PRELIMINARY ENGINEERING OF A SEAWALL TO MITIGATE TYPHOON-INDUCED WAVE OVERTOPPING ALONG ROXAS BOULEVARD, MANILA

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August 3, 2018
1. Introduction
2. Methodology
3. Project Area Data
4. Analysis of Historical Typhoons
5. Coastal Engineering
6. Preliminary Engineering
7. Conclusions
INTRODUCTION

Project Location

Map showing the location of Luzon Island, Manila Bay, Taft Avenue, Manila Yacht Club, START of Seawall coordinates (N 1611982.1, E 497644.2), END of Seawall coordinates (N 1610753.7, E 498204.4), and the US Embassy.
INTRODUCTION

Notes
- Observed water level nearly at level with seawall crest
- Nearly constant wave overtopping

https://www.youtube.com/watch?v=F_IkbxHawlW
INTRODUCTION

Project Background

http://www.demokrathaber.net/images/album
INTRODUCTION

2011
• Typhoon Nesat/Pedring caused overtopping which led to the seawall collapse; rehabilitation of the seawall was immediately undertaken.

2012
• High waves induced by Typhoon Saola/Gener overtopped the recently rehabilitated seawall but the seawall was not damaged extensively.

2013
• National Public Works Agency (DPWH) – commissioned a study to understand the typhoon hazards and recommend mitigating measures.

1. Technical Considerations
   - Hazards, such as typhoons and earthquakes
     - Storm Tides and Waves
     - Liquefaction and Lateral Spreading

1990 Luzon Earthquake – resulted in wide-scale liquefaction on the island of Luzon

Photo on the left: thepoc.net
Extent of Liquefaction map from Punongbayan and Umbal (1990)
INTRODUCTION

2. Non-Technical Considerations
   • Preservation of the sunset view on Manila Bay
   • Existing adjacent structures
   • Cost-effective design

http://2.bp.blogspot.com/_a8b750mNSbM/TVj2dCDImZI/AAAAAAAAAji4/gAdlASWWpyo/s1600/roxas%2Bbblvd.JPG
METHODOLOGY

Conceptual Framework

PRELIMINARY ENGINEERING DESIGN

- Storm Tide Level
- Wave Run-up

Non-Overtopping Crest Elevation (NOCE) Storm Generated Forces

Other Forces:
- Self weight
- Surcharge
- Earthquake Load
- Lateral Pressures

Geotechnical Analysis and Evaluation

Check for Seawall External Stability:
- Overturning
- Sliding
- Bearing Capacity

Check for Other modes of Failure:
- Liquefaction
- Lateral Spreading

Soil Investigation

Seawall Cross-section
METHODOLOGY

Conceptual Framework

COASTAL ENGINEERING STUDY

- Bathymetry Data
  - Astronomic Tide Data
  - Meteorologic Data
  - AdCirc Simulations
    - Storm Tide Level
      - Wave Simulation
        - Local Waves
        - Wave Run-up
      - Total Overtopping Potential
        - Seawall Crest Elevation
  - Wave Run-up
• Consolidation of bathymetric data from available nautical maps and commissioned bathymetric survey
Typhoon Analysis

• Typhoon Tracks of 30 historical typhoons

Legend:
- Class 2: Vsus < 62 kph
- Class 3: Vsus < 88 kph
- Class 4: Vsus < 118 kph
- Class 5: Vsus > 118 kph
- RB Sea Wall

R = 180 km
### Summary of Meteorological Data of Historical Typhoons

<table>
<thead>
<tr>
<th>Year</th>
<th>Name Int’l/ Local</th>
<th>Vmax (kph)</th>
<th>Rmax (km)</th>
<th>Pc (hPa)</th>
<th>Relative Track</th>
<th>Distance to site (km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1977</td>
<td>Kim/ Unding</td>
<td>205</td>
<td>230</td>
<td>920</td>
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<td>60</td>
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<td>1981</td>
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<td>280</td>
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<td>1984</td>
<td>Betty / Konsing</td>
<td>95</td>
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<td>330</td>
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<tr>
<td>1986</td>
<td>Georgia / Ruping</td>
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<td>S</td>
<td>160</td>
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<tr>
<td>1987</td>
<td>Betty/ Herming</td>
<td>205</td>
<td>190</td>
<td>890</td>
<td>S</td>
<td>100</td>
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<td>1988</td>
<td>Ruby / Unsang</td>
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<td>280</td>
<td>950</td>
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<td>100</td>
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<tr>
<td>1989</td>
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<tr>
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<td>95</td>
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<td>1991</td>
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<td>992</td>
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</table>
### Typhoon Analysis

**Summary of Meteorological Data of Historical Typhoons**

<table>
<thead>
<tr>
<th>Year</th>
<th>Name Int’l/ Local</th>
<th>Vmax (kph)</th>
<th>Rmax (km)</th>
<th>Pc (hPa)</th>
<th>Relative Track</th>
<th>Distance to site (km)</th>
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<tr>
<td>1992</td>
<td>Eli / Konsing</td>
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<tr>
<td>1994</td>
<td>Teresa / Katring</td>
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<td>150</td>
<td>955</td>
<td>S</td>
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<tr>
<td>1995</td>
<td>Sibyl / Mameng</td>
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<td>15</td>
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<tr>
<td>1998</td>
<td>Babs / Loleng</td>
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<td>260</td>
<td>940</td>
<td>N</td>
<td>110</td>
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<tr>
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<td>Eve / Rening</td>
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<td>0</td>
<td>960</td>
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<td>Xangsane/ Reming</td>
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<td>150</td>
<td>960</td>
<td>S</td>
<td>10</td>
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<td>E</td>
<td>180</td>
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<tr>
<td>2006</td>
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<td>940</td>
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<tr>
<td>2008</td>
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<td>165</td>
<td>90</td>
<td>945</td>
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<td>20</td>
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<td>2011</td>
<td>Nesat/ Pedring</td>
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<td>220</td>
<td>950</td>
<td>N</td>
<td>200</td>
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<tr>
<td>2012</td>
<td>Saola/ Gener</td>
<td>130</td>
<td>110</td>
<td>960</td>
<td>E</td>
<td>505</td>
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<td>2014</td>
<td>Rammasun / Glenda</td>
<td>165</td>
<td>130</td>
<td>935</td>
<td>S</td>
<td>45</td>
</tr>
</tbody>
</table>
TYPHOOON ANALYSIS

- Advance Circulation (AdCirc) Numerical Model

![Tidal graph at South Harbor, Manila](image)

- Storm Tides

![Map of Manila Bay and West Philippine Sea](image)

- Manila Bay
- Seawall
- West Philippine Sea
TYphoon Analysis

Results - Rammasun / Glenda (2014)

Results - Xangsane / Milenyo (2006)

Results Fengshen / Frank (2008)
## Typhoon Analysis

### Highest 6 Storm Tide Levels

<table>
<thead>
<tr>
<th>Typhoon / Local name</th>
<th>Astronomic Tide (m)</th>
<th>Storm Tide Level (m)</th>
<th>Max. Storm Surge (m)</th>
<th>Time of Occurrence of Max STL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rammasun / Glenda 2014</td>
<td>1.125</td>
<td>2.358</td>
<td>1.233</td>
<td>7/16 10:41 AM</td>
</tr>
<tr>
<td>Xangsane / Milenyo 2006</td>
<td>0.473</td>
<td>2.088</td>
<td>1.614</td>
<td>9/28 2:43 PM</td>
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<tr>
<td>Fengshen / Frank 2008</td>
<td>1.244</td>
<td>1.763</td>
<td>0.519</td>
<td>6/21 11:13 AM</td>
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<tr>
<td>Dot / Saling 1985</td>
<td>1.283</td>
<td>1.714</td>
<td>0.431</td>
<td>10/19 1:10 AM</td>
</tr>
<tr>
<td>Vera / Bebeng 1983</td>
<td>1.232</td>
<td>1.607</td>
<td>0.375</td>
<td>7/15 12:06 PM</td>
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<tr>
<td>Betty / Herming 1987</td>
<td>1.246</td>
<td>1.515</td>
<td>0.269</td>
<td>8/11 11:09 AM</td>
</tr>
</tbody>
</table>
**TYPHOON ANALYSIS**

- Offshore storm wave conditions at time of highest STL

<table>
<thead>
<tr>
<th>Typhoon / Local name</th>
<th>Offshore significant waves</th>
<th>Wave Height (m)</th>
<th>Wave Period (s)</th>
<th>Wave direction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ramassun / Glenda 2014</td>
<td></td>
<td>3.6</td>
<td>10.93</td>
<td>SW-5°</td>
</tr>
<tr>
<td>Xangsane / Milenyo 2006</td>
<td></td>
<td>4.45</td>
<td>11.20</td>
<td>SW-10°</td>
</tr>
<tr>
<td>Fengshen / Frank 2008</td>
<td></td>
<td>4.2</td>
<td>12.52</td>
<td>WNW</td>
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</table>
Results of the analysis were compared to the crest elevation of the existing seawall.

<table>
<thead>
<tr>
<th>Typhoon</th>
<th>Maximum wave runup</th>
<th>Minimum Deficit</th>
<th>Maximum Deficit</th>
<th>Required Vertical Siting</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rammasun 2014</td>
<td>2.23</td>
<td>1.50</td>
<td>2.18</td>
<td>4.59</td>
</tr>
<tr>
<td>Xangsane 2006</td>
<td>2.51</td>
<td>1.41</td>
<td>2.19</td>
<td>4.60</td>
</tr>
<tr>
<td>Frank 2008</td>
<td>2.92</td>
<td>0.05</td>
<td>2.20</td>
<td>4.68</td>
</tr>
</tbody>
</table>
Seawall Stationing

<table>
<thead>
<tr>
<th>Stationing</th>
<th>0+200</th>
<th>0+440</th>
<th>0+680</th>
<th>0+920</th>
<th>1+160</th>
<th>1+300</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crest Elev.</td>
<td>1.99</td>
<td>2.16</td>
<td>2.21</td>
<td>2.21</td>
<td>2.41</td>
<td>2.48</td>
</tr>
<tr>
<td>Vertical Siting</td>
<td>3.93</td>
<td>4.20</td>
<td>3.71</td>
<td>4.30</td>
<td>4.60</td>
<td>4.68</td>
</tr>
<tr>
<td>Additional Height</td>
<td>1.94</td>
<td>2.04</td>
<td>1.50</td>
<td>2.09</td>
<td>2.19</td>
<td>2.20</td>
</tr>
</tbody>
</table>
GEOTECHNICAL ENGINEERING

Geotechnical Investigation

Project Area

Manila Bay
- Stability Analysis under Earthquake Condition considering the reduction in soil strength due to liquefaction using Slide™
• Considering the presence of the boulder layer, the utilization of **shallow foundation** is feasible.

• Cost comparison between the use of shallow foundation and pile foundation is provided below for reference.

<table>
<thead>
<tr>
<th>Foundation System</th>
<th>Indicative Costs per linear meter</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shallow Foundation</td>
<td>~ PhP 120,000.00 ~ USD 2,300.00</td>
<td>This includes the rehabilitation of the seawall should liquefaction occur.</td>
</tr>
<tr>
<td>Deep Foundation</td>
<td>~ PhP 360,000.00 ~ USD 6,800.00</td>
<td>This includes bored pile construction only.</td>
</tr>
</tbody>
</table>
Preliminary Engineering

- Vertical Siting (foregoing)
- Seawall Stability Analysis
- Seawall Cross Section
Design Cases:
1. Storm Conditions
2. Non-Storm Condition

Loads and Load Combinations:
• Philippine Ports Authority (PPA) Design Guidelines
• National Structural Code of the Philippines (NSCP)
• Coastal Engineering Manual
Case 1: Storm Condition

Dead Load – Dead weight of the concrete seawall structure and fill within the seawall footing.

\[ W_{SW} = 100.67 \text{ kN/m} \]
\[ W_{SU} = 95.59 \text{ kN/m} \]

Passive Earth Pressure – Stabilizing Passive Force due to the backfill on the leeward side of the seawall.

\[ F_{PA} = 305.03 \text{ kN/m} \]

Wave Force – Force Generated by wave hitting the seawall, solved by using the Goda Formula from the Coastal Engineering Manual.

\[ p_1 = 33.03 \text{ kN/m}^2 \]
\[ p_2 = 15.54 \text{ kN/m}^2 \]
\[ p_3 = 32.98 \text{ kN/m}^2 \]

Upward Force due to Seawall Geometry – Wave force that was added because of the geometry of the re-entrant, based on the calculated wave forces.

\[ p_u = 21.95 \text{ kN/m}^2 \]
\[ p_v = 17.04 \text{ kN/m}^2 \]

Hydrostatic Force – Hydrostatic forces composed of Horizontal component and Uplift due to seepage.

\[ F_{H} = 2.2 \text{ kN/m} \]
\[ F_{U} = 13.33 \text{ kN/m} \]

Earthquake Forces – Earthquake forces from soil and hydrostatic forces determined by multiplying seismic coefficient and obtained formula from PPA.
Case 2: Non-storm Conditions

Dead Load – Dead weight of the concrete seawall structure and fill within the seawall footing.

\[ W_{SW} = 100.66 \text{ kN/m} \]
\[ W_{SW} = 95.59 \text{ kN/m} \]

Hydrostatic Force – Hydrostatic forces composed of Horizontal component and Uplift due to seepage.

\[ F_{H} = 29.09 \text{ kN/m} \]
\[ F_{U} = 48.48 \text{ kN/m} \]

Active Earth Pressure – Overturning Active Force due to the backfill on the leeward side of the seawall and estimated surcharge based from NSCP.

\[ F_{A} = 33.82 \text{ kN/m} \]
\[ F_{Q} = 3.33 \text{ kN/m} \]

Earthquake Forces – Earthquake forces from soil and hydrostatic forces determined by multiplying seismic coefficient and obtained formula from PPA.

\[ F_{AE} = 25.12 \text{ kN/m} \]
\[ F_{EQ} = 2.47 \text{ kN/m} \]
\[ F_{HE} = 6.55 \text{ kN/m} \]
\[ F_{EU} = 5.45 \text{ kN/m} \]
Seawall Promenade is raised to maintain view of Manila Bay sunset from land.

Interior drainage to allow overtopping water to flow back to sea or detained temporarily.
CONCLUSIONS

• Historical typhoons tracking within the project seawall are analyzed to obtain historical storm tide levels and wave runup

• The non-overtopping crest elevation (MTL +4.68 m) is used as basis of the crest elevation of the rehabilitated seawall.

• A geotechnical investigation and analysis established that a shallow foundation is best for the seawall site considering safety and economy.

• Preliminary engineering is completed by carrying out external stability analyses to obtain seawall geometry and cross-section

• The access to the sunset view of the bay is considered in the site development concept.
THANK YOU for your attention.