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Hazard Assessment and Mitigation using Remote Monitoring of Scouring and Bed Degradation at the Pasig-Potrero River

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Abstract

The 1991 Mt. Pinatubo eruption caused up to 6 cu. km. of lahar deposition on adjacent rivers, including the Pasig Potrero River. Since then, the river morphology has been continuously changing. Due to the large river flow and size of the lahar grains comprising the riverbed, the river became prone to bank erosion and bed degradation. One of the structures on the river affected by the hazard is the Pasig Potrero Bridge. Major rainfall events from 2018 to 2021 caused massive sediment transport resulting in a decrease in riverbed elevation of approximately 20m at the bridge location. Several pier foundations have been exposed, warranting the need for both immediate and long-term solutions to protect the bridge.

This paper presents the methodology for monitoring the river morphology, and the findings related to scouring and bed degradation using aerial photography, satellite imagery and periodic site survey. The study highlights the shifting river regime due to both natural and man-made causes. An observed unnatural scouring of the banks upstream of the bridge, which may be attributed to quarrying, is also presented. The information gathered from the remote monitoring was considered in formulating the type and extent of mitigating measures along the river regime.

Keywords: remote monitoring, bed degradation; scouring; bridge protection; lahar

1. Introduction

The Pasig-Potrero Bridge is located along the SCTEx (Subic-Clark-Tarlac Expressway), which is a 94-km expressway that connects the provinces of Zambales, Bataan, Pampanga and Tarlac in Central Luzon, Philippines. Based on observation, this portion of the Pasig-Potrero River is prone to sediment transport, in the form of scouring and degradation, which are expected to be aggravated during strong rainfall events. The bridge is located at a bend of the Pasig-Potrero River approximately 17km from the crater of Mt. Pinatubo (Figure 1).

![Figure 1. Location of the Pasig-Potrero Bridge (Google Earth)](image)

The bridge is 721.4m long with 12 spans. Out of the 11 piers, 4 piers are located within the current river regime and are at great risk of scouring. Among the bridge components affected are the 6-1500mm diameter bored piles with depths ranging from 13m to 23m, and 10.5m x 7.5m x 2.0m pile cap of each pier.
2. Historical Background

Mount Pinatubo is a major stratovolcano at the boundaries of Zambales, Tarlac, and Pampanga that has been superposed on the Zambales range.

The volcano’s violent eruption on 15 June 1991 produced the world’s second largest eruption of the 20th century. Complicating the eruption was the arrival of a typhoon resulting in massive lahars around the volcano that buried entire towns and infrastructure projects years after the eruption.

The 1991 eruption, which came 450 to 500 years after the last eruption, ejected 10 cubic kilometers of material. The eruption was followed by massive lahars which buried entire towns, agricultural lands, and infrastructure projects. The lahars, which filled valleys with deep pyroclastic material as much as 140 meters peak near the crater, continued for several years after the eruption.

Much of the loose pyroclastic material on the slopes have now more or less stabilized with the generations of a cover of grass and fast-growing trees. Less lahar events are now expected compared to the five post-eruption years although events can still be triggered by strong typhoons or monsoon rains.

The natural decline of sediment supply following the eruption was further aggravated by the various quarrying activities along the Pasig-Potrero River. According to the data of quarry operation in Porac from Provincial Environment and National Resources Office (PENRO), the total amount of sand and gravel extracted annually in the upstream reaches of the Pasig-Potrero River ranges from 5.3 to 6.9 million $m^3$. Based on the sediment and riverbed movement analysis conducted by the Nippon Koei Co., Ltd., the amount of sand and gravel being quarried in the Pasig-Potrero River was found to be excessive compared to the amount of sediment being discharged from the upstream basin. This interrupts the sediment balance and results in riverbed degradation. Hence, it is important not to extract more than the amount of sediment that flows in and deposited in the area in order to maintain sediment balance (Nippon Koei Co., Ltd., 2019).

3. Methodology

Because of the highly dynamic nature of the river as discussed in the preceding section, it is imperative that a monitoring program be set up to protect the high-value infrastructure. Although the problem has been recurring even before the bridge construction, detailed documentation and monitoring had not been fully implemented. Therefore, hazard assessment during the past 3 years relied on satellite imagery and site observations.
The changes in river morphology were identified using available topographic data and were validated through series of site inspections. It is then compared with satellite imagery to observe how the topography changed through time. With this, the areas or piers most critical have been identified and prioritized for repair works.

4. Pasig Potrero River Morphology

4.1. Bank scouring from 2006 to 2014

Large amount of riverbank near Pier 9 to Pier 11 has been scoured from 2006 to 2014. The scouring of banks is consistently moving to the left of the river until 2014 as shown in Figure 3. Extreme rainfall events such as the Typhoon Maring in 2013 have contributed to large scouring of banks. The bank at the outer bend has moved approximately 150m from 2006 to 2014.

Due to heavy rainfall, the river current, whose discharge is a combination of lahar and water, overflowed from the river channel and eroded the embankment of the Pasig-Potrero Bridge at the SCTEX. This event triggered the ultimate failure of the approach embankment of the bridge at the abutment (Figure 4).

The river meandered again to the right from 2014 to 2016 as shown in Figure 5. To stabilize the river and prevent migration to the left, slope protection and river training structures were constructed to mitigate the failure. Construction of spur dikes was implemented in 2016. The spur dikes may have prevented further scouring based on the satellite image from 2016 to 2019.

Latest bank alignment in the Pasig-Potrero River is shown in Figure 5. The river channel alignment moved back to the center on early quarters of 2021. After the construction of sheet piles on the right side to prevent further scouring of piers, the channel migrated again to the left.

Figure 3. Observed Bank Erosion at Pasig-Potrero Bridge from 2006 to 2014 (Google Earth©)

Figure 4. Failure of Embankment at SCTEX (2013)
4.2. Bed Degradation and Scouring until 2019

As observed during a site inspection on February 2019, the bed elevation of the Pasig Potrero River at the SCTEX bridge has already reached the level of the pile caps. Comparing the topographic surveys in 2015 and 2019, the maximum difference in elevation of the channel bed is approximately 9m, as shown in Figure 6.

Scouring at the piers (specifically at Piers 6, 7, and 8) accelerated during the Habagat-influenced rainy season usually occurring from June to November every year. This is apparent in the photo taken by NLEX in October 2019 shown in Figure 7. Due to the rainy season, almost two (2) meters of the bored piles at some piers are already exposed.
4.3. Scouring at Pier 6 to Pier 8 (2020)

In November 11-12, 2020, Typhoon Ulysses caused the scouring of sand deposits, further exposing the piles of the piers of the bridge, as shown in Figure 8. Without intervention, scouring and bed degradation will continue throughout the river until the lahar deposits (from the latest Mt. Pinatubo eruption) covering the channel bed would stabilize.

![Figure 8](image)

**Figure 8.** Scouring at the Bridge Piers as of November 2020 (Source: NLEX)

Sheet piles were installed as immediate measure to prevent further scouring of Pier 6 to Pier 8. The proposed plan was to install sheet piles from Pier 6 to Pier 11 (Figure 9). However, the sheet piling works was completed until Pier 8 only due to bad weather conditions. Some of the sand filled mattress were washed out but had helped in aggradation of sediments as shown in Figure 10.

![Figure 9](image)

**Figure 9.** Cross section of immediate mitigating measure (2021)

![Figure 10](image)

**Figure 10.** Scouring at the Bridge Piers as of July 2021 (left) and October 2021 (right)

4.4. Scouring at Pier 9 to Pier 11 (2021)

After the July 2021 rainfall event, the river channel moved towards left in between Pier 8 and Pier 9. One of the piles in Pier 9 was fully exposed as shown in Figure 11. The bank at Pier 10 is not yet scoured.
From the site visit conducted in October 2021, the river channel moved in between Pier 8 and Pier 9 as shown in Figure 12. The sheet pile from Pier 6 to Pier 8 have protected the bridge piers from further degradation. Aggradation of sediments is visible behind the sheet pile located at Pier 8.

![Figure 11. Scouring at the Bridge Pier 9 as of October 2021](image)

![Figure 12. River cross section looking upstream taken in October 2021](image)

To further illustrate the highly dynamic phenomenon at the Pasig Potrero River, the volume changes from 2006 to 2021 have been roughly estimated and summarized in Table 1. Figure 13 presents the longitudinal section of the bridge showing the approximate ground elevations for the observed years.

<table>
<thead>
<tr>
<th>Year</th>
<th>Volume Change* (m³) Erosion / (Deposition)</th>
<th>Elevation Change* (m) Bed Degradation</th>
<th>Max. Exposed Pile Length (m) Total Pile Length (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2006</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>2009</td>
<td>54,000</td>
<td>1</td>
<td>-</td>
</tr>
<tr>
<td>2012</td>
<td>200,000</td>
<td>2</td>
<td>-</td>
</tr>
<tr>
<td>2014</td>
<td>41,200</td>
<td>2</td>
<td>-</td>
</tr>
<tr>
<td>2016</td>
<td>(818,500)</td>
<td>5</td>
<td>-</td>
</tr>
<tr>
<td>2019</td>
<td>194,800</td>
<td>4</td>
<td>1 / 22 (Pier 7)</td>
</tr>
<tr>
<td>July 2021</td>
<td>(940,800)</td>
<td>7</td>
<td>7 / 22 (Pier 7)</td>
</tr>
<tr>
<td>October 2021</td>
<td>550,800</td>
<td>9</td>
<td>13 / 13 (Pier 9)</td>
</tr>
</tbody>
</table>

*Approximate measurements done in the absence of complete topographic data

**Table 1.** Estimated changes at the Pasig Potrero River banks within 1km of the bridge
4.5. Continuous quarrying of lahar materials

It was also reported that quarries operate at both the upstream and downstream side of the bridge. Continuous quarrying could worsen and hasten the rate of scouring at the Pasig-Potrero Bridge. As seen in Figure 5, an area near Pier 6 has been continuously carved out which may be due to the quarrying activities in the area. This may pose a problem at Pier 6 if further degradation occurs.

4.6. Recommendations and actions taken

Aside from the abutment collapse in 2013, there have been no observed damage at both bridge deck and foundation. The integrity of the structure is maintained despite the massive bed degradation surrounding the foundation. The current bridge condition can withstand the dead and live load; however, it is expected that the bridge would be incapable of resisting seismic loads should an earthquake occur. Therefore, mitigating measures should be in place to ensure that the bridge foundation is protected.

Based on the hazard assessment using remote monitoring, site observations, and previous studies, construction of series of ground sill downstream of the bridge is the most practicable approach. This addresses the root cause of the problem which is the bed degradation of the river. Since lahar deposits could still be found upstream of the Pasig-Potrero River, it was assumed that sediments could still be transported to the Pasig-Potrero Bridge and accumulated by providing a ground sill.

As a short-term solution while the design of ground sill is underway, sheet piles have been installed 5.0m downstream of the bridge to prevent further scouring at the piles. Gabion mattress laid below the sheet pile wall serves as apron that prevents erosion below the sheet piles.

It is imperative that consistent monitoring of the mitigating measures and close coordination with concerned local government units and agencies are implemented. Regular monitoring of the pier protection scheme, at least semi-annually, should be done. Any change in the Pasig-Potrero River upstream may affect the conditions throughout the river and should also be monitored. Human activities such as quarrying that could affect the rate of aggradation/degradation should also be addressed with concerned government agencies accordingly.

5. Conclusions and Way Forward

SCTEX (Subic-Clark-Tarlac Expressway) is a major expressway located northwest of Manila. The imminent failure of the bridge would result in disruptions in transportation to the Subic, Clark, and Tarlac areas. Erosion of the channel bed and banks is continuous, and the resulting exposure of the piles and failure of the abutments could affect the structural integrity of the bridge. Using the methodology presented, hazard assessment was conducted, and appropriate mitigating measures have been proposed for both short and long term.

References

