TYPHOON HAZARD ANALYSIS OF THE CEBU-CORDOVA LINK EXPRESSWAY ACROSS MACTAN CHANNEL

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INTRODUCTION

The Mactan Channel is a critical hub of economic activity in Cebu as it serves as the main accessway to the Port of Cebu, one of the largest ports in the Philippines. The channel is spanned by three inter-island bridges that connect mainland Cebu from Cebu City to Mactan Island.

The Cebu-Cordova Link Expressway (CCLEX) is an inter-island bridge that links Cebu City to Mactan Island through the municipality of Cordova. The 8.9-km-long structure spans from the Cebu South Coastal Road (CSCR), crosses the Mactan Channel and Mactan Reef Flat, then connects to a causeway in Barangay Pilipog in Cordova (Fig. 1). It is the longest and tallest bridge in the Philippines as of 2022.

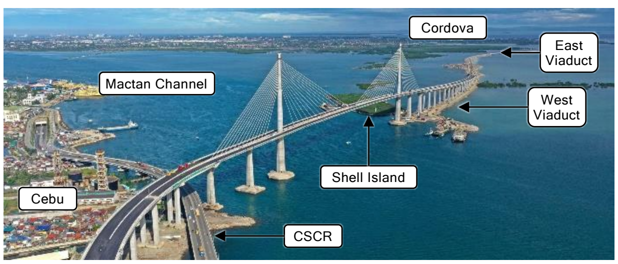

Figure 1 - CCLEX construction as of February 2022

Figure 2 - Satellite image of Mactan Island as of July 2021

The channel is approximately 12-km-long strait bound to the northwest by Cebu Island and to the southeast by Mactan Island (Fig. 2). Both ends of the channel are approximately 0.5 km wide. Adjacent to the southwest end of the channel is the Mactan Reef Flat. It is a 3,000-hectare expanse of mangroves, corals, and seagrass. CCLEX, with its local features, consisting of causeways, viaducts, pylons with pile foundations, piers, bridges, tidal inlets, and a toll plaza, is found to have affected the wave climate within the Mactan Channel and Mactan Reef Flat during extreme typhoons.

This paper presents the analyses and synthesis of the effects of the CCLEX substructure on the extreme hazards of storm tide and typhoon waves of typhoons that tracked Mactan Channel.

METHODOLOGY

Due to the complexity of the coastal morphometry and the presence of multiple local features such as coral reefs, causeways, islands, shoals, and reclaimed lands, a flexible nested mesh was designed for the regional and local computational domains. The domain was subjected to coupled hydrodynamic and storm wave forcing due to the identified critical north- and south-tracking typhoons that traversed the infrastructure.

Historical tropical cyclone data was gathered from the database of the Japan Meteorological Agency - Regional Specialized Meteorological Center (JMA-RSMC). The criteria in selecting these potentially critical typhoons included maximum wind speed (V_{max}), minimum central pressure (P_c), ratio of the typhoon's radius of developed winds (R_{max}) to its closest distance to the project area, and whether it tracked north or south of the project coast. Based on these criteria, the typhoons that were considered for the typhoon hazard analysis are 1951 Typhoon Amy and 1964 Typhoon Louise.

The Holland Single Vortex Model (1980) was used in modelling the wind gradient of the typhoons.

$$V_g(r) = \sqrt{\left[\frac{AB(p_n - p_c)exp\left(-A/_{r^B}\right)}{(\rho r^B)} + \left(\frac{rf}{2}\right)^2\right]} - \frac{rf}{2} \quad (1)$$

$$R_{max} = A^{\frac{1}{B}} \quad (2)$$

where r is the radius, f the Coriolis factor, p_n the ambient pressure, p_c the central pressure, R_{max} the radius of maximum winds (RMW), ρ the density of air (1.15 kg/m^3), $V_g(r)$ is velocity gradient at any radius r, and A and B are scaling parameters.

NUMERICAL MODEL OF HYDRODYNAMICS AND WAVES

Numerical simulations were conducted using a modeling system governed by the 2-dimensional depth averaged shallow water equations derived from the equations of conservation of mass and momentum. It simulates water level variations and flows in response to forcing functions like bottom shear stress, wind shear stress, momentum dispersion, and wave radiation stresses.

Two basic scenarios were considered namely pre-development and post-development. Pre-development assumes the existing coastline and is thus based on satellite imagery, Interferometric Synthetic Aperture Radar (IFSAR) data, and nautical charts. The post-development scenario imposed the CCLEX by removing the computational mesh within the pile caps and toll plaza. The piers and viaducts were modeled as line structures with specific hydraulic properties.

DATA, CALIBRATION, AND VALIDATION

The hydrodynamic model was calibrated and validated by comparing the observed water surface elevation data at the nearby Cebu Port and Tagbilaran Port, respectively, from NAMRIA tidal observations against simulated water levels for both the regional and local meshes. Calibration was done by adjusting the mesh cell sizes and varying the Manning's coefficient n for the roughness of the seabed of the local mesh to achieve an acceptable measure of fit of both the amplitude and phases of the simulated water surface levels against the observed water levels.

SYNTHESIS OF STORM TIDE LEVELS OF HISTORICALLY CRITICAL TYPHOONS

Fig. 3 shows the track and met-ocean data of Typhoon Amy 1951.

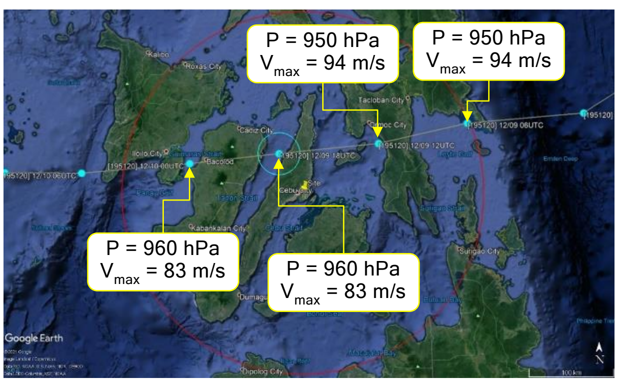

Figure 3 - Track, V_{max}, R_{max} of T.Amy

For the pre-development case, Amy caused maximum STLs ranging from 1.3 to 1.4 maMSL around the project area. Slightly higher tide levels reaching up to 2.6 to 2.7 maMSL were observed in southwestern Mactan's embayment coasts (Fig. 4). Results for the post-development case showed a similar range of STLs from 1.3 to 1.4 maMSL, with variations along the East Viaduct of the CCLEX (Fig. 5). The East Viaduct impedes the storm currents on the southern side of the embankment causing the amplification of storm tides in an isolated area. The more notable change is the decrease in maximum STL in the embayment coasts from 2.6 to 2.7 maMSL in the pre-development scenario to 1.5 to 1.6 maMSL with the CCLEX.

It is seen that the storm tides (astronomic tide, storm surge, wave set-up) are magnified in the inner concave bays of Cordova in the pre-development condition. This implies that CCLEX, with closed pier walls of East Viaduct, provides significant sheltering against storm surges and tides along the western coast of Cordova induced by a strong north-tracking typhoon like Amy.

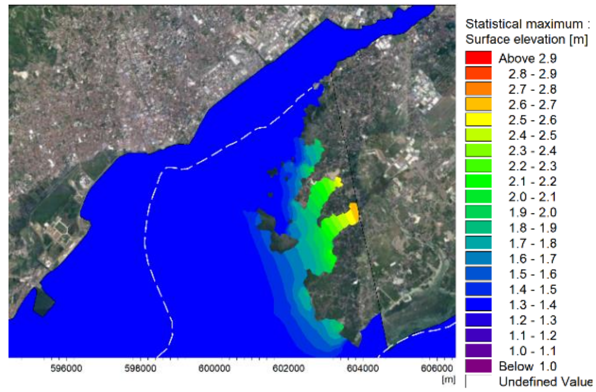

Figure 4 - Simulated maximum STLs of 1951 Amy for pre-development case

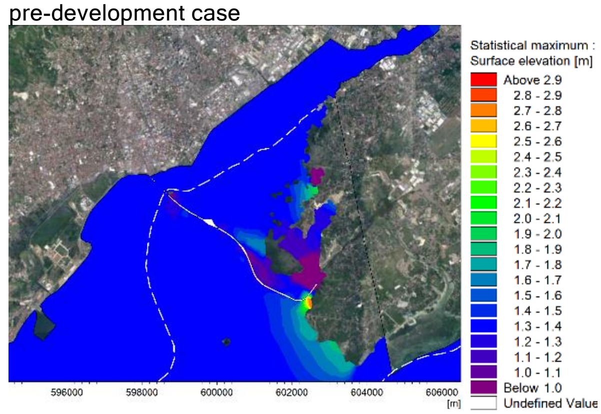

Figure 5 - Simulated maximum STLs of 1951 Amy for post-development case

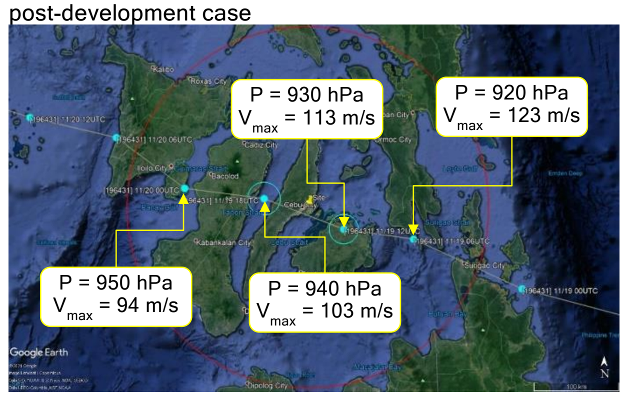

Figure 6 - Track, V_{max}, R_{max} of T.Louise

Fig. 6 shows the track and met-ocean data of Typhoon Louise 1964. In contrast, Louise brought generally higher maximum STLs. For the pre-development case, the maximum STL at the southwest end of the channel and across a large area of the reef flat ranges from 2.7 to 2.8 maMSL (Figure 8). The maximum STL along the channel ranges from 2.7 to 2.9 maMSL. Meanwhile, the simulation for post-development resulted in maximum STL ranging from 2.6 to 2.9 maMSL across the reef flat, and even exceeded 3 maMSL at the northeast end of the channel and at some areas along the CCLEX East Viaduct (Figure 9). In the post-development scenario, the CCLEX impedes the storm currents within the channel and reef flat causing amplification of storm tides along the channel and the CCLEX East Viaduct.

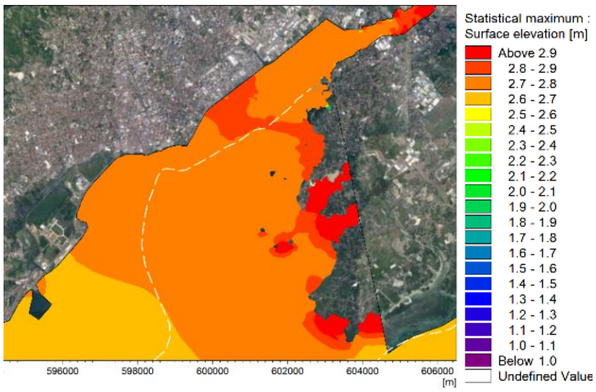

Figure 7 - Simulated maximum STLs of 1964 Louise for pre-development case

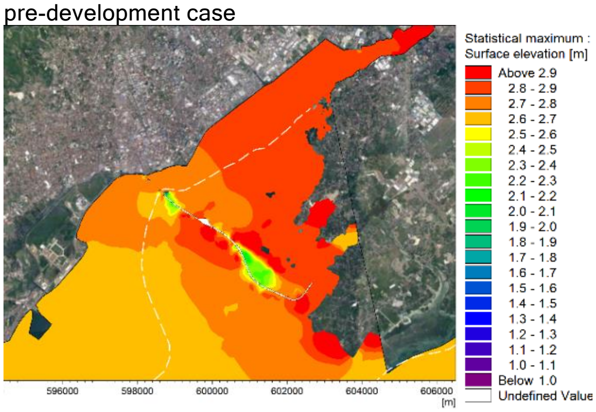

Figure 8 - Simulated maximum STLs of 1964 Louise for post-development case

The simulation results show that Louise is the more critical typhoon for the Mactan Channel based on maximum STL. It is observed that the maximum STLs are amplified for Typhoon Louise, a south tracking typhoon, and reduced for Typhoon Amy, a north-tracking typhoon. This is attributed to the geography of the area wherein entry of the storm tide is promoted for south-tracking typhoons and restricted for north-tracking typhoons.

SYNTHESIS OF STORM WAVES OF HISTORICALLY CRITICAL TYPHOONS

The wave climate along the Mactan Channel is calm due to the sheltering effect from Mactan Island against offshore waves from the northeast direction. For waves approaching offshore from the southwest, the Mactan Reef Flat reduces the waves reaching the deep channel of the strait. The reef flat, which is an expansive shallow water region of mangroves, corals, and seagrass and hence with hydraulically rough bottom, dissipates wave energy. It is a largely effective barrier of waves from these southerly approaches.

The simulated maximum significant wave heights of Typhoon Amy are nearly identical in the pre- and post-development cases (Fig. 9). The wave heights have the same range in both scenarios with slightly varied spatial extents. The most notable difference between the two scenarios is that the post-development case showed 0.5 m lower wave heights along the northern side of the CCLEX East Viaduct. The CCLEX has a slight effect on waves approaching offshore from the south and southwesterly. Over 5-m-high offshore waves from Cebu Strait are primarily dissipated to 1.5 m by the reef flat, then further reduced to below 1.0 m by the CCLEX. Maximum significant wave heights along the channel range from 1.0 to 3.0 m.

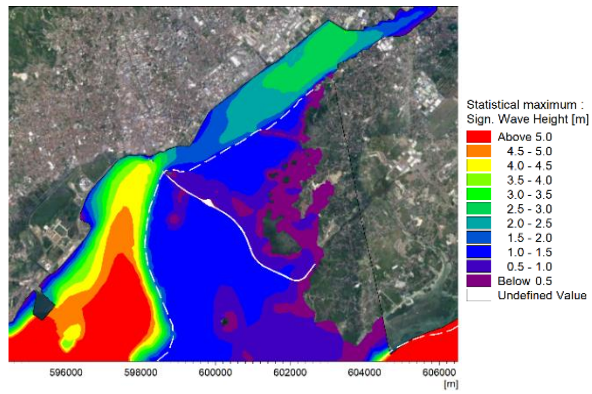

Figure 9 - Simulated maximum storm wave heights of 1951 Amy for post-development case

CONCLUSIONS

Storm tides generated by a north-tracking typhoon like Amy are modulated by the East Viaduct of CCLEX, particularly along the concave western coasts of Cordova. For a south-tracking typhoon as Louise, the modulating effects along Western Cordova are reduced due to considerable penetration of the surges along the deep Mactan Channel. For waves approaching offshore from the southwest, the CCLEX provides minimal sheltering to the Mactan Reef Flat and negligible effect on the significant wave heights along the channel. The East Viaduct, consisting of a long embankment with negligibly small culvert-type tidal inlets, can reduce wave heights on the reef flat by around 0.5 m.

The inter-island bridge also has negligible effect on the storm tide levels of the Mactan Channel. The maximum STL ranging from 2.7 to 2.8 maMSL increased to 2.8 to 2.9 maMSL with the CCLEX.

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