Load Carrying Capacity Condition for Post-1945 Bridges in PR with Distinctive Characteristics using NBIS Load Rating Database

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Abstract *— Particular relevant characteristics and project delivery are sometimes in discussion. Historic and aesthetics relevance of a structure has key requirements to enter a consideration process for undertaking effects that delay the process for the completion of highway projects. Sometimes the tools used to address the preservation issues are based in historical documents that points out the relevance of the structure and aesthetics. Engineering judgement using mathematical calculations tools and evaluation concepts address the safety concerns in bridge performance. The structures in question are bridges whom historical, design or aesthetics type background are relevance, load rating database will be used as a terminology tool to indicate the structurally load carrying capacity of the bridges in question.*

Key Terms *— Bridge Load Rating, Historic Bridges, Load rating, Posting.*

INTRODUCTION

Historic preservation has been always a public concern. The federal government passed the Antiquities Act in 1906 to provide the protection of historic and prehistoric remains and monuments on federal lands. The concern is actually more challenging because today's transportation network has to address issues 0of deteriorated infrastructure, overcrowded roadways, and severely restricted public sector budgets and speed up highway major projects that over 10 to 15 years. Lately, bridge preservation has taken a major importance and is set as a national goal to maintain bridges in a state of good condition consistent with load-carrying capacity. The main objective of this article is to identify and apply the tools to evaluate the current state of the historically significant bridges.

The Advisory Council on Historic Preservation (ACHP) has issued a Program Comment [1] at the request of the U.S. Department of Transportation Federal Highway Administration (FHWA) to relieve all federal agencies from Section 106 requirement to consider the effects of undertakings on common bridges and culverts constructed of concrete or steel after 1945. According to the requirements for obtaining a Program Comment, the FHWA formally requested the ACHP to comment on the effects of a category of undertakings in lieu of conducting individual reviews for effects to certain types of bridges commonly constructed in the United States of America.

A total of 1,906 post 1945 bridges were evaluated by the State Historic Preservation Office (SHPO) and Puerto Rico Highway Authority (PRHTA) staffs to the development of the Program Comment Issued for Streamlining Section 106 Review for Affecting Post-1945 and Steel Bridges included in the PRHTA Bridge Program.

The cooperative evaluation consultation toe e address the program comment required the following considerations:

a) The bridge is listed in or has previously been determined eligible for the National Register of Historic Places or its located adjacent to or within a National Register listed or eligible historic district such as parkway, historic road, or canal.
b) The bridge in question is or includes spans of the following types: arch bridges, truss bridges, bridges with movable spans, suspension bridges, cable-stayed bridges, or covered bridges.
c) The bridges were identified in a list created through the process detailed below as having

exceptional significance associated with an event or individual, or being very early or particularly important example of its type in a State or the nation, having distinctive engineering or architectural features that depart from standard designs, such as an aesthetic railing or balustrade, includes spans of exceptional length or complexity, or displaying other elements that were engineered to respond to a unique environmental context.

Of the 1,906 bridges evaluated, 1,368 were constructed from 1970 to present and 538 bridges were constructed from 1945 to 1969. As result 44 bridges from 1970 to present required additional SHPO consultation under Section 106, 31 bridges were included under the Criteria A, 9 bridges under Criteria B and 4 bridges under Criteria C. The rest of the bridges evaluated (1,324) do not require additional SHPO consultation under Section 106.

For the bridges evaluated from 1945-1969, 29 bridges require additional SHPO consultation under Section 106, 19 bridges were included under Criteria A, 7 bridges under Criteria B and 3 bridges under Criteria C, a total of 73 bridges in total through 1945 to present. The rest of the bridges evaluated (509) not required additional SHPO consultation under Section 106. The objective of this project was to identify the bridges with historical significance and to use the tools from routine inspections and structural evaluations, to describe the condition of these structures. These evaluation tools will serve the PRHTA to determine which bridges are in need of rehabilitation or preservation, and also to continually monitor the condition of the inventory of bridges with historical value.

BRIDGE INSPECTION HISTORY

On December 15, 1967, the Silver Bridge [2] an eye bar link suspension bridge carrying Route 35 between Point Pleasant West Virginia and Gallipolis, Ohio spanning the Ohio River collapsed sending 46 people to their death. This tragedy put bridge safety into national focus. Congressional hearings took place and through testimony it was found that neither states, authorities, counties nor municipalities who were owners of bridges had programs in place for structural inspections and there were no national standards on how they should be accomplished or at what frequency.

In 1968 Congress passed the Federal Highway Act: US code Title 23 Section 151 that set forth the requirement to establish National Bridge Inspection Standards (NBIS) [2].

The NBIS required all public bridges on the Federal-aid highway system to have a Structure Inventory and Appraisal (SIA) conducted by 1972 and data reported to the FHWA. In 1978 the NBIS was extended to include all public bridges whether or not on the Federal-aid highway system.

Important aspects of the NBIS were:

1. All states must perform periodic inspections of bridges greater than 20 feet in span on at least a biennial basis.
2. Data collection was standardized and must be reported to FHWA.
3. Qualifications for inspection personnel were defined.
4. Training programs were developed and implemented.
5. The Bridge Replacement Program (BRP) was established to provide funding for bridge replacement on the system.

Further bridge collapses have modified and evolved inspection standards procedures like guidelines on fracture critical bridges and underwater inspections due to scouring in bridge foundations. This guidelines and standards are outlined in the Recording and Coding Guide for the Structure Inventory and Appraisal of the Nation’s Bridges [3]; in this report the items 58 through 62 indicate the general condition ratings that are used to describe the existing, in-place bridge as compared to the as-built condition. Evaluation is for the materials related, physical condition of the deck, superstructure, and substructure components of a bridge. The following general condition ratings are used as a guide in evaluating items 58, 59, 60 that represent the structural components of the bridges in a visual inspection:

Table 1
Point Sizes and Type Styles

Code	Description	
N	NOT APPLICABLE	
9	EXCELLENT CONDITION	
8	VERY GOOD CONDITION	No problems noted
7	GOOD CONDITION	Some minor problems
6	SATISFACTORY CONDITION	Structural elements show some minor deterioration
5	FAIR CONDITION	All primary structural elements are sound but may have minor section loss, cracking, spalling or scour
4	POOR CONDITION	Advanced section loss, deterioration, spalling or scour
3	SERIOUS CONDITION	Loss of section, deterioration, spalling or scour has seriously affected primary structural components. Local failures are possible. Fatigue cracks in steel or shear cracks in in concrete may be present.
2	CRITICAL CONDITION	Advanced deterioration of primary structural elements. Fatigue cracks in steel or shear cracks in concrete may be present or scour may have removed substructure support. Unless closely monitored it may be necessary to close the bridge until corrective action is taken
1	IMMINENT FAILURE	Major deterioration or section loss
0	FAILED CONDITION	Out of service-beyond corrective action

LOAD RATING EVOLUTION

The history of highway bridge design codification [4], including provisions applicable to the live load, had their origin in a joint effort by designers of highway bridges and railroad bridges, working together on the Special Committee on Specifications for Bridge Design and Construction. Their Final Report on Specifications for Design and Construction of Steel Highway Bridge Superstructure was presented at the spring meeting of ASCE (American Society of Civil Engineering) on April 9, 1924.

Then in 1931 1st edition of AASHO's Standard Specification for Highway Design [4], contained a representation of a truck and/or a group of trucks for use in design. The basic design truck was a single unit weighing up to 40 kips, which was known as the H20 truck, in the early 1940's the truck was extended into a tractor-semi-trailer combination, known 1944 Standard Specification as the simply HS-20 truck. The H denotes highway, the S denotes semitrailer, and the 20 is the weight of the tractor in tons. This vehicle weighed a total of 72 kips and was comprised of a single steering axle weighing 8 kips and two axles that supported the semitrailer each weighing 32 kips. The axle spacing on the semi-trailer could vary from 14 to 30 ft., and it was assumed 14 ft. between the steering axle and the adjacent axle that formed part of the tractor. These loads are shown in Figure 1. The HS20 truck was and idealization and did not represent one particular truck, although it was clearly indicative of the group of vehicles commonly known as 3-S2s, the common 18 wheeler.

The first edition also instituted the lane load to be used in specific circumstances. For the HS20 loading, this consisted of a uniform load of 0.64 k/ft. and a moving concentrated load or loads. A concentrated load of 26 kip was used for shear and for reaction, two 18-kip concentrated loads were used for negative moment at a support and were positioned in two adjacent spans, and a single 18-kip load was used for all other moment calculations. Another group of load models commonly used are HS-30-44.

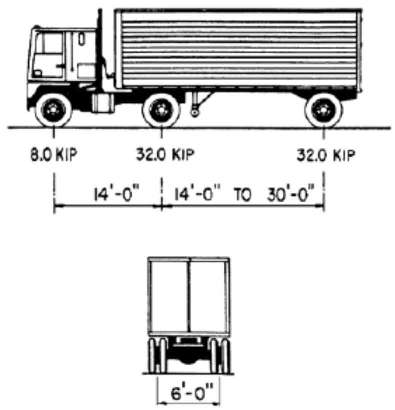

Figure 1
HS20 Truck Loading

Through time in the interstate period and post-interstate era live load design models were periodically change until the HL93 loading in the AASHTO LRFD Specification is implemented. And not forget to mention the commonly 18 wheeler or 3S2 in the latter half of the interstate era.

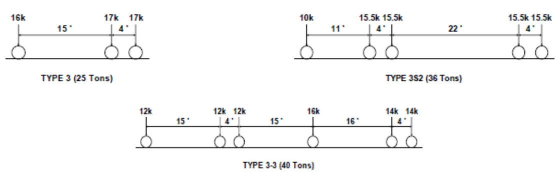

Figure 2
AASHTO Rating Vehicles

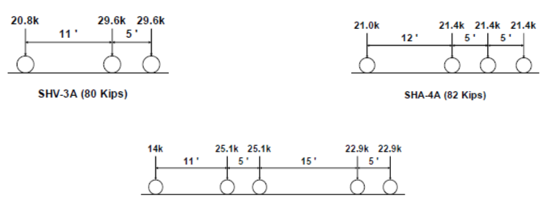

Figure 3
NTWAC Special Hauling Vehicles

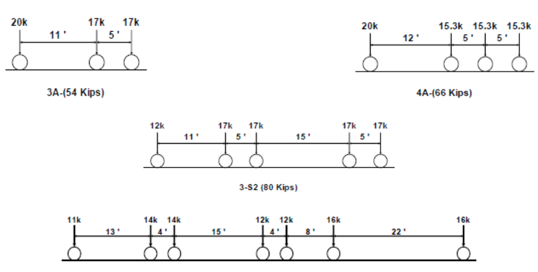

Figure 4
AASHTO Rating Vehicles

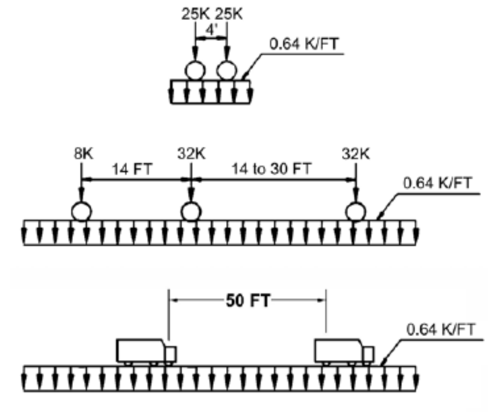

Figure 5
HL93 Design Load (subset)

Then, the load rating can be applied as a key element for structural integrity of historic bridges for it conservation using the same key elements that meets the Quality Bridges Inspection Program for NBIS Requirements. Because a large number of historical bridges still in-service for the public and are included in the NHS (National Highway System), load rate each bridge and keep it's posting monitoring compliance it could be a useful tool, not only for safety features or QC/QA inspections compliance, for structural integrity/historical preservation either.

BRIDGE LOAD RATING

Bridge load rating involves performing a series of calculations synonymous with bridge design calculations in order to determine if a bridge is safe for public traffic loads. Load rating is the safe live load carrying capacity of a highway structure and it is usually expressed as the Rating Factor (RF) or in terms of tonnage for a particular vehicle. The RF equation is as follows:

$$RF = \frac{C - A_1 * D}{A_2 * L * (1 + I)} \qquad (1)$$

Where;

A_1 =Factor for dead loads

A_2 =Factor for live load

C =Capacity of the bridge

D =Dead load effect

I =Impact factor (Dynamic Load Allowance)

L =Live load effect

The load factor rating (LFR) is the method currently being used in bridge load rating. The Load and Resistance Factor Rating (LRFR) is a new guide manual adopted by AASHTO, in Puerto Rico the existing structures can be load rated with LFR or LRFR. The AASHTO Manual for Bridge Evaluation [5] shall be used for guidance on load rating of existing structures. The two commonly used categories are Inventory Rating and Operating Rating. The Inventory Rating is the load, including loads in multiple lanes that can safely utilize the bridge for an indefinite period of time. The Operating Rating is the maximum permissible live load that can be placed on the bridge. This load rating also includes the same load in multiple lanes. Allowing unlimited usage at the Operating Rating level will reduce the life of the bridge.

All structures must be load rated for the following vehicles [6]:

- LFR Method at Inventory and Operating Levels:
  - AASHTO HS20 Live Load Model.
  - AASHTO HS30 Live Load Model.
- LRFR Method:
  - At Design Level
    - AASHTO HL93 Live Load Model at design level rating.
  - At Legal Load Level:
    - Single Unit Truck-SHV-3A.
    - Truck with semi haul-SHV-3S2.
    - Truck with haul and semi haul-Exclusion vehicles FM 3-S2-2 with axle weights multiplied by (110/105.5) in order to upscale the weight to 110 kips.

When rating with LRFR Method the Live Load factor for legal or Permit Level rating shall be 1.35 in all cases. The analysis and rating assumptions are to be reviewed as part of each scheduled inspection. A statement shall be placed in the structural analysis section of the inspection report stating that the rating has been reviewed. If it determined that a reduction in capacity may take place due to one or more changed conditions, the posting may be lowered using engineering judgment.

AASHTO LRFR Load Rating Process

1) Design Load Rating (HL-93)

2) Design Load Rating (Posting)

3) Permit Load Rating (Overweight trucks)

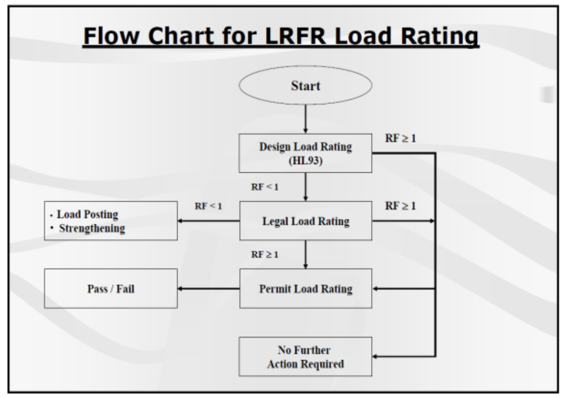

Figure 6
LRFR Flow Chart Process

All posting decisions must be based on the results of a current field inspection and LRFR load rating. Bridges which cannot carry the maximum weight for the vehicles described in the legal load rating criteria are posted with one of the standard signs showing the bridge capacity for the governing

- Legal load ratings are used to identify vulnerable bridges for further evaluations or bridge strengthening.
- Bridges with RF<1.0 for legal loads should be posted.
- Posting analysis translates rating factors into posting loads. Provides a more rational assessment of bridges safe load capacity.

POSTING ANALYSIS

When for any legal truck the RF is between 0.3 and 1.0, then the following equation should be used to establish the LRFR posting load [5] for that vehicle type:

MBE Eq. (6A.8.3-1)

$$PostingLoad = \frac{W}{0.7}\left[(RF) - 0.3\right] \qquad (2)$$

Where:

RF = Legal load rating factor

W = Weight of rating vehicle (Tons)

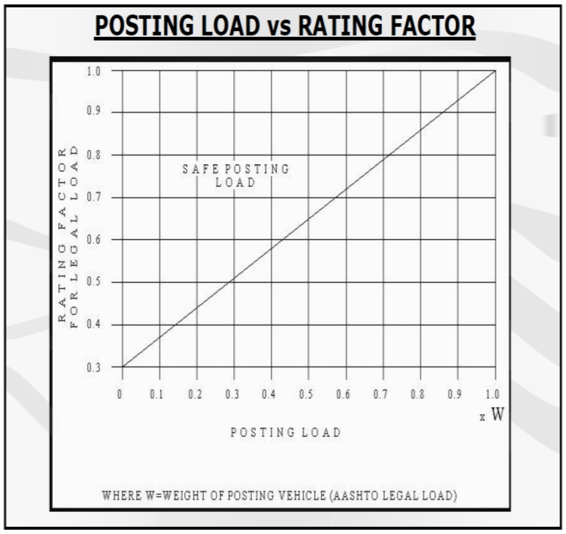

Figure 7
Posting Load Vs Rating Factor Chart

The Load Rating Engineer shall make a recommendation as to the need for posting and the weight limit for posting should posting be required. When the RF for any vehicle type falls below 0.3, then a recommendation should be made to not allow that particular vehicle type on the bridge. Other vehicle types with RF>0.3 may continue to use the bridge. Bridges that are determined not capable of carrying 3 tons shall be closed. Below are examples of bridge posting assessment for two type of bridge, in Puerto Rico it is recommended that the load rating factor below 1, the bridge should be posted with MUTCD [7] (Manual of Uniform Traffic Control Devices) Sign R12-5, Bridge 770 is a concrete tee beam structure constructed in 1948, Bridge 1883 is a concrete box beam constructed in 1989, BR 770 rating factor is below 1 for each vehicle type, not the same for BR 1883, so the bridge has to be posted with the appropriated operating/tonnage, as with BR 1883 RF>1 so posting is not necessary.

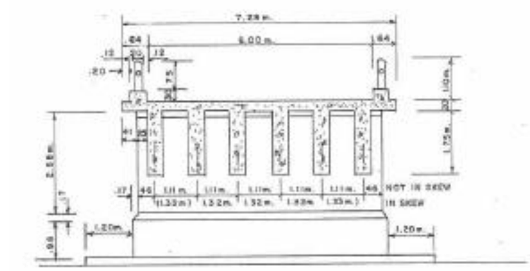

Figure 8
BR-770 Front Views

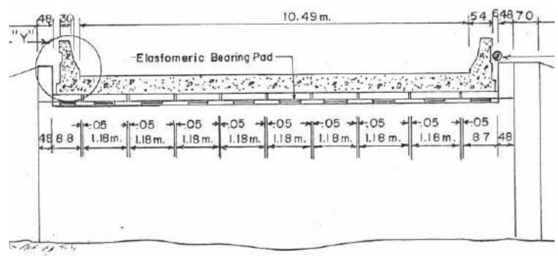

Figure 9
BR-1883 Front Views

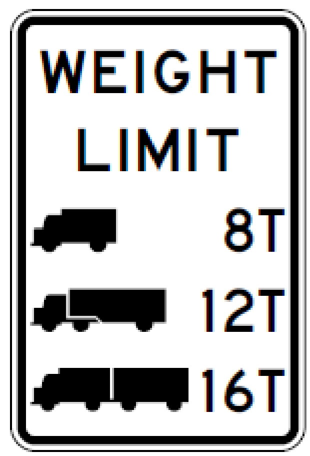

Figure 10
MUTCD R12-5

Table 2
Bridges 770 & 1883 Posting Assessment

Vehicle Type	Rating Factor	TONS	POST-TONS
(770)			
SHV-3A	0.64	25	25
SHV-3S2	0.76	41.8	40
FM3-S2-2	0.92	50.6	50
(1883)			
SHV-	1.68	40	40

3A			
SHV-3S2	1.73	55	55
FM3-S2-2	2.53	55	55

RESULTS

Taking into reference the *Recording Guide for the Structure Inventory and Appraisal of the Nation's Bridge's (The NBIS Coding Guide),* that apply to PR, as mentioned before in the introduction, the outcome of the Program Comment applied to Puerto Rico a total of 73 bridges needs consultation under section 106. The 73 bridges were evaluated with premise Item 70 of the NBIS Coding Guide title Bridge Posting. The NBIS require the posting of load limits only if the maximum legal load configuration in the State exceeds the load permitted under the operating rating. If the load capacity at the operating rating is such that posting is required, this item shall be coded 4 or less. If no posting is required at the operating rating, this item shall be coded 5.

Table 3
Bridge Posting

Code	Relationship of Operating Rating to Maximum Legal Load
5	Equal to or above legal loads
4	0.1 – 9.9% below
3	10.0 – 19.9% below
2	20.0 – 29.9% below
1	30.0 – 39.9% below
0	> 39.9% below

This item evaluates the load capacity of a bridge in comparison to the State legal load; the bridge posting is based and related to the operating rating.

Next table shows the estimate relationship between Operating Rating to State Loads, the outcomes of these relationships may conclude in the widening, rehabilitation or closing of the bridge for reparation purposes.

The Chart Figure 11 indicate the radiography of the load carrying-capacity of the 73 bridges from the Program Comment a 67% doesn't need posting and it said that the bridge structurally capable for operating service, and approximately 33% from those 73 bridges needs posting, also shows the relationship of operating rating to maximum legal load percentile quantities are display for each code mentioned in table 3 above.

Items 58,59,60,62 indicates the Condition Ratings, as mentioned in the introduction, this items are used as a general condition for classification of bridges below and above the structurally deficient criteria, the Chart Figure 12 the ratio of SD Bridges from the 73 scrutinized bridges using as a reference the minimum condition rating outlined in Table 1 (CDR), above or equal to 6 are 59%, equal to 5 are an 30% below or equal to 4 there is an 11%, bridges below 4 are considered SD, within that universe there are critical finding cases (CF) those below or equal to 3 (serious, critical and imminent failure conditions), a 25% (2 bridges) of the 73 bridges are Critical Finding, the critical finding criteria brings the situation of priority funding and budgeting to attend emergency and corrective action. Tonnage features shows feasible results, 55% (40 bridges) of sampling of 73 bridges are in compliance (above 55 tons) so no posting is required for this bridges and structure integrity can be upheld. The bridges of major concern are those below 36 tons, from this sampling just 19% (14 bridges), from an interval of 36@55 tons there is a result of 26 % (19 bridges), less than 5 tons in this sampling doesn't apply, the lesser load in this sampling is just one bridge of 11.88 tons.

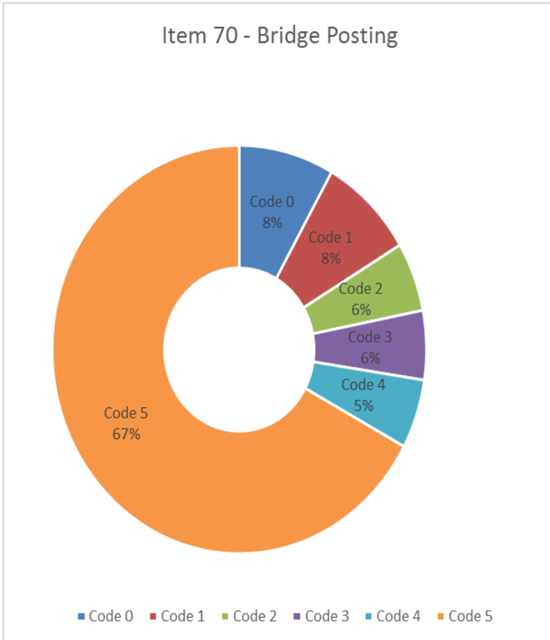

Figure 11
Item 70 Charts

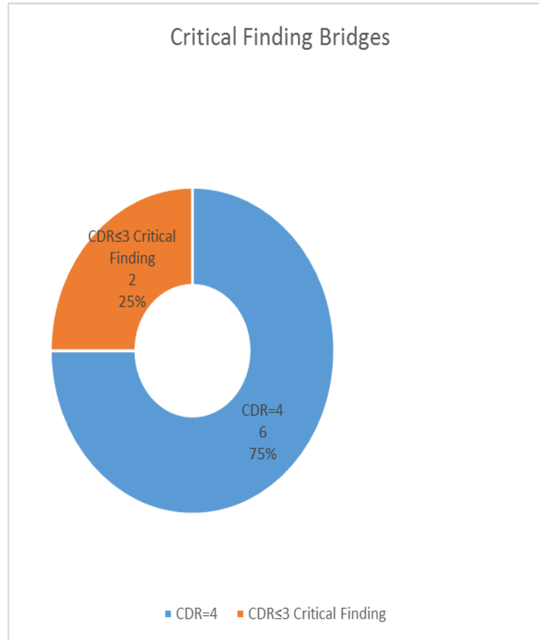

Figure 13
Critical Finding

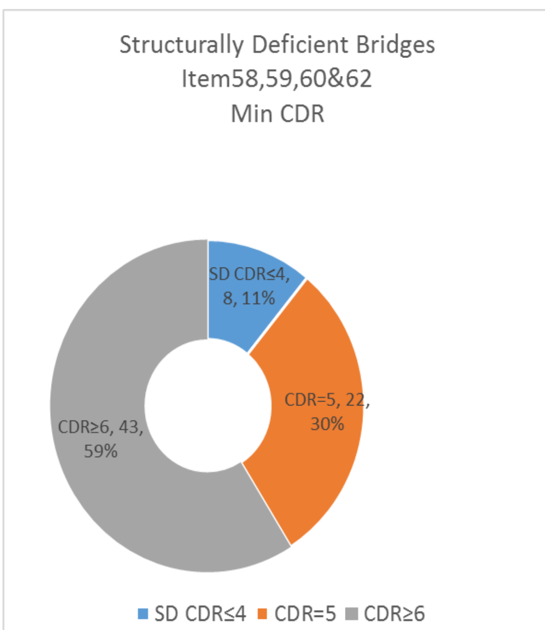

Figure 12
General Condition Rating Charts

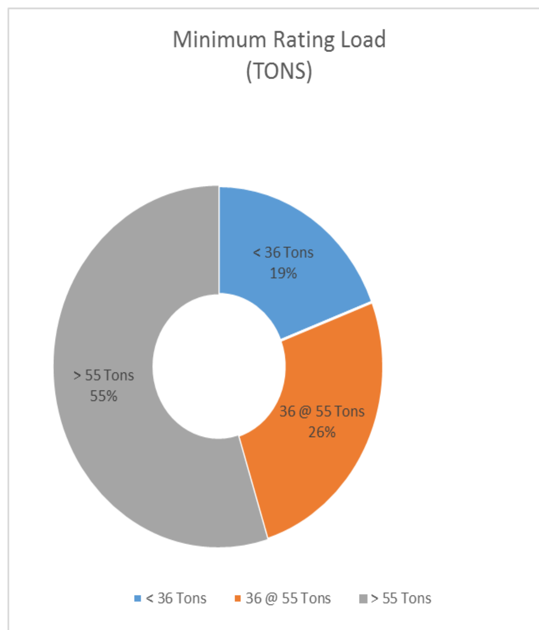

Figure 14
Tonnage Radiography

BRIDGE 753

The Bridge 753 over Roberto H. Todd Avenue is a structure supported on two continuous spans, built in 1960 and located in the roadway PR-25 km 1.5 in San Juan. This is an overview of before and after of the rehabilitation of the bridge.

Figure 15
BR-753 Elevation View

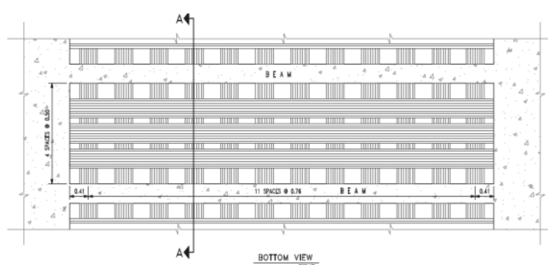

Figure 16
CFR BR-753 Top View

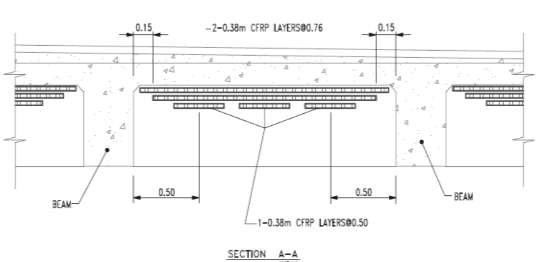

Figure 17
CFR BR-753 Front View

The bridge was in a stage 4 structural condition (poor) and shows deterioration or distresses that affect its structural capacity. Evidence **of** spalling or cracks near the bearings of the girders in the tension zone at the mid-span was observed. Excessive deflection or misalignment was noted in the underneath of the girders. Minimal vibrations were noted during the live load traffic at the time of inspection, visible diagonal or shear cracks were observed near the supports. No rehabilitation work has been performed to beams at the time of the bridge inspection. Detachment of various beams was observed at the joint of the beam with the abutment caps. The southwest detached beam is being supported by a temporary steel support and vertical cracks were observed at the beams flange. It is requested to maintain a structural integrity and load carrying capacity on bridges, you have the option of posting or strengthening like the bridge in questioning, bridge 753 is exceptionally important due that is carrying and important road with a high average daily traffic (ADT) in variable type vehicles that decision making for strengthening with fiber reinforced polymer materials was taking into account. A unidirectional high strength carbon with a fiber tensile strength of 720 ksi with a nominal thickness of 0.013 inches were apply to the bridge superstructure, after the strengthening (see figures 10 and 11) applied to the bridge with CRP (carbon reinforced polymer) the operating rating for a common type truck HS-30-44 is 1.65.

CONCLUSION

The sampling results prequalify bridges with particularly characteristics as historic, construction or otherwise to determine the procedure to preserve bridge structures. Bridge has been analyzed and load carrying capacity has been determined. Load rating process can be useful not only in the security structural integrity concerns, it could be considered as part of a strategic plan assessment for bridge preservation with an important historical/aesthetics background. The load rating and condition assessment of bridges of historical significance presented in this paper is a valuable tool for the preparation of a preservation and maintenance program for this structures. Structures identified with RF less than 1.0 and/or classified as structurally deficient can benefit from modern techniques for preservation, as the fiber reinforced polymer (FRP) presented herein. The PRHTA recommended next step is to develop a plan for preservation and maintenance of the historical significant structures and continue to use the load rating and condition evaluations to monitor the effectiveness of the plan through time.

Table 4
Priority Bridges for Rehab/Preservation from the Historic Bridge Program

Bridge	CR	RF	Road	Municipality
511	0 *	0.51	PR-647	Vega Alta
548	0 *	0.59	Local	Guayanilla
1371	4	0.55	PR-455	Camuy
1497	4	0.55	PR-826	Naranjito
2200	4	0.69	PR-250	Culebra
1772	4	1.31	PR-167	Bayamon
1819	4	1.56	PR-181	Trujillo Alto
667	4	28.2	PR-830	Bayamon

*CR is 0 because the bridge is not operating for safety reasons and has bridge beside it.

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[3] “Recording and Coding Guide for the Structure Inventory and Appraisal of the Nation’s Bridge”, Report No. FHWA-PD-96-001, December 1995.

[4] J. M. Kulicki, D. R. Mertz, “Evolution of Vehicular Live Load Models During the Interstate Design Era and Beyond”, *Transportation Research*, Circular No. E-C104, September 2006, pp.1-19

[5] AASHTO Manual for Bridge Evaluation 1st Edition, 2008, pp. 6-1 to 6-66.

[6] Bridge Safety Inspection Manual, Inventory and Inspection Requirements for Bridge, July 31 2014, Department of Transportation and Public Works / Puerto Rico Highway & Transportation Authority.

[7] Bridge Safety Inspection Manual, Inventory and Inspection Requirements for Bridge, July 31 2014, Department of Transportation and Public Works / Puerto Rico Highway & Transportation Authority.