [3] [4].

Operating Rating describes the maximum permissible live load to which the structure may be subjected. The use of bridge by unlimited number of heavier vehicles would exceed capacity and is not permitted [3] [4].

DESIGN CRITERIA

The following design criteria were applied for structural assessment:

- "AASHTO LRFD Bridge Design Specifications" Fifth Edition would be the underlying for the design of the bridges [5].
- The dimension of the parapet was designed according to Design Manual of Puerto Rico Highways and Transportation Authority [6]. It utilized a load of 0.40 kip/ft for purpose of structural design calculations.
- Future Wearing Surface specific weight was 0.14 kip/ft^3 with a thickness of 2 inches for purpose of structural design calculation and structural evaluation. The future wearing surface utilized was bituminous concrete.
- Structural Concrete Deck and Integral Concrete Surface were designed according to design guideline 304 known as Design Criteria of Bridge Deck of Rico Highways and Transportation Authority for structural design calculation and structural evaluation [7]. The structural thickness was 8 inches by establishing the location of the bridge outside coastal area delimited by Puerto Rico Department of Natural and Environmental Resources. Integral Concrete Surface thickness was 1.5 inches. Ultimate Concrete Compression Strength utilized for purpose of structural analysis 4 ksi.
- Concrete Compression utilized for AASTHO Prestressed Concrete Girders were designed according to design guideline 301 known as Criteria for Prestressed Concrete of Rico Highways and Transportation Authority [7]. Transfer Concrete Compression Strength for purpose of structural evaluation was 4 ksi. Ultimate Concrete Compression Strength for purpose of structural evaluation was 5 ksi.
- High Strength Steel Cables utilized for AASTHO Prestressed Concrete Girders

according to design guideline 303 known as AASTHO Prestressed Precast Girder Design of Rico Highways and Transportation Authority [7]. The steel cables utilized were grade 270 low-relaxations in which means the ultimate strength of the cable was 270 ksi . The modulus of elasticity utilized for purpose of design was 28,500 ksi. The nominal diameter of the steel cables was 0.5 inches with effective area of 0.167 in^2. These steel cables were designed in straight lines.

- Vehicular Live Loads utilized for purpose of structural design calculation and structural evaluation was HL-93 according to design guideline 300 known as Design Loads for Bridges of Rico Highways and Transportation Authority [7].

STRUCTURAL DESIGN CALCULATION & STRUCTURAL ASSESSMENT CRITERIA

The following design calculations and structural assessment criteria were applied for structural assessment:

- The computer program performed for structural assessment was made in CSI Bridge developed by Computers & Structures, Inc. This program modeled the bridge in three dimensions to get loads required for structural design calculations and structural evaluations.
- Structural Evaluation for the bridge was made by applying The Manual for Bridge Evaluation first edition of 2008. This manual indicated the equation and loads rating utilized for the evaluation of the girders.

PROBLEM DEFINITION

The target line of the structural assessment was to find out the effects of loads redistribution in bridges with AASTHO girders located on traffic underpass once exterior girder receives an impact due to oversized transportation respect to the vertical clearance of the bridge affected to other girders as shown in Figure 1. The bridge selected was bridge number 995 located on road number 30 over road number 1 at kilometer 0.58 in the municipality of Caguas. The bridge was assessed according to design criteria previously explained and the structural dimensions and description are shown in Table 1. Figure 2 shows the bridge overview respect to interior girder spacing, exterior spacing, girders length, and amount of girder realized in CSI program. The external girders are labeled as left exterior girder one and right exterior girder thirteen. The internal girders are labeled from left to right and numbered from two to twelve. Figure 3 shows bridge traffic deck on bridge deck.

Figure 1
Bridge 897 - Cracking on Prestressed Concrete Girder Located P.R. 22 Eastbound Highway over P.R. 2 (Obtained from: Puerto Rico Highway and Transportation Authority)

Table 1
Structural Dimensions & Description

Width Deck (feet)	84.5
Exterior Girder Spacing center to center (feet)	6.5
Interior Girder Spacing center to center (feet)	3.25
Girder Length center to center (feet)	92
Amount of Girder	13
Amount of Parapets (two on the corner and one in the middle)	3
Amount of Traffic Lanes	6
Vertical Clearance (feet)	17
AASTHO Girder Type	IV

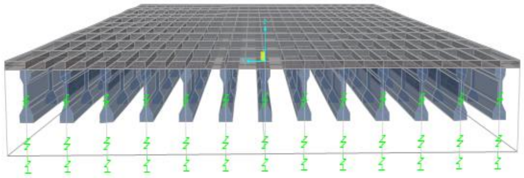

Figure 2
Bridge Overview

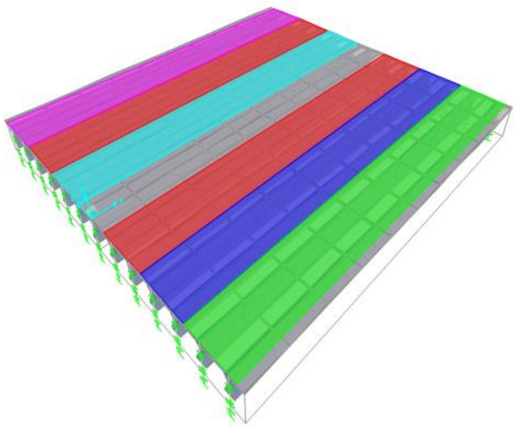

Figure 3
Six Traffic Lanes

The structural assessment started designing the girders under normal conditions with the information specified in the design criteria and structural dimensions and description. This information was utilized to get the bending moment and shear force from the structural program for parapet, future wearing surface, integral concrete surface, structural deck slab, and vehicular live load. The bending moment was used to compute the amount of steel cables, top compressive bending stress, bottom tensile bending stress and bending moment resistance. The top compressive bending stress and bottom tensile bending stress was checked with the stresses limit given by the code for purpose of design being stress limit greater than bending stresses calculated. The bending moment resistance was checked with factored bending moment given by the code for purpose of design being factored bending moment lower than resistance calculated. The shear force was used to compute the transverse reinforcement spacing. The shear force resistance was checked with factored shear force given by the code for purpose of design being factored bending moment lower than resistance calculated.

Once the girders were designed explained previously, each girder was rated by applying HL-93 design load for bottom tensile bending stress, bending moment, and shear force. These rating factors were obtained from Manual for Bridge Evaluation for inventory rating and operating rating. The bottom tensile bending stress was rated only for inventory rating. The bending moment and shear for were rated for inventory rating and operating rating.

The bottom tensile bending stress resistance for rating factor was computed based on effective prestress stress after all losses of the steel cables plus allowable bottom tensile stress given by the code. The bending moment resistance for rating factor was calculated based on the amount of steel cables in the design. The shear force for rating factor was calculated based on the transverse reinforcement spacing in the design.

After each girder was rated under normal conditions, it assumed an impact in the right exterior girder thirteen being the impact in the middle of the girder. The percent of section loss including the girder and structural deck slab respect to the length was 0.625 percent. The immediate solution was to close the traffic lane next to the right exterior girder thirteen and install a temporary concrete barrier to avoid traffic in the area affected. Furthermore, it found out the rating of the girders affected with this arrangement to be compared with the rating computed for normal girders. The load redistribution was assessed for dead loads and vehicular live load already explained in the design criteria. The temporary concrete barrier installed was computed and added to the parapet load values already calculated respect to normal girders. The vehicular live load was computed again with five traffic lanes as shown in Figure 4. The rating factors were calculated again to for bottom tensile bending stress, bending moment, and shear force. The rating factor for each case mentioned was made for each girder in terms ten points analysis selecting critical value of the ten points.

Finally, it compared the rating of each girder for both cases mentioned to find out the corresponding values varied.

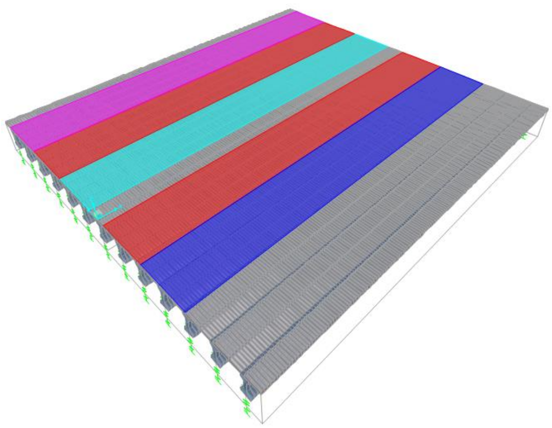

Figure 4
Five Traffic Lanes

PROBLEM DEVELOPMENT

This section contains the equations used to compute the rating factor for bottom tensile bending stress, bending moment, and shear force. Furthermore, it contains the rating load factors as shown in Table 2. The rating load factors for Service III were utilized for bottom tensile bending stress. The rating load factors for Strength I was utilized for bending moment and shear force.

Table 2
Limit States & Load Factors for Load Rating

Limit State	γ_{DC}	γ_{WS}	(γ_{LL})	
			Inventory	Operating
Service III	1	1	0.8	N/A
Strength I	1.25	1.50	1.75	1.35

Rating Factor Equation

$$RF = \frac{C - \gamma_{DC} * DC - \gamma_{DW} * DW}{\gamma_{LL} * LL} \quad (1)$$

Table 3
Rating Factor Capacity Variable & Description

Variable	Description
C	Capacity
γ_{DC}	LRFD load factor for structural component and attachment
γ_{WS}	LRFD load factor for wearing surface
γ_{LL}	Evaluation live load factor
DC	Dead load effect due to structural component and attachment (structural deck slab + concrete wearing surface + parapet)
DW	Dead load effect due to wearing surface
LL	Live load effect

The capacity was obtained by computing the effective prestress plus allowable bottom tensile stress given by the code. The effective tensile force and tensile eccentricity were computed previously for the design of the girder.

Effective Prestress Stress Equation

$$C_{EPS} = \frac{F_{pa}}{A_g} + \frac{F_{pa} * ecc_t}{S_b} \quad (2)$$

Allowable Bottom Tensile Stress Equation

$$C_{ABTS} = 0.19\sqrt{f_{c-girder}(ksi)} \quad (3)$$

Bottom Tensile Bending Stress Capacity Equation

$$C_{CE} = C_{EPS} + C_{ABTS} \quad (4)$$

Dead Load Bending Stress

$$f_{DC} = \frac{M_{SDS} + M_{cws}}{S_b} + \frac{M_P}{S_{bc}} \quad (5)$$

Wearing Surface Bending Stress

$$f_{WS} = \frac{M_{ws}}{S_{bc}} \quad (6)$$

Vehicular Live Load Stress

$$f_{VLL} = \frac{M_{VLL}}{S_{bc}} \quad (7)$$

Bottom Tensile Bending Stress Rating Factor Equation

$$RF_{BTBS} = \frac{C_{CE} - 1.25 * f_{DC} - 1.50 * f_{WS}}{0.8 * f_{VLL}} \quad (8)$$

Bending Moment Equation for Inventory

$$RF_{BMI} = \frac{ØM_n - 1.25 * M_{DC} - 1.50 * M_{WS}}{1.75 * M_{VLL}} \quad (9)$$

Bending Moment Equation for Operating

$$RF_{BMO} = \frac{ØM_n - 1.25 * M_{DC} - 1.50 * M_{WS}}{1.75 * M_{VLL}} \quad (10)$$

Shear Force Equation for Inventory

$$RF_{SFI} = \frac{ØV_n - 1.25 * V_{DC} - 1.50 * V_{WS}}{1.75 * V_{VLL}} \quad (11)$$

Shear Force Equation for Operating

$$RF_{SFO} = \frac{ØV_n - 1.25 * V_{DC} - 1.50 * V_{WS}}{1.35 * V_{VLL}} \quad (12)$$

Table 4
Variable & Description for AASTHO Girder, Bottom Tensile Bending Stress, Bending Moment, & Shear Force

Variable	Description
A_g	AASTHO cross sectional area
S_b	AASTHO bottom section modulus
S_{bc}	AASTHO bottom composite section modulus
F_{pa}	Effective tensile force from girder center of gravity
ecc_t	Tensile eccentricity from girder center of gravity
$f_{c\text{-}girder}$	Concrete compression stress
f_{DC}	Bottom tensile dead load effect due to structural component and attachment
f_{WS}	Bottom tensile dead load effect due to wearing surface
f_{VLL}	Bottom tensile vehicular live load
M_{SDS}	Structural deck slab load bending moment
M_{CWS}	Concrete wearing surface bending moment
M_P	Parapet Bending Moment
M_{DC}	$M_{SDS} + M_{CWS} + M_P$
M_{WS}	Wearing surface bending moment
M_{VLL}	Vehicular live load bending moment
$ØM_n$	Bending Moment Resistance
V_{SDS}	Structural deck slab load shear force
V_{CWS}	Concrete wearing surface shear force
V_P	Parapet shear force
V_{DC}	$V_{SDS} + V_{CWS} + V_P$
V_{WS}	Wearing surface shear force
V_{VLL}	Vehicular live load shear force
$ØV_n$	Shear force Resistance

CALCULATIONS & ANALYSIS OF RESULTS

The following tables contain the calculations for the girders and the rating factors explained in the problem definition and problem development.

Table 5
Description & Values for AASTHO Girder

Description	Value
A_g (in^2)	789
S_b (in^3)	10544
S_{bc} (in^3)	16242.096
F_{pa} (kip)	1010.185
ecc_t (in)	16.467
Amount of Steel Cables	38
Transverse Reinforcement Spacing (#rebar @ inches)	#5@8
C_{CE} (ksi)	3.283
$ØM_n$ (kip-ft)	7077.563
$ØV_n$ (kip)	391.095

Table 5 contains the properties utilized for AASTHO girder and the values calculated explained in the problem definition and problem development.

Table 6
Bending Moment Inventory Rating

Girder	Normal Girder	Right Exterior Girder Thirteen Broken
1	1.949	N/A
2	2.201	N/A
3	2.358	N/A
4	2.484	N/A
5	2.779	N/A
6	3.215	2.969
7	3.605	3.142
8	3.215	2.920
9	2.779	2.711
10	2.484	N/A
11	2.358	N/A
12	2.201	N/A
13	1.949	N/A

Table 7
Bending Moment Operating Rating

Girder	Normal Girder	Right Exterior Girder Thirteen Broken
1	2.507	N/A
2	2.830	N/A
3	3.032	N/A
4	3.193	N/A
5	3.572	N/A
6	4.131	3.815
7	4.633	4.037
8	4.131	3.751
9	3.572	3.482
10	3.193	N/A
11	3.032	N/A
12	2.830	N/A
13	2.507	N/A

Table 6 and Table 7 show the bending moment inventory rating and bending moment operating rating in each girder indicating the critical value of flexion at 46 feet. The values located in respective tables for right exterior girder thirteen broken were the values lower than the normal girders.

Table 8
Shear Force Inventory Rating

Girder	Normal Girder	Right Exterior Girder Thirteen Broken
1	2.822	N/A
2	3.213	N/A
3	3.298	N/A
4	3.338	N/A
5	3.470	N/A
6	4.621	4.110
7	5.943	4.410
8	4.621	3.938
9	3.470	3.202
10	3.338	N/A
11	3.298	N/A
12	3.213	N/A
13	2.822	N/A

Table 9
Shear Force Operating Rating

Girder	Normal Girder	Right Exterior Girder Thirteen Broken
1	3.658	N/A
2	4.166	N/A
3	4.276	N/A
4	4.327	N/A
5	4.499	N/A
6	5.991	5.329
7	7.706	5.718
8	5.991	5.106
9	4.499	4.151
10	4.327	N/A
11	4.276	N/A
12	4.166	N/A
13	3.658	N/A

Table 8 and Table 9 show the shear force inventory rating and shear force operating rating in each girder indicating the critical value next to the supports. . The values located in respective tables for right exterior girder thirteen broken were the values lower than the normal girders.

Table 10
Bottom Bending Stress Inventory Rating

Girder	Normal Girder	Right Exterior Girder Thirteen Broken
1	1.412	N/A
2	1.666	N/A
3	1.825	N/A
4	1.909	N/A
5	2.118	N/A
6	2.420	2.226
7	2.696	2.329
8	2.420	2.152
9	2.118	1.961
10	1.909	N/A
11	1.825	N/A
12	1.666	N/A
13	1.412	N/A

Table 10 shows the bottom bending stress inventory rating in each girder indicating the critical value of flexion at 46 feet. The values located in respective tables for right exterior girder thirteen broken were the values lower than the normal girders.

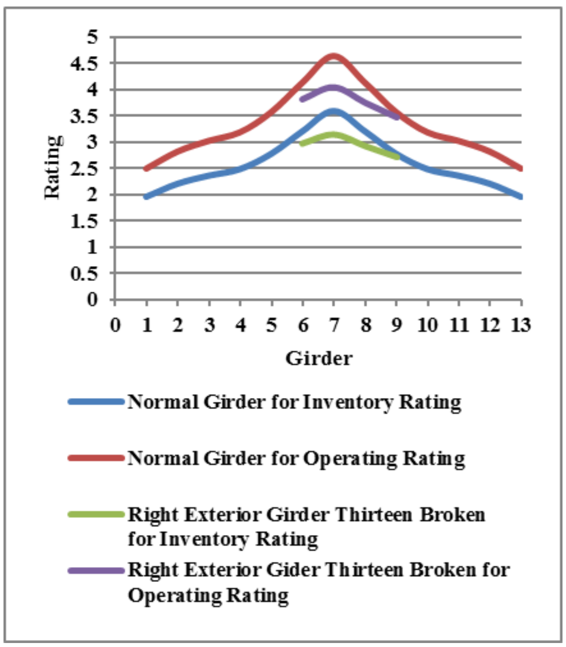

Figure 5
Bending Moment vs. Girders Graph

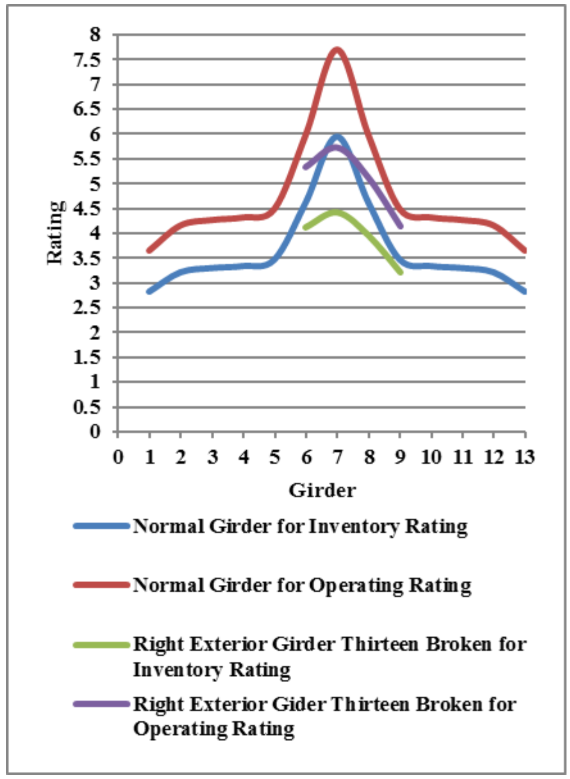

Figure 6
Shear Force vs. Girders Graph

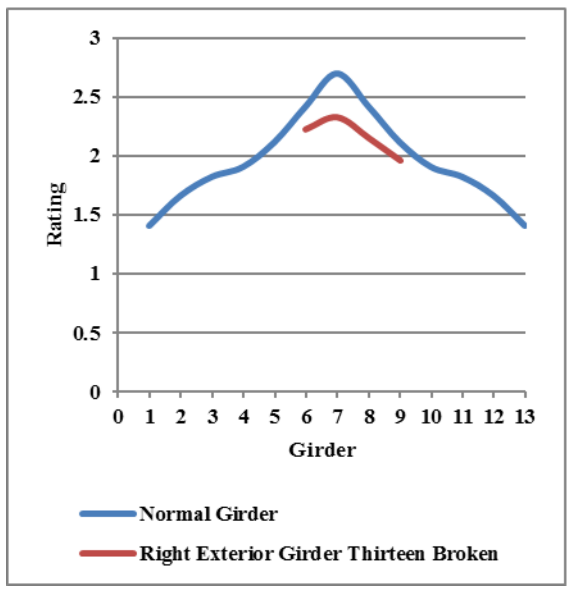

Figure 7
Bottom Bending Stress vs. Girders Graph

CONCLUSIONS

In concluded that the inventory rating and operating rating increased from the exterior girder to interior girder under normal condition with six lanes and no exterior girders impacted. These variations were based on the exterior girders received more vehicular live load than interior girder due to the distribution load factor established by the design code for bending moment and shear force and the lanes design.

The lowest inventory rating value for bending moment was left exterior girder one and the right exterior girder thirteen with a value of 1.949. The highest inventory rating value for bending moment was interior girder seven with a value of 3.605. The lowest operating rating value for bending moment was left exterior girder one and the right exterior girder thirteen with a value of 2.507. The highest operating rating value for bending moment was interior girder seven with a value of 4.633. The lowest inventory rating value for shear force was left exterior girder one and the right exterior girder thirteen with a value of 2.822. The highest inventory value for shear force was interior girder seven with a value of 5.943. The lowest operating rating value for shear force was left exterior girder one and the right exterior girder thirteen with a value of 3.658. The highest operating value for shear force was interior girder seven with a value of 7.706. The lowest operating rating value for bottom bending stress was left exterior girder one and the right exterior girder thirteen with a value of 1.412. The highest operating value for bottom bending stress was interior girder seven with a value of 2.696.

The structural assessment made for right exterior girder thirteen impacted with the closure of the traffic lane next to the right exterior girder thirteen and install a temporary concrete barrier found out the inventory rating and operating rating decreased respect to the bending moment, shear force, and bottom bending stress. The girders that suffered the reduction of the rating were from the interior girder six to the interior girder nine. The reasons of the inventory rating and operating rating were due to the installation of the temporary concrete barrier and rearrangement of the lanes locating next to the middle parapet. The temporary concrete parapet value was added to the parapet value previously computed under normal conditions.

The lowest inventory rating value for bending moment was the interior girder nine with a value of 2.711. The highest inventory rating value for bending moment was interior girder seven with a value of 3.142. The lowest operating rating value for bending moment was interior girder nine with a value of 3.482. The highest operating rating value for bending moment was interior girder seven with a value of 4.037. The lowest inventory rating value for shear force was interior girder nine with a value of 3.202. The highest inventory value for shear force was interior girder seven with a value of 4.410.The lowest operating rating value for shear force was interior girder nine with a value of 4.151. The highest operating value for shear force was interior girder seven with a value of 5.718. The lowest operating rating value for bottom bending stress was interior girder nine with a value of 1.961. The highest operating value for bottom bending stress was interior girder seven with a value of 1.961.

Finally, it demonstrated that the closure of the lane affected the right exterior girder thirteen and the installation of the temporary concrete barrier was an effective solution at short-term. The rating factor at inventory was greater than one, then the bridge meets the current design requirements and further action is necessary. The design load rating at operating was greater than one, then the bridge has adequate capacity and is not necessary to be rated to determine whether load posting is required for the bridge.

RECOMMENDATIONS

The long-term solution could be made in two ways. The first solution would be sealing the cracks injecting epoxy to avoid the corrosion to the steel strands and reinforce the girder with fiber reinforced polymer to increase the strength respect to vehicular live load due to dead load cannot be recovered although it installs hydraulic jack to girder affect to eliminate the deflection caused by the redistribution of the loads. The fiber reinforced polymer will act as additional reinforcement to compensate the damaged tendons. The second solution would be the removal of the girders affected based on the structural assessment and the field inspection and install new girders. Comparing the second solution with the first solution, the second solution would require removal of the structural concrete deck and the parapet. In contrast of the both solutions, it has to coordinate the movement of the lanes and install barriers to protect the workers during the rehabilitation as much overpass as underpass.

REFERENCES

[1] Nawy, E.G., *Prestressed Concrete: A Fundamental Approach*, Prentice-Hall, New Jersey, 2010, pp. 1-5.

[2] American Association of State Highway and Transportation Officials, *The Manual for Bridge Evaluation*, 1st Edition, 2008, pp.6-1- 6-32.

[3] Zhao, J.,J., and Tonias, D., E., *Bridge Engineering Design Rehabilitation, and Maintenance of Modern Highway Bridges*, McGraw-Hill, New York, 2012, pp. 13, 317-321.

[4] Khan, M., A., Bridge and Highway Structure Rehabilitation and Repair, McGraw-Hill, New York, 2010 pp. 187-188.

[5] American Association of State Highway and Transportation Officials, *AASTHO LRFD Bridge Design Specifications*, 5th Edition, 2010, pp. 5-1 – 5-243.

[6] Puerto Rico Highways and Transportation Authority, Design Manuals, 1979, pp. 6-1.

[7] Puerto Rico Highways and Transportation Authority, Design Guidelines, 2009.