PRHTA BRIDGE ASSESSMENT AND REMEDIATION STRATEGIES POST-HURRICANE MARIA

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Hurricane María caused serious disruption to Puerto Rico's transportation network, specifically its bridges. This paper describes the damages observed on the pre-screened bridges that required an additional in-depth structural assessment and discussions on proposed remediation measures. Damages include erosion, scouring and slope stability. A Detailed Damage Inspection Report (DDIR) for each bridge was prepared with observed bridge damages, proposed emergency and permanent bridge repair work and an opinion on probable cost per the Federal Highway Administration.

Bridge emergency and permanent repair work are in the order of magnitude of $10MM, with the emergency repair work determined to be $5.5MM, an amount that excludes temporary bridge construction work.

On September 20, 2017 Hurricane María made landfall in Yabucoa, Puerto Rico, as a Category 4 hurricane with maximum sustained winds of 155 mph. The hurricane center moved west-northwestward with winds and heavy rainfall widespread over the main island of Puerto Rico where catastrophic and flash floods were reported. The National Weather Service in San Juan preliminarily reported an estimated maximum rainfall between 30 to 37.9 inches in the southeast region of Puerto Rico and between 15 to 25 inches in the central region[1]. Although many stations were not able to report due to damage, the heavy rainfall raised the levels of many rivers to historical levels.

In the weeks following the impact of the storm, the Puerto Rico Highway and Transportation Authority (PRHTA) performed an initial bridge reconnaissance to provide emergency responders and government agencies up-to-date information about the existing conditions of the bridges within the network. From their initial assessment, approximately 200 bridges were identified as requiring in-depth structural assessment due to the damages reported post Hurricane María.

CMA Architects & Engineers LLC formed part of the team contracted by the PRHTA to perform in-depth structural assessments for sixty-seven (67) bridges throughout the island. A Detailed Damage Inspection Report (DDIR) for each bridge was prepared with observed bridge damages, proposed emergency bridge repairs and an opinion on probable cost per the Federal Highway Administration (FHWA). Furthermore, CMA aided PRHTA in providing the necessary information for the contractors to execute the emergency repairs in compliance with the local and federal permitting agencies.

Two teams from CMA consisting of at least three professionals from the fields of civil engineering, structural engineering and environmental sciences conducted the in-depth structural assessments and field data gathering for permit documentation. During each site visit, the damages observed were documented with photographs, sketches and measurements of damage extent. To assess the notable erosion and scour conditions, upstream and downstream measurements of the river bed were taken. The observation and data obtained were then compared with the latest available pre-hurricane PRHTA bridge inspection report where the pre-existing conditions and the National Bridge Inventory Rating were reported. The DDIR reported only damages to the bridges that corresponded to the hurricane event.

Damages Observed and Emergency Remediation

Damages registered for each bridge were classified as bridge emergency repairs and bridge permanent repairs. Bridge emergency repairs included work that was determined to be a safety hazard for the functionality and structural stability of the bridge based on the judgment of the assessment team. The damage descriptions corresponded to the observed state of damage: extensive, moderate, slight and no damage. Table 1 refers to the state of damage description classification.

Table 1. State of damage description

Damage Classification	Description
Slight	Small debris, no apparent damage to structural elements. Pre-existing condition were not aggravated due to major event
Moderate	Large amount of debris creating river stream blockage and minor footing exposure. Notable erosion on wingwalls and embankment.
Extensive	Potential damage or partial collapse of structural elements due to scouring, slope stability, potential risk to adjacency of nearby structures due to instability at embankment, safety barrier damage

Figure 1 presents the severity damage distribution for the sixty-seven bridges included in the DDIR to the PRHTA.

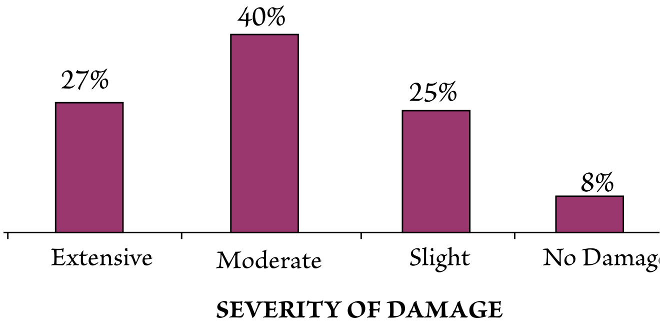


Fig. 1. Bridge severity damage distribution.

Bridge emergency and permanent repair work were on the order of magnitude of $10MM. The emergency repair work was determined to be $5.5MM. This amount excluded temporary bridge construction work.

The most common damages observed were: debris accumulation upstream, obstructing the flow of the river; river embankment erosion; scour at wingwall backfill; and erosion and scour around footing areas. In addition, damages were observed to the road pavement and safety barriers due to debris impact and overtopping. Partial collapse of roads and areas adjacent to the embankment and wingwalls were also observed. Pre-existing conditions related to erosion and scour were worsened when compared with the last PRHTA bridge report.

A summary of the damages observed and proposed emergency remediation measures are listed in Table 2.

Table 2. Summary of damages and proposed remediation.

Impacted Area	Damage Observed	Proposed Remediation
River Bed and Embankment	· Erosion and landslide	· Dumped or grouted riprap · Gabions or concrete gravity walls
Bridge Wingwall	· Erosion and scour at the backfill · Scour at wingwall footings · Collapsed wingwall	· Backfill with borrowed material · Grouted riprap · Reconstruction of wingwall with gabions or concrete gravity wall
Bridge Abutment and pier footings	· Exposed footings due to erosion · Scour at footings	· Pour flowable concrete beneath the footing · Protect the footing with grouted riprap
Bridge	· Debris accumulation	· Debris removal

Impacted Area: River Bed and Embankment

The river bed and embankment were impacted from the erosion and floating debris caused by the high velocity of the river flow. In the worst cases, adjacent roads or parking lots partially collapsed due to the failure of the embankment. No apparent damage was observed at embankments already protected by gabions or stone revetment.

To prevent further soil slope instability, the installation of riprap over a filter blanket was recommended. For steep slopes, grouted riprap was selected as the soil stabilization method. In cases were protection of an adjacent structure was required, the construction of a gabion gravity wall or a concrete gravity retaining wall as specified in the PRHTA standard drawings were specified.

Fig. 2. Upstream embankment landslide Bridge No. 879, Utuado PR

Impacted Area: Bridge Wingwalls

During the bridge assessments, it was observed that considerations are needed not only for the upstream embankment, but the downstream embankment as well. It was noted that the overtopping of the bridge roadway in addition to the debris blockage at the bridge underpass created a turbulent condition that caused instability on the downstream embankment. The turbulent flow infiltrated behind the bridge wingwalls resulting in erosion and scour. Similar damage occurred at bridges where the river bank had been diverted over time or had shifted from its original position due to previous major flood events.

Fig. 3. Downstream wingwall slope instability Bridge No. 446, San Sebastián P.R.

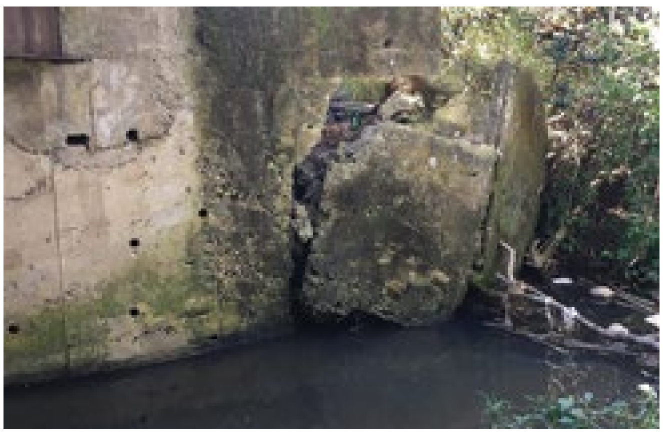


Fig. 4. Upstream partial wingwall collapsed Bridge No. 141, Cabo Rojo, PR

To prevent further erosion and instability behind the wingwalls, a deposit of borrowed fill material and the installation of dumped or grouted riprap were considered.

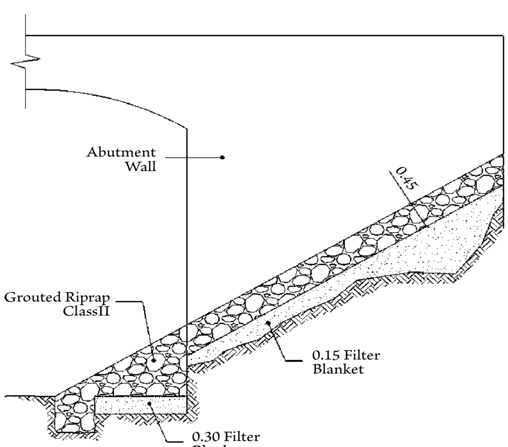


Fig. 5. Typical section of grouted riprap over filter blanket for embankment repair.

Impacted Area: Bridge Abutment and Pier Footings

The erosion and scour at the abutment and pier footings was one of the observed damages of major concern due to the potential risk of bridge load capacity reduction and instability. After detailed evaluations, measurements and analysis, no apparent load capacity reduction was determined at the assessed bridges. Nonetheless, the critical condition was remediated to avoid incremental degradation due to future flood events.

Fig. 6. Scour and exposed footing and piles at interior pier of Bridge No. 2086, Sabana Grande PR

To address the scouring conditions of the bridge abutment and pier footings, it was determined to specify a flowable concrete pour with a 28-day concrete compressive strength of 500 psi beneath the footing. If the scour extent was measured to be beyond one meter in depth below the existing footing, a filter fabric was placed around the piles to avoid negative friction loads. Negative friction reduces the vertical load carrying capacity of the bridge. A grouted riprap was then installed above the exposed footing with a minimum thickness of 0.45meters with a slope of 2H:1V measured from the river stream line for additional protection.

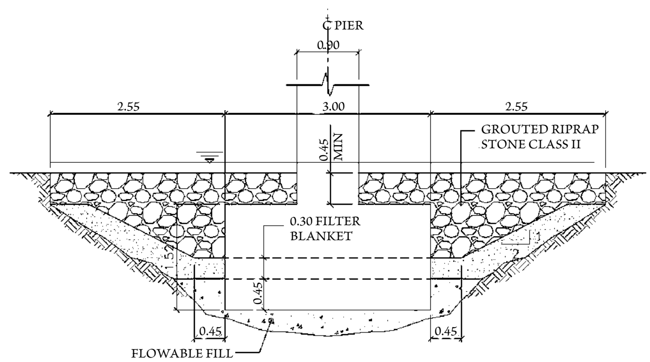


Fig. 7. Typical section for scour and exposed footing repair with flowable fill and grouted riprap.

During the assessment, it was noted that various bridges that had previous scouring damage reports were observed without apparent scouring. The area was further evaluated by probing a measuring rod into the loose sediments, and it was determined that loose sediments from the river flow during the storm had accumulated at the previously observed scoured location, thus aggradation occurred. It was concluded that the loose sediments deposited during the floor event did not have the corresponding properties to be able to safely disregard scouring conditions at the bridge supports. A grout-injection stability procedure and a riprap grouted detail were considered for the emergency stabilization of the footing.

Impacted Area: Debris Accumulation and Damage due to Impact

The debris accumulation at the upstream side of the bridge was typically observed at all the bridges assessed. The major concern was in low elevation multi-cell box culvert type bridges where the debris accumulated at the upstream thus creating an obstruction to the water flow. This obstruction generated excessive lateral loading at the bridge and in cases creating turbulent flow and instability at the downstream embankment due to river overflow. Damages to the safety barriers at bridges where debris totally obstructed the water flow were observed, thus requiring emergency repairs for safe access. In addition, the asphalt wearing surface on some of the bridges was damaged requiring new asphalt to be placed.

Fig. 8. Typical debris at low elevation multi-cell box culvert type bridges.

The immediate removal of debris was recommended to avoid potential bridge failure due to excessive lateral load. The accumulation of debris at the center piers impeded the detailed inspection at these areas. Future inspections were recommended to assess footing exposure and scour effects

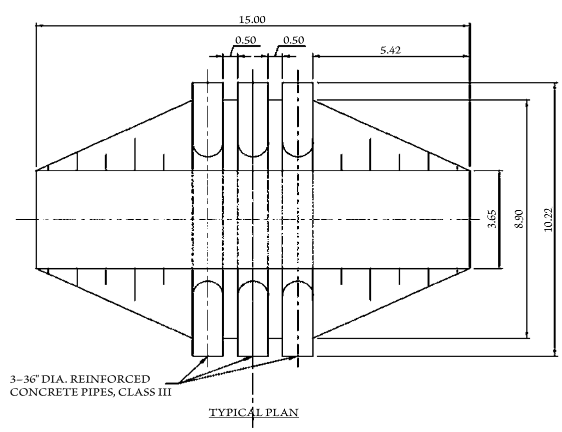
Fig. 9. Damage at approach pavement on Bridge No. 256, San Sebastian PR

Environmental Consideration for Remediation

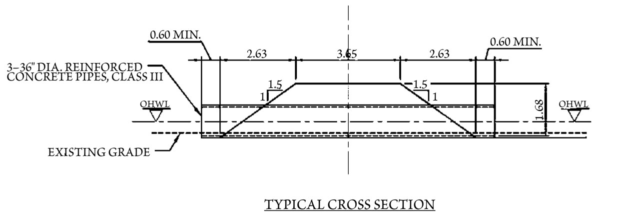
Emergency repair and permanent work to mitigate damages were required to comply with local and federal environmental laws and regulations. An environmental permit from the US Army Corp of Engineers was required for all the work to be performed in the water bodies. For historic structures and roads, a permit from the State Historic Preservation Officer was required. In addition, the documentation related to endangered species or habitats was submitted to the Fish and Wildlife Service.

The permitting documentation required the location and description of the situation and justification for emergency repairs. Photos and description of the damages observed were included along with: sketches showing the proposed work, the Ordinary High Water Level (OHWL), means of entry and exit from the water body and means for dewatering. The areas and volume of impacts were estimated and indicated in the plan drawings.

Most of the work required the removal of debris, removal of loose sediments, and the installation of dumped or grouted riprap inside the limits of OHWL. During the construction phase, soil erosion and sedimentation control measures needed to be implemented to protect the surrounding ecosystem. Furthermore, the installation of silt fences and floating sediment barriers and the construction of earth berms with temporary fill for the transportation of light vehicles and equipment over the river stream were mandated.



(a) Plan



(b) Section

Fig. 10. Typical earth berm plan (a) and section (b) for the temporary bridge access.

Cost of environmental means of emergency and permanent reports were included in the DDIR submitted.

Conclusion

The flooding event caused by the passing of Hurricane Maria through Puerto Rico significantly impacted the PRHTA bridge infrastructure. Damages to the embankments, wingwalls and bridge footings and piers due to erosion, scouring and debris were extensive. The nature of the damages reveal various vulnerabilities at the bridge downstream embankment and structural elements due to overtopping and turbulent flow that cause instability on those components of the bridge that will require special attention during future bridge assessments and new bridge designs. The proposed repair methods included in the DDIR can be developed further for potential revision to the PRHTA standard drawings.

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Notes

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