Memorandum

To: Rhode Island Department of Transportation
Two Capitol Hill
Providence, RI 02903

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From: David Cloutier, P.E.

Floodplain Tech Memo
Reconstruction of Pell Bridge Approach
Newport, Rhode Island

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1. Introduction

The Claiborne Pell Newport Bridge (Pell Bridge) carries State Route 138 between Jamestown and Newport and is the only road connection between Jamestown and Aquidneck Island. The Proposed Action Alternative of the Pell Bridge Interchange Project (Project) would provide direct connection from the northern part of the City to the downtown area, reduce queued vehicle traffic onto the Pell Bridge, reduce traffic in downtown Newport, and provide a portion of the bicycle and pedestrian facilities envisioned in the Aquidneck Island Transportation Study. The Proposed Action (Project) would occur in the City of Newport and Town of Middletown, Rhode Island. In accordance with the National Environmental Policy Act (NEPA), an Environmental Assessment (EA) is being developed to evaluate the impacts of construction and operation of the re-designed interchange on environmental resources.

The Project is located within the 1-percent-annual-chance floodplain (1% Floodplain) as depicted on the National Flood Insurance Program (NFIP) Flood Insurance Rate Map (FIRM) Number 44005C0089J (Effective Date September 4, 2013). The principal flood risk in the Project is associated with coastal flooding from Narragansett Bay. The NFIP Flood Insurance Study (FIS) for Newport County, Rhode Island provides a summary of the coastal flooding analysis used as a basis for the delineation of the 1% Floodplain in the Project Area. For this analysis, all flooding in the Project Area is assumed to be coastal. A small unnamed stream does cross the Project Area, but was not studied as part of the NFIP and is likely not a significant source of flooding. The drainage area of this stream is less than one quarter square mile, and the stream consists almost entirely of drainage culverts and man-made channels less than 10 feet wide.

To predict the impact of the Project on the 1% Floodplain horizontal and vertical extents, VHB prepared the following analysis:

- Developed a site-specific coastal flooding transect model to quantify what effect, if any, the proposed Project would have on flooding due to wave setup and wave runup, and
- Using GIS mapping, quantified changes to the areas inundated by coastal flooding due to relocated roadways and proposed grading associated with Project.

The following technical memorandum presents a detailed summary of the methodology, results, and implications of VHB's coastal flooding analysis.

2. Study Area and Methodology

VHB developed a hydraulic model encompassing the Project area and the surrounding environs for this analysis. The following section provides a detailed explanation of the study area and methodology used for this model.

2.1 Study Area

Figure 1 depicts the study area for this analysis. The primary study area encompasses the immediate area of the existing Pell Bridge Interchange, including a proposed Park & Ride facility and consideration of future redevelopment of land made available by the Project. The interchange improvements consist of extensive roadway re-alignment and re-grading that has the potential to affect the extent and function of the 1% Floodplain.

In addition, the Project includes additional transit improvements outside of the primary study area: resurfacing of the JT Connell Highway to the north, a shared-use bicycle and pedestrian path connection to downtown Newport, and lane re-alignment of Americas Cup Avenue at its intersection with Farewell Street. These additional transit improvements are either located outside of the 1% Floodplain, or consist entirely of pavement resurfacing and re-striping. As such, these additional highway improvements have a negligible impact on the 1% Floodplain and the following analysis focuses on the primary study area.

The majority of the Project site is located within a low area draining northwest to Coasters Harbor within Narragansett Bay, with an unnamed stream flowing across from the southeast to the northwest. The primary flooding source within the study area is coastal flooding due to storm surge and high tides. Route 138 crosses the study area running north-south along a raised embankment, providing limited protection from coastal flooding to the east. Although the study area is largely sheltered from wave action by Coasters Harbor Island to the west, there are two potential sources of coastal flooding:

- Storm surge and wave setup from the northwest, via Coasters Harbor
- Wave runup overtopping the low ridge west of 3rd Street

The Project site is located within the 1% Floodplain according to NFIP FIRM Panel 44005C0089J (2013), with associated 1% Floodplain Base Flood Elevations (BFE) of 13 feet and 12 feet NAVD 88. FIRM mapping indicates that the study area is located outside of the area of coastal storm-induced velocity wave action (Zone VE) and the Limit of Moderate Wave Action (LiMWA), and is therefore not subject to additional hazards due to coastal storm-induced velocity wave action. FEMA defines Zone VE and the LiMWA based on the predicted wave height: Zone VE corresponds to wave heights greater than 3 feet (where structures are at risk due to significant wave energy and the LiMWA corresponds to wave heights greater than 1.5 feet (where structures not designed to withstand wave impacts are at risk). Figure 2 depicts the Federal Emergency Management Agency (FEMA) Special Flood Hazard Areas (SHFAs) in the vicinity of the study area; refer to Appendix A for excerpts from the FEMA study. The FIS estimates flood elevations using a coastal transect model such as the Coastal Hazard Analysis Modeling Program (CHAMP) developed by FEMA. Flood zones between transect locations are interpolated from nearby transect model results using various topographic datasets and the engineering judgement of the NFIP mapper.

As indicated on Figure 1, the primary study area is located between two FEMA transects: Transect 38 (approx. 0.5 mile north of the study area) and Transect 39 (approx. 0.3 mile south of the study area). Although these FEMA transects do cross the additional transit improvements associated with the JT Connell Highway and Americas Cup Avenue, they do not provide a representative model of the primary study area surrounding the exiting Pell Bridge interchange. Table 1 below presents a summary of coastal flood elevations for these transects.

Table 1 – NFIP Coastal Transect Data Near the Project Site

FEMA Transect No.	1% Annual Chance Stillwater[a]	1% Annual Chance Total Water Level[b]	Base Flood Elevation[c]
38	10.7 ft NAVD88	13.4 ft NAVD88	13 ft NAVD88
39	10.5 ft NAVD88	12.9 ft NAVD88	12-13 ft NAVD88

[a] Stillwater means the flood level not including the effects of waves but including storm surge and tides.
[b] Total Water Level is the combination of tides, storm surge, wave setup, and wave runup (where present).
[c] NFIP mapping policy rounds BFEs to the nearest whole foot.

Because there are no transects located within the primary study area, the flood elevations presented in the FIS are approximate for the existing Pell Bridge Interchange area and do not account for site-specific effects on wave setup or runup. To address this deficiency and to quantify potential Project impacts to flooding from wave action in the study area, VHB developed a site-specific coastal flooding model with two new transects located along the likely sources of flooding identified above. This model was used to create a baseline conditions model of the existing flooding on-site and as a comparison for post-project modeling.

2.2 Study Methodology

VHB developed a coastal transect model using CHAMP v2.0 software in accordance with guidance from the "Atlantic Ocean and Gulf of Mexico Coastal Guidelines Update" from February 2007 (2007 Update) developed by FEMA. This is the same methodology used by FEMA to develop coastal flooding models for the Effective FIS for Newport Country. The results of the coastal model analysis are used to estimate flood elevations and wave heights, evaluate the protection of the Project site, and estimate any changes in flood risk to neighboring properties due to the Project.

2.2.1 Data Collection

VHB collected, reviewed, and assembled the following data for this study:

- VHB photogrammetric topographic survey for study area collected in 2018
- 1-meter topobathymetric Digital Elevation Model (DEM) data for Aquidneck Island and Narragansett Bay (USGS, 2016)
- Aerial photographs and field observations to estimate land cover and roughness coefficients
- Effective FEMA FIS model data and supporting documentation
- Preliminary highway alignment and grading for Pell Bridge Interchange improvements by VHB

FEMA published the currently effective FIS 44005CV000B and FIRMs for all jurisdictions of Newport County, Rhode Island on September 4, 2013. FEMA has since published a preliminary FIS dated April 4, 2018, but this preliminary FIS does not revise any coastal or riverine flooding analysis for the City of Newport. The effective FIS was therefore evaluated as the "current" conditions in conjunction with this analysis. Coastal flooding analysis in the FIS ("2013 Coastal Study") was prepared by the Strategic Alliance for Risk Reduction (STARR). The 2013 Coastal Study determined the current FEMA SFHAs abutting this Project using CHAMP 2.0 software with 1-dimensional transects to perform storm-induced erosion treatments, wave height analyses, and wave runup analyses. CHAMP wave input parameters were sourced from a 2-dimensional spectral wave field for Narragansett using STWAVE software. This STWAVE model was also developed by STARR and is the same model used for coastal flood analysis in the Kent County, Rhode Island FIS (September 18, 2013) and Bristol County, Rhode Island FIS (July 7, 2014). For the 2013 Coastal Study, STARR developed current effective stillwater elevations (SWELs) by regional frequency analysis using L-moments of five tide gages located in and adjacent to Newport County. Figure 2 depicts the effective SHFAs within the study area.

In August 2017, VHB coordinated with FEMA to obtain the 2013 STWAVE and CHAMP models, stillwater elevation calculations, and backup data associated with creating the coastal models for the effective FIS. VHB reviewed the effective FEMA models and noted a discrepancy between the STWAVE wave field data outputs and CHAMP transect inputs for FEMA transect numbers 38 and 39. The FEMA CHAMP model uses for input deepwater wave heights and periods that do not match any values in the STWAVE spectral wave field in the vicinity of the transect locations, and provides no documentation explaining this discrepancy. Without this information, VHB cannot duplicate the FEMA study to verify if the discrepancy is due to an undocumented adjustment or an error in calculations. Accordingly, VHB has not included the FEMA flood profiles from those transects in this study.

2.2.2 Engineering Methods

VHB used CHAMP v2.0, including the Wave Height Analysis for Flood Insurance Studies ("WHAFIS") to perform wave height and overland wave propagation analysis for the Project site. The CHAMP program with WHAFIS module is approved for use by FEMA for the purpose of performing coastal analyses.

VHB performed a 1-D coastal transect analysis at two locations. The locations of the two analyzed transects are shown in Figure 1. Using guidance from section D.7.2 (2007 Update), both transects were laid out to best understand potential impacts of the proposed grading on flooding over the Project and the areas that are subject to the highest potential flooding. Transect 1 corresponds to flooding from the northwest via Coasters Harbor, and Transect 2 corresponds to flooding from the west via wave action overtopping 3rd Street.

The CHAMP transect model uses the following inputs to estimate wave heights:

- 1% Stillwater Elevation (SWEL)
- 1% Deepwater Wave Height,
- 1% Deepwater Wave Period,
- 1% Wave Setup Magnitude
- Transect cross-sectional geometry, and
- Transect inland fetch codes.

For this analysis, VHB used the same data input sources as the effective FEMA FIS model for stillwater elevation, significant wave height, and wave period. Transect cross-sectional geometry was extracted from a composite 3D surface based on the VHB photogrammetric survey supplemented with 1-meter resolution topobathymetric data provided by USGS (2016), with inland fetch characteristics extracted from aerial photography and field observations using guidance from Section 2.7.6 (2007 Update). Both transects can be represented by a rip-rap seawall located at the shoreline with an urban area covered by buildings extending inland; Transect 2 includes a small vegetated area immediately landward of the seawall. Refer to Appendix B for detailed CHAMP and WHAFIS model data including inland fetch codes. For the proposed conditions model, VHB used preliminary grading of the replacement Pell Bridge approach and accessory roads to develop transect cross-sectional geometry. The proposed conditions model assumes that the entire existing raised bridge approach embankment will be removed and re-graded for future development. In the parcels available for potential future development between proposed roadways, VHB assumed flat parcel grading set to match the elevations of the surrounding roadway. For areas slated for roadway resurfacing, VHB assumed that existing grades will be maintained when generating cross-section geometry.

The 1% deepwater wave height and 1% deepwater wave period for VHB Transects 1 and 2 were calculated using the STWAVE 2D spectral wave field values at the deepwater end of each transect. This is the same wave field that FEMA used to generate the model inputs for the effective transects. The static 1% wave setup magnitude values were calculated for each transect using MathCAD worksheets that follow procedures Section 2.6.3 (2007 Update). Detailed wave setup and runup worksheets are included in Appendix B. The following table shows the CHAMP model inputs used for each transect:

Table 2 – CHAMP Model Inputs

VHB Transect No.	1% Deepwater Wave Height[a]	1% Deepwater Wave Period[a]	1% Stillwater Elevation[b]	1% Wave Setup Magnitude[c]
1	6.23 ft	5 seconds	10.68 ft NAVD88	1.41 ft
2	5.41 ft	4 seconds	10.58 ft NAVD88	1.25 ft

[a] Values taken from STWAVE spectral wave field
[b] Values interpolated from Effective FIS Transects 38 and 39
[c] Values calculated using MathCAD.

VHB used WHAFIS to estimate the magnitude of wave heights associated with coastal storm surges and their potential impact on the Project. WHAFIS 4.0 was developed and is distributed by FEMA as part of the CHAMP 2.0 software package. The WHAFIS Model uses SWELs, fetch length, wave setup, deepwater conditions, and transect geometry to estimate wave heights, wave periods, locations where the waves break, and flood hazard designations continuously at points along the transect. The station-elevation data and the fetch length vary for each transect. Fetch length is the maximum distance traveled by wind across open water.

VHB completed WHAFIS model runs for existing and proposed conditions at each of two transects for the 1% annual exceedance coastal storm event. The peak 1% annual exceedance wave crest elevations were evaluated for each run for the entire transect and for the portion of the transect within the Project area. In addition to wave setup and wave propagation, VHB calculated wave runup on the rip-rap coastal seawalls at both transect locations, using guidance from Section D.2.8.1 (2007 Update). VHB calculated runup for each transect using the USACE *Technical Advisory Committee for Water Retaining Structures* (TAW) method. Detailed wave setup and runup worksheets are included in Appendix B. Based on the results of the WHAFIS model and runup analysis, VHB applied calculated flood elevations to determine the inundation limits corresponding to the 1% Floodplain for coastal flooding. VHB delineated the 1% Floodplain based on guidance from Section D.2.11 (2007 Update), using the calculated WHAFIS wave envelope elevation for Transect 1 through the study area.

3. Applicable Regulations and Criteria

VHB reviewed relevant floodplain laws, requirements, and guidance to develop the following list of applicable regulations:

Executive Order 11988

Under Executive Order (EO) 11988 Section 2.(a)(2) (EO11988), federally-financed projects located within the NFIP-designated 1% Floodplain are required to be designed to minimize potential harm to or within the floodplain, and are required to prepare and circulate a notice containing an explanation of why the action is proposed to be located in the floodplain. FEMA provides guidance on implementing EO 11988 in its publication "Guidelines for Implementing Executive Order 11988," dated October 8, 2015. According to FEMA, the public notification requirement can be met through the public comment aspect of the NEPA review process, and documentation supporting the requirement to minimize adverse effects to or within the floodplain can be provided as part of the Environmental Assessment for the Project.

National Flood Insurance Program

The Flood Disaster Protection Act of 1973 and the Flood Insurance Reform Act of 1994 require federally-regulated and insured lenders to mandate the purchase of flood insurance for properties located within an area having special flood hazards for the term of the loan. Any future development within the Project area located within the 1% Floodplain would be subject to this requirement, unless development is raised above the floodplain Base Flood Elevation to provide adequate freeboard.

Rhode Island Coastal Resources Management Council Aquidneck Island Special Area Management Plan (SAMP)

The Coastal Development Regulations of the Aquidneck Island SAMP requires projects to minimize flood impacts and shoreline erosion by requiring that the "Coastal Greenway" shoreline land area be maintained and managed to protect resources from coastal flood hazards. In particular, areas identified as high hazard wave areas (Zone VE) should be preserved as open space. The limit of disturbance for the proposed Project does not extend into any areas designated as Zone VE on NFIP flood hazard maps, or into any areas identified as Zone VE based on VHB's site-specific coastal flooding model. As a result, the coastal greenway requirements of the Rhode Island RI Coastal Resources Management Council (CMRC) Aquidneck Island SAMP are not applicable. However, CMRC and SAMP regulations for development within the 1% Floodplain will apply to the Project.

Rhode Island Freshwater Wetlands Act

Under the 2007 Rhode Island Fresh Water Wetlands Act (the Act) enforced by the Rhode Island Department of Environmental Management (DEM), the 1% Floodplain is designated as a wetland. However, VHB interprets Section 2-2-20(3) of the Act to apply only to floodplains subject to flooding associated with rivers, streams, or other flowing bodies of water; areas subject to coastal flooding are not considered to be freshwater wetlands. Because the 1% Floodplain in the Project area is due solely with coastal flooding, the Act should not apply to the 1% Floodplain for this Project. Because the Project crosses the jurisdictional boundary of the Aquidneck Island SAMP, the DEM and

CMRC shall jointly determine which agency will have jurisdiction over the Project per Rule 3.03 of the 2007 RIDEM Fresh Water Wetlands Act Rules and Regulations.

Rhode Island State Building Code (RISCB)

Pursuant to Rhode Island General Laws Section 46-23-6, the Rhode Island Coastal Resources Management Council (CRMC) is authorized to develop and adopt freeboard calculations for proposed development within the coastal floodplain. The CRMC requires all applicants proposing construction within flood hazard zones to demonstrate that all applicable portions of the RISBC, and more specifically RISBC-8, are met. Any future building development within the flood zone in the Project Area may be subject to additional RISBC floodplain construction requirements.

City of Newport Flood Hazard Area Development Ordinance

Chapter 15.24 of the City of Newport Code of Ordinances requires permits for all projects that meet the definition of development, not just "building" projects. Development projects include any filling, grading, excavation, mining, drilling, storage of materials, temporary stream crossings. If the construction or other development within a special flood hazard area is not covered by a building permit, all other non-structural activities shall be permitted by either the Rhode Island Coastal Resources Management Council and/or the Rhode Island Department of Environmental Management as applicable.

4. Coastal Floodplain Impact Assessment

VHB model results indicate no adverse impacts to coastal floodplain associated with increased flood elevations, wave heights, wave setup, or wave runup associated with the Project. The results of the WHAFIS and TAW model runs are presented in Tables 3 and 4, respectively.

Table 3 – WHAFIS Model Results

VHB Transect No.	1	2
Peak Transect 1% Wave Crest Elevation- Existing[a] (ft)	17.78	16.91
Peak Transect 1% Wave Crest Elevation- Proposed[a] (ft)	17.78	16.91
Limit of Zone VE – Existing[a,b] (ft)	169	56
Limit of Zone VE – Proposed[a,b] (ft)	169	56
Limit of Moderate Wave Action (LiMWA) – Existing[a,b] (ft)	212	56
Limit of Moderate Wave Action (LiMWA) – Existing[a,b] (ft)	212	56
Peak Project Area 1% Wave Crest Elevation- Existing[a] (ft)	10.77	11.08
Peak Project Area 1% Wave Crest Elevation- Existing[a] (ft)	10.78	11.19
Total Water Elevation including Setup – Existing[a] (ft)	**12.1**	**11.8**
Total Water Elevation including Setup – Proposed[a] (ft)	**12.1**	**11.8**

[a] Values calculated using WHAFIS.

[b] Measured distance from shoreline.

WHAFIS model results indicate that Zone VE (representing high-hazard areas of wave height exceeding 3 feet) and the LiMWA (representing wave heights exceeding 1.5 feet) end well outside of the Project area (over 1,000 feet landward of the shoreline). Because the Project would not include any proposed work within the VE Zone, wave action from deepwater waves is predicted to be unchanged from existing conditions. The model does show a slight (up to 0.11-foot) increase in peak wave crest elevations within the Project area, which can be attributed to longer inland wave fetch distance from the removal of the existing raised bridge ramp embankments. However, wave heights in the Project area are well below the LiMWA 1.5-foot limit associated with wave damage to structures, so this increase is not sufficient to change the FEMA flood hazard zone or BFE.

Table 4 – TAW Runup Analysis Results

VHB Transect No.	1	2
Top of Seawall Elevation[a] (ft)	5.5	13.6
1% SWEL[b] (ft)	10.68	10.58
1% Deepwater Wave Height[c] (ft)	6.23	5.41
TAW Runup Height[d] (ft) - Existing	N/A	2.87
TAW Runup Height[d] (ft) - Proposed	N/A	2.87
Seawall Overtopped?	Yes	No
Total SWEL + Runup Elevation (ft)	N/A	13.45[e]

[a] Values taken from transect geometry
[b] Values interpolated from Effective FIS Transects 38 and 39
[c] Values taken from STWAVE spectral wave field
[d] Values calculated using MathCAD
[d] Elevation only applicable to seaward side of 3rd Street ridge

TAW model results similarly indicate no change under proposed conditions due to wave breaking action occurring well seaward of the Project area. Transect 1 presents a unique case in that the seawall is be completely submerged below the 1% SWEL but is still high enough to cause waves to break completely before encountering the first structure taller than the 1% SWEL – a railroad embankment located approximately 1,000 feet landward. Because there are no significant waves impacting the structure rising above the 1% SWEL, runup is not applicable for this transect. For Transect 2, the Project area is located approximately 1,000 feet landward of the seawall with a low ridge along 3rd Street that rises higher than the total runup elevation. Therefore, runup only applies to the seaward side of this ridge, and increased flood elevations due to runup do not apply to the landward side of the ridge where the Project area is located. Because the Project would not include any proposed work near these seawalls, the proposed conditions are predicted to be unchanged from existing conditions.

The results from the CHAMP model analysis and proposed grading topography were compiled to predict proposed condition SFHAs for the Project to compare to existing conditions. Using the CHAMP model results for VHB Transects 1 and 2, VHB delineated the inundation area corresponding to the 1% Floodplain in the study area for both existing and proposed conditions. Because model results indicate that storm surge along Transect 2 would not overtop the low ridge along 3rd Street, VHB used Transect 1 results to map the inundation area. Figures 3 and 4 depict the resulting inundation areas for existing and proposed conditions, respectively.

Modeling confirms that all Project work is beyond the landward limit of breaking waves, zone of wave action (Zone VE), and zone of moderate wave action (LiMWA). Furthermore, the model results demonstrate that the Proposed Action would not change storm surge elevations, wave setup, or wave runup elevations in the study area. Therefore, coastal flooding WSEs would remain unchanged and the only Project impact to the 1% Floodplain would be revised inundation areas due to the proposed changes in topography. Table 5 below presents a summary of the changes to the 1% Floodplain within the limit of disturbance for the Project:

Table 5 – Summary of Coastal Floodplain Impacts

Scenario	Existing Conditions	Proposed Buildout
Area of 1% Floodplain (acres) [a]	44.4	51.6

[a] Values calculated within the Project limit of disturbance

Changes in proposed grading within the Project area result in approximately 6.0 acres being removed from the floodplain, and approximately 13.2 acres being added to the floodplain. The area added is primarily due to removing the raised embankment carrying the existing Pell Bridge roadway approach ramps; roadway elevations range from 12 to 26 feet NAVD88 under existing conditions, but the surrounding area is almost entirely below the BFE. The additional transit improvements to the JC Connell Highway and Americas Cup Avenue outside of the primary study area have no associated proposed changes to grading and will not result in any change to the floodplain.

In addition to roadway improvements, the Project would make parcels of land between the new Pell Bridge Interchange available for redevelopment. VHB has included potential redevelopment of these parcels as part of this floodplain analysis. Because there is no specific design plan in place for the new development parcels created by the Project, VHB calculated proposed floodplain areas by assuming flat parcel grading for parcels set at the same elevation as the surrounding roadway. Site-specific grading for these parcels could be raised by fill to move these areas out of the 1% Floodplain. VHB estimates that approximately 15 acres of the intermediate areas between proposed roadways could feasibly be raised above the BFE of 12 feet NAVD88, resulting in a net reduction of the 1% Floodplain within the Project area.

5. Cumulative Impacts and Indirect Effects

Model results indicate no predicted change in the BFE associated with the Project. The direct floodplain impact of the Project will be limited to changing the area inundated by the 1% Floodplain within the limit of disturbance due to proposed Project grading.

Increased sea levels and greater storm intensity associated with climate change present potential for cumulative floodplain impacts. Increased storm rainfall intensity would result in greater riverine flooding associated with the unnamed stream flowing through the Project area, and this could be exacerbated by increased impervious cover and fill from parcel development. However, the flood elevations and extents associated with the unnamed stream are negligible compared to coastal flooding, and this would not be predicted to have a cumulative impact on the 1% Floodplain.

Future increases in sea levels will exacerbate coastal flooding by raising stillwater elevations, increasing the area of the 1% Floodplain. Similar to existing conditions, the Project is not predicted to have a cumulative effect on flood elevations from sea level rise, but the specific area inundated will be affected by proposed grading within the limit of disturbance.

As a consequence of sea level rise, higher stillwater elevations will submerge more coastal during coastal flood events and the effects of breaking wave action and wave setup will extend further inland. Modeling indicates that the limits of significant wave action (Zone VE) and moderate wave action (LiMWA) will remain seaward of the Project area, but wave setup effects will propagate further into the Project area. The existing raised embankment carrying the Pell Bridge approach ramp serves as a barrier against wave setup propagating further eastward, but this embankment would be removed under proposed Project grading. The cumulative impact of sea level rise with the removal of this barrier could result in higher future coastal flood elevations east of Route 138.

Additionally, warmer water temperatures in the Atlantic Ocean could lead to more severe storm events than the scenario analyzed in the FEMA FIS and this memo. This technical memo does not analyze any of these climate change scenarios in detail; please refer to the VHB Climate Change technical memorandum for further discussion of climate change impacts.

The majority of the Project area is located within the existing 1% Floodplain, but development is restricted by the alignment of the Pell Bridge access ramp. By opening more land to development, the Project could have an indirect effect of increasing the flood risk liability of the City of Newport. More development and infrastructure within the 1% Floodplain would place a greater burden on emergency services during and after a coastal flooding event, and would increase the costs to repair damaged infrastructure following the event.

Please note that without a specific design plan in place for the new development parcels created by the Project, this memorandum assumes flat parcel grading set at the same elevation as the surrounding roadway. The impacts and effects listed in this section can all be mitigated or reduced within the development parcels by designing site grading, building floor elevations, and utility infrastructure to provide adequate freeboard above the current and predicted future BFE.

6. Mitigation

The majority of the Project area is located within the existing 1% Floodplain, and under proposed grading conditions a majority of the Project area will remain within the 1% Floodplain. However, because there is no specific design plan in place for the new development parcels created by the Project, VHB calculated proposed floodplain areas by assuming flat parcel grading for parcels set at the same elevation as the surrounding roadway. VHB recommends that future development mitigate the flood risk by following best design practices and floodplain construction requirements set by the Newport Flood Hazard Area Development Ordinance, the Rhode Island State Building Code, the Rhode Island Coastal Resources Management Council, and FEMA. Flood risk can all be mitigated or reduced within the development parcels by designing site grading, building floor elevations, and utility infrastructure to provide adequate freeboard above the current and predicted future 1% Floodplain elevation. Development parcels can be removed from the 1%

Floodplain by placing fill to raise proposed grades above the 1% Floodplain elevation, thereby reducing the net change in floodplain area.

As noted in Section 4, modeling indicates that there would be no predicted increase in the 1% Floodplain elevation associated with the Project. Because the floodplain within the study area is associated with coastal flooding and not riverine flooding, any gain or loss of floodplain storage has no effect on flood elevations for adjacent properties. Therefore, no compensatory floodplain storage mitigation is required.

Model results do indicate a slight (up to 0.11-foot) increase in wave heights during a coastal flooding event within the Project area. This increase is due to removal of the existing raised Pell Bridge approach ramp embankments creating a larger open area of water and corresponding increased inland fetch length for wave generation. However, the proposed model does not account for any wind breaks created by new building or landscaping within the newly-opened Project area. VHB recommends that proposed development within the new parcels of the Project Area incorporate building construction and landscaping design to provide wind and wave breaks.

7. Regulatory Coordination and Required Permits

Any future building development in the Project area within the 1% Floodplain would require a building permit from the City of Newport, and would be subject to the Use Regulations listed in Chapter 15.24.040 of the City of Newport Code of Ordinances. In addition, any future building development within the 1% Floodplain will require submittal to the CMRC demonstrating that all applicable portions of the RISBC and specifically RISBC-8 are met.

EO 11988 requires public notification documentation supporting efforts to minimize adverse effects for federally-supported projects located within the 1% Floodplain. The NEPA public review process and this Environmental Assessment study satisfies this requirement.

The City of Newport is a participating community in the NFIP. Given the anticipated changes to the delineated extents of the Zone AE floodplain resulting from proposed grading, VHB recommends coordinating with the local City of Newport Floodplain Administrator. The City and/or the developer of new parcels in the Project Area may want to apply for a Letter of Map Revision (LOMR) to update floodplain maps to better reflect the actual horizontal limits of the 1% Floodplain, especially if individual parcel grading would raise new construction above the 1% BFE.

The Project crosses the jurisdictional boundary of the Aquidneck Island SAMP. Per Rule 3.03 of the 2007 RIDEM Fresh Water Wetlands Act Rules and Regulations, the CMRC and DEM will make a joint determination of which agency will serve as the freshwater wetland review agency. Depending on the result of this determination, either an Application to Alter a Freshwater Wetland will need to be filed with the RIDEM or an Application to Alter Freshwater Wetlands in the Vicinity of the Coast Application Package will need to be filed with the CRMC. Refer to the Wetlands and Waterways technical memorandum for a detailed review of this permit.

8. Conclusions

The current Effective FEMA FIS for Newport County estimates 1% Floodplain elevations and areas by interpolating between two coastal transect models located outside of the primary Project area, and as such does not reflect the distinct coastal flooding behavior within the Pell Bridge Interchange area. VHB performed a site-specific analysis using the same methodology as the Effective FIS to evaluate floodplain elevations in the Project area, evaluating both existing and proposed buildout conditions to estimate the impact of the Project on the 1% Floodplain. A summary of the model results comparing the Effective FIS study, existing conditions, and proposed buildout conditions is presented in Table 6.

Table 6 – Summary of Coastal Floodplain Analysis[a]

Scenario	Effective FIS[b]	Existing Conditions	Proposed Buildout
1% Stillwater Elevation (SWEL)	10.58 to 10.68	10.58	10.58
1% Total Water Elevation (including setup)	12.9 to 13.4	12.1	12.1
BFE[c]	12 to 13	12	12
Area of 1% Floodplain (acres) [d]	44.4	44.4	51.6

[a] All elevations are referenced to NAVD88

[b] Because the Effective FIS interpolates between transects outside of the study area to estimate conditions, elevations vary across the study area

[c] NFIP mapping policy rounds BFEs to the nearest whole foot.

[d] Values calculated within the Project limit of disturbance

Model results indicate similar to but slightly lower flood elevations than the FIS, and show no adverse impacts to coastal flood elevations as a result of the Project. Therefore, no mitigation is required to address flood elevations. A significant portion of the Project area is located within the 1% Floodplain under existing conditions. Re-grading associated with relocated roadways and removal of the existing raised bridge approach embankments new development is predicted to result in a net increase of approximately 7.2 acres of the area inundated by 1% Floodplain area. The majority of the future development parcels are located within the 1% Floodplain, and future development will need to follow best practices for construction within flood-prone areas. Flood risk can be mitigated or reduced by designing site grading, building floor elevations, and utility infrastructure to provide adequate freeboard above the current and predicted future BFE. Development parcels can be removed from the 1% Floodplain by placing fill to raise proposed grades above the 1% Floodplain elevation, mitigating the net increase in floodplain area.

Depending on development of the parcels, future sea level changes due to climate change may have cumulative effects on coastal flooding elevations and wave propagation. Development should consider future sea level rise when addressing flood risk mitigation.

9. Figures and Appendices

March 14, 2019 | **FIGURE 1**

\\vhb\gbl\proj\Providence\72900.00\graphics\FIGURES\Tech Memo\March 2019\B5 - EA Technical Studies Memo - Floodplains\Figure1_StudyArea.mxd

0 500 1000 2000 Feet

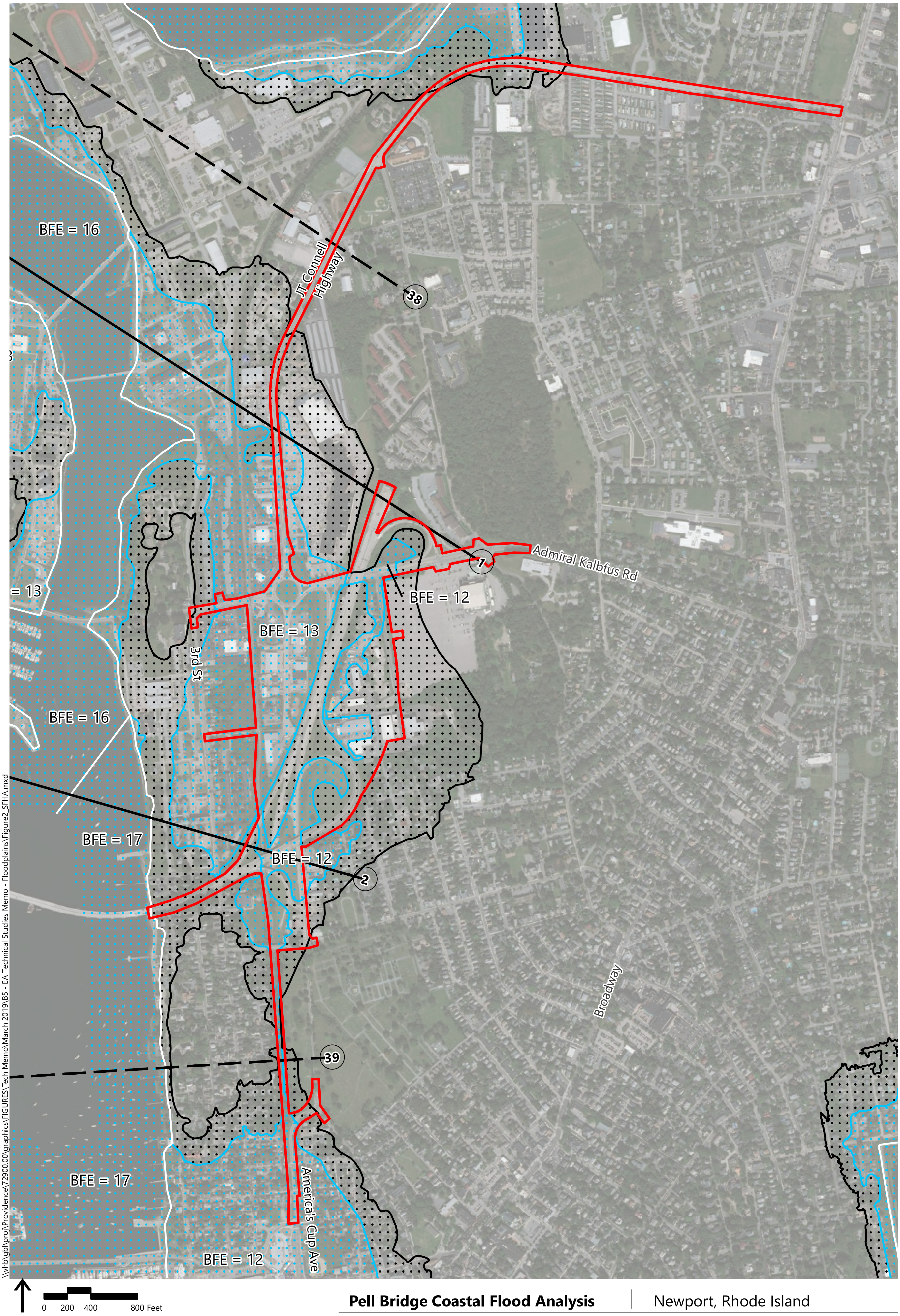
Pell Bridge Coastal Flood Analysis | Newport, Rhode Island

- VHB Transect
- FEMA Transect
- 🟥 Project Study Area
- ☐ Town Boundary

Study Area

Source Info: RIGIS, ESRI World Imagery
FEMA, VHB

March 15, 2019 | **FIGURE 2**



\\vhb\gbl\proj\Providence\72900.00\graphics\FIGURES\Tech Memo\March 2019\B5 - EA Technical Studies Memo - Floodplains\Figure2_SFHA.mxd

Pell Bridge Coastal Flood Analysis | Newport, Rhode Island

— VHB Transect

– – FEMA Transect

▭ Project Study Area

Special Flood Hazard Areas

⁘ Zone VE

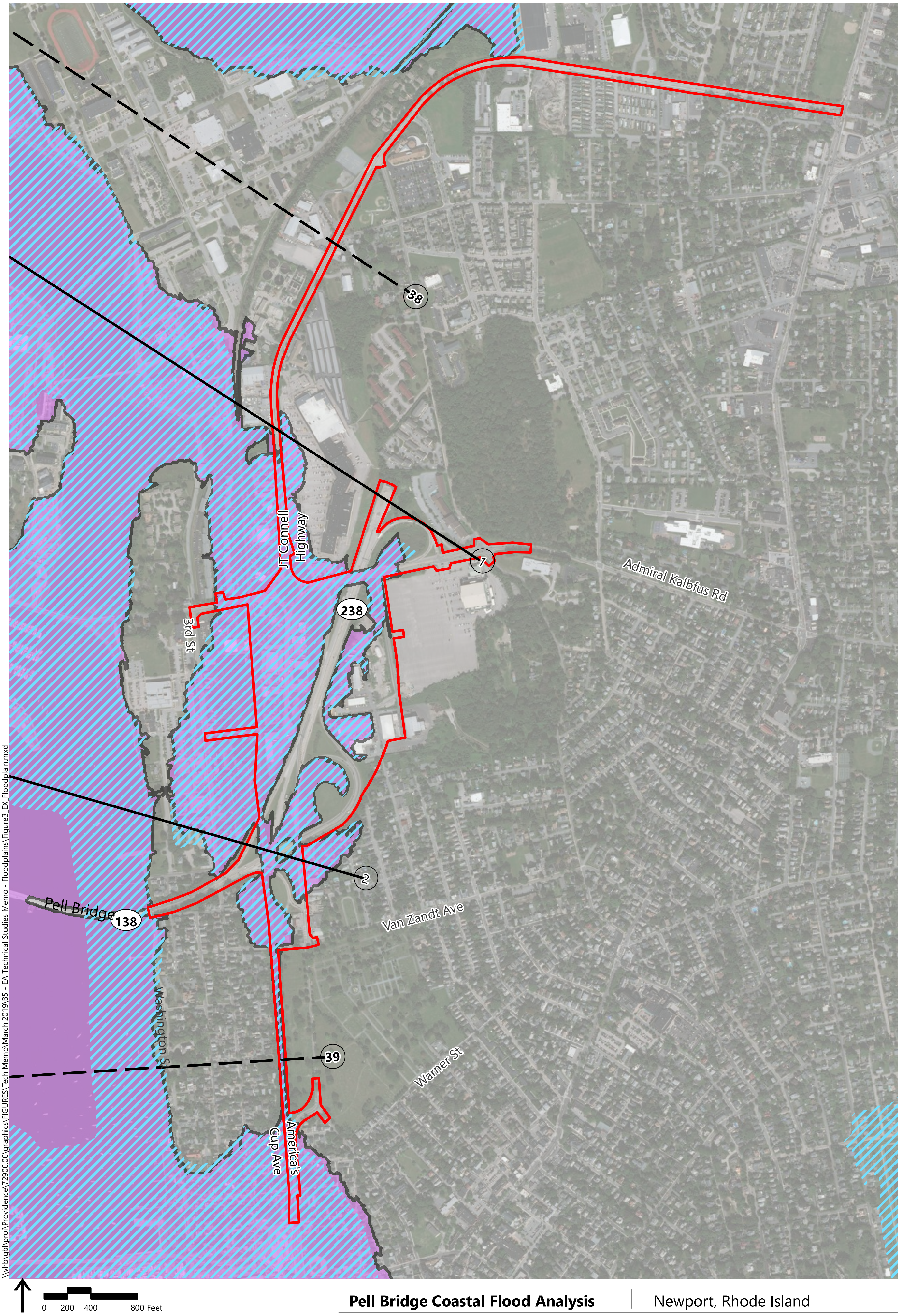
▨ Zone AE

⁘ Areas of 0.2% chance flood

☐ Zone X

Special Flood Hazard Areas

Source Info: ESRI World Imagery
FEMA, VHB



\\vhb\gbl\proj\Providence\72900.00\graphics\FIGURES\Tech Memo\March 2019\B5 - EA Technical Studies Memo - Floodplains\Figure3_EX_Floodplain.mxd

Pell Bridge Coastal Flood Analysis | Newport, Rhode Island

— VHB Transect

– – FEMA Transect

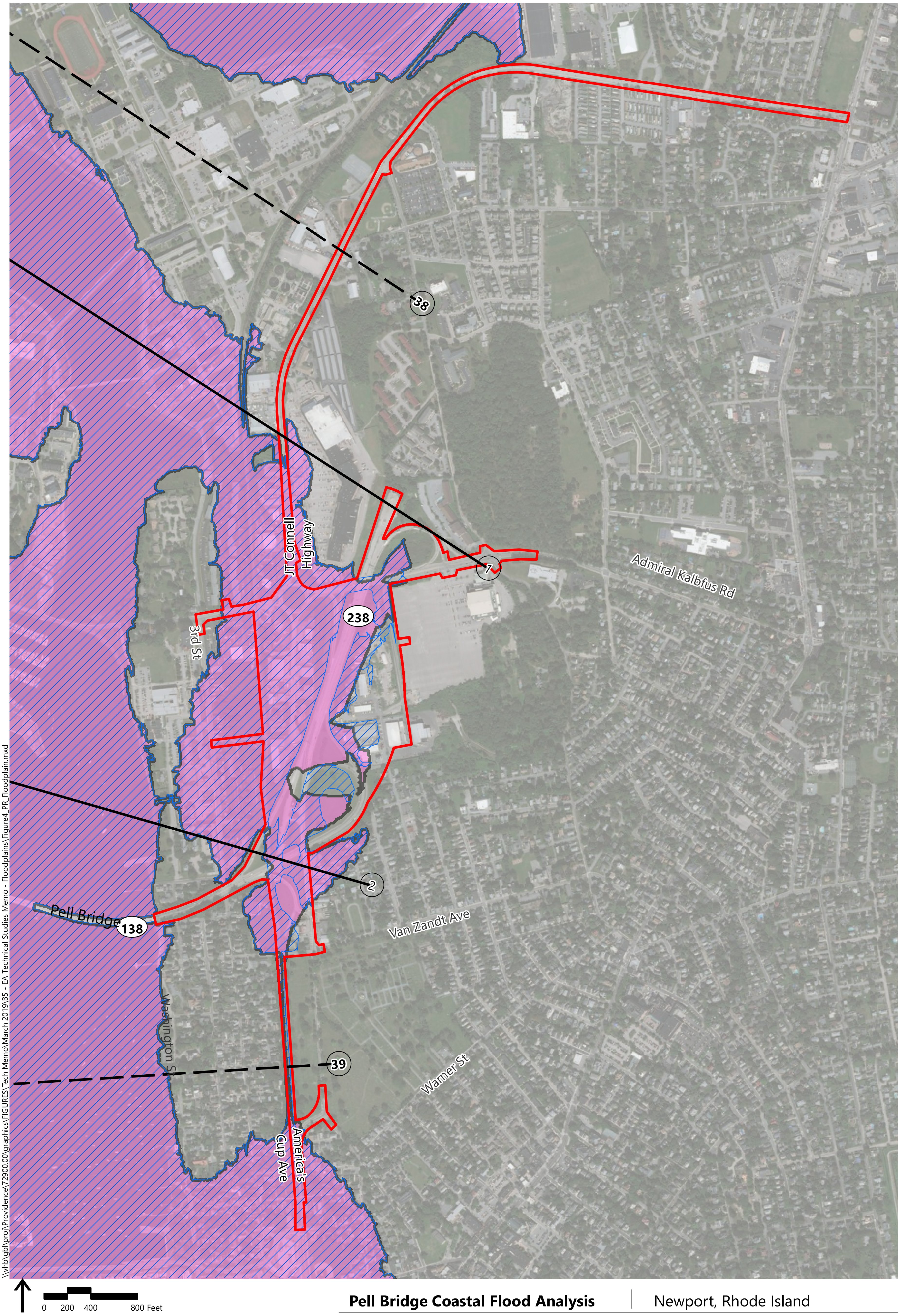
🟥 Project Study Area

▨ Existing VHB 1% Floodplain

▨ Effective FIS 1% Floodplain (Zones VE and AE)

Existing Conditions - 1% Floodplain

Source Info: ESRI World Imagery
FEMA, VHB



Pell Bridge Coastal Flood Analysis | Newport, Rhode Island

— VHB Transect

– – FEMA Transect

▭ Project Study Area

▨ Existing VHB 1% Floodplain

■ Proposed Floodplain

Proposed Conditions - 1% Floodplain

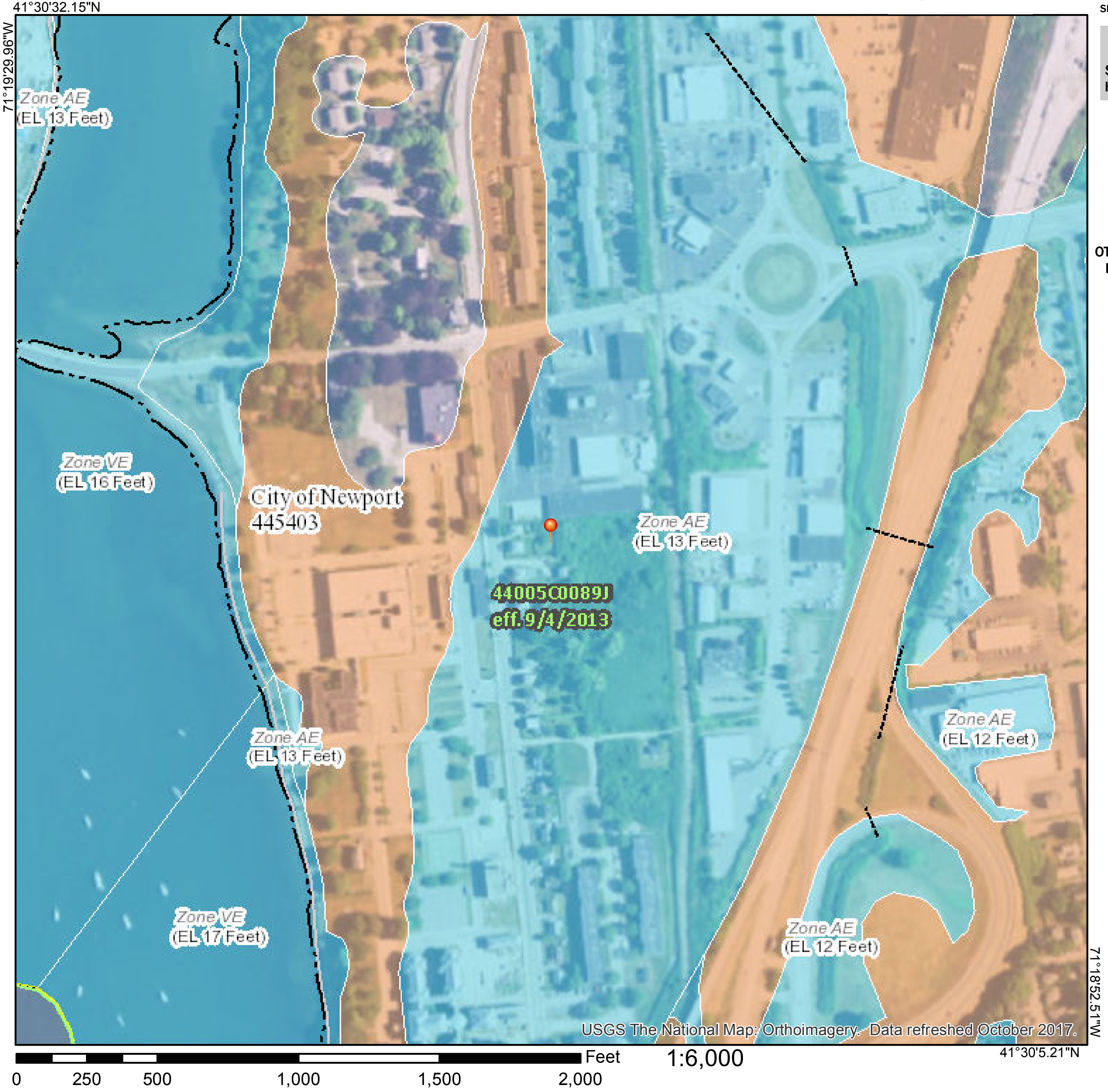
Source Info: ESRI World Imagery
FEMA, VHB

\\vhb\gbl\proj\Providence\72900.00\graphics\FIGURES\Tech Memo\March 2019\B5 - EA Technical Studies Memo - Floodplains\Figure4_PR_Floodplain.mxd

Appendix A
Effective FEMA FIS and FIRM Excerpts

National Flood Hazard Layer FIRMette

FEMA



Legend

SEE FIS REPORT FOR DETAILED LEGEND AND INDEX MAP FOR FIRM PANEL LAYOUT

SPECIAL FLOOD HAZARD AREAS	■	Without Base Flood Elevation (BFE) *Zone A, V, A99* With BFE or Depth *Zone AE, AO, AH, VE, AR*
	▨	Regulatory Floodway
OTHER AREAS OF FLOOD HAZARD	■	0.2% Annual Chance Flood Hazard, Areas of 1% annual chance flood with average depth less than one foot or with drainage areas of less than one square mile *Zone X*
	▨	Future Conditions 1% Annual Chance Flood Hazard *Zone X*
	▨	Area with Reduced Flood Risk due to Levee. See Notes. *Zone X*
	▨	Area with Flood Risk due to Levee *Zone D*
OTHER AREAS	NO SCREEN	Area of Minimal Flood Hazard *Zone X*
	☐	Effective LOMRs
	■	Area of Undetermined Flood Hazard *Zone D*
GENERAL STRUCTURES	— — —	Channel, Culvert, or Storm Sewer
	❘❘❘❘❘❘❘	Levee, Dike, or Floodwall
OTHER FEATURES	B 20.2 17.5	Cross Sections with 1% Annual Chance Water Surface Elevation
	8 — —	Coastal Transect
	513	Base Flood Elevation Line (BFE)
	—	Limit of Study
	—	Jurisdiction Boundary
	--- ---	Coastal Transect Baseline
	—	Profile Baseline
	—	Hydrographic Feature
MAP PANELS	☐	Digital Data Available
	☐	No Digital Data Available
	☒	Unmapped

N

The pin displayed on the map is an approximate point selected by the user and does not represent an authoritative property location.

This map complies with FEMA's standards for the use of digital flood maps if it is not void as described below. The basemap shown complies with FEMA's basemap accuracy standards

The flood hazard information is derived directly from the authoritative NFHL web services provided by FEMA. This map was exported on 11/12/2018 at 1:23:51 PM and does not reflect changes or amendments subsequent to this date and time. The NFHL and effective information may change or become superseded by new data over time.

This map image is void if the one or more of the following map elements do not appear: basemap imagery, flood zone labels, legend, scale bar, map creation date, community identifiers, FIRM panel number, and FIRM effective date. Map images for unmapped and unmodernized areas cannot be used for regulatory purposes.

FLOOD INSURANCE STUDY

NEWPORT COUNTY, RHODE ISLAND

(ALL JURISDICTIONS)

COMMUNITY NAME	COMMUNITY NUMBER
JAMESTOWN, TOWN OF	445399
LITTLE COMPTON, TOWN OF	440035
MIDDLETOWN, TOWN OF	445401
NEWPORT, CITY OF	445403
PORTSMOUTH, TOWN OF	445405
TIVERTON, TOWN OF	440012

Revised:
September 4, 2013

U.S. DEPARTMENT OF HOMELAND SECURITY

Federal Emergency Management Agency

FLOOD INSURANCE STUDY NUMBER
44005CV000B

For the 2010 countywide study, floodplains within the Town of Middletown for coastal areas, as well as for Maidford River and Bailey Brook, were redelineated using updated topographic data provided to FEMA by Town of Middletown Geographic Information Systems (GIS). This work was done for FEMA by Dewberry (the study contractor) under FEMA Contract No. HSFE01-07-D-0037, Task Order 0001 in 2008. The coastal and riverine floodplain redelineation effort was performed using the information contained in the previously published FIRMs and FIS report. No new analyses was performed to define the coastal special flood hazard areas.

Base map information shown on the 2010 countywide study FIRM panels was provided by the Rhode Island Geographic Information System (RI GIS). This information was derived from digital orthophotos produced at a scale of 1:5,000 with 2-foot Ground Sample Distance (GSD) from photography dated April 2003 (Reference 2).

The coordinate system used for the production of FIRM panels for the 2010 study was Rhode Island State Plane, FIPSZONE 3800, North American Datum of 1983 (NAD 83), GRS80 spheroid. Corner coordinates shown on the FIRM are in latitude and longitude referenced to the UTM projection, NAD 83. Differences in the datum, spheroid, projection or State Plane zones used in the production of FIRMs for adjacent counties may result in slight positional differences in map features at the county boundaries. These differences do not affect the accuracy of information shown on the FIRM.

The coastal wave height analysis for this coastal study was prepared by the Strategic Alliance for Risk Reduction (STARR) for FEMA under Contract No. HSFEHQ-09-D-0370 and completed in July 2011. This new analysis resulted in revisions to the Special Flood Hazard Areas (SFHAs) within the Towns of Jamestown, Little Compton, Middletown, Portsmouth, Tiverton, and City of Newport.

Base map information shown on the FIRM panels produced for this coastal study revision was derived from USGS High Resolution orthophotography dated spring of 2011, produced at six inch resolution. The horizontal datum used was North American Datum of 1983 (NAD 83) (Reference 3).

1.3 Coordination

Consultation Coordination Officer's (CCO) meetings may be held for each jurisdiction in this countywide FIS. An initial CCO meeting is held typically with representatives of FEMA, the community, and the study contractor to explain the nature and purpose of a FIS, and to identify the streams to be studied by detailed methods. A final CCO meeting is held typically with representatives of FEMA, the community, and the study contractor to review the results of the study.

Prior to this countywide FIS, the dates of the initial and final CCO meetings held for all jurisdictions within Newport County are shown in Table 1, "Initial and Final CCO Meetings."

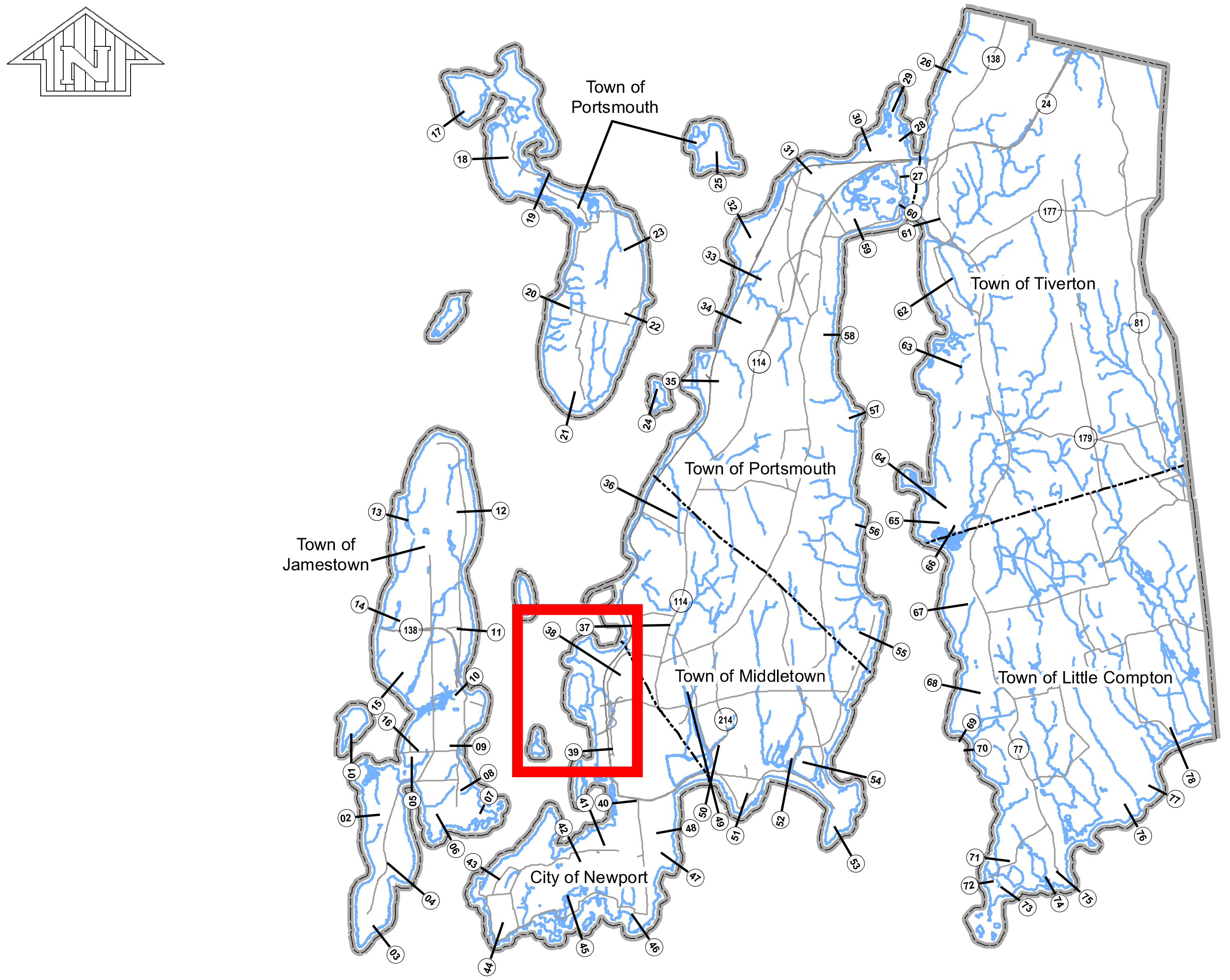


FIGURE 2

FEDERAL EMERGENCY MANAGEMENT AGENCY

NEWPORT COUNTY, RI

(ALL JURISDICTIONS)

APPROXIMATE SCALE

0 7,500 15,000 30,000 45,000 60,000 Feet

TRANSECT LOCATION MAP

TABLE 9 - TRANSECT DATA – continued

Flooding Source and Transect Number	Stillwater Elevation				Total Water Level[1]		Base Flood Elevation (Feet NAVD 88)[2]
	10-percent-annual-chance	2-percent-annual-chance	1-percent-annual-chance	0.2-percent-annual-chance	1-percent-annual-chance	Zone	
NARRAGANSETT BAY - continued							
Transect 36	5.7	8.9	11.3	21.3	13.2	VE	16
						AE	13
Transect 37	5.4	8.5	10.8	20.4	13.4	VE	16
						AE	14
Transect 38	5.4	8.4	10.7	20.2	13.4	VE	16
						AE	13
Transect 39	5.3	8.3	10.5	19.8	12.9	VE	17
						AE	12-13
Transect 40	5.3	8.3	10.5	19.8	10.8	VE	13
						AE	12
Transect 41	5.3	8.3	10.5	19.8	11.2	VE	13
						AE	12
Transect 42	5.3	8.3	10.5	19.8	12.1	VE	17
						AE	12
Transect 43	5.3	8.3	10.5	19.8	16.9	VE	26
						AE	17
MOUNT HOPE BAY							
Transect 26	6.2	9.7	12.3	23.2	13.8	VE	20-22
						AE	*
Transect 29	6.2	9.6	12.2	23.1	13.8	VE	18
						AE	14
Transect 30	6.1	9.5	12.1	22.9	13.0	VE	15
						AE	13-14
Transect 31	6.1	9.5	12.0	22.8	14.8	VE	20
						AE	13
RHODE ISLAND SOUND							
Transect 3	5.2	8.2	10.4	19.6	15.6	VE	24-30
						AE	*
Transect 4	5.3	8.3	10.5	19.8	17.3	VE	17-30
						AE	15

[1] Including stillwater elevation and effects of wave setup.

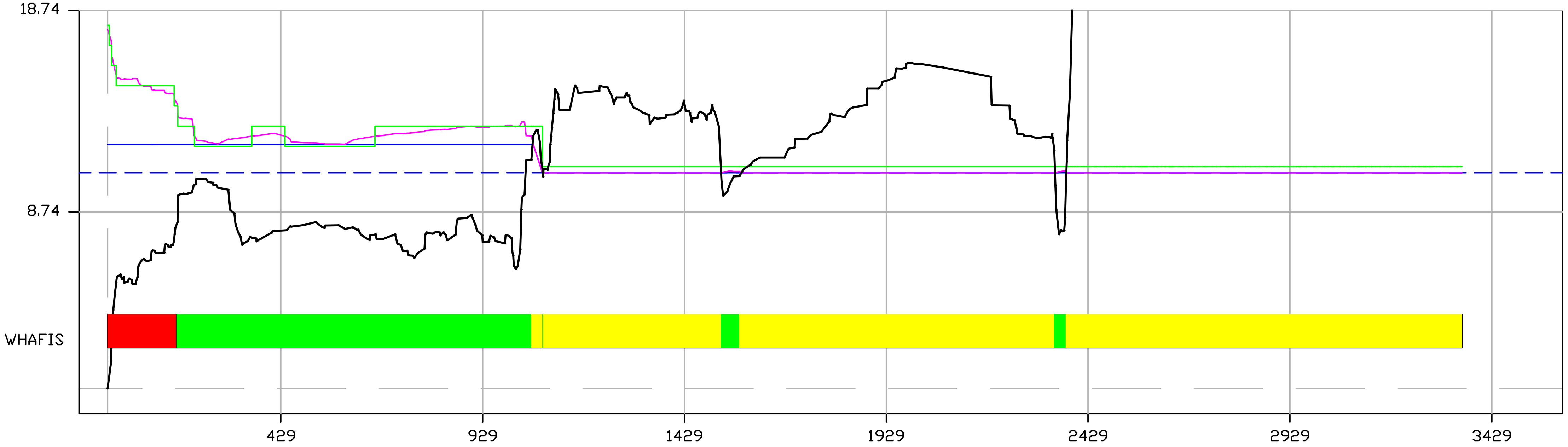
[2] Because of map scale limitations, base flood elevations shown on the FIRM represent average elevations for the zones depicted.

* Data not available

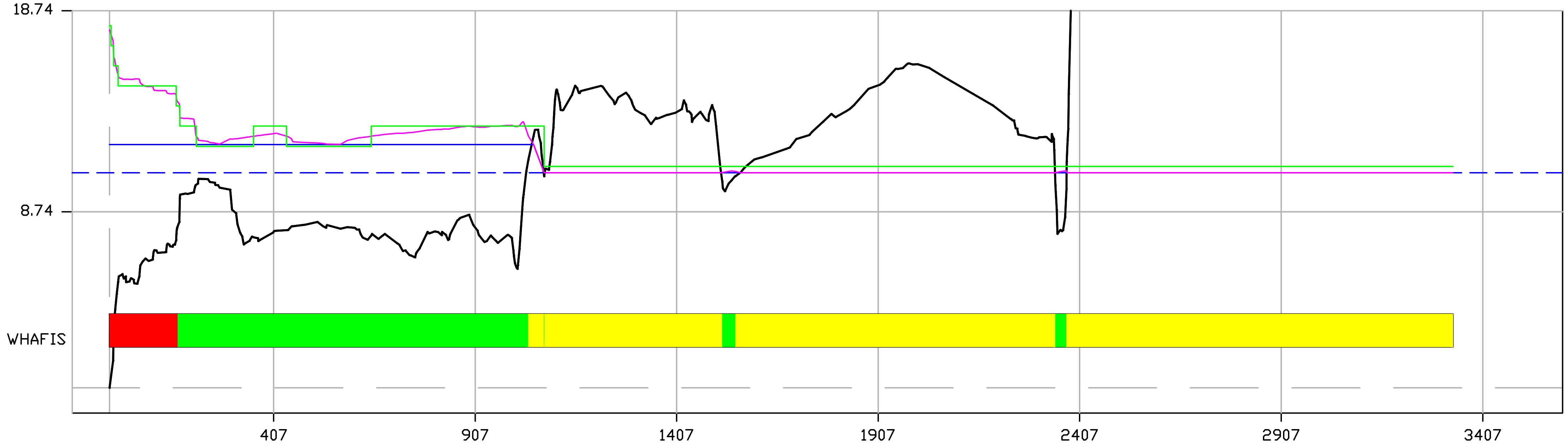
Appendix B

VHB Coastal Transect Analysis: Calculations, Model Inputs, and Model Results

EXISTING PROFILE



PROPOSED PROFILE



LEGEND

🟥 ZONE VE - AREA INUNDATED BY THE 1% ANNUAL-CHANCE FLOOD EVENT ADDITIONAL HAZARDS DUE TO STORM INDUCED VELOCITY WAVE ACTION

🟩 ZONE AE - AREA INUNDATED BY THE 1% ANNUAL-CHANCE FLOOD EVENT

🟨 ZONE X - AREA ABOVE THE 1% ANNUAL-CHANCE FLOOD EVENT

– – – 100 YEAR STILL WATER ELEVATION

— WHAFIS CREST

— WHAFIS STEPS

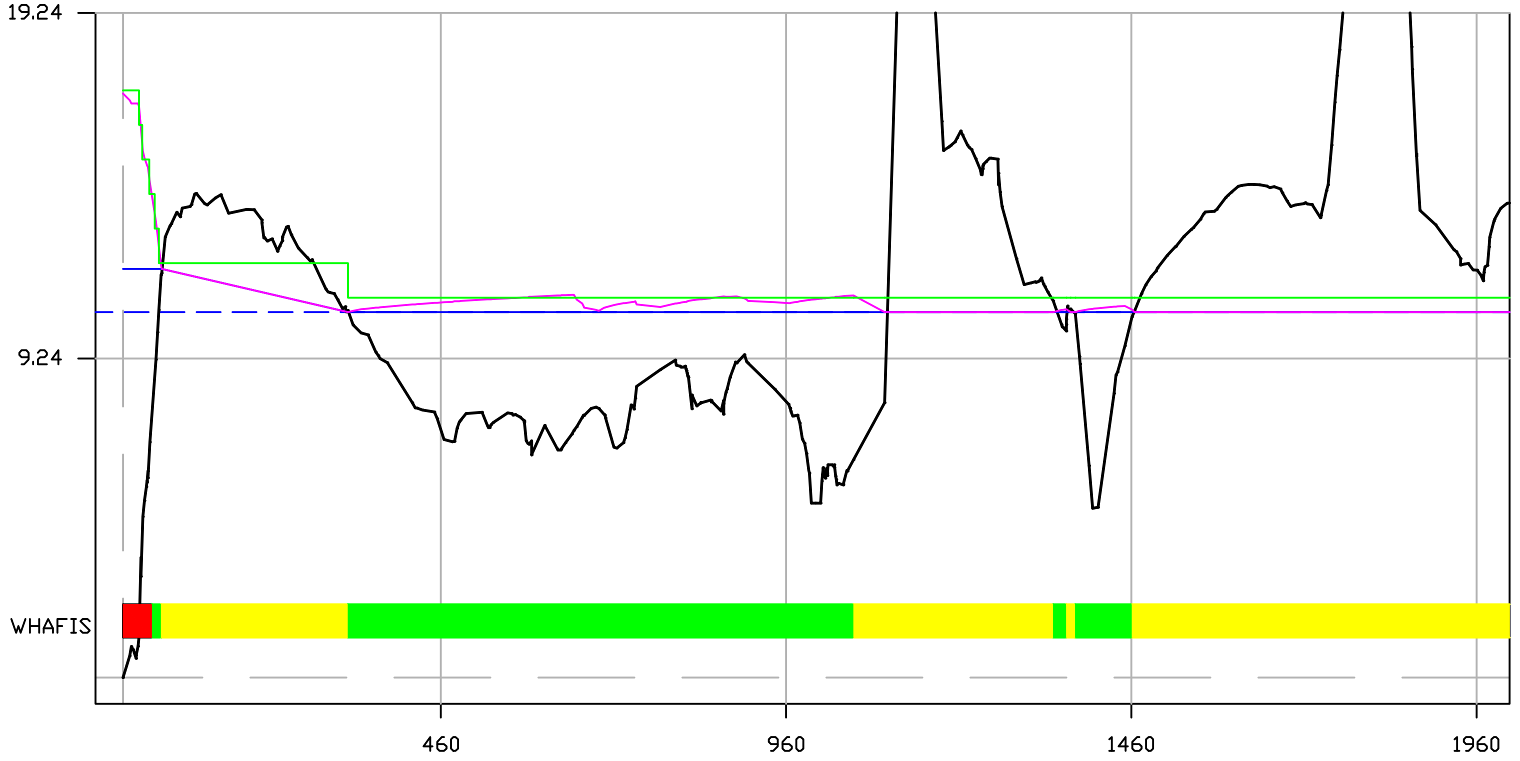
— WHAFIS STILL WATER

— TRANSECT GROUND SURFACE

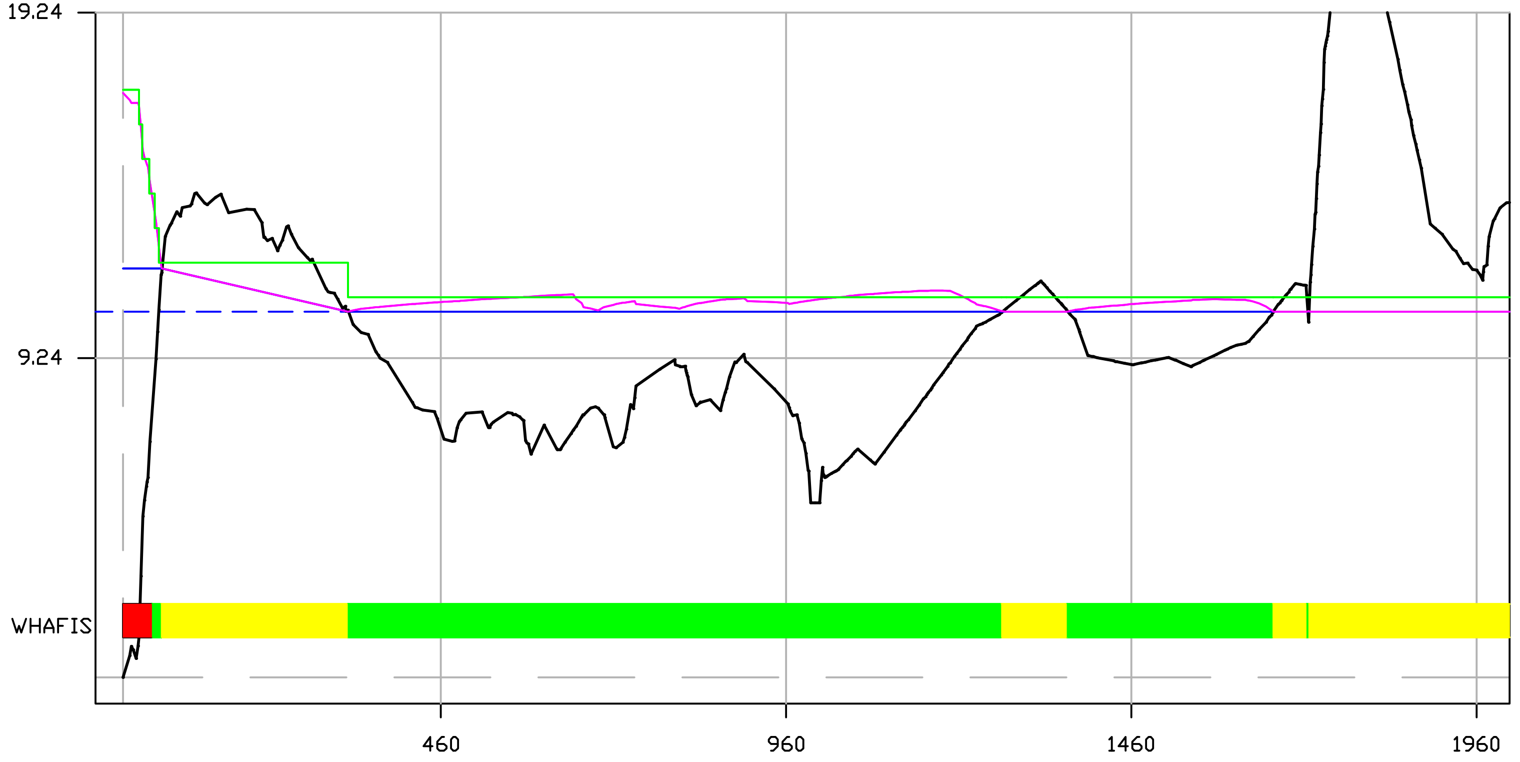
Pell Bridge Coastal Flood Analysis
Newport, RI
VHB Transect 1
Existing & Proposed Profiles

Nov. 2018

EXISTING PROFILE



PROPOSED PROFILE



LEGEND

🟥 ZONE VE - AREA INUNDATED BY THE 1% ANNUAL-CHANCE FLOOD EVENT ADDITIONAL HAZARDS DUE TO STORM INDUCED VELOCITY WAVE ACTION
🟩 ZONE AE - AREA INUNDATED BY THE 1% ANNUAL-CHANCE FLOOD EVENT
🟨 ZONE X - AREA ABOVE THE 1% ANNUAL-CHANCE FLOOD EVENT
– – – 100 YEAR STILL WATER ELEVATION
— WHAFIS CREST
— WHAFIS STEPS
— WHAFIS STILL WATER
— TRANSECT GROUND SURFACE

Pell Bridge Coastal Flood Analysis
Newport, RI
VHB Transect 2
Existing & Proposed Profiles

Nov. 2018

Pell Bridge EA Floodplain Tech Memo
CHAMP-WHAFIS Model Inputs - Transect 1, Existing Conditions
November 12, 2018

Station	Elevation	WHAFIS Card	Total 1% SWEL	Total 10% SWEL	CM	PS
0	0.00	IE	12.09	0		
9	1.35	IF				
10	3.19	IF				
12	3.45	IF				
14	3.88	IF				
18	4.66	IF				
21	5.25	IF				
23	5.53	IF				
31	5.62	IF				
32	5.65	IF				
35	5.42	IF				
40	5.53	IF				
41	5.24	IF				
49	5.28	IF				
53	5.45	IF				
60	5.37	IF				
61	5.19	IF				
69	5.17	IF				
74	5.53	IF				
76	6.07	IF				
82	6.28	IF				
89	6.42	IF				
97	6.30	IF				
107	6.36	IF				
109	6.76	IF				
111	6.84	IF				
116	6.83	IF				
119	6.70	IF				
140	6.73	IF				
142	7.11	IF				
144	7.16	IF				
148	7.12	IF				
150	7.03	IF				
152	7.03	IF				
156	7.01	IF				
158	7.11	IF				
162	7.11	IF				
165	7.34	IF				
166	7.65	IF				
167	7.90	IF				
168	7.98	IF				

173	8.24	IF				
174	9.39	IF				
175	9.59	IF				
180	9.62	IF				
184	9.63	IF				
188	9.65	IF				
193	9.63	IF				
209	9.71	IF				
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213	10.06	BU				
214	10.08	BU				
219	10.14	BU				
220	10.38	BU				
244	10.37	BU				
249	10.22	BU				
261	10.19	BU				
262	10.08	BU				
269	10.07	BU				
273	9.94	BU				
299	9.84	IF				
304	8.84	IF				
314	8.67	IF				
317	8.13	IF				
324	7.70	IF				
329	7.52	IF				
333	7.12	IF				
338	7.20	IF				
347	7.30	IF				
353	7.51	IF				
359	7.46	IF				
368	7.43	IF				
369	7.29	IF				
372	7.33	IF				
379	7.41	IF				
406	7.71	IF				
408	7.79	IF				
409	7.80	IF				
414	7.80	IF				
443	7.84	BU				
452	8.03	BU				
453	8.03	BU				
455	8.02	BU				
486	8.10	BU				
516	8.24	BU				

530	8.02	BU				
537	7.95	BU				
539	8.07	BU				
572	8.08	BU				
588	7.90	BU				
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608	7.95	IF				
612	7.94	IF				
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621	7.87	IF				
627	7.63	IF				
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1571	10.68	AS				
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2348	10.06	IF				

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2370	7.83	IF				
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2374	9.89	IF				
2376	10.68	AS				
3528	10.68	AS				
3533	10.68	ET				

Pell Bridge EA Floodplain Tech Memo
CHAMP-WHAFIS Model Inputs - Transect 1, Proposed Conditions
November 12, 2018

Station	Elevation	WHAFIS Card	Total 1% SWEL	Total 10% SWEL	CM	PS
0	0.00	IE	12.09	0		
9	1.35	IF				
10	3.19	IF				
12	3.45	IF				
14	3.88	IF				
18	4.66	IF				
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23	5.53	IF				
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168	7.98	IF				

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188	9.65	IF				
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Pell Bridge EA Floodplain Tech Memo
CHAMP-WHAFIS Model Inputs - Transect 1, Proposed Conditions
November 12, 2018

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996	7.49	IF				
998	7.44	IF				
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1010	5.96	IF				
1012	5.91	IF				
1013	6.09	IF				
1017	6.90	IF				
1024	8.87	IF				
1026	9.45	IF				
1027	9.61	IF				
1034	10.75	IF				
1039	11.32	IF				
1054	12.09	AS				
1077	10.68	AS	10.68			
1079	10.50	IF				
1081	10.68	AS				
1520	10.68	AS				
1522	9.90	IF				
1527	9.76	IF				
1536	10.15	IF				
1543	10.30	IF				
1552	10.51	IF				
1553	10.52	IF				
1566	10.68	AS				
2347	10.68	AS				
2350	8.83	IF				
2352	7.64	IF				
2359	7.85	IF				

Pell Bridge EA Floodplain Tech Memo
CHAMP-WHAFIS Model Inputs - Transect 1, Proposed Conditions
November 12, 2018

2363	7.78	IF				
2366	7.83	IF				
2371	8.47	IF				
2374	9.89	IF				
2376	10.68	AS				
3528	10.68	AS				
3533	10.68	ET				

Pell Bridge EA Floodplain Tech Memo
CHAMP-WHAFIS Model Results - Transect 1, Existing Conditions
November 12, 2018

STATION BEGIN	ELEVATION BEGIN	STATION END	ELEVATION END	ZONE	ZONE ELEVATION	FHF
0	17.78	4	17.5	V29	18	190
4	17.5	10	16.5	V29	17	190
10	16.5	21	15.5	V29	16	190
21	15.5	165	14.5	V29	15	190
165	14.5	169	14.19	V29	14	190
169	14.19	174	13.5	A21	14	110
174	13.5	215	12.5	A21	13	110
215	12.5	357	12.5	A21	12	110
357	12.5	439	12.5	A21	13	110
439	12.5	662	12.5	A21	12	110
662	12.5	1050	12.51	A21	13	110
1050	12.51	1054	12.09	X	13	110
1054	12.09	1077	10.68	X	13	110
1077	10.68	1079	10.7	A21	11	110
1079	10.7	1080	10.68	X	11	110
1080	10.68	1519	10.68	X	11	110
1519	10.68	1565	10.75	A21	11	110
1565	10.75	1571	10.68	X	11	110
1571	10.68	2345	10.68	X	11	110
2345	10.68	2374	10.78	A21	11	110
2374	10.78	2376	10.68	X	11	110
2376	10.68	3528	10.68	X	11	110

Pell Bridge EA Floodplain Tech Memo
CHAMP-WHAFIS Model Results - Transect 1, Proposed Conditions
November 12, 2018

STATION BEGIN	ELEVATION BEGIN	STATION END	ELEVATION END	ZONE	ZONE ELEVATION	FHF
0	17.78	4	17.5	V29	18	190
4	17.5	10	16.5	V29	17	190
10	16.5	21	15.5	V29	16	190
21	15.5	165	14.5	V29	15	190
165	14.5	169	14.19	V29	14	190
169	14.19	174	13.5	A21	14	110
174	13.5	215	12.5	A21	13	110
215	12.5	357	12.5	A21	12	110
357	12.5	439	12.5	A21	13	110
439	12.5	664	12.5	A21	12	110
664	12.5	1039	12.51	A21	13	110
1039	12.51	1054	12.09	X	13	110
1054	12.09	1077	10.68	X	13	110
1077	10.68	1079	10.7	A21	11	110
1079	10.7	1081	10.68	X	11	110
1081	10.68	1520	10.68	X	11	110
1520	10.68	1553	10.75	A21	11	110
1553	10.75	1566	10.68	X	11	110
1566	10.68	2347	10.68	X	11	110
2347	10.68	2374	10.78	A21	11	110
2374	10.78	2376	10.68	X	11	110
2376	10.68	3528	10.68	X	11	110

Pell Bridge EA Floodplain Tech Memo
CHAMP-WHAFIS Model Inputs - Transect 2, Existing Conditions
November 12, 2018

Station	Elevation	WHAFIS Card	Total 1% SWEL	Total 10% SWEL	CM	PS
0	0.00	IE	11.83	0		
10	0.63	IF				
12	0.90	IF				
15	0.80	IF				
19	0.55	IF				
22	0.91	IF				
23	1.17	IF				
26	2.93	IF				
29	4.66	IF				
31	5.12	IF		0		
34	5.52	IF		0		
35	5.65	IF		0		
36	5.78	VE		0		
39	6.82	VE				
48	9.21	VE				
50	10.00	VE				
52	10.64	VE				
55	11.65	VE				
56	11.83	AS				
326	10.58	AS	10.58	0		
333	10.21	IF				
345	9.98	IF				
355	9.92	IF				
366	9.42	IF		0		
370	9.32	IF				
372	9.24	IF				
383	9.12	IF				
419	7.96	IF				
423	7.81	IF				
426	7.80	IF				
434	7.74	IF				
451	7.69	IF				
455	7.49	IF				
465	6.89	IF				
477	6.83	IF				
480	6.84	IF				
484	7.22	IF				
487	7.40	IF				
489	7.45	IF				
497	7.64	IF				
520	7.68	IF				

528	7.29	IF				
529	7.23	IF				
531	7.23	IF				
533	7.32	IF				
536	7.38	IF				
557	7.66	IF				
563	7.64	IF				
565	7.60	IF				
568	7.61	IF				
575	7.54	IF				
580	7.45	IF				
581	7.38	IF				
584	6.85	IF				
586	6.78	IF				
588	6.75	IF				
592	6.46	IF				
611	7.30	IF				
629	6.62	IF				
630	6.59	IF				
634	6.59	IF				
635	6.62	IF				
641	6.80	IF				
650	7.05	IF				
653	7.15	IF				
657	7.26	BU				
665	7.53	BU				
667	7.60	BU				
668	7.59	BU				
678	7.79	BU				
685	7.83	BU				
689	7.79	BU				
697	7.61	IF				
698	7.60	IF				
699	7.51	IF				
711	6.67	IF				
715	6.64	IF				
725	6.80	IF				
727	6.94	IF				
730	7.18	IF				
736	7.89	IF				
738	7.86	IF				
740	7.77	IF				
742	8.09	IF				
744	8.43	BU				

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CHAMP-WHAFIS Model Inputs - Transect 2, Existing Conditions
November 12, 2018

778	8.91	BU				
800	9.19	IF				
801	9.04	IF				
807	9.01	IF				
808	8.99	IF				
811	8.99	IF				
814	9.01	IF				
815	8.94	IF				
816	8.88	IF				
817	8.81	IF				
818	8.72	IF				
819	8.69	IF				
824	7.78	IF				
831	7.86	IF				
836	7.94	IF				
837	7.97	IF				
838	7.96	IF				
851	8.03	IF				
852	7.98	IF				
866	7.72	IF				
870	7.62	IF				
873	8.25	IF				
875	8.36	IF				
879	8.69	IF				
887	9.12	IF				
889	9.11	IF				
900	9.35	BU				
903	9.14	BU				
905	9.11	BU				
944	8.35	BU				
964	7.91	BU				
966	7.79	IF				
967	7.71	IF				
970	7.57	IF				
972	7.58	IF				
977	7.60	IF				
980	7.36	IF				
984	6.90	IF				
987	6.78	IF				
990	6.48	IF				
993	5.99	IF				
994	5.92	IF				
997	5.05	IF				
1003	5.05	IF				

Pell Bridge EA Floodplain Tech Memo
CHAMP-WHAFIS Model Inputs - Transect 2, Existing Conditions
November 12, 2018

1010	5.05	IF				
1012	5.69	IF				
1013	5.88	IF				
1014	6.05	IF				
1015	5.86	IF				
1017	5.77	IF				
1018	5.95	IF				
1019	6.06	IF				
1020	5.86	IF				
1021	6.16	IF				
1027	6.16	IF				
1030	6.09	IF				
1032	5.83	IF				
1033	5.73	IF				
1034	5.58	IF				
1036	5.62	IF				
1043	5.58	IF				
1048	5.99	IF				
1049	5.97	IF				
1058	6.31	IF				
1103	10.58	AS				
1347	10.58	AS				
1359	10.22	IF				
1360	10.15	IF				
1361	10.14	IF				
1366	10.03	IF				
1372	10.58	AS				
1379	10.58	AS				
1385	9.29	IF				
1386	9.08	IF				
1399	6.13	IF				
1404	4.90	IF				
1406	4.91	IF				
1412	4.93	IF				
1435	8.23	IF				
1438	8.75	IF				
1440	8.85	IF				
1451	9.61	IF				
1461	10.44	IF				
1465	10.58	AS				
2444	10.58	AS				
2445	10.58	ET				

Pell Bridge EA Floodplain Tech Memo
CHAMP-WHAFIS Model Inputs - Transect 2, Proposed Conditions
November 12, 2018

Station	Elevation	WHAFIS Card	Total 1% SWEL	Total 10% SWEL	CM	PS
0	0.00	IE	11.83	0		
10	0.63	IF				
12	0.90	IF				
15	0.80	IF				
19	0.55	IF				
22	0.91	IF				
23	1.17	IF				
26	2.93	IF				
29	4.66	IF				
31	5.12	IF				
34	5.52	IF				
35	5.65	IF				
36	5.78	VE				
39	6.82	VE				
48	9.21	VE				
50	10.00	VE				
52	10.64	VE				
55	11.65	VE				
56	11.83	AS				
326	10.58	AS	10.58			
333	10.21	IF				
345	9.98	IF				
355	9.92	IF				
366	9.42	IF				
370	9.32	IF				
372	9.24	IF				
383	9.12	IF				
419	7.96	IF				
423	7.81	IF				
426	7.80	IF				
434	7.74	IF				
451	7.69	IF				
455	7.49	IF				
465	6.89	IF				
477	6.83	IF				
480	6.84	IF				
484	7.22	IF				
487	7.40	IF				
489	7.45	IF				
497	7.64	IF				
520	7.68	IF				

528	7.29	IF				
529	7.23	IF				
531	7.23	IF				
533	7.32	IF				
536	7.38	IF				
557	7.66	IF				
563	7.64	IF				
565	7.60	IF				
568	7.61	IF				
574	7.54	IF				
579	7.45	IF				
580	7.43	IF				
583	6.85	IF				
585	6.78	IF				
587	6.75	IF				
591	6.46	IF				
610	7.30	IF				
628	6.62	IF				
629	6.59	IF				
633	6.59	IF				
634	6.62	IF				
640	6.80	IF				
649	7.05	IF				
652	7.15	IF				
656	7.26	BU				
664	7.53	BU				
666	7.60	BU				
667	7.59	BU				
677	7.79	BU				
684	7.83	BU				
688	7.79	BU				
696	7.61	IF				
697	7.60	IF				
698	7.51	IF				
710	6.67	IF				
714	6.64	IF				
724	6.80	IF				
726	6.94	IF				
729	7.18	IF				
735	7.89	IF				
737	7.86	IF				
739	7.77	IF				
741	8.09	IF				
743	8.43	BU				

Pell Bridge EA Floodplain Tech Memo
CHAMP-WHAFIS Model Inputs - Transect 2, Proposed Conditions
November 12, 2018

777	8.91	BU				
800	9.04	BU				
806	9.01	BU				
807	8.99	IF				
810	8.99	IF				
814	9.01	IF				
815	8.88	IF				
816	8.81	IF				
817	8.74	IF				
818	8.69	IF				
823	8.18	IF				
830	7.86	IF				
835	7.94	IF				
836	7.97	IF				
837	7.96	IF				
850	8.03	IF				
851	8.02	IF				
865	7.72	IF				
869	8.02	IF				
872	8.25	IF				
874	8.36	IF				
878	8.69	IF				
886	9.13	IF				
888	9.11	IF				
899	9.35	IF				
902	9.14	BU				
904	9.11	BU				
943	8.35	BU				
963	7.91	BU				
965	7.80	BU				
966	7.71	IF				
970	7.57	IF				
971	7.58	IF				
976	7.60	IF				
979	7.36	IF				
983	6.90	IF				
986	6.78	IF				
989	6.48	IF				
992	5.99	IF				
993	5.97	IF				
996	5.05	IF				
1002	5.05	IF				
1009	5.05	IF				
1011	5.69	IF				

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CHAMP-WHAFIS Model Inputs - Transect 2, Proposed Conditions
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1012	5.88	IF				
1013	6.08	IF				
1014	5.87	IF				
1015	5.85	IF				
1016	5.78	IF				
1017	5.79	IF				
1018	5.80	IF				
1019	5.82	IF				
1020	5.83	IF				
1026	5.90	IF				
1029	5.94	IF				
1031	5.96	IF				
1032	5.97	IF				
1033	5.98	IF				
1035	6.00	IF				
1036	6.02	IF				
1042	6.15	IF				
1047	6.25	IF				
1048	6.27	IF				
1054	6.39	IF				
1057	6.47	IF				
1060	6.53	IF				
1064	6.61	IF				
1082	6.29	IF				
1086	6.22	IF				
1089	6.17	IF				
1102	6.51	IF				
1120	7.00	IF				
1125	7.14	IF				
1126	7.17	IF				
1129	7.24	IF				
1131	7.29	IF				
1132	7.33	IF				
1134	7.38	IF				
1137	7.45	IF				
1147	7.71	IF				
1153	7.88	IF				
1159	8.06	IF				
1162	8.12	IF				
1164	8.18	IF				
1166	8.24	IF				
1169	8.31	IF				
1171	8.37	IF				
1174	8.46	IF				

1185	8.75	IF				
1187	8.81	IF				
1194	9.00	IF				
1196	9.07	IF				
1198	9.10	IF				
1204	9.28	IF				
1207	9.37	IF				
1212	9.49	IF				
1215	9.59	IF				
1222	9.76	IF				
1224	9.83	IF				
1228	9.94	IF				
1234	10.09	IF				
1236	10.16	IF				
1241	10.21	IF				
1244	10.23	IF				
1245	10.25	IF				
1249	10.28	IF				
1254	10.34	IF				
1256	10.36	IF				
1266	10.47	IF				
1267	10.48	IF				
1269	10.50	IF				
1272	10.55	IF				
1279	10.58	AS				
1367	10.58	AS				
1371	10.51	IF				
1378	10.37	IF				
1379	10.33	IF				
1384	10.06	IF				
1385	10.00	IF				
1397	9.31	IF				
1398	9.31	IF				
1403	9.28	IF				
1405	9.28	IF				
1411	9.25	IF				
1434	9.16	IF				
1437	9.14	IF				
1439	9.14	IF				
1450	9.09	IF				
1460	9.05	IF				
1462	9.04	IF				
1464	9.05	IF				
1474	9.10	IF				

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CHAMP-WHAFIS Model Inputs - Transect 2, Proposed Conditions
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1475	9.10	IF				
1480	9.12	IF				
1489	9.16	IF				
1495	9.18	IF				
1497	9.19	IF				
1511	9.25	IF				
1514	9.26	IF				
1523	9.18	IF				
1524	9.18	IF				
1535	9.08	IF				
1546	9.00	IF				
1547	8.99	IF				
1549	9.02	IF				
1559	9.11	IF				
1564	9.16	IF				
1566	9.18	IF				
1579	9.30	IF				
1583	9.34	IF				
1596	9.47	IF				
1599	9.50	IF				
1604	9.54	IF				
1612	9.61	IF				
1614	9.62	IF				
1619	9.64	IF				
1625	9.66	IF				
1629	9.71	IF				
1630	9.72	IF				
1636	9.86	IF				
1645	10.06	IF				
1655	10.28	IF				
1660	10.42	IF				
1663	10.48	IF				
1665	10.55	IF				
1666	10.58	AS				
1714	10.58	AS				
1717	10.28	IF				
1719	10.58	AS				
2444	10.58	AS				
2445	10.58	ET				

Pell Bridge EA Floodplain Tech Memo
CHAMP-WHAFIS Model Results - Transect 2, Existing Conditions
November 12, 2018

STATION BEGIN	ELEVATION BEGIN	STATION END	ELEVATION END	ZONE	ZONE ELEVATION	FHF
0	16.91	23	16.5	V28	17	180
23	16.5	28	15.5	V28	16	180
28	15.5	38	14.5	V28	15	180
38	14.5	42	13.93	V28	14	180
42	13.93	46	13.5	A21	14	110
46	13.5	52	12.5	A21	13	110
52	12.5	55	11.93	A21	12	110
55	11.93	56	11.83	X	12	110
56	11.83	326	10.58	X	12	110
326	10.58	1058	11.06	A21	11	110
1058	11.06	1103	10.58	X	11	110
1103	10.58	1347	10.58	X	11	110
1347	10.58	1366	10.66	A21	11	110
1366	10.66	1372	10.58	X	11	110
1372	10.58	1379	10.58	X	11	110
1379	10.58	1461	10.65	A21	11	110
1461	10.65	1465	10.58	X	11	110
1465	10.58	2444	10.58	X	11	110

Pell Bridge EA Floodplain Tech Memo
CHAMP-WHAFIS Model Results - Transect 2, Existing Conditions
November 12, 2018

STATION BEGIN	ELEVATION BEGIN	STATION END	ELEVATION END	ZONE	ZONE ELEVATION	FHF
0	16.91	23	16.5	V28	17	180
23	16.5	28	15.5	V28	16	180
28	15.5	38	14.5	V28	15	180
38	14.5	42	13.93	V28	14	180
42	13.93	46	13.5	A21	14	110
46	13.5	52	12.5	A21	13	110
52	12.5	55	11.93	A21	12	110
55	11.93	56	11.83	X	12	110
56	11.83	326	10.58	X	12	110
326	10.58	1272	10.6	A21	11	110
1272	10.6	1279	10.58	X	11	110
1279	10.58	1367	10.58	X	11	110
1367	10.58	1665	10.6	A21	11	110
1665	10.6	1666	10.58	X	11	110
1666	10.58	1714	10.58	X	11	110
1714	10.58	1717	10.6	A21	11	110
1717	10.6	1719	10.58	X	11	110
1719	10.58	2444	10.58	X	11	110

Wave Height, Wave Period, Wave Setup, and Failed Revetment / Coastal Barrier / Steep Bluff Worksheet

1.0 Purpose/Objective

This worksheet was created to determine the unrestricted H_{m0} and T_p where H_{m0} is the energy-based significant wave height in meters and Tp is the limiting wave period, or use user input H_{m0} and T_P values from ACES or STWAVE models. This worksheet also calculates the open coast wave setup, η_{open}, which is the increase in stillwater elevation against a barrier caused by the attenuation of waves in shallow water. Wave setup is based upon wave breaking characteristics and profile slope. Wave setup can be a significant contributor to the total water level at the shoreline and must be included in the determination of coastal base flood elevations. This worksheet also evaluates the wave setup against a coastal structure, $\eta_{structure}$. For profiles with sloping revetments, this worksheet will also perform a failed structure analysis and generate a new profile of the failed structure and calculate the wave setup on the failed revetment.

2.0 Procedure

For unrestricted fetch length analysis where no STWAVE or ACES model run was produced, an extremal analysis was performed to determine three thresholds for peak wind speeds. The threshold with the highest correlation to either the Fisher-Tippett Type 1 (Gumbel), Fisher-Tippett Type II (Frecher), or Wiebull distribution is input parameter U_{10}, or the wind speed at 10m elevation (m/sec). Fetch, X, was also determined for each location. An excel spreadsheet for each transect was generated to calculate the 1% annual chance stillwater elevation. These variables are input into this worksheet from external worksheets and used for calculation within this worksheet.

Calculation worksheet details:

1. Go to View> Header and Footer... and fill out ALL relevant information to worksheet
2. Enter similar information on Page 2
3. Use radio buttons to select if analysis is based on "Unrestricted Fetch Wind Speed Input", "Restricted Fetch Input From ACES (H_{m0}, T_P)", or "STWAVE Input (H_{m0}, T_p)"

Section 5.1 - Wave Height and Wave Period

4. Fill in value of U_{10} and list peak threshold, regression, and correlation coefficient and associated files
5. If fetch length is unrestricted, continue to section 5.1.1, otherwise, skip section 5.1.1

Section 5.1.1 - Unrestricted Wave Height and Wave Period Calculation

6. Fill in value of Fetch, X, and list associated calculation files.

7. Skip Section 5.1.2 and Section 5.1.3 if fetch length is unrestricted

Section 5.1.2 - Restricted Wave Height and Wave Period Calculation

8. If ACES model run was complete enter ACES program inputs including the fetch angles and fetch lengths used in the restricted analysis in ACES

9. List the .mxd file and associated information involved in the calculation of fetch lengths

10. Fill in results of H_{m0} and T_p from the ACES analysis and any ACES output files which were saved

11. Skip section 5.1.3

Section 5.1.3 - STWAVE Wave Height and Wave Period

12. If STWAVE model run was complete enter the associated wave height and wave period

13. List the associated STWAVE model file

Section 5.2 - Wave Setup

Section 5.2.1 - Open Coast Wave Setup Calculation

14. Enter value for average transect slope and associated .mxd file from which average slope was calculated

Section 5.2.2 - Wave Setup on a Revetment Calculation

15. Enter Profile variable excel file path information. Excel file should be formatted with the first row of the file having column headings. The first column within the file should have station data in ascending order. The second column within the file should have the associated station elevation in order of ascending station. All data should be in feet. This file needs to be an .xls file as Mathcad is not currently compatible with .xlsx files.

16. Enter horizontal distance from shoreline along transect which identifies the start of the coastal structure, Toe_{sta}, in feet

17. Enter horizontal distance from shoreline along transect which identifies the top of the coastal structure, Top_{sta}, in feet

18. Enter value for SWEL, 1% annual chance stillwater elevation in feet and name and path of associated excel file from which SWEL was calculated

Section 5.3 - Wave Runup - TAW Method

19. Check $Slope_{Check}$ and $Iribarren_{Check}$ variables to determine if TAW method holds for these situations

20. Use radio buttons to select runup reduction factors

21. Enter incident angle, β, if known, otherwise, assume 0

Section 5.4 - Failed Revetment Analysis

22. Enter approximate depth of armor layer in feet based on photographs and site inspections (ft)

23. Check value of $Toe_{location}$, $Mid_{location}$, $Quarter_{location}$, and $Top_{location}$, which should be the location in the Station array which holds the value of Toe_{sta}, Mid_{sta}, $Quarter_{sta}$, and Top_{sta}. If the horizontal distance from the shoreline along the transect to these locations were not measured points

in the Station array, then $\text{Toe}_{\text{location}}$, $\text{Mid}_{\text{location}}$, $\text{Quarter}_{\text{location}}$, and/or $\text{Top}_{\text{location}}$ should be arrays of two values representing the indices which the value of Toe_{sta}, Mid_{sta}, $\text{Quarter}_{\text{sta}}$, and.or Top_{sta} are between. If none or more than two values are listed, adjust the convergence tolerance (TOL) from the Tools > Worksheet Options option in the menu bar, until two values are listed for the $\text{Toe}_{\text{location}}$, $\text{Mid}_{\text{location}}$, $\text{Quarter}_{\text{location}}$, and/or $\text{Top}_{\text{location}}$ variables.

Section 5.5 - Wave Setup on Failed Revetment

Section 5.6 - Wave Runup on Failed Revetment

24. Check SlopeCheck and IribarrenCheck variables to determine if TAW method holds for these situations
25. Use radio buttons to select runup reduction factors
26. Enter incident angle, β, if known, otherwise, assume 0

Section 6.0 - Conclusions

3.0 References/Data Sources

Equation taken from Coastal Engineering Manual Part II (Publication date: August 1, 2008)
Atlantic Ocean and Gulf of Mexico Coastal Guidelines Update, FEMA, February, 2007
Guidelines and Specifications for Flood Hazard Mapping Partners [February 2007]
Coastal Engineering Manual Part VI

4.0 Assumptions

Unrestricted Wave Height and Wave Period Mathcad Calculation:

1. One of the following situations hold:
   - Wind blows, with essentially constant direction, over a fetch for sufficient time to achieve steady-state, fetch-limited values
   - Wind increases very quickly through time in an area removed from any close boundaries. Wave growth is considered duration-limited. RARE condition
   - Fully developed wave height, however, open-ocean waves rarely attain a limiting wave height for wind speeds above 50 knots of so.
2. Wave growth with fetch.
3. Wind speeds collected were taken at 10 m, to be a U_{10} measurement of wind speeds

Open Coast Wave Setup and Wave Setup on Existing and Failed Structures Analysis

1. Wave height, H_{m0}, is the deepwater wave height and is not in water of transitional depth
2. The wave setup calculated is a "static" wave setup, during which the storm tide and incident wave conditions remain unchanged

3. The open coast wave setup calculation does not consider wave nonlinearity, wave breaking characteristics, profile slope, or wave propagation through vegetation
4. Dynamic wave setup component is not considered, as it is small by comparison with the static component for the locations considered.
5. Wave period, T_P, remains constant and independent of depth for oscillatory waves

Wave Runup Analysis on Failed and Existing Structures - ***Technical Advisory Committee for Water Retaining Structures (TAW) Method***

1. The TAW method is assumed to hold for all barriers, revetments, or dunes which have a slope of 1:8 or steeper
2. The shallow water significant wave height is assumed to be 88% of the deep water significant wave height
3. The breaking wave height is assumed to be 78% of the water depth at the toe of the barrier, revetment, or dune
4. The TAW method is assumed to hold for Iribarren numbers in the range of 0.5 to 10
5. The incident wave angle is assumed to be 0 in most cases
6. Assuming berm width is unknown, minimum and maximum berm section breakwater reduction factors were assumed for conditions when a berm does and does not exist respectively
7. The runup values calculated are the 2% exceendence probability values

Failure of a Sloping Revetment

1. Landslide of revetment has constant slope
2. The scour depth does not include any parameters relating to sediment properties, which are expected to have some influence on the scouring process.
3. The scour at the base of the structure is equal to the depth of the armored layer
4. The structure will collapse in place into a triangular section throughout the structure footprint, with side slopes equal to the original structure slope
5. The landward side of the failed configuration will be half exposed and half buried
6. The soil slope landward from the failed structure fails to a uniform 1:1.5 slope, which extends to existing grade
7. Slope recedes back from the toe of the revetment at a 1:3 slope

Wave Height, Wave Period, Wave Setup, Failed Vertical Structure Calculation Worksheet

Modeler Name: Nick Rutigliano
Date: September 25, 2018
County: Newport, RI
Transect Number: VHB 1
Airport: N/A
Years of Data set: N/A
Associated Files:

5.0 Calculations

List of Variables:

Constants:

g - Gravitational acceleration (m/sec^2)

Inputs:

X - straight line fetch distances over which the wind blows (miles)

U_{10} - Wind speed at 10 m elevation (ft/sec)

$H_{m0STWAVE}$ - Deep water signficant wave height input by user from STWAVE model

$T_{PSTWAVE}$ - Wave period input by user from STWAVE model

m - Average slope of transect (dimensionless)

Profile - Excel file with station (ft) and elevations (ft) of transect profile

Toe_{sta} - Horizontal location of toe of structure relative to shoreline (ft)

Top_{sta} - Horizontal location of top of structure relative to shoreline (ft)

SWEL - 1% Annual Chance Stillwater Elevation (ft)

$Armor_D$ - Depth of armor layer on a sloping revetment (ft)

$ACESInput_{Ang}$ - Angle of fetches input into ACES analysis (deg)

$ACESInput_{Fetch}$ - Fetch length of fetches input into ACES analysis (ft)

H_{m0ACES} - Deepwater significant wave height from ACES analysis (ft)

T_{PACES} - Limiting wave period from ACES analysis (sec)

Working Variables:

C_D - Coefficient of drag for winds measured at 10 meters (dimensionless)

u_s - Wind friction velocity (m/sec)

L_0 - Deep water wave length (ft)

S - Wave slope (dimensionless)

$Toe_{ele,}$ $Mid_{ele,}$ $Quarter_{ele,}Top_{ele}$ - Elevation of toe, midpoint, upper quarter, and top of revetment from interpolation (ft)

Station - Array of station (ft) of existing (non-failed) profile

Elevation - Array of elevations (ft) of existing (non-failed) profile

h - Water depth from the top of the water surface against a structure to the toe of the structure (ft)

b_h - Dimensionless breaking wave height

H_b - Breaking wave height (ft)

b_d - Dimensionless breaking wave depth (dimensionless)

H_d - Breaking wave depth (ft)

R - Wave setup relative to maximum wave setup (dimensionless)

η_{open} - Open coast wave setup (ft)

η_1 - Wave setup component on a coastal structure from the water depth at the toe of a coastal structure (ft)

η_2 - Wave setup component determined for a sloping coastal structure (ft)

h_2 - Water depth over coastal structure when overtopping occurs (ft)

$\eta_{structure}$ - Total wave setup on a structure or steep slope (ft)

H_{fail} - Wave height used for analysis of failed structure equal to H_{m0}, or the energy-based significant wave height, H_{m0}, but limited to a maximum equal to the breaking wave height, H_b (ft)

S_m - Maximum scour depth (ft)

$ToeV_{scour}$ - Elevation of toe of vertical coastal structure after scour occurs (ft)

$Toe_{location}$, $Mid_{location}$, $Quarter_{location}$, $Top_{location}$- Index of location of bottom of vertical coastal structure or revetment, midpoint of revetment, quarter distance, and top of revetment within the Station array (dimensionless)

Offset, $Offset_{toe}$, $Offset_{mid}$, $Offset_{qua}$, $Offset_{top,}$ $Offset_{failTop}$ - Dummy variable equal to 0 if the horizontal location of the bottom of the vertical structure, revetment toe, revetment midpoint, revetment quarter distance, revetment top is listed in the Station array, equal to 1 if the horizontal location of the bottom of the vertical structure is not listed in the station array (dimensionless)

Toe_{staloc}, Mid_{staloc}, $Quarter_{staloc}$, Top_{staloc} - Index of location of toe of vertical coastal structure or revetment, midpoint of revetment, quarter length of revetment, and top of revetment within the station array (dimensionless)

$Sta_{lastloc}$ - Index to the last element in the Station array (dimensionless)

failed - Index to the last element in the Station array (dimensionless)

i,x,y,z,a,w - Counter variables (dimensionless)

Slope - Slope of a revetment (dimensionless)

Length - Length of a revetment (ft)

Midpoint, Quarter - Midpoint and Quarter of the distance along length of revetment (ft)

Mid_{sta}, $Quarter_{sta}$- Distance from shoreline to midpoint and quarter distance of sloping revetment (ft)

$ToeR_{scour}$ - Elevation of toe of sloping revetment structure after scour occurs (ft)
end - last index of the station and elevation of the partial failure of a sloping revetment arrays
$FailRevet_{Ele}$ - Array of elevations of partial failure of a sloping revetment (ft)
$FailRevet_{Sta}$ - Array of station data of partial failure of a sloping revetment (ft)
$Slope_{Revet}$ - Slope or revetment expressed as a decimal or percentage (dimensionless)
$Slope_{RevetOneOn}$ - Slope of revetment expressed as the horizontal distance associated with an increase in one vertical foot (string)
$Slope_{Check}$ - Indicator variable associated with determining if the TAW method is applicable based on barrier slope (string)
$Slope_{Check}$ - Indicator variable associated with determining if the TAW method is applicable based on barrier slope of failed revetment (string)
$Depth_{Limited}$ - Indicator variable associated with determining if the wave is depth limited at the toe of the revetment or structure (string)
WaveType - Indicator variable associated with determining if water is considered to be shallow, deep, or transitional at the toe of the barrier
β - Incident wave angle (degrees)
T_{m10} - Spectral wave period (sec)
$H_{m0Runup,}$ $H_{m0Runup1}$ - Significant wave height adjusted if necessary for runup calculations (ft)
γ_r - Roughness reduction factor (dimensionless)
γ_b - Berm section in breakwater (dimensionless)
γ_p - Porosity factor (dimensionless)
γ_β - Wave direction factor (dimensionless)
$Slope_{FAILRevet}$ - Slope or revetment expressed as a decimal or percentage (dimensionless)
$Slope_{FAILRevetOneOn}$ - Slope of revetment expressed as the horizontal distance associated with an increase in one vertical foot (string)
$Iribarren_{Check}$ - Indicator variable to determine if the TAW method is applicable based on the Iribarren number (string)
$FAILIribarren_{Check}$ - Indicator variable to determine if the TAW method is applicable based on the Iribarren number for the failed revetment (string)
$FailTop_{Sta}$ - Station of top of revetment after failure (ft)
$FailTop_{Ele}$ - Elevation of top of revetment after failure (ft)

Output:

H_{m0} - Energy-based significant wave height (ft)
T_P - Limiting wave period (sec)
FetchLength - Reports if fetch length is "Restricted" or "Unrestricted" based on user input

FetchStatus - Indicator of restricted or unrestricted fetch length based on user input (string)
η - Wave setup (ft)
FailEle - Array of elevation of existing profile if no coastal structure exists, or elevations of a failed vertical structure or sloping revetment (ft)
FailSta - Array of stations of existing profile if no coastal structure exists, or stations of a failed vertical structure or sloping revetment (ft)
Out_1 - Output file of failed elevation profile data if a coastal structure exists
Out_2 - Output file of failed station profile data if a coastal structure exists
Overtopped - Indicator of overtopping of a coastal structure with wave setup
$R_{2\%}$ - Two percent exceedence wave runup on revetment / barrier / or dune (ft)
$R_{FAIL2\%}$ - Two percent exceedence wave runup on failed revetment / barrier / or dune (ft)
OVERTOPPEDRunup - Indicator variable to determine if revetment was overtopped by wave runup (string)
$OVERTOPPEDFAIL_{Runup}$ - Indicator variable to determine if the failed revetment was overtopped by wave runup (string)

○ Unrestricted Fetch
○ Restricted Fetch Input from ACES (Hmo, Tp)
● STWAVE Input (Hmo, Tp)

Select using radio buttons if input(s) is Unrestricted Fetch Length, Restricted Fetch Length, or Wave Height and Wave Period from STWAVE

5.1 Wave Height, H_{m0}, and Wave Period, T_p Calculation

Definition of Variables:

$$g = 9.81 \cdot \frac{m}{s^2}$$

Insert $U_{10,}$ wind speed in meters per second:

These fields must be populated, but will only be used for calculations if unrestricted radio button is selected above

$$U_{10} := 26.822 \frac{m}{s}$$

Wind speed based on: N/A -- placeholder value used
Airport: N/A

$U_{10} = 88 \cdot \frac{ft}{s}$

Taken from file: N/A

5.1.1 Calculation of Unrestricted Wave Height, H_{m0}, and Wave Period, T_P

Insert X, fetch in miles:

$X := 2.5 \cdot mi$ $X = 4023.36 \cdot m$

Feature Class used: N/A

Calculate Coefficient of Drag, C_D:

$C_D := 0.001 \cdot \left[1.1 + \left(0.035 \cdot U_{10} \cdot \frac{s}{m}\right)\right]$ $C_D = 0.002$

Calculate Wind Friction Velocity, u_s (m/sec):

initialize u_s: $u_s := 1 \cdot \frac{m}{s}$

Given

$C_D = \frac{u_s^2}{U_{10}^2}$ $u_s := \text{Find}(u_s)$ $u_s = 1.21 \cdot \frac{m}{s}$

Calculate Wave Height, H_{m0} (m):

initialize H_{m0}: $H_{m0} := 0.01 \cdot m$

$X = 4023.36 \cdot m$ $u_s = 1.21 \cdot \frac{m}{s}$ $g = 9.81 \frac{1}{s} \cdot \frac{m}{s}$

Given

$\frac{g \cdot H_{m0}}{u_s^2} = 0.0413 \cdot \left(\frac{g \cdot X}{u_s^2}\right)^{0.5}$ $H_{m0} := \text{Find}(H_{m0})$ $H_{m0} = 1.01 \cdot m$ $H_{m0} = 3.32 \, ft$

Calculate Wave Period, T_P (sec):

initialize T_P: $T_P := 0.01 \cdot s$

$X = 4023.36 \cdot m$ $u_s = 1.21 \cdot \frac{m}{s}$ $g = 9.81 \frac{1}{s} \cdot \frac{m}{s}$

Given

$$\frac{g \cdot T_P}{u_s} = 0.751 \cdot \left(\frac{g \cdot X}{u_s^{2}}\right)^{\frac{1}{3}} \qquad T_P := Find(T_P) \qquad T_P = 2.78 \cdot s$$

5.1.2 Calculation of Restricted Wave Height, H_{m0}, and Wave Period, T_p

The calculation of restricted wave height, Hm0, and Wave Period, Tp, require the use of ACES software.

$$ACESInput_{Ang} := \begin{pmatrix} \blacksquare \\ \blacksquare \\ \blacksquare \\ \blacksquare \\ \blacksquare \\ \blacksquare \\ \blacksquare \\ \blacksquare \\ \blacksquare \end{pmatrix} \qquad ACESInput_{Fetch} := \begin{pmatrix} \blacksquare \\ \blacksquare \\ \blacksquare \\ \blacksquare \\ \blacksquare \\ \blacksquare \\ \blacksquare \\ \blacksquare \\ \blacksquare \end{pmatrix}$$

Input angle of fetch and fetch length as input to ACES with 0° facing North.

Feature Class File: N/A

Aces Output:

$H_{m0ACES} := 0 \cdot ft$ $T_{PACES} := 0 \cdot sec$

These fields must be populated, but will only be used for calculations if restricted radio button is selected above

ACES result file: N/A

5.1.3 Input Significant Wave Height (H_{m0}) and Wave Period (T_P) taken from STWAVE

$H_{m0STWAVE} := 1.9 \cdot m$ $T_{PSTWAVE} := 5 \cdot sec$

These fields must be populated, but will only be used for calculations if STWAVE Input radio button is selected above

Input the path to the STWAVE Model File:

RESULT:

$H_{m0} = 6.23\,ft$ $T_P = 5\,s$ FetchStatus = "STWAVE Input (Hmo, Tp)"

5.2 Wave Setup, η, Calculation

5.2.1 Open Coast Wave Setup Analysis

Definition of Variables:

$m := .01951$ Insert value of average transect slope based on GIS data

Calculate Deep Water Wave Length, L_0:

$$L_0 := \frac{g \cdot T_P^2}{2 \cdot \pi} \qquad L_0 = 128.02\,ft$$

Equation source: Coastal Engineering Manual Part VI Page VI-5-236

Calculate Wave Slope, S:

$$S := \frac{H_{m0}}{L_0} \qquad S = 0.0487 \qquad S = 4.87 \cdot \%$$

Calculate Static Open Coast Wave Setup:

$$\eta_{open} := H_{m0} \cdot 0.160 \cdot \frac{m^{0.2}}{s^{0.2}}$$

$$\eta_{open} = 0.83\,ft$$

Equation Source: Atlantic Ocean and Gulf of Mexico Coastal Guidelines Update Feb 2007 - Equation D.2.6-1

5.2.2 Wave Setup On Structures Analysis for Structures/Steep Slopes (1:8 or Steeper) which Intersect the SWEL

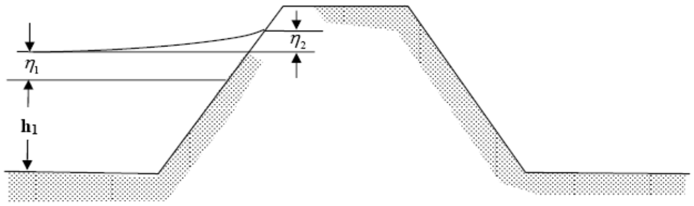


Figure D.2.6-6. Definition Sketch for Nonovertopped Levee

Figure from: Atlantic Ocean and Gulf of Mexico Coastal Guidelines Update Feb 2007

Definition of Variables:

Enter path and file name of .xls file containing station and elevation data for transect within the "" below:

Profile := READFILE("\\vhb\gbl\proj\Providence\72900.00\tech\PreliminaryHH\2018HydraulicStudy\Pr_Transect1.csv" ,"delimited" ,2 ,1)*

Note: The Path name above corresponds to an excel file containing station and elevation data. The 1st row of the excel file should contain column headings. The 1st column in the spreadsheet should contain the Station (ft) starting at station 0 and listed in ascending order. Column B, or the 2nd column, should contain elevation data (ft) corresponding with the associated station listed in Column A, or column 1, in ascending order by station. THIS FILE NEEDS TO BE AN .XLS FILE!!! MATHCAD WILL NOT SUPPORT 2007 VERSION OF EXCEL.

The following displays Profile data from excel worksheet identified above and lists Station and Elevation as two separate arrays and define elevation and station in feet:

	0	1
0	0	0
1	9.01	1.35
2	10.27	3.19

$Station := Profile^{\langle 0 \rangle}$

$Elevation := Profile^{\langle 1 \rangle}$

$Station := Station \cdot 1 \cdot ft$

$Elevation := Elevation \cdot 1 \cdot ft$

Array of horizontal

Array of Elevations associated with each

Profile =

2	10.27	3.19
3	11.59	3.45
4	13.75	3.88
5	17.62	4.66
6	20.6	5.25
7	23.46	...

distance from the shoreline

Station =

	0
0	0
1	9.01
2	10.27
3	...

ft

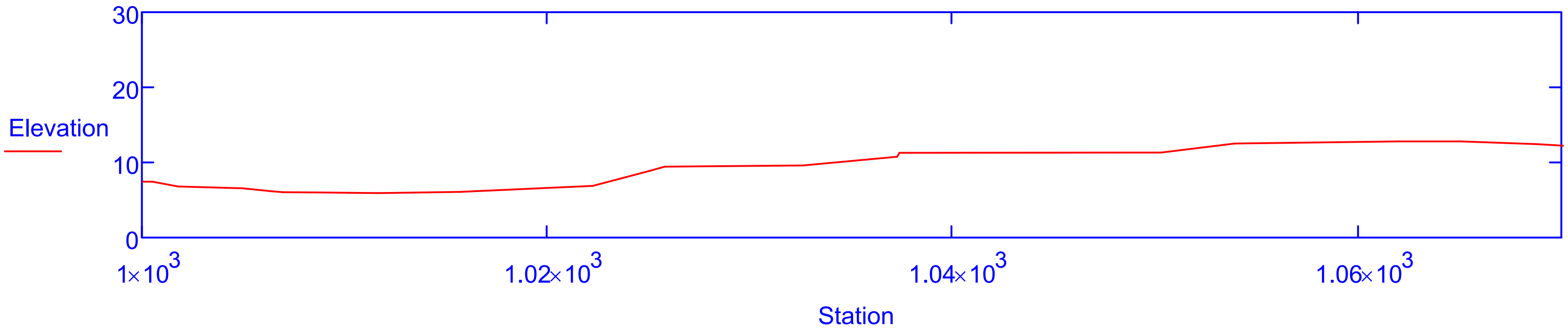
horizontal distance from the shoreline:

Elevation =

	0
0	0
1	1.35
2	3.19
3	...

ft

The following displays the profile of the transect:



Identify station and elevation of the toe of the structure:

$Toe_{sta} := 0\cdot ft$

Input value representing coastal structure's bottom station (Toe_{sta})

$Toe_{ele} := \mathrm{linterp}(Station, Elevation, Toe_{sta})_{*}$

$Toe_{ele} = 0\,ft$

Identify station and elevation of the top of the structure:

$Top_{sta} := 23.46\cdot ft$

Input value representing coastal structure's top station (Top_{sta})

Client: HYM
County: Revere and Boston, MA
Transect Number: 1

Wave Height and Wave Period Calculation Worksheet

CHK By/Date:
RVW By/Date:

Calc By: Erika Towne
Date: 10/25/2018

$Top_{ele} := linterp(Station, Elevation, Top_{sta})$ $Top_{ele} = 5.53\,ft$

Enter 1% annual chance stillwater elevation (ft):

$SWEL := 10.68\cdot ft$ Associated excel file for calculation of 1% annual chance stillwater elevation (SWEL):

Calculate Water Depth at Structure, h

$h := SWEL - Toe_{ele}$ $h = 10.68\,ft$

Calculate the Breaking Wave Height, H_b:

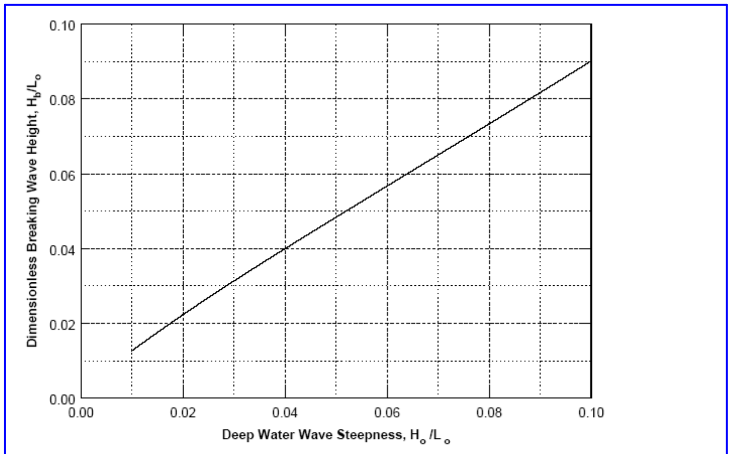


Figure D.2.6-7. Dimensionless Breaking Wave Height vs. Deepwater Wave Steepness

Figure from: Atlantic Ocean and Gulf of Mexico Coastal Guidelines Update Feb 2007

$b_h := 0.8481\cdot S + 0.0057$ $b_h = 0.05$ Estimated curve equation in Figure D.2.6-7

$H_b := b_h\cdot L_0$ $H_b = 6.02\,ft$

Calculate the Breaking Wave Depth, H_d:

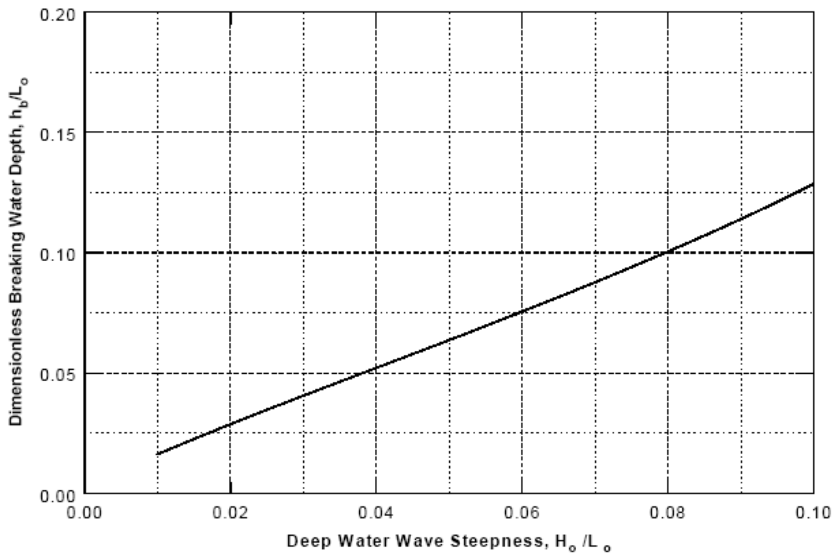


Figure D.2.6-8. Dimensionless Breaking Water Depth vs. Deepwater Wave Steepness.

Figure from: Atlantic Ocean and Gulf of Mexico Coastal Guidelines Update Feb 2007

$b_d := 1.2205 \cdot S + 0.0033$ $\quad b_d = 0.06$ Estimated curve equation from Figure D.2.6-8

$H_d := b_d \cdot L_0$ $\quad H_d = 8.03\,\text{ft}$

Calculate Wave Setup on a Structure, $\eta_{structure}$:

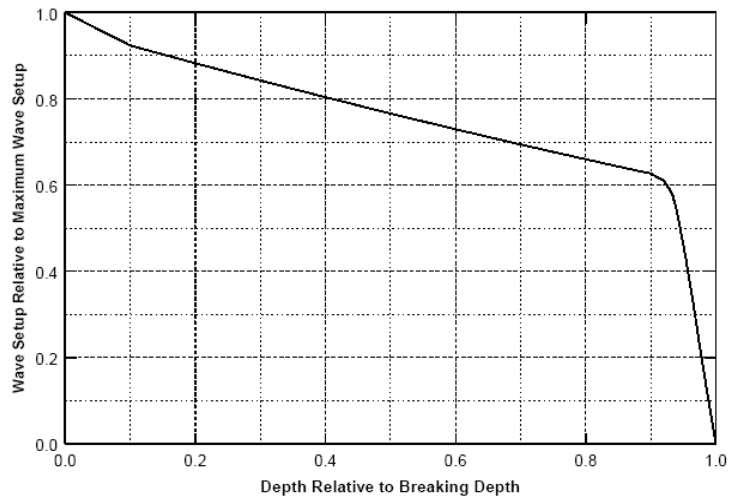


Figure D.2.6-9. Proportion of Maximum Wave Setup that Has Occurred vs. a Proportion of the Breaking Depth.

Figure from: Atlantic Ocean and Gulf of Mexico Coastal Guidelines Update Feb 2007

$$R := \begin{cases} \left[-0.8\cdot\left(\frac{h}{H_d}\right)+1\right] & \text{if } \left(\frac{h}{H_d}\right) \le 0.092 \\ \left[-0.3919\cdot\left(\frac{h}{H_d}\right)+0.9585\right] & \text{if } 0.092 < \frac{h}{H_d} \le 0.4 \\ \left[-0.3475\cdot\left(\frac{h}{H_d}\right)+0.9379\right] & \text{if } 0.4 < \frac{h}{H_d} \le 0.9 \\ \left[-33.312\cdot\left(\frac{h}{H_d}\right)^2+59.811\cdot\left(\frac{h}{H_d}\right)-26.223\right] & \text{if } 0.9 < \left(\frac{h}{H_d}\right) \le 0.94444 \\ \left[-9.8703\cdot\left(\frac{h}{H_d}\right)+9.8703\right] & \text{if } 0.94444 < \left(\frac{h}{H_d}\right) \le 1 \\ 0 & \text{otherwise} \end{cases}$$

Equation based on estimated curve from Figure D.2.6-9

$R = 0$ $\qquad \frac{h}{H_d} = 1.33$

$\eta_1 := R \cdot \eta_{open}$ $\qquad \eta_1 = 0\,ft$ $\qquad \eta_2 := 0.15 \cdot (h + \eta_1)$ $\qquad \eta_2 = 1.6\,ft$

$\eta_{Structure} := \eta_1 + \eta_2$ $\qquad \eta_{Structure} = 1.6\,ft$ $\qquad$ Total Setup against a coastal structure without considering overtopping

Check Overtopping if Coastal Structure Exists:

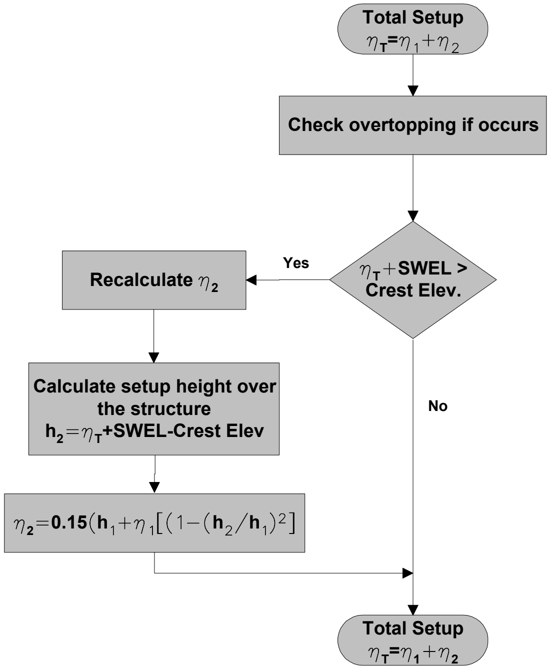
$$Overtopped := \begin{vmatrix} \text{"Yes"} & \text{if } (\eta_{Structure} + SWEL) > Top_{ele} \\ \text{"No"} & \text{otherwise} \end{vmatrix} \qquad Overtopped = \text{"Yes"}$$

$$h_2 := \begin{vmatrix} (\eta_{Structure} + SWEL - Top_{ele}) & \text{if } Overtopped = \text{"Yes"} \\ 0 & \text{otherwise} \end{vmatrix}$$

Equation D.2.6-12 for η_2 from Atlantic Ocean and Gulf of Mexico Coastal Guidelines Update

$$\eta_2 := \begin{vmatrix} 0.15 \cdot (h + \eta_1) \cdot \left[1 - \left(\frac{h_2}{h}\right)^2\right] & \text{if } Overtopped = \text{"Yes"} \\ \eta_2 & \text{otherwise} \end{vmatrix}$$

$\eta_{Structure} := \eta_1 + \eta_2$ $\qquad \eta_{Structure} = 0.96\,ft$ $\qquad$ Total Setup with a coastal structure



5.3 Wave Runup Analysis (Using TAW Method)

Flow Chart of Process of Calculating Wave Runup:

Checking Slope of Revetment to determine if it is between 1:1 and 1:8:

$$Slope_{Revet} := \frac{(Top_{ele} - Toe_{ele})}{(Top_{sta} - Toe_{sta})} \qquad Slope_{Revet} = 23.57\cdot\%$$

$$Slope_{RevetOneOn} := \frac{1}{Slope_{Revet}} \qquad Slope_{RevetOneOn} = 4.24$$

$$Slope_{Check} := \begin{cases} \text{"TAW Method of Runup Calculation Applies"} & \text{if } 0 < Slope_{RevetOneOn} \le 8 \\ \text{"TAW Method Does Not Apply, Switch to Runup-2.0"} & \text{otherwise} \end{cases}$$

$$Slope_{Check} = \text{"TAW Method of Runup Calculation Applies"}$$

Check if Wave is Depth Limited at the Toe of the Revetment / Barrier:

$$Depth_{Limited} := \begin{cases} \text{"Limited"} & \text{if } H_{m0} \ge 0.78\cdot h \\ \text{"Not Limited"} & \text{otherwise} \end{cases}$$

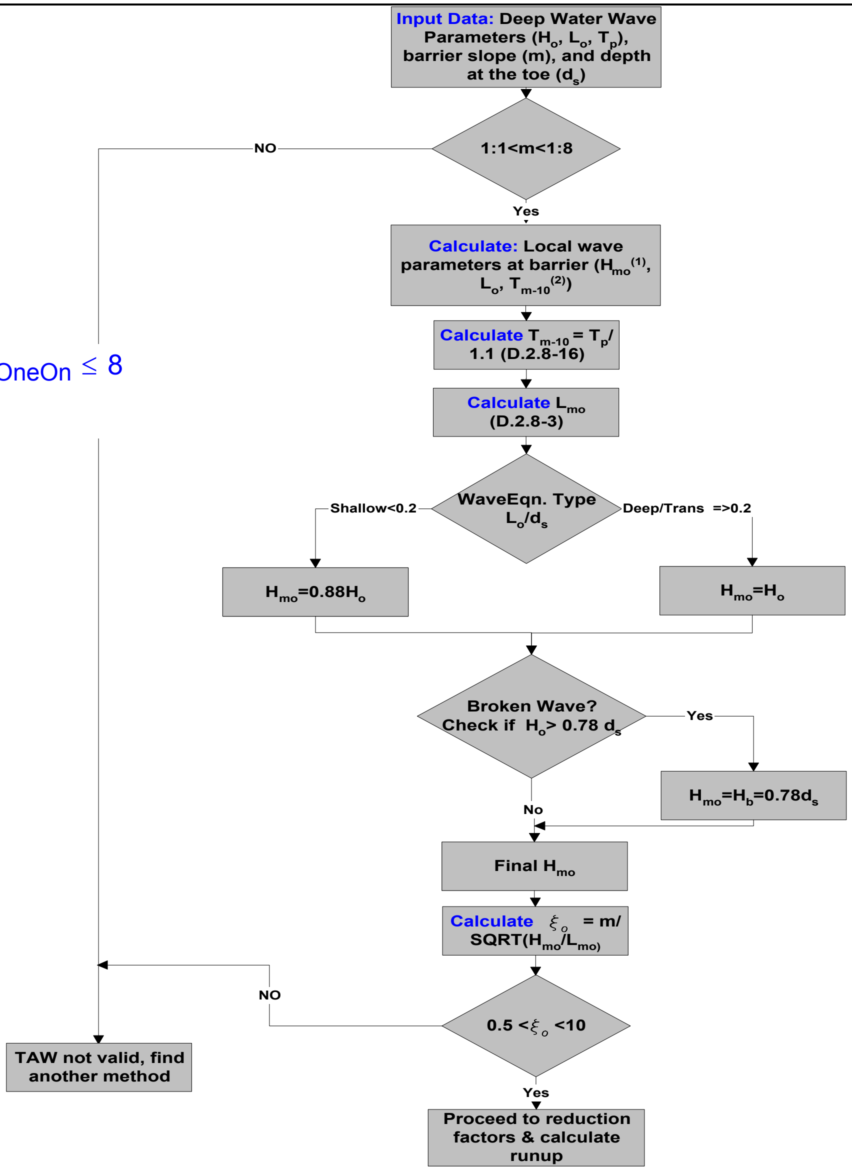
If wave is depth limited, H_b *will be used rather than* H_{m0}

$$Depth_{Limited} = \text{"Not Limited"}$$

Determine Wave Type:

$$WaveType := \begin{cases} \text{"Shallow"} & \text{if } \frac{h}{L_0} < 2 \\ \text{"Transitional"} & \text{if } 0.2 \le \frac{h}{L_0} < 0.5 \\ \text{"Deep"} & \text{otherwise} \end{cases}$$

$$WaveType = \text{"Shallow"}$$



Client: HYM
County: Revere and Boston, MA________
Transect Number:_1_

Wave Height and Wave Period Calculation Worksheet
CHK By/Date:
RVW By/Date:________

Calc By: Erika Towne
Date: 10/25/2018

Determine Significant Wave Height Depending on Wave Type and DepthLimited Condi

$$H_{m0runup1} := \begin{cases} 0.88 \cdot H_{m0} & \text{if } \ WaveType = \text{"Shallow"} \\ H_{m0} & \text{otherwise} \end{cases} \qquad H_{m0runup1} = 5.49\,\text{ft}$$

$$H_{m0runup} := \begin{cases} 0.78 \cdot h & \text{if } \ Depth_{Limited} = \text{"Limited"} \\ H_{m0runup1} & \text{otherwise} \end{cases} \qquad H_{m0runup} = 5.49\,\text{ft}$$

Calculate the Spectral Wave Period, T_{m10}

$$T_{m10} := \frac{T_P}{1.1}$$

Equation D.2.8-16

$$T_{m10} = 4.55\,\text{s}$$

Calculate the Wave Length Associated with the Spectral Wave Period, L_{m0}:

$$L_{m0} := \frac{g \cdot T_{m10}^{\ 2}}{2 \cdot \pi}$$

Equation D.2.8-3

$$L_{m0} = 105.8\,\text{ft}$$

Calculate the Iribarren Number, ξ_{0m}:

$$\xi_{om} := \frac{Slope_{Revet}}{\sqrt{\frac{H_{m0runup}}{L_{m0}}}} \qquad \xi_{om} = 1.04$$

Check TAW Method for Validity based on Iribarren Number:

$$Iribarren_{Check} := \begin{cases} \text{"TAW method is Valid"} & \text{if } \ 0.5 < \xi_{om} < 10 \\ \text{"TAW method is NOT vaild for this Irbarren value. Please seek alternative method."} & \text{otherwise} \end{cases}$$

$$Iribarren_{Check} = \text{"TAW method is Valid"}$$

Calculate Runup Reduction Factors in Accordance with Table D.2.8-5 of Guidelines and Specifications for Flood Hazard Mapping:

Select Roughness Reduction Factor, γ_r:

$\gamma_r :=$
- ○ Smooth Concrete, Asphalt, and Smooth Block Revetment
- ○ 1 Layer of Rock with Diameter, D, where Hs/D = 1 to 3
- ● 2 or More Layers of Rock where Hs/D = 1.5 to 6
- ○ Quadratic Blocks

$$\gamma_r := \begin{cases} \gamma_r & \text{if } \gamma_r \geq 0.53 \\ \text{"Please Select Radio Button"} & \text{otherwise} \end{cases}$$

$\gamma_r = 0.53$

Select Berm Section in Breakwater, γ_b:

$\gamma_b :=$
- ● Berm Present
- ○ No Berm Present

$$\gamma_b := \begin{cases} \gamma_b & \text{if } \gamma_b > 0.5 \\ \text{"Please Select Radio Button"} & \text{otherwise} \end{cases}$$

$\gamma_b = 0.6$

Select Wave Direction Factor, γ_β:

$\beta := 0$ 0º for normally incident wave

$\gamma_\beta :=$
- ● Short-Crested Wave
- ○ Long-Crested Wave

$$\gamma_\beta := \begin{cases} (1 - 0.0022 \cdot \beta) & \text{if } |\beta| \leq 80 \land \gamma_\beta = 1 \\ (1 - 0.0022 \cdot |80|) & \text{if } (|\beta| \geq 80) \land \gamma_\beta = 1 \\ 1 & \text{if } 0 \leq |\beta| < 10 \land \gamma_\beta = 2 \\ \cos\left[(|\beta| - 10) \cdot \left(\frac{\pi}{180}\right)\right] & \text{if } (10 < |\beta| < 63 \land \gamma_\beta = 2) \\ 0.63 & \text{if } |\beta| > 63 \land \gamma_\beta = 2 \\ \text{"Please Select Radio Button"} & \text{otherwise} \end{cases}$$

$\gamma_\beta = 1$

Select Porosity Factor, γ_P:

Porosity :=
○ 0.1
○ 0.4
● 0.5
○ 0.6

Default Porosity = 0.5

$$\gamma_p := \begin{cases} 1 & \text{if } (\text{Porosity} = 0.5) \wedge \xi_{om} \le 3.3 \\ \left(\left(\dfrac{2}{1.17 \cdot \xi_{om}^{\;0.46}}\right)\right) & \text{if } (\text{Porosity} = 0.5) \wedge \xi_{om} > 3.3 \\ 0.5 & \text{otherwise} \end{cases}$$

$\gamma_p = 1$

Summary of Reduction Factors:

$\gamma_p = 1$

$\gamma_\beta = 1$

$\gamma_b = 0.6$

$\gamma_r = 0.53$

Calculate Runup Reduction Factors in Accordance with Table D.2.8-5 of Guidelines and Specifications for Flood Hazard Mapping:

$$R_{2\%} := \begin{cases} H_{m0runup} \cdot (1.77 \cdot \gamma_r \cdot \gamma_b \cdot \gamma_\beta \cdot \gamma_p \cdot \xi_{om}) & \text{if } 0.5 \le \gamma_b \cdot \xi_{om} < 1.8 \\ H_{m0runup} \cdot \left[\gamma_r \cdot \gamma_b \cdot \gamma_\beta \cdot \gamma_p \cdot \left(4.3 - \dfrac{1.6}{\sqrt{\xi_{om}}}\right)\right] & \text{if } 1.8 \le \gamma_b \cdot \xi_{om} \\ 0 & \text{otherwise} \end{cases}$$

$$R_{2\%} := \begin{cases} \text{"TAW Not Valid"} & \text{if } Slope_{Check} = \text{"TAW Method Does Not Apply, Switch to Runup-2.0"} \\ \text{"TAW Not Valid"} & \text{if } Iribarren_{Check} = \text{"TAW method is NOT vaild for this Irbarren value. Please seek alternative method."} \\ R_{2\%} & \text{otherwise} \end{cases}$$

$R_{2\%} = 3.2\,\text{ft}$

Check for Overtopping:

$$OVERTOPPED_{Runup} := \begin{cases} \text{"Overtopped... Please consider 3 foot rule"} & \text{if } (R_{2\%} + SWEL) > Top_{ele} \\ \text{"NO Overtopping"} & \text{otherwise} \end{cases}$$

$OVERTOPPED_{Runup}$ = "Overtopped... Please consider 3 foot rule"

$R_{2\%} + SWEL = 13.88\,ft$

$Top_{ele} = 5.53\,ft$

5.4 Failed Revetment Structure Analysis

$Armor_D := 4 \cdot ft$ Insert Depth of Armor layer in Feet

Calculate Slope of the Revetment:

$$Slope := \frac{(Top_{ele} - Toe_{ele})}{(Top_{sta} - Toe_{sta})} \qquad Slope = 0.24$$

Calculate the Midpoint of the Revetment:

$$Length := \sqrt{(Top_{sta} - Toe_{sta})^2 + (Top_{ele} - Toe_{ele})^2} \qquad Length = 24.1\,ft$$

$$Midpoint := \frac{Length}{2} \qquad Midpoint = 12.05\,ft$$

Determine the Distance from the Shoreline to the Midpoint of the Revetment:

$$Mid_{sta} := \left[\left(\frac{Midpoint}{Length}\right) \cdot (Top_{sta} - Toe_{sta})\right] + Toe_{sta} \qquad Mid_{sta} = 11.73\,ft$$

Determine the Elevation of the Midpoint of the Revetment:

$$Mid_{ele} := \text{linterp}(Station, Elevation, Mid_{sta}) \qquad Mid_{ele} = 3.48\,ft$$

Calculate the Upper Quarter of the Revetment:

$\text{Quarter} := \frac{\text{Length} \cdot 3}{4}$ $\qquad$ $\text{Quarter} = 18.08\,\text{ft}$

Determine the Distance from the Shoreline to the Upper Quadrant of the Revetment:

$\text{Quarter}_{\text{sta}} := \left[\left(\frac{\text{Quarter}}{\text{Length}} \right) \cdot \left(\text{Top}_{\text{sta}} - \text{Toe}_{\text{sta}} \right) \right] + \text{Toe}_{\text{sta}}$ $\qquad$ $\text{Quarter}_{\text{sta}} = 17.6\,\text{ft}$

Determine the Elevation of the Upper Quadrant of the Revetment:

$\text{Quarter}_{\text{ele}} := \text{linterp}\left(\text{Station}, \text{Elevation}, \text{Quarter}_{\text{sta}}\right)$ $\qquad$ $\text{Quarter}_{\text{ele}} = 4.65\,\text{ft}$

Calculate Scour at the Toe of the Revetment:

$\text{ToeR}_{\text{scour}} := \text{Toe}_{\text{ele}} - \text{Armor}_{\text{D}}$ $\qquad$ $\text{ToeR}_{\text{scour}} = -4\,\text{ft}$

Adjusting the Existing Profile:

The following calculations determine the index values in the array Station which identify the toe, midpoint, upper quadrant, and top of the revetment. If the value of $\text{Toe}_{\text{location}}$, $\text{Mid}_{\text{location}}$, $\text{Quarter}_{\text{location}}$, or $\text{Top}_{\text{location}}$ exists within the Station array, then only one value should appear for Toe location. If two values appear, then the station location is between two points in the Station array. If more than two value appears, adjust the TOL, convergence tolerance, in Tools > Worksheet Options... to be lower until only 2 values appear for Toelocation, $\text{Mid}_{\text{location}}$, $\text{Quarter}_{\text{location}}$, and $\text{Top}_{\text{location}}$.

$\text{Offset}_{\text{toe}}$, $\text{Offset}_{\text{mid}}$, $\text{Offset}_{\text{qua}}$, and $\text{Offset}_{\text{top}}$ are equal to 0 if the horizontal distance from the shoreline to the bottom of the vertical structure already exists in the station array, otherwise, offset is set to 1. If no data point exists to represent the station of these locations, a data point is created in the FailSta array, which is the array of horizontal distances from the shoreline along the transect which is used to generate a profile of the failed structures.

Determine if station of the toe of the revetment is within the Station array and if not, add a data point

$\text{Toe}_{\text{location}} := \text{match}\left(\text{Toe}_{\text{sta}}, \text{Station}\right)$ $\qquad$ $\text{Toe}_{\text{location}} = (\,0\,)$ $\qquad$ $\text{Toe}_{\text{location}_0} = 0$

$$\text{Offset}_{\text{toe}} := \begin{cases} 0 & \text{if } \text{Station}_{\left(\text{Toe}_{\text{location}_0}\right)} = \text{Toe}_{\text{sta}} \\ 1 & \text{otherwise} \end{cases}$$

$$\text{Offset}_{\text{toe}} = 0$$

$$\text{Toe}_{\text{Staloc}} := \begin{cases} \text{Toe}_{\text{location}_0} + \text{Offset}_{\text{toe}} & \text{if } \text{Toe}_{\text{sta}} \ge \text{Station}_{\left(\text{Toe}_{\text{location}_0}\right)} \\ \text{Toe}_{\text{location}_0} & \text{otherwise} \end{cases}$$

$$\text{Toe}_{\text{Staloc}} = 0$$

Determine if station of the midpoint of the revetment is within the Station array and if not, add a data point

$$\text{Mid}_{\text{sta}} = 11.73\,\text{ft}$$

$\text{Mid}_{\text{location}} := \text{match}\left(\text{Mid}_{\text{sta}}, \text{Station}\right)$ $\text{Mid}_{\text{location}} := \blacksquare$ $\text{Mid}_{\text{location}_0} = 2$

$$\text{Offset}_{\text{mid}} := \begin{cases} 0 & \text{if } \text{Station}_{\left(\text{Mid}_{\text{location}_0}\right)} = \text{Mid}_{\text{sta}} \\ 1 & \text{otherwise} \end{cases}$$

$$\text{Offset}_{\text{mid}} = 1$$

$$\text{Mid}_{\text{Staloc}} := \begin{cases} \text{Mid}_{\text{location}_0} + \text{Offset}_{\text{toe}} + \text{Offset}_{\text{mid}} & \text{if } \text{Mid}_{\text{sta}} \ge \text{Station}_{\left(\text{Mid}_{\text{location}_0}\right)} \\ \left(\text{Mid}_{\text{location}_0} + \text{Offset}_{\text{toe}}\right) & \text{otherwise} \end{cases}$$

$\text{Mid}_{\text{Staloc}} = 3$ $\text{FailRevetSta}_{\text{Mid}_{\text{Staloc}}} := \text{Mid}_{\text{sta}}$

Determine if station of the upper quadrant of the revetment is within the Station array and if not, add a data point

$\text{Quarter}_{\text{location}} := \text{match}\left(\text{Quarter}_{\text{sta}}, \text{Station}\right)$ $\text{Quarter}_{\text{location}} := \blacksquare$ $\text{Quarter}_{\text{location}_0} = 5$

$$\text{Offset}_{\text{qua}} := \begin{cases} 0 & \text{if } \text{Station}_{\left(\text{Quarter}_{\text{location}_0}\right)} = \text{Quarter}_{\text{sta}} \\ 1 & \text{otherwise} \end{cases}$$

$$\text{Offset}_{\text{qua}} = 1$$

$$Quarter_{Staloc} := \begin{cases} Quarter_{location_0} + Offset_{toe} + Offset_{mid} + Offset_{qua} & \text{if } Quarter_{sta} \geq Station_{\left(Quarter_{location_0}\right)} \\ \left(Quarter_{location_0} + Offset_{toe} + Offset_{mid}\right) & \text{otherwise} \end{cases}$$

$Quarter_{Staloc} = 6$ $\quad$ $FailRevetSta_{Quarter_{Staloc}} := Quarter_{sta}$

Determine if station of the top of the revetment is within the Station array and if not, add a data point

$Top_{location} := match(Top_{sta}, Station)$ $\quad$ $Top_{location} = (7)$ $\quad$ $Top_{location_0} = 7$ $\quad$ $Top_{sta} = 23.46\,ft$

$$Offset_{top} := \begin{cases} 0 & \text{if } Station_{\left(Top_{location_0}\right)} = Top_{sta} \\ 1 & \text{otherwise} \end{cases}$$

$Offset_{top} = 1$

$$Top_{Staloc} := \begin{cases} Top_{location_0} + Offset_{toe} + Offset_{mid} + Offset_{qua} + Offset_{top} & \text{if } Top_{sta} \geq Station_{\left(Top_{location_0}\right)} \\ \left(Top_{location_0} + Offset_{toe} + Offset_{mid} + Offset_{qua}\right) & \text{otherwise} \end{cases}$$

$Top_{Staloc} = 10$ $\quad$ $FailRevetSta_{Top_{Staloc}} := Top_{sta}$

Sets the station of the failed profile to be equal to the existing profile station from the shore to the toe of the revetment

$i := Toe_{location_0} .. 0$ $\quad$ $FailRevetSta_i := Station_i$ $\quad$ $FailRevetSta_{Toe_{Staloc}} := Toe_{sta}$

Sets the station of the failed profile to be equal to the existing profile station from the toe of the revetment to the midpoint of the revetment, offsetting if a data point was added to represent the toe of the revetment

$$x := \left|\begin{array}{ll} \left(\text{Toe}_{\text{Staloc}}+1\right)..\left(\text{Mid}_{\text{Staloc}}-1\right) & \text{if } \left(\text{Toe}_{\text{Staloc}}+1\right) \le \left(\text{Mid}_{\text{Staloc}}-1\right) \\ \text{Toe}_{\text{Staloc}} & \text{otherwise} \end{array}\right.$$

$$\text{FailRevet}_{\text{Sta}_x} := \left|\begin{array}{ll} \text{Station}_{x-\text{Offset}_{\text{toe}}} & \text{if } x \ne \text{Toe}_{\text{Staloc}} \\ \text{Toe}_{\text{sta}} & \text{otherwise} \end{array}\right.$$

$$\text{FailRevet}_{\text{Sta}_{\text{Mid}_{\text{Staloc}}}} := \text{Mid}_{\text{sta}}$$

Sets the station of the failed profile to be equal to the existing profile station from the midpoint of the revetment to the upper quadrant of the revetment, offsetting values if a data point was added to represent the midpoint of the revetment

$$y := \left|\begin{array}{ll} \left(\text{Mid}_{\text{Staloc}}+1\right)..\left(\text{Quarter}_{\text{Staloc}}-1\right) & \text{if } \left(\text{Mid}_{\text{Staloc}}+1\right) \le \left(\text{Quarter}_{\text{Staloc}}-1\right) \\ \text{Mid}_{\text{Staloc}} & \text{otherwise} \end{array}\right.$$

$$\text{FailRevet}_{\text{Sta}_y} := \left|\begin{array}{ll} \text{Station}_{y-\text{Offset}_{\text{toe}}-\text{Offset}_{\text{mid}}} & \text{if } y \ne \text{Mid}_{\text{Staloc}} \\ \text{Mid}_{\text{sta}} & \text{otherwise} \end{array}\right.$$

$$\text{FailRevet}_{\text{Sta}_{\text{Quarter}_{\text{Staloc}}}} := \text{Quarter}_{\text{sta}}$$

Sets the station of the failed profile to be equal to the existing profile station from the upper quadrant of the revetment to the top of the revetment, offsetting values if a data point was added to represent the upper quadrant of the revetment

$$z := \left|\begin{array}{ll} \left(\text{Quarter}_{\text{Staloc}}+1\right)..\left(\text{Top}_{\text{Staloc}}-1\right) & \text{if } \left(\text{Quarter}_{\text{Staloc}}+1\right) \le \left(\text{Top}_{\text{Staloc}}-1\right) \\ \text{Quarter}_{\text{Staloc}} & \text{otherwise} \end{array}\right.$$

$$\text{FailRevet}_{\text{Sta}_z} := \left|\begin{array}{ll} \text{Station}_{z-\text{Offset}_{\text{toe}}-\text{Offset}_{\text{mid}}-\text{Offset}_{\text{qua}}} & \text{if } z \ne \text{Quarter}_{\text{Staloc}} \\ \text{Quarter}_{\text{sta}} & \end{array}\right.$$

$$FailRevet_{Sta_{Top_{Staloc}}} := Top_{sta}$$

Sets the station of the failed profile to be equal to the existing profile station from the top of the revetment to the end of the transect, offsetting values to compensate for any added data points

$$end := last(Station) + Offset_{toe} + Offset_{mid} + Offset_{qua} + Offset_{top} \qquad end = 257$$

$$w := \left(Top_{Staloc} + 1\right) .. end \qquad FailRevet_{Sta_w} := Station_{w-Offset_{toe}-Offset_{mid}-Offset_{qua}-Offset_{top}}$$

Sets the elevation of the failed profile to be equal to the existing profile from the shore to the toe of the revetment and then slopes towards the shoreline at a 3h:1v slope from the toe of the revetment

$$FailRevet_{Ele_i} := Elevation_i$$

$$FailRevet_{Ele_i} := \left| \begin{array}{l} \left[\left[\left[\left(Toe_{sta} - FailRevet_{Sta_i}\right)\cdot\left(\frac{1}{3}\right)\right] + ToeR_{scour}\right]\right] \ \text{ if } \left[\left[\left[\left(Toe_{sta} - FailRevet_{Sta_i}\right)\cdot\left(\frac{1}{3}\right)\right] + ToeR_{scour}\right]\right] \le Elevation_i \\ \text{break} \ \text{ otherwise} \end{array} \right.$$

Sets the elevation at the toe of the revetment to the elevation after failure occurs:

$$FailRevet_{Ele_{Toe_{Staloc}}} := ToeR_{scour}$$

Sets the elevation of the failed revetment from the toe to the midpoint of the revetment based on armor depth if points exist between the toe and midpoint of the revetment

$$FailRevet_{Ele_x} := \left| \begin{array}{l} Elevation_{x-Offset_{toe}} - Armor_D \ \text{ if } \ x \ne Toe_{Staloc} \\ ToeR_{scour} \ \text{ otherwise} \end{array} \right.$$

Sets the elevation of the middle of the revetment

$$FailRevet_{Ele_{Mid_{Staloc}}} := \left(Mid_{ele} - Armor_D\right)$$

Sets the elevation of the failed revetment from the midpoint to the upper quadrant of the revetment assuming a constant slope equal to the slope of the original revetment, only sloping downwards instead.

$$FailRevet_{Ele_y} := \left| \begin{array}{ll} \left(Station_{y-Offset_{toe}-Offset_{mid}} - Mid_{sta}\right)\cdot(Slope\cdot -1) + \left(Mid_{ele} - Armor_D\right) & \text{if } \ y \neq Mid_{Staloc} \\ \left(\left(Mid_{ele} - Armor_D\right)\right) & \text{otherwise} \end{array} \right.$$

Sets the elevation of the upper quadrant of the revetment

$$FailRevet_{Ele_{Quarter_{Staloc}}} := \left(Quarter_{sta} - Mid_{sta}\right)\cdot(Slope\cdot -1) + \left(Mid_{ele} - Armor_D\right)$$

Sets the elevation of the failed revetment from the upper quadrant to the top of the failed revetment assuming a constant slope of 1v:1.5h until it reaches the existing elevation, or the top of the revetment.

$$j := \left(Quarter_{Staloc} + 1\right) .. end$$

$$FailRevet_{Ele_j} := \left| \begin{array}{ll} \left[\left(FailRevet_{Sta_j} - Quarter_{sta}\right)\cdot\left(\frac{1}{1.5}\right)\right] + FailRevet_{Ele_{Quarter_{Staloc}}} & \text{if } \left[\left(FailRevet_{Sta_j} - Quarter_{sta}\right)\cdot\left(\frac{1}{1.5}\right)\right] + FailRevet_{Ele_{Quarter_{Staloc}}} \leq \\ \text{break} & \text{otherwise} \end{array} \right.$$

$$failed := last\left(FailRevet_{Ele}\right) \qquad failed = 10$$

$$Offset_{failTop} := \left| \begin{array}{l} 0 \ \text{ if } \ FailRevet_{Sta_{failed}} = Station_{failed-Offset_{toe}-Offset_{mid}-Offset_{qua}} \\ 1 \end{array} \right.$$

$$Offset_{failTop} = 1$$

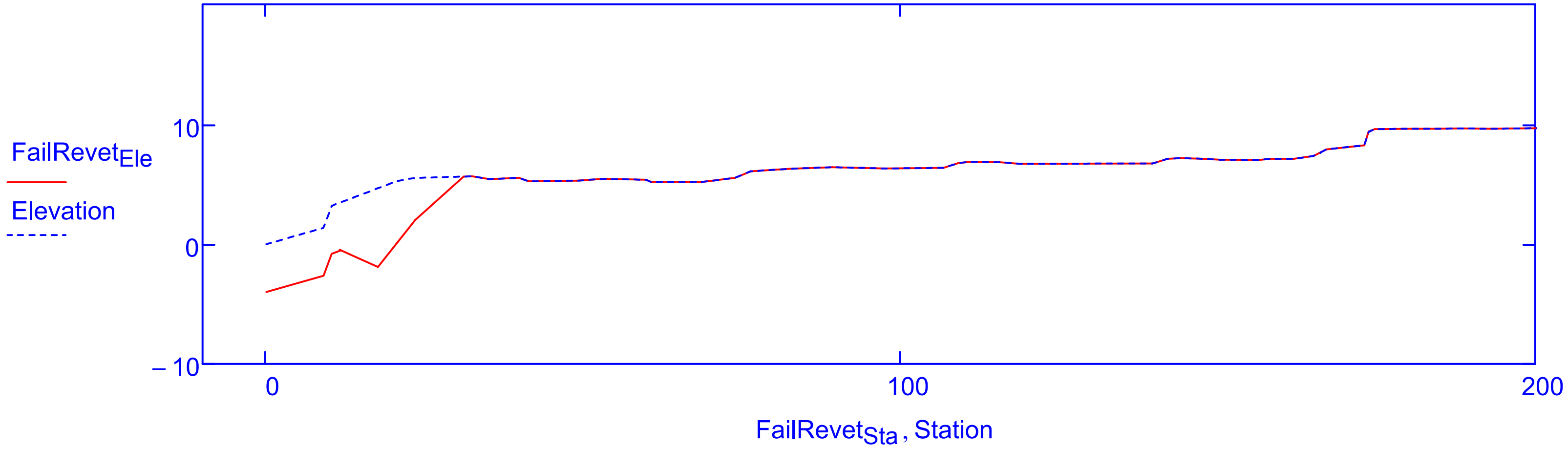
$$FailTop_{Sta} := Station_{failed-Offset_{toe}-Offset_{mid}-Offset_{qua}+Offset_{failTop}} \qquad FailTop_{Sta} = 32.41\,ft$$

$$FailTop_{Ele} := Elevation_{failed-Offset_{toe}-Offset_{mid}-Offset_{qua}+Offset_{failTop}} \qquad FailTop_{Ele} = 5.65\,ft$$

$$a := \left(failed + Offset_{failTop}\right) .. end$$

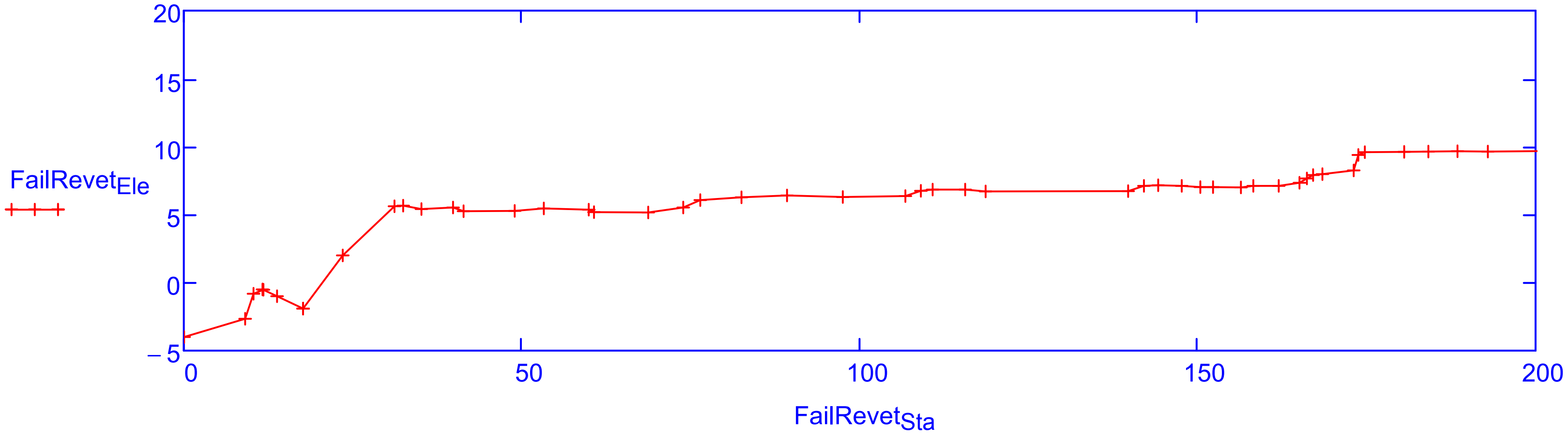
$$FailRevet_{Sta_a} := Station_{a-Offset_{toe}-Offset_{mid}-Offset_{qua}-Offset_{failTop}}$$

$$FailRevet_{Ele_a} := Elevation_{a-Offset_{toe}-Offset_{mid}-Offset_{qua}-Offset_{failTop}}$$



5.5 Wave Setup, η, Calculation on Failed Revetment

The following displays the failed profile of the transect:



Calculate Water Depth at Failed Structure, h

$h := SWEL - ToeR_{scour}$ $\qquad h = 14.68\,ft$

$H_b := b_h \cdot L_0$ $\qquad H_b = 6.02\,ft$ $\qquad H_d := b_d \cdot L_0$ $\qquad H_d = 8.03\,ft$

Calculate Wave Setup on a FailedStructure, $\eta_{structure}$:

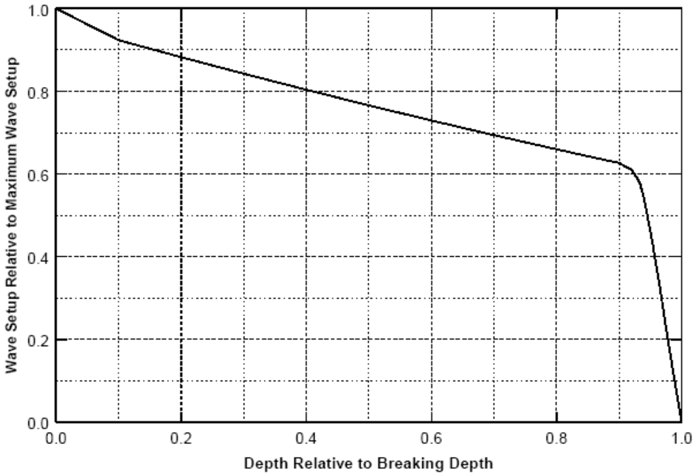


Figure D.2.6-9. Proportion of Maximum Wave Setup that Has Occurred vs. a Proportion of the Breaking Depth.

Figure from: Atlantic Ocean and Gulf of Mexico Coastal Guidelines Update Feb 2007

$$R := \begin{cases} \left[-0.8\cdot\left(\frac{h}{H_d}\right)+1\right] & \text{if } \left(\frac{h}{H_d}\right) \le 0.092 \\ \left[-0.3919\cdot\left(\frac{h}{H_d}\right)+0.9585\right] & \text{if } 0.092 < \frac{h}{H_d} \le 0.4 \\ \left[-0.3475\cdot\left(\frac{h}{H_d}\right)+0.9379\right] & \text{if } 0.4 < \frac{h}{H_d} \le 0.9 \\ \left[-33.312\cdot\left(\frac{h}{H_d}\right)^2+59.811\cdot\left(\frac{h}{H_d}\right)-26.223\right] & \text{if } 0.9 < \left(\frac{h}{H_d}\right) \le 0.94444 \\ \left[-9.8703\cdot\left(\frac{h}{H_d}\right)+9.8703\right] & \text{if } 0.94444 < \left(\frac{h}{H_d}\right) \le 1 \\ 0 & \text{otherwise} \end{cases}$$

Equation based on estimated curve from Figure D.2.6-9

$R = 0$

$\frac{h}{H_d} = 1.83$

$\eta_1 := R \cdot \eta_{open}$ $\eta_1 = 0\,\text{ft}$ $\eta_2 := 0.15 \cdot (h + \eta_1)$ $\eta_2 = 2.2\,\text{ft}$

$\eta_{FailedStructure} := \eta_1 + \eta_2$ $\eta_{FailedStructure} = 2.2\,\text{ft}$

Total Setup against a coastal structure without considering overtopping

Check Overtopping if Coastal Structure Exists:

$$Overtopped := \left| \begin{array}{ll} \text{"Yes"} & \text{if } (\eta_{FailedStructure} + SWEL) > Top_{ele} \\ \text{"No"} & \text{otherwise} \end{array} \right.$$

$Overtopped = \text{"Yes"}$

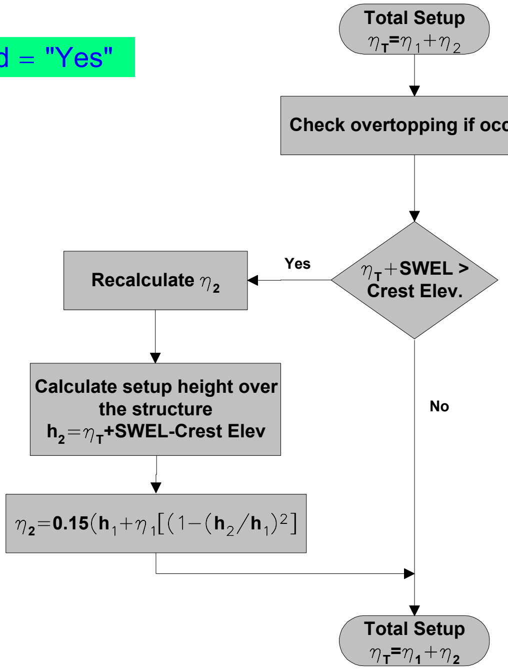
$$h_2 := \left| \begin{array}{ll} (\eta_{FailedStructure} + SWEL - Top_{ele}) & \text{if } Overtopped = \text{"Yes"} \\ 0 & \text{otherwise} \end{array} \right.$$

Equation D.2.6-12 for η_2 from Atlantic Ocean and Gulf of Mexico Coastal Guidelines Update

$$\eta_2 := \left| \begin{array}{ll} 0.15 \cdot (h + \eta_1) \cdot \left[1 - \left(\frac{h_2}{h} \right)^2 \right] & \text{if } Overtopped = \text{"Yes"} \\ \eta_2 & \text{otherwise} \end{array} \right.$$

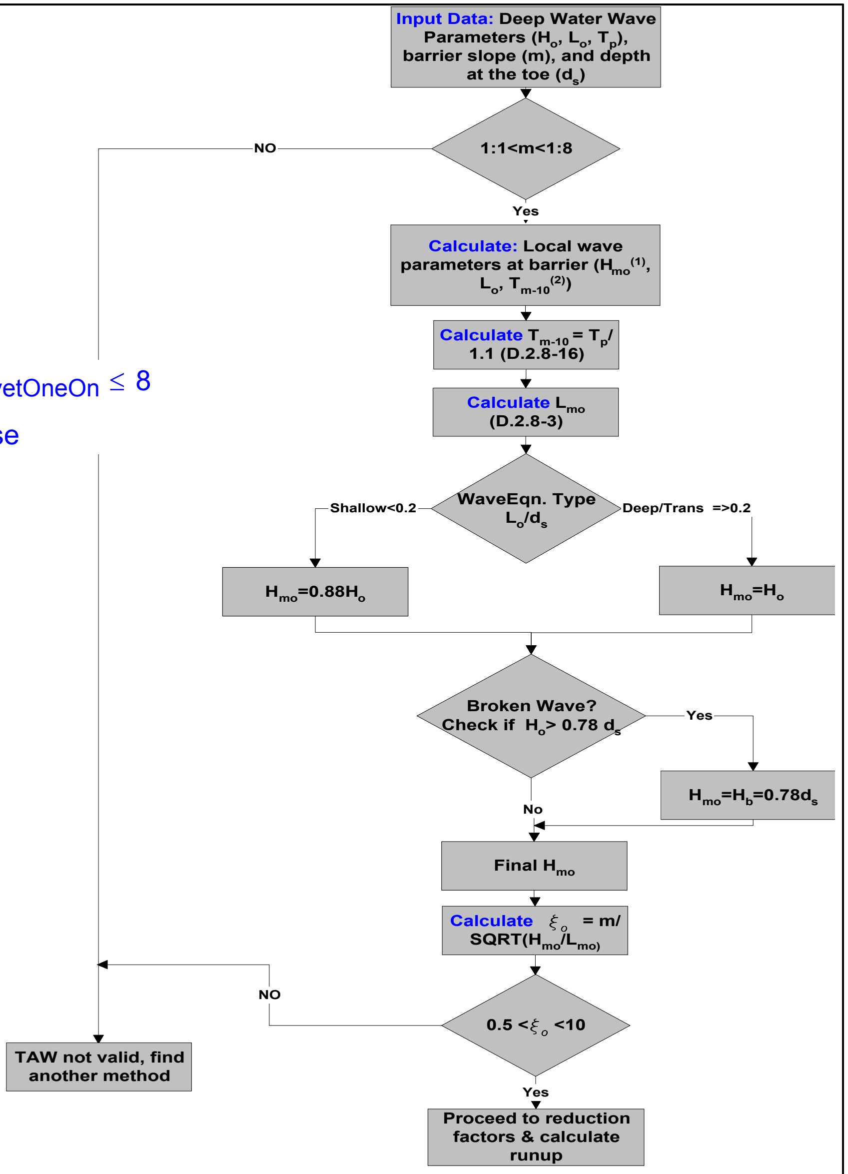
$\eta_{FailedStructure} := \eta_1 + \eta_2$ $\eta_{FailedStructure} = 1.65\,\text{ft}$

Total Setup with a failed coastal structure



5.6 Wave Runup Analysis (Using TAW Method) on a Failed Revetment

Flow Chart of Process of Calculating Wave Runup:



Checking Slope of Revetment to determine if it is between 1:0 and 1:8:

$$Slope_{FAILRevet} := \frac{\left(FailTop_{Ele} - ToeR_{scour}\right)}{\left(FailTop_{Sta} - Toe_{sta}\right)} \qquad Slope_{FAILRevet} = 29.78 \cdot \%$$

$$Slope_{FAILRevetOneOn} := \frac{1}{Slope_{FAILRevet}} \qquad Slope_{FAILRevetOneOn} = 3.36$$

$$FAILSlope_{Check} := \left| \begin{array}{ll} \text{"TAW Method of Runup Calculation Applies"} & \text{if } 0 < Slope_{RevetOneOn} \le 8 \\ \text{"TAW Method Does Not Apply, Switch to Runup-2.0"} & \text{otherwise} \end{array} \right.$$

$$FAILSlope_{Check} = \text{"TAW Method of Runup Calculation Applies"}$$

Check if Wave is Depth Limited at the Toe of the Revetment / Barrier:

$$Depth_{Limited} := \left| \begin{array}{ll} \text{"Limited"} & \text{if } H_{m0} \ge 0.78 \cdot h \\ \text{"Not Limited"} & \text{otherwise} \end{array} \right.$$

If wave is depth limited, H_b will be used rather than H_{m0}

$$Depth_{Limited} = \text{"Not Limited"}$$

Determine Wave Type:

$$WaveType := \left| \begin{array}{ll} \text{"Shallow"} & \text{if } \frac{h}{L_0} < 2 \\ \text{"Transitional"} & \text{if } 0.2 \le \frac{h}{L_0} < 0.5 \\ \text{"Deep"} & \text{otherwise} \end{array} \right.$$

$$WaveType = \text{"Shallow"}$$

Determine Significant Wave Height Depending on WaveType and DepthLimited Condition:

$$H_{m0runupFAIL1} := \left| \begin{array}{ll} 0.88 \cdot H_{m0} & \text{if } \ WaveType = \text{"Shallow"} \\ H_{m0} & \text{otherwise} \end{array} \right. \qquad H_{m0runupFAIL1} = 5.49\,ft$$

$$H_{m0runupFAIL} := \left| \begin{array}{ll} 0.78 \cdot h & \text{if } \ Depth_{Limited} = \text{"Limited"} \\ H_{m0runupFAIL1} & \text{otherwise} \end{array} \right. \qquad H_{m0runupFAIL} = 5.49\,ft$$

Calculate the Iribarren Number, ξ_{0m}:

$$\xi_{om} := \frac{Slope_{FAILRevet}}{\sqrt{\dfrac{H_{m0runupFAIL}}{L_{m0}}}} \qquad \xi_{om} = 1.31$$

Check TAW Method for Validity based on Iribarren Number:

$$FAILIribarren_{Check} := \left| \begin{array}{ll} \text{"TAW method is Valid"} & \text{if } \ 0.5 < \xi_{om} < 10 \\ \text{"TAW method is NOT vaild for this Irbarren value. Please seek alternative method."} & \text{otherwise} \end{array} \right.$$

$$FAILIribarren_{Check} = \text{"TAW method is Valid"}$$

Calculate Runup Reduction Factors in Accordance with Table D.2.8-5 of Guidelines and Specifications for Flood Hazard Mapping:

Select Roughness Reduction Factor, γ_r:

$\gamma_r :=$

$$\gamma_r := \begin{cases} \gamma_r & \text{if } \gamma_r \geq 0.53 \\ \text{"Please Select Radio Button"} & \text{otherwise} \end{cases}$$

$\gamma_r = 0.58$

Select Berm Section in Breakwater, γ_b:

$\gamma_b :=$

$$\gamma_b := \begin{cases} \gamma_b & \text{if } \gamma_b > 0.5 \\ \text{"Please Select Radio Button"} & \text{otherwise} \end{cases}$$

$\gamma_b = 1$

Select Wave Direction Factor, γ_β:

$\beta := 0$ 0º for normally incident wave

$\gamma_\beta :=$

$$\gamma_\beta := \begin{cases} (1 - 0.0022 \cdot \beta) & \text{if } |\beta| \leq 80 \wedge \gamma_\beta = 1 \\ (1 - 0.0022 \cdot |80|) & \text{if } (|\beta| \geq 80) \wedge \gamma_\beta = 1 \\ 1 & \text{if } 0 \leq |\beta| < 10 \wedge \gamma_\beta = 2 \\ \cos\left[(|\beta| - 10) \cdot \left(\frac{\pi}{180}\right)\right] & \text{if } (10 < |\beta| < 63 \wedge \gamma_\beta = 2) \\ 0.63 & \text{if } |\beta| > 63 \wedge \gamma_\beta = 2 \\ \text{"Please Select Radio Button"} & \text{otherwise} \end{cases}$$

$\gamma_\beta = 1$

Select Porosity Factor, γ_P:

$\text{Porosity} :=$

Default Porosity = 0.5

$$\gamma_p := \begin{cases} 1 & \text{if } (\text{Porosity} = 0.5) \wedge \xi_{om} \leq 3.3 \\ \left(\left(\frac{2}{1.17 \cdot \xi_{om}^{\ 0.46}}\right)\right) & \text{if } (\text{Porosity} = 0.5) \wedge \xi_{om} > 3.3 \\ 0.5 & \text{otherwise} \end{cases}$$

$\gamma_p = 1$

Summary of Reduction Factors:

$\gamma_p = 1$

$\gamma_\beta = 1$

$\gamma_b = 1$

$\gamma_r = 0.58$

Calculate Runup Reduction Factors in Accordance with Table D.2.8-5 of Guidelines and Specifications for Flood Hazard Mapping:

$$R_{FAIL2\%} := \left| \begin{array}{ll} H_{m0runup} \cdot \left(1.77 \cdot \gamma_r \cdot \gamma_b \cdot \gamma_\beta \cdot \gamma_p \cdot \xi_{om}\right) & \text{if } \ 0.5 \le \gamma_b \cdot \xi_{om} < 1.8 \\ H_{m0runup} \cdot \left[\gamma_r \cdot \gamma_b \cdot \gamma_\beta \cdot \gamma_p \cdot \left(4.3 - \frac{1.6}{\sqrt{\xi_{om}}}\right)\right] & \text{if } \ 1.8 \le \gamma_b \cdot \xi_{om} \\ 0 \ \ \text{otherwise} & \end{array} \right.$$

$$R_{FAIL2\%} := \left| \begin{array}{l} \text{"TAW Not Valid" if } FAILSlope_{Check} = \text{"TAW Method Does Not Apply, Switch to Runup-2.0"} \\ \text{"TAW Not Valid" if } FAILIribarren_{Check} = \text{"TAW method is NOT vaild for this Irbarren value. Please seek alternative me} \\ R_{FAIL2\%} \ \ \text{otherwise} \end{array} \right.$$

$R_{FAIL2\%} = 7.36\,ft$

Check for Overtopping:

$$OVERTOPPEDFAIL_{Runup} := \left| \begin{array}{l} \text{"Overtopped... Please consider 3 foot rule" if } \left(R_{FAIL2\%} + SWEL\right) > Top_{ele} \\ \text{"NO Overtopping" otherwise} \end{array} \right.$$

$OVERTOPPEDFAIL_{Runup} = \text{"Overtopped... Please consider 3 foot rule"}$

6.0 Conclusions/Results

Wave Height, H_{m0} $H_{m0} = 6.23\,ft$ FetchStatus = "STWAVE Input (Hmo, Tp)"

Wave Period, T_P $T_P = 5\,s$ FetchStatus = "STWAVE Input (Hmo, Tp)"

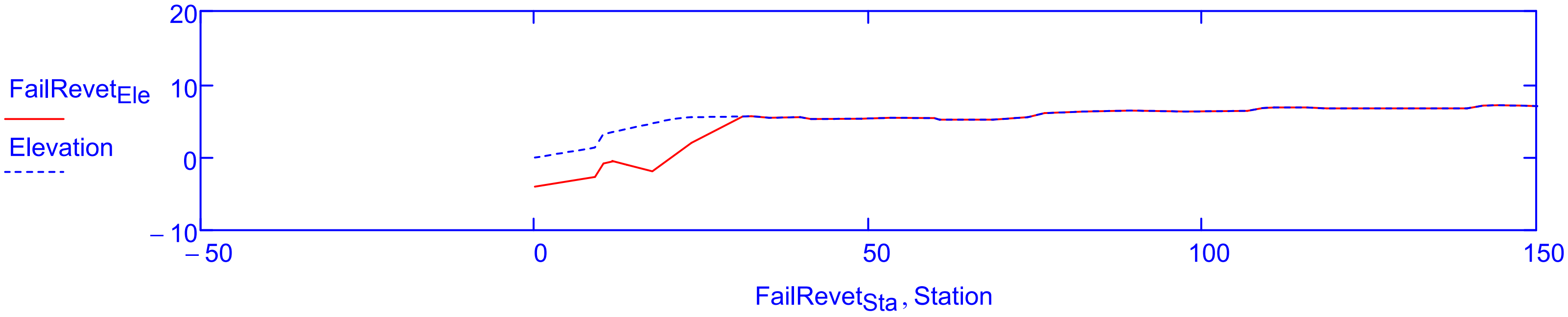
Wave Setup on an open coast, η_{open} $\eta_{open} = 0.83\,ft$

Wave Setup on a revetment, $\eta_{Structure}$ $\eta_{Structure} = 0$

Wave Runup on a revetment, $R_{2\%}$ $R_{2\%} = 3.2\,ft$

$OVERTOPPED_{Runup}$ = "Overtopped... Please consider 3 foot rule"

Failed Structure Profile:



Wave Setup on a Failed Structure, η $\eta_{FailedStructure} = 1.65\,ft$

Wave Runup on a Failed Structure, $R_{FAIL2\%}$ $R_{FAIL2\%} = 7.36\,ft$

$OVERTOPPEDFAIL_{Runup}$ = "Overtopped... Please consider 3 foot rule"

Wave Height, Wave Period, Wave Setup, and Failed Revetment / Coastal Barrier / Steep Bluff Worksheet

1.0 Purpose/Objective

This worksheet was created to determine the unrestricted H_{m0} and T_p where H_{m0} is the energy-based significant wave height in meters and Tp is the limiting wave period, or use user input H_{m0} and T_P values from ACES or STWAVE models. This worksheet also calculates the open coast wave setup, η_{open}, which is the increase in stillwater elevation against a barrier caused by the attenuation of waves in shallow water. Wave setup is based upon wave breaking characteristics and profile slope. Wave setup can be a significant contributor to the total water level at the shoreline and must be included in the determination of coastal base flood elevations. This worksheet also evaluates the wave setup against a coastal structure, $\eta_{structure}$. For profiles with sloping revetments, this worksheet will also perform a failed structure analysis and generate a new profile of the failed structure and calculate the wave setup on the failed revetment.

2.0 Procedure

For unrestricted fetch length analysis where no STWAVE or ACES model run was produced, an extremal analysis was performed to determine three thresholds for peak wind speeds. The threshold with the highest correlation to either the Fisher-Tippett Type 1 (Gumbel), Fisher-Tippett Type II (Frecher), or Wiebull distribution is input parameter U_{10}, or the wind speed at 10m elevation (m/sec). Fetch, X, was also determined for each location. An excel spreadsheet for each transect was generated to calculate the 1% annual chance stillwater elevation. These variables are input into this worksheet from external worksheets and used for calculation within this worksheet.

Calculation worksheet details:

1. Go to View> Header and Footer... and fill out ALL relevant information to worksheet
2. Enter similar information on Page 2
3. Use radio buttons to select if analysis is based on "Unrestricted Fetch Wind Speed Input", "Restricted Fetch Input From ACES (H_{m0}, T_P)", or "STWAVE Input (H_{m0}, T_p)"

Section 5.1 - Wave Height and Wave Period

4. Fill in value of U_{10} and list peak threshold, regression, and correlation coefficient and associated files
5. If fetch length is unrestricted, continue to section 5.1.1, otherwise, skip section 5.1.1

Section 5.1.1 - Unrestricted Wave Height and Wave Period Calculation

6. Fill in value of Fetch, X, and list associated calculation files.

7. Skip Section 5.1.2 and Section 5.1.3 if fetch length is unrestricted

Section 5.1.2 - Restricted Wave Height and Wave Period Calculation

8. If ACES model run was complete enter ACES program inputs including the fetch angles and fetch lengths used in the restricted analysis in ACES

9. List the .mxd file and associated information involved in the calculation of fetch lengths

10. Fill in results of H_{m0} and T_p from the ACES analysis and any ACES output files which were saved

11. Skip section 5.1.3

Section 5.1.3 - STWAVE Wave Height and Wave Period

12. If STWAVE model run was complete enter the associated wave height and wave period

13. List the associated STWAVE model file

Section 5.2 - Wave Setup

Section 5.2.1 - Open Coast Wave Setup Calculation

14. Enter value for average transect slope and associated .mxd file from which average slope was calculated

Section 5.2.2 - Wave Setup on a Revetment Calculation

15. Enter Profile variable excel file path information. Excel file should be formatted with the first row of the file having column headings. The first column within the file should have station data in ascending order. The second column within the file should have the associated station elevation in order of ascending station. All data should be in feet. This file needs to be an .xls file as Mathcad is not currently compatible with .xlsx files.

16. Enter horizontal distance from shoreline along transect which identifies the start of the coastal structure, Toe_{sta}, in feet

17. Enter horizontal distance from shoreline along transect which identifies the top of the coastal structure, Top_{sta}, in feet

18. Enter value for SWEL, 1% annual chance stillwater elevation in feet and name and path of associated excel file from which SWEL was calculated

Section 5.3 - Wave Runup - TAW Method

19. Check $Slope_{Check}$ and $Iribarren_{Check}$ variables to determine if TAW method holds for these situations

20. Use radio buttons to select runup reduction factors

21. Enter incident angle, β, if known, otherwise, assume 0

Section 5.4 - Failed Revetment Analysis

22. Enter approximate depth of armor layer in feet based on photographs and site inspections (ft)

23. Check value of $Toe_{location}$, $Mid_{location}$, $Quarter_{location}$, and $Top_{location}$, which should be the location in the Station array which holds the value of Toe_{sta}, Mid_{sta}, $Quarter_{sta}$, and Top_{sta}. If the horizontal distance from the shoreline along the transect to these locations were not measured points

in the Station array, then $Toe_{location}$, $Mid_{location}$, $Quarter_{location}$, and/or $Top_{location}$ should be arrays of two values representing the indices which the value of Toe_{sta}, Mid_{sta}, $Quarter_{sta}$, and.or Top_{sta} are between. If none or more than two values are listed, adjust the convergence tolerance (TOL) from the Tools > Worksheet Options option in the menu bar, until two values are listed for the $Toe_{location}$, $Mid_{location}$, $Quarter_{location}$, and/or $Top_{location}$ variables.

Section 5.5 - Wave Setup on Failed Revetment

Section 5.6 - Wave Runup on Failed Revetment

24. Check SlopeCheck and IribarrenCheck variables to determine if TAW method holds for these situations
25. Use radio buttons to select runup reduction factors
26. Enter incident angle, β, if known, otherwise, assume 0

Section 6.0 - Conclusions

3.0 References/Data Sources

Equation taken from Coastal Engineering Manual Part II (Publication date: August 1, 2008)
Atlantic Ocean and Gulf of Mexico Coastal Guidelines Update, FEMA, February, 2007
Guidelines and Specifications for Flood Hazard Mapping Partners [February 2007]
Coastal Engineering Manual Part VI

4.0 Assumptions

Unrestricted Wave Height and Wave Period Mathcad Calculation:

1. One of the following situations hold:
- Wind blows, with essentially constant direction, over a fetch for sufficient time to achieve steady-state, fetch-limited values
- Wind increases very quickly through time in an area removed from any close boundaries. Wave growth is considered duration-limited. RARE condition
- Fully developed wave height, however, open-ocean waves rarely attain a limiting wave height for wind speeds above 50 knots of so.

2. Wave growth with fetch.
3. Wind speeds collected were taken at 10 m, to be a U_{10} measurement of wind speeds

Open Coast Wave Setup and Wave Setup on Existing and Failed Structures Analysis

1. Wave height, H_{m0}, is the deepwater wave height and is not in water of transitional depth
2. The wave setup calculated is a "static" wave setup, during which the storm tide and incident wave conditions remain unchanged

3. The open coast wave setup calculation does not consider wave nonlinearity, wave breaking characteristics, profile slope, or wave propagation through vegetation
4. Dynamic wave setup component is not considered, as it is small by comparison with the static component for the locations considered.
5. Wave period, T_P, remains constant and independent of depth for oscillatory waves

Wave Runup Analysis on Failed and Existing Structures - ***Technical Advisory Committee for Water Retaining Structures (TAW) Method***

1. The TAW method is assumed to hold for all barriers, revetments, or dunes which have a slope of 1:8 or steeper
2. The shallow water significant wave height is assumed to be 88% of the deep water significant wave height
3. The breaking wave height is assumed to be 78% of the water depth at the toe of the barrier, revetment, or dune
4. The TAW method is assumed to hold for Iribarren numbers in the range of 0.5 to 10
5. The incident wave angle is assumed to be 0 in most cases
6. Assuming berm width is unknown, minimum and maximum berm section breakwater reduction factors were assumed for conditions when a berm does and does not exist respectively
7. The runup values calculated are the 2% exceendence probability values

Failure of a Sloping Revetment

1. Landslide of revetment has constant slope
2. The scour depth does not include any parameters relating to sediment properties, which are expected to have some influence on the scouring process.
3. The scour at the base of the structure is equal to the depth of the armored layer
4. The structure will collapse in place into a triangular section throughout the structure footprint, with side slopes equal to the original structure slope
5. The landward side of the failed configuration will be half exposed and half buried
6. The soil slope landward from the failed structure fails to a uniform 1:1.5 slope, which extends to existing grade
7. Slope recedes back from the toe of the revetment at a 1:3 slope

Wave Height, Wave Period, Wave Setup, Failed Vertical Structure Calculation Worksheet

Modeler Name: Nick Rutigliano
Date: September 26, 2018
County: Newport, RI
Transect Number: VHB 2
Airport: N/A
Years of Data set: N/ A
Associated Files:

5.0 Calculations

List of Variables:

Constants:

g - Gravitational acceleration (m/sec^2)

Inputs:

X - straight line fetch distances over which the wind blows (miles)
U_{10} - Wind speed at 10 m elevation (ft/sec)
$H_{m0STWAVE}$ - Deep water signficant wave height input by user from STWAVE model
$T_{PSTWAVE}$ - Wave period input by user from STWAVE model
m - Average slope of transect (dimensionless)
Profile - Excel file with station (ft) and elevations (ft) of transect profile
Toe_{sta} - Horizontal location of toe of structure relative to shoreline (ft)
Top_{sta} - Horizontal location of top of structure relative to shoreline (ft)
SWEL - 1% Annual Chance Stillwater Elevation (ft)
$Armor_D$ - Depth of armor layer on a sloping revetment (ft)
$ACESInput_{Ang}$ - Angle of fetches input into ACES analysis (deg)
$ACESInput_{Fetch}$ - Fetch length of fetches input into ACES analysis (ft)
H_{m0ACES} - Deepwater significant wave height from ACES analysis (ft)
T_{PACES} - Limiting wave period from ACES analysis (sec)

Working Variables:

C_D - Coefficient of drag for winds measured at 10 meters (dimensionless)
u_s - Wind friction velocity (m/sec)
L_0 - Deep water wave length (ft)
S - Wave slope (dimensionless)
$Toe_{ele,}$ $Mid_{ele,}$ $Quarter_{ele,}$$Top_{ele}$ - Elevation of toe, midpoint, upper quarter, and top of revetment from interpolation (ft)
Station - Array of station (ft) of existing (non-failed) profile
Elevation - Array of elevations (ft) of existing (non-failed) profile
h - Water depth from the top of the water surface against a structure to the toe of the structure (ft)

b_h - Dimensionless breaking wave height

H_b - Breaking wave height (ft)

b_d - Dimensionless breaking wave depth (dimensionless)

H_d - Breaking wave depth (ft)

R - Wave setup relative to maximum wave setup (dimensionless)

η_{open} - Open coast wave setup (ft)

η_1 - Wave setup component on a coastal structure from the water depth at the toe of a coastal structure (ft)

η_2 - Wave setup component determined for a sloping coastal structure (ft)

h_2 - Water depth over coastal structure when overtopping occurs (ft)

$\eta_{structure}$ - Total wave setup on a structure or steep slope (ft)

H_{fail} - Wave height used for analysis of failed structure equal to H_{m0}, or the energy-based significant wave height, H_{m0}, but limited to a maximum equal to the breaking wave height, H_b (ft)

S_m - Maximum scour depth (ft)

$ToeV_{scour}$ - Elevation of toe of vertical coastal structure after scour occurs (ft)

$Toe_{location}$, $Mid_{location}$, $Quarter_{location}$, $Top_{location}$- Index of location of bottom of vertical coastal structure or revetment, midpoint of revetment, quarter distance, and top of revetment within the Station array (dimensionless)

Offset, $Offset_{toe}$, $Offset_{mid}$, $Offset_{qua}$, $Offset_{top,}$ $Offset_{failTop}$ - Dummy variable equal to 0 if the horizontal location of the bottom of the vertical structure, revetment toe, revetment midpoint, revetment quarter distance, revetment top is listed in the Station array, equal to 1 if the horizontal location of the bottom of the vertical structure is not listed in the station array (dimensionless)

Toe_{staloc}, Mid_{staloc}, $Quarter_{staloc}$, Top_{staloc} - Index of location of toe of vertical coastal structure or revetment, midpoint of revetment, quarter length of revetment, and top of revetment within the station array (dimensionless)

$Sta_{lastloc}$ - Index to the last element in the Station array (dimensionless)

failed - Index to the last element in the Station array (dimensionless)

i,x,y,z,a,w - Counter variables (dimensionless)

Slope - Slope of a revetment (dimensionless)

Length - Length of a revetment (ft)

Midpoint, Quarter - Midpoint and Quarter of the distance along length of revetment (ft)

Mid_{sta}, $Quarter_{sta}$- Distance from shoreline to midpoint and quarter distance of sloping revetment (ft)

$ToeR_{scour}$ - Elevation of toe of sloping revetment structure after scour occurs (ft)

end - last index of the station and elevation of the partial failure of a sloping revetment arrays

$FailRevet_{Ele}$ - Array of elevations of partial failure of a sloping revetment (ft)

$FailRevet_{Sta}$ - Array of station data of partial failure of a sloping revetment (ft)

$Slope_{Revet}$ - Slope or revetment expressed as a decimal or percentage (dimensionless)

$Slope_{RevetOneOn}$ - Slope of revetment expressed as the horizontal distance associated with an increase in one vertical foot (string)

$Slope_{Check}$ - Indicator variable associated with determining if the TAW method is applicable based on barrier slope (string)

$Slope_{Check}$ - Indicator variable associated with determining if the TAW method is applicable based on barrier slope of failed revetment (string)

$Depth_{Limited}$ - Indicator variable associated with determining if the wave is depth limited at the toe of the revetment or structure (string)

WaveType - Indicator variable associated with determining if water is considered to be shallow, deep, or transitional at the toe of the barrier

β - Incident wave angle (degrees)

T_{m10} - Spectral wave period (sec)

$H_{m0Runup,}$ $H_{m0Runup1}$ - Significant wave height adjusted if necessary for runup calculations (ft)

γ_r - Roughness reduction factor (dimensionless)

γ_b - Berm section in breakwater (dimensionless)

γ_p - Porosity factor (dimensionless)

γ_β - Wave direction factor (dimensionless)

$Slope_{FAILRevet}$ - Slope or revetment expressed as a decimal or percentage (dimensionless)

$Slope_{FAILRevetOneOn}$ - Slope of revetment expressed as the horizontal distance associated with an increase in one vertical foot (string)

$Iribarren_{Check}$ - Indicator variable to determine if the TAW method is applicable based on the Iribarren number (string)

$FAILIribarren_{Check}$ - Indicator variable to determine if the TAW method is applicable based on the Iribarren number for the failed revetment (string)

$FailTop_{Sta}$ - Station of top of revetment after failure (ft)

$FailTop_{Ele}$ - Elevation of top of revetment after failure (ft)

Output:

H_{m0} - Energy-based significant wave height (ft)

T_P - Limiting wave period (sec)

FetchLength - Reports if fetch length is "Restricted" or "Unrestricted" based on user input

FetchStatus - Indicator of restricted or unrestricted fetch length based on user input (string)
η - Wave setup (ft)
FailEle - Array of elevation of existing profile if no coastal structure exists, or elevations of a failed vertical structure or sloping revetment (ft)
FailSta - Array of stations of existing profile if no coastal structure exists, or stations of a failed vertical structure or sloping revetment (ft)
Out_1 - Output file of failed elevation profile data if a coastal structure exists
Out_2 - Output file of failed station profile data if a coastal structure exists
Overtopped - Indicator of overtopping of a coastal structure with wave setup
$R_{2\%}$ - Two percent exceedence wave runup on revetment / barrier / or dune (ft)
$R_{FAIL2\%}$ - Two percent exceedence wave runup on failed revetment / barrier / or dune (ft)
OVERTOPPEDRunup - Indicator variable to determine if revetment was overtopped by wave runup (string)
$OVERTOPPEDFAIL_{Runup}$ - Indicator variable to determine if the failed revetment was overtopped by wave runup (string)

○ Unrestricted Fetch
○ Restricted Fetch Input from ACES (Hmo, Tp)
● STWAVE Input (Hmo, Tp)

Select using radio buttons if input(s) is Unrestricted Fetch Length, Restricted Fetch Length, or Wave Height and Wave Period from STWAVE

5.1 Wave Height, H_{m0}, and Wave Period, T_p Calculation

Definition of Variables:

$$g = 9.81 \cdot \frac{m}{s^2}$$

Insert $U_{10,}$ wind speed in meters per second:

These fields must be populated, but will only be used for calculations if unrestricted radio button is selected above

$$U_{10} := 26.822 \frac{m}{s}$$

Wind speed based on: N/A -- placeholder value used
Airport: N/A

$U_{10} = 88 \cdot \frac{ft}{s}$

Taken from file: N/A

5.1.1 Calculation of Unrestricted Wave Height, H_{m0}, and Wave Period, T_P

Insert X, fetch in miles:

$X := 2 \cdot mi$ $\qquad X = 3218.69 \cdot m$

Feature Class used: N/A

Calculate Coefficient of Drag, C_D:

$C_D := 0.001 \cdot \left[1.1 + \left(0.035 \cdot U_{10} \cdot \frac{s}{m}\right)\right] \qquad C_D = 0.002$

Calculate Wind Friction Velocity, u_s (m/sec):

initialize u_s: $u_s := 1 \cdot \frac{m}{s}$

Given

$C_D = \frac{u_s^2}{U_{10}^2} \qquad u_s := \text{Find}(u_s) \qquad u_s = 1.21 \cdot \frac{m}{s}$

Calculate Wave Height, H_{m0} (m):

initialize H_{m0}: $H_{m0} := 0.01 \cdot m$

$X = 3218.69 \cdot m \qquad u_s = 1.21 \cdot \frac{m}{s} \qquad g = 9.81 \frac{1}{s} \cdot \frac{m}{s}$

Given

$\frac{g \cdot H_{m0}}{u_s^2} = 0.0413 \cdot \left(\frac{g \cdot X}{u_s^2}\right)^{0.5} \qquad H_{m0} := \text{Find}(H_{m0}) \qquad H_{m0} = 0.91 \cdot m \qquad H_{m0} = 2.97\,ft$

Calculate Wave Period, T_P (sec):

initialize T_P: $T_P := 0.01\cdot s$

$X = 3218.69\cdot m$ $u_s = 1.21\cdot\frac{m}{s}$ $g = 9.81\frac{1}{s}\cdot\frac{m}{s}$

Given

$$\frac{g\cdot T_P}{u_s} = 0.751\cdot\left(\frac{g\cdot X}{u_s^{\,2}}\right)^{\frac{1}{3}} \qquad T_P := \mathrm{Find}(T_P) \qquad T_P = 2.58\cdot s$$

5.1.2 Calculation of Restricted Wave Height, H_{m0}, and Wave Period, T_p

The calculation of restricted wave height, Hm0, and Wave Period, Tp, require the use of ACES software.

$$ACESInput_{Ang} := \begin{pmatrix} \blacksquare \\ \blacksquare \\ \blacksquare \\ \blacksquare \\ \blacksquare \\ \blacksquare \\ \blacksquare \\ \blacksquare \\ \blacksquare \end{pmatrix} \qquad ACESInput_{Fetch} := \begin{pmatrix} \blacksquare \\ \blacksquare \\ \blacksquare \\ \blacksquare \\ \blacksquare \\ \blacksquare \\ \blacksquare \\ \blacksquare \\ \blacksquare \end{pmatrix}$$

Input angle of fetch and fetch length as input to ACES with 0° facing North.

Feature Class File: N/A

Aces Output:

$H_{m0ACES} := 0\cdot ft$ $T_{PACES} := 0\cdot sec$

These fields must be populated, but will only be used for calculations if restricted radio button is selected above

ACES result file: N/A

5.1.3 Input Significant Wave Height (H_{m0}) and Wave Period (T_P) taken from STWAVE

$H_{m0STWAVE} := 1.65 \cdot m$ $T_{PSTWAVE} := 4 \cdot sec$

These fields must be populated, but will only be used for calculations if STWAVE Input radio button is selected above

Input the path to the STWAVE Model File:

RESULT:

$H_{m0} = 5.41\,ft$ $T_P = 4\,s$ FetchStatus = "STWAVE Input (Hmo, Tp)"

5.2 Wave Setup, η, Calculation

5.2.1 Open Coast Wave Setup Analysis

Definition of Variables:

$m := .01764$ Insert value of average transect slope based on GIS data

Calculate Deep Water Wave Length, L_0:

$$L_0 := \frac{g \cdot T_P^2}{2 \cdot \pi} \qquad L_0 = 81.93\,ft$$

Equation source: Coastal Engineering Manual Part VI Page VI-5-236

Calculate Wave Slope, S:

$$S := \frac{H_{m0}}{L_0} \qquad S = 0.0661 \qquad S = 6.61 \cdot \%$$

Calculate Static Open Coast Wave Setup:

$$\eta_{open} := H_{m0}\cdot 0.160\cdot \frac{m^{0.2}}{s^{0.2}}$$

$\eta_{open} = 0.67\,\text{ft}$

Equation Source: Atlantic Ocean and Gulf of Mexico Coastal Guidelines Update Feb 2007 - Equation D.2.6-1

5.2.2 Wave Setup On Structures Analysis for Structures/Steep Slopes (1:8 or Steeper) which Intersect the SWEL

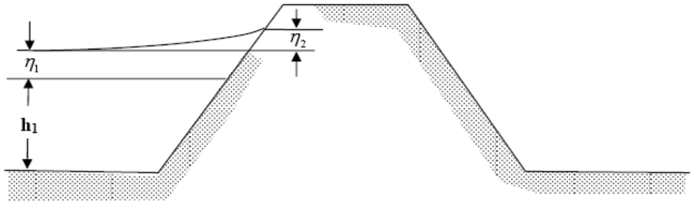


Figure D.2.6-6. Definition Sketch for Nonovertopped Levee

Figure from: Atlantic Ocean and Gulf of Mexico Coastal Guidelines Update Feb 2007

Definition of Variables:

Enter path and file name of .xls file containing station and elevation data for transect within the "" below:

Profile := READFILE("\\vhb\gbl\proj\Providence\72900.00\tech\PreliminaryHH\2018HydraulicStudy\Pr_Transect2.csv" ,"delimited" ,2 ,1)*

Note: The Path name above corresponds to an excel file containing station and elevation data. The 1st row of the excel file should contain column headings. The 1st column in the spreadsheet should contain the Station (ft) starting at station 0 and listed in ascending order. Column B, or the 2nd column, should contain elevation data (ft) corresponding with the associated station listed in Column A, or column 1, in ascending order by station. THIS FILE NEEDS TO BE AN .XLS FILE!!! MATHCAD WILL NOT SUPPORT 2007 VERSION OF EXCEL.

The following displays Profile data from excel worksheet identified above and lists Station and Elevation as two separate arrays and define elevation and station in feet:

	0	1
17	55	11.65
18	56	11.71
19	61	12.76

$Station := Profile^{\langle 0\rangle}$

$Elevation := Profile^{\langle 1\rangle}$

$Station := Station\cdot 1\cdot ft$

$Elevation := Elevation\cdot 1\cdot ft$

Array of horizontal

Array of Elevations associated with each

Profile =

20	68	13.08
21	70	13.14
22	78	13.47
23	83	13.34
24	86	...

distance from the shoreline

Station =

	0
0	0
1	10
2	12
3	...

ft

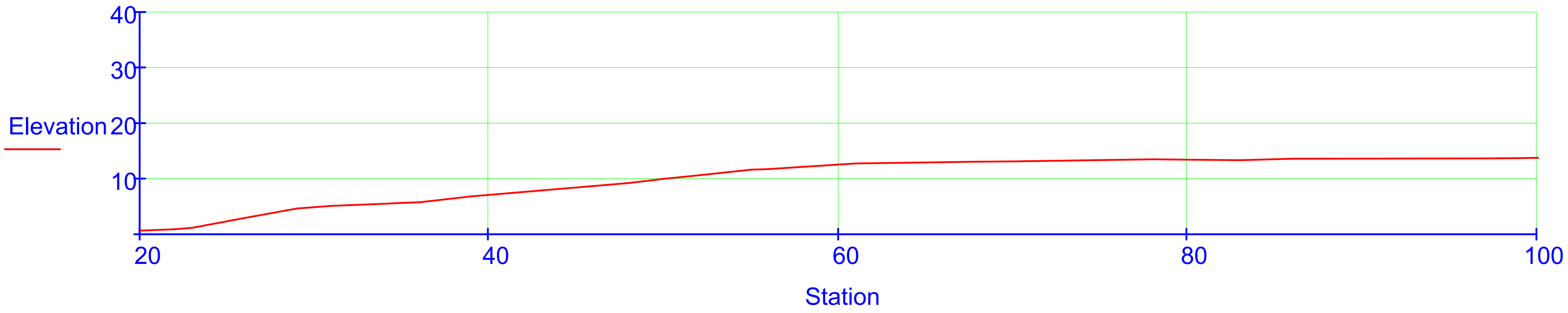
horizontal distance from the shoreline:

Elevation =

	0
0	0
1	0.63
2	0.9
3	...

ft

The following displays the profile of the transect:



Identify station and elevation of the toe of the structure:

$Toe_{sta} := 10 \cdot ft$ Input value representing coastal structure's bottom station (Toe_{sta})

$Toe_{ele} := \text{linterp}(Station, Elevation, Toe_{sta})_*$ $Toe_{ele} = 0.63\,ft$

Identify station and elevation of the top of the structure:

$Top_{sta} := 86 \cdot ft$ Input value representing coastal structure's top station (Top_{sta})

$Top_{ele} := \mathrm{linterp}(Station, Elevation, Top_{sta})$ $Top_{ele} = 13.59\,ft$

Enter 1% annual chance stillwater elevation (ft):

$SWEL := 10.58 \cdot ft$

Associated excel file for calculation of 1% annual chance stillwater elevation (SWEL):

Calculate Water Depth at Structure, h

$h := SWEL - Toe_{ele}$ $h = 9.95\,ft$

Calculate the Breaking Wave Height, H_b:

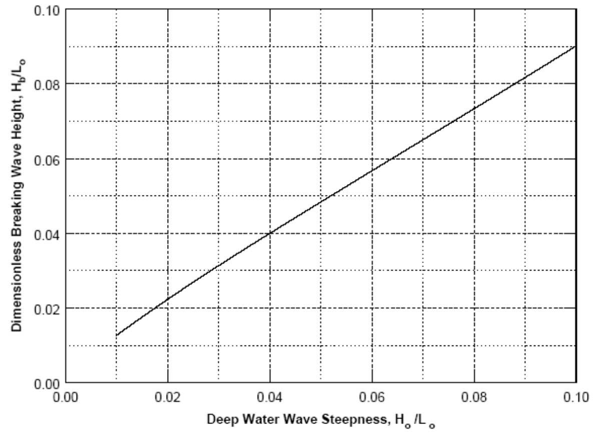


Figure D.2.6-7. Dimensionless Breaking Wave Height vs. Deepwater Wave Steepness

Figure from: Atlantic Ocean and Gulf of Mexico Coastal Guidelines Update Feb 2007

$b_h := 0.8481 \cdot S + 0.0057$ $b_h = 0.06$ Estimated curve equation in Figure D.2.6-7

$H_b := b_h \cdot L_0$ $H_b = 5.06\,ft$

Calculate the Breaking Wave Depth, H_d:

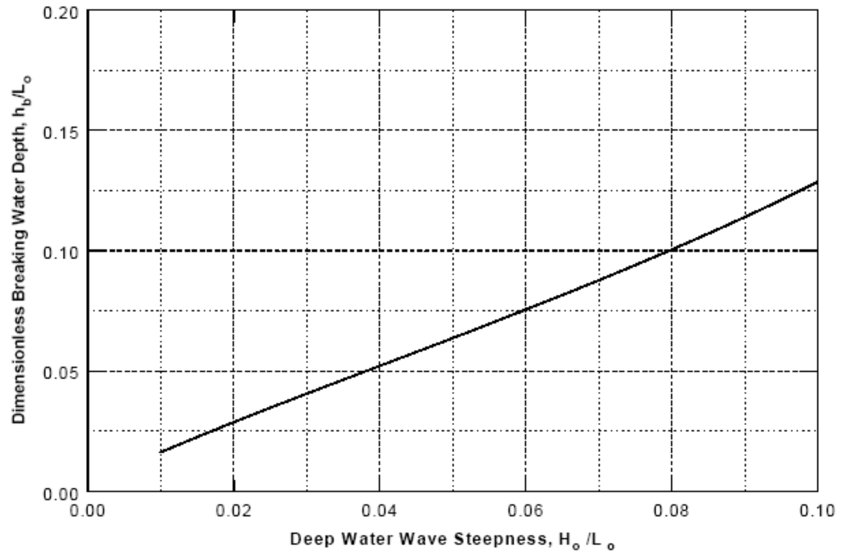


Figure D.2.6-8. Dimensionless Breaking Water Depth vs. Deepwater Wave Steepness.

Figure from: Atlantic Ocean and Gulf of Mexico Coastal Guidelines Update Feb 2007

$b_d := 1.2205 \cdot S + 0.0033$ $b_d = 0.08$ Estimated curve equation from Figure D.2.6-8

$H_d := b_d \cdot L_0$ $H_d = 6.88\,\text{ft}$

Calculate Wave Setup on a Structure, $\eta_{structure}$:

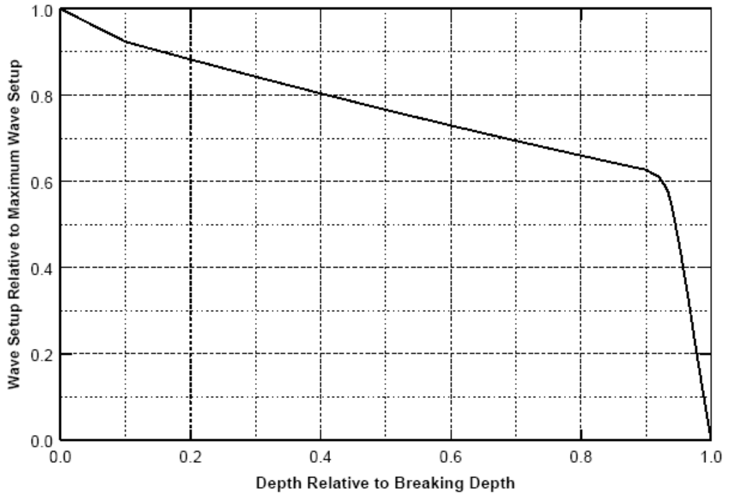


Figure D.2.6-9. Proportion of Maximum Wave Setup that Has Occurred vs. a Proportion of the Breaking Depth.

Figure from: Atlantic Ocean and Gulf of Mexico Coastal Guidelines Update Feb 2007

$$R := \begin{cases} \left[-0.8\cdot\left(\frac{h}{H_d}\right)+1\right] & \text{if } \left(\frac{h}{H_d}\right) \le 0.092 \\ \left[-0.3919\cdot\left(\frac{h}{H_d}\right)+0.9585\right] & \text{if } 0.092 < \frac{h}{H_d} \le 0.4 \\ \left[-0.3475\cdot\left(\frac{h}{H_d}\right)+0.9379\right] & \text{if } 0.4 < \frac{h}{H_d} \le 0.9 \\ \left[-33.312\cdot\left(\frac{h}{H_d}\right)^2+59.811\cdot\left(\frac{h}{H_d}\right)-26.223\right] & \text{if } 0.9 < \left(\frac{h}{H_d}\right) \le 0.94444 \\ \left[-9.8703\cdot\left(\frac{h}{H_d}\right)+9.8703\right] & \text{if } 0.94444 < \left(\frac{h}{H_d}\right) \le 1 \\ 0 & \text{otherwise} \end{cases}$$

Equation based on estimated curve from Figure D.2.6-9

$R = 0$ $\frac{h}{H_d} = 1.45$

$\eta_1 := R \cdot \eta_{open}$ $\eta_1 = 0\,ft$ $\eta_2 := 0.15 \cdot (h + \eta_1)$ $\eta_2 = 1.49\,ft$

$\eta_{Structure} := \eta_1 + \eta_2$ $\eta_{Structure} = 1.49\,ft$ Total Setup against a coastal structure without considering overtopping

Check Overtopping if Coastal Structure Exists:

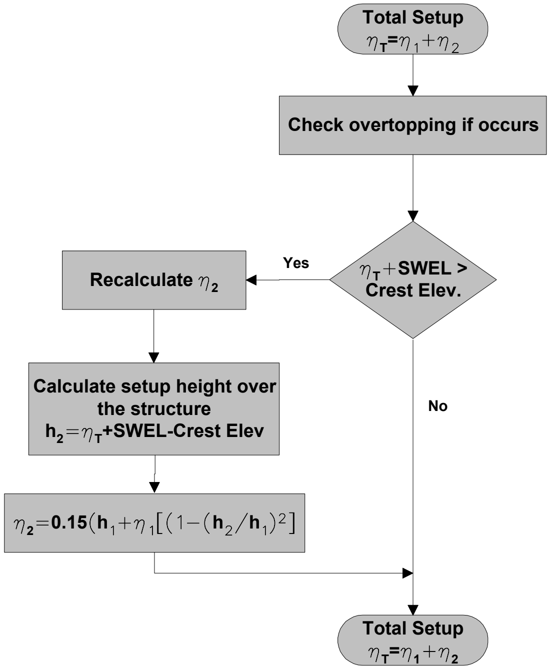
$$Overtopped := \begin{cases} "Yes" & \text{if } (\eta_{Structure} + SWEL) > Top_{ele} \\ "No" & \text{otherwise} \end{cases}$$ $Overtopped = "No"$

$$h_2 := \begin{cases} (\eta_{Structure} + SWEL - Top_{ele}) & \text{if } Overtopped = "Yes" \\ 0 & \text{otherwise} \end{cases}$$

Equation D.2.6-12 for η_2 from Atlantic Ocean and Gulf of Mexico Coastal Guidelines Update

$$\eta_2 := \begin{cases} 0.15 \cdot (h + \eta_1) \cdot \left[1 - \left(\frac{h_2}{h}\right)^2\right] & \text{if } Overtopped = "Yes" \\ \eta_2 & \text{otherwise} \end{cases}$$

$\eta_{Structure} := \eta_1 + \eta_2$ $\eta_{Structure} = 1.49\,ft$ Total Setup with a coastal structure



5.3 Wave Runup Analysis (Using TAW Method)

Flow Chart of Process of Calculating Wave Runup:

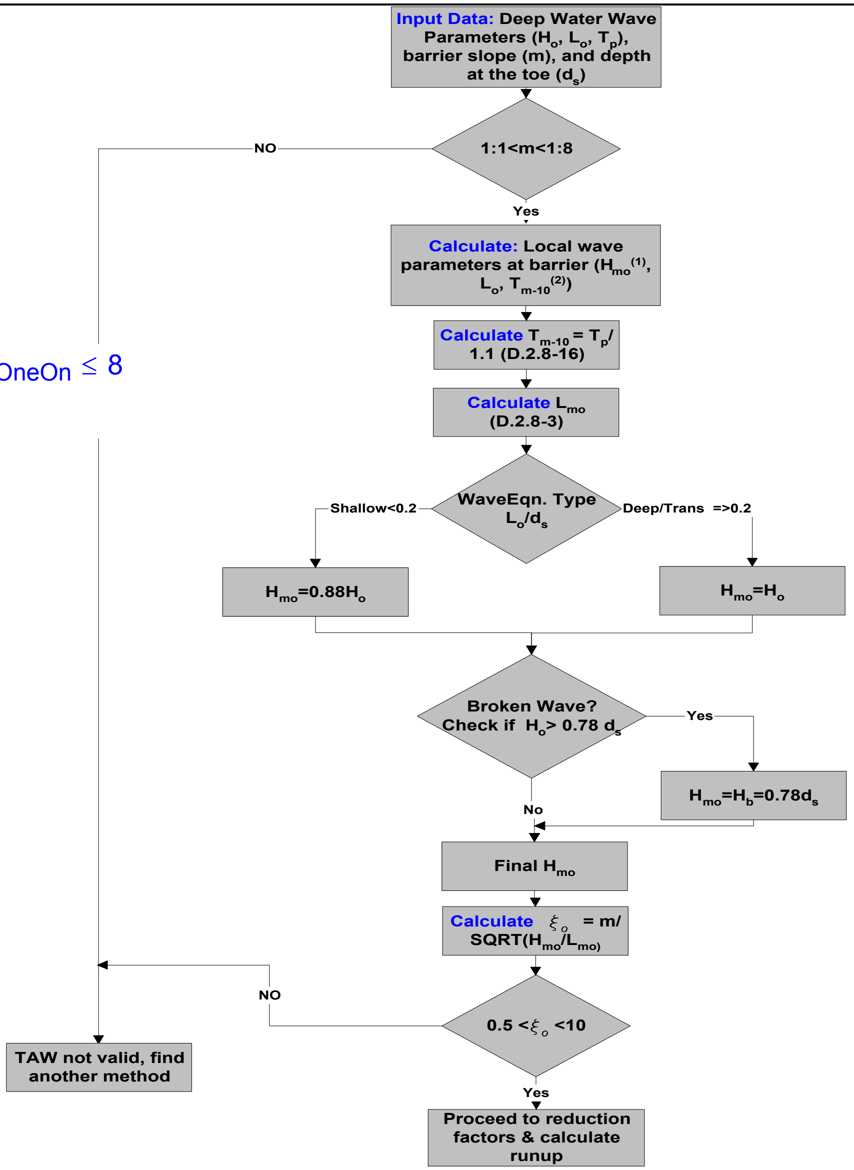
Checking Slope of Revetment to determine if it is between 1:1 and 1:8:

$$\mathrm{Slope_{Revet}} := \frac{(\mathrm{Top_{ele}} - \mathrm{Toe_{ele}})}{(\mathrm{Top_{sta}} - \mathrm{Toe_{sta}})} \qquad \mathrm{Slope_{Revet}} = 17.05 \cdot \%$$

$$\mathrm{Slope_{RevetOneOn}} := \frac{1}{\mathrm{Slope_{Revet}}} \qquad \mathrm{Slope_{RevetOneOn}} = 5.86$$

$$\mathrm{Slope_{Check}} := \begin{cases} \text{"TAW Method of Runup Calculation Applies"} & \text{if } 0 < \mathrm{Slope_{RevetOneOn}} \le 8 \\ \text{"TAW Method Does Not Apply, Switch to Runup-2.0"} & \text{otherwise} \end{cases}$$

$$\mathrm{Slope_{Check}} = \text{"TAW Method of Runup Calculation Applies"}$$



Check if Wave is Depth Limited at the Toe of the Revetment / Barrier:

$$\mathrm{Depth_{Limited}} := \begin{cases} \text{"Limited"} & \text{if } H_{m0} \ge 0.78 \cdot h \\ \text{"Not Limited"} & \text{otherwise} \end{cases}$$

If wave is depth limited, H_b will be used rather than H_{m0}

$$\mathrm{Depth_{Limited}} = \text{"Not Limited"}$$

Determine Wave Type:

$$\mathrm{WaveType} := \begin{cases} \text{"Shallow"} & \text{if } \frac{h}{L_0} < 2 \\ \text{"Transitional"} & \text{if } 0.2 \le \frac{h}{L_0} < 0.5 \\ \text{"Deep"} & \text{otherwise} \end{cases}$$

$$\mathrm{WaveType} = \text{"Shallow"}$$

Determine Significant Wave Height Depending on Wave Type and DepthLimited Condi

$$H_{m0runup1} := \begin{cases} 0.88 \cdot H_{m0} & \text{if } \ WaveType = \text{"Shallow"} \\ H_{m0} & \text{otherwise} \end{cases} \qquad H_{m0runup1} = 4.76\,\text{ft}$$

$$H_{m0runup} := \begin{cases} 0.78 \cdot h & \text{if } \ Depth_{Limited} = \text{"Limited"} \\ H_{m0runup1} & \text{otherwise} \end{cases} \qquad H_{m0runup} = 4.76\,\text{ft}$$

Calculate the Spectral Wave Period, T_{m10}

$$T_{m10} := \frac{T_P}{1.1}$$ Equation D.2.8-16 $$T_{m10} = 3.64\,\text{s}$$

Calculate the Wave Length Associated with the Spectral Wave Period, L_{m0}:

$$L_{m0} := \frac{g \cdot {T_{m10}}^2}{2 \cdot \pi}$$ Equation D.2.8-3 $$L_{m0} = 67.71\,\text{ft}$$

Calculate the Iribarren Number, ξ_{0m}:

$$\xi_{om} := \frac{Slope_{Revet}}{\sqrt{\dfrac{H_{m0runup}}{L_{m0}}}} \qquad \xi_{om} = 0.64$$

Check TAW Method for Validity based on Iribarren Number:

$$Iribarren_{Check} := \begin{cases} \text{"TAW method is Valid"} & \text{if } \ 0.5 < \xi_{om} < 10 \\ \text{"TAW method is NOT vaild for this Irbarren value. Please seek alternative method."} & \text{otherwise} \end{cases}$$

$$Iribarren_{Check} = \text{"TAW method is Valid"}$$

Calculate Runup Reduction Factors in Accordance with Table D.2.8-5 of Guidelines and Specifications for Flood Hazard Mapping:

Select Roughness Reduction Factor, γ_r:

$\gamma_r :=$

○ Smooth Concrete, Asphalt, and Smooth Block Revetment
○ 1 Layer of Rock with Diameter, D, where Hs/D = 1 to 3
● 2 or More Layers of Rock where Hs/D = 1.5 to 6
○ Quadratic Blocks

$$\gamma_r := \left| \begin{array}{ll} \gamma_r & \text{if } \gamma_r \ge 0.53 \\ \text{"Please Select Radio Button"} & \text{otherwise} \end{array} \right.$$

$$\gamma_r = 0.53$$

Select Berm Section in Breakwater, γ_b:

$\gamma_b :=$

○ Berm Present
● No Berm Present

$$\gamma_b := \left| \begin{array}{ll} \gamma_b & \text{if } \gamma_b > 0.5 \\ \text{"Please Select Radio Button"} & \text{otherwise} \end{array} \right.$$

$$\gamma_b = 1$$

Select Wave Direction Factor, γ_β:

$\beta := 0$

0° for normally incident wave

$\gamma_\beta :=$

● Short-Crested Wave
○ Long-Crested Wave

$$\gamma_\beta := \left| \begin{array}{ll} (1 - 0.0022 \cdot \beta) & \text{if } |\beta| \le 80 \wedge \gamma_\beta = 1 \\ (1 - 0.0022 \cdot |80|) & \text{if } (|\beta| \ge 80) \wedge \gamma_\beta = 1 \\ 1 & \text{if } 0 \le |\beta| < 10 \wedge \gamma_\beta = 2 \\ \cos\left[(|\beta| - 10) \cdot \left(\frac{\pi}{180}\right)\right] & \text{if } (10 < |\beta| < 63 \wedge \gamma_\beta = 2) \\ 0.63 & \text{if } |\beta| > 63 \wedge \gamma_\beta = 2 \\ \text{"Please Select Radio Button"} & \text{otherwise} \end{array} \right.$$

$$\gamma_\beta = 1$$

Select Porosity Factor, γ_P:

Porosity :=
○ 0.1
○ 0.4
● 0.5
○ 0.6

Default Porosity = 0.5

$$\gamma_p := \left|\begin{array}{ll} 1 & \text{if } \ (\text{Porosity} = 0.5) \wedge \xi_{om} \le 3.3 \\ \left(\left(\dfrac{2}{1.17\cdot \xi_{om}{}^{0.46}}\right)\right) & \text{if } \ (\text{Porosity} = 0.5) \wedge \xi_{om} > 3.3 \\ 0.5 & \text{otherwise} \end{array}\right.$$

$\gamma_p = 1$

Summary of Reduction Factors:

$\gamma_p = 1$

$\gamma_\beta = 1$

$\gamma_b = 1$

$\gamma_r = 0.53$

Calculate Runup Reduction Factors in Accordance with Table D.2.8-5 of Guidelines and Specifications for Flood Hazard Mapping:

$$R_{2\%} := \left|\begin{array}{ll} H_{m0runup}\cdot\left(1.77\cdot\gamma_r\cdot\gamma_b\cdot\gamma_\beta\cdot\gamma_p\cdot\xi_{om}\right) & \text{if } \ 0.5 \le \gamma_b\cdot\xi_{om} < 1.8 \\ H_{m0runup}\cdot\left[\gamma_r\cdot\gamma_b\cdot\gamma_\beta\cdot\gamma_p\cdot\left(4.3 - \dfrac{1.6}{\sqrt{\xi_{om}}}\right)\right] & \text{if } \ 1.8 \le \gamma_b\cdot\xi_{om} \\ 0 & \text{otherwise} \end{array}\right.$$

$$R_{2\%} := \left|\begin{array}{ll} \text{"TAW Not Valid"} & \text{if } \ Slope_{Check} = \text{"TAW Method Does Not Apply, Switch to Runup-2.0"} \\ \text{"TAW Not Valid"} & \text{if } \ Iribarren_{Check} = \text{"TAW method is NOT vaild for this Irbarren value. Please seek alternative method."} \\ R_{2\%} & \text{otherwise} \end{array}\right.$$

$R_{2\%} = 2.87\,\text{ft}$

Check for Overtopping:

$$OVERTOPPED_{Runup} := \begin{cases} \text{"Overtopped... Please consider 3 foot rule"} & \text{if } (R_{2\%} + SWEL) > Top_{ele} \\ \text{"NO Overtopping"} & \text{otherwise} \end{cases}$$

$OVERTOPPED_{Runup}$ = "NO Overtopping"

$R_{2\%} + SWEL = 13.45\,ft$

$Top_{ele} = 13.59\,ft$

5.4 Failed Revetment Structure Analysis

$Armor_D := 4 \cdot ft$ Insert Depth of Armor layer in Feet

Calculate Slope of the Revetment:

$$Slope := \frac{(Top_{ele} - Toe_{ele})}{(Top_{sta} - Toe_{sta})} \qquad Slope = 0.17$$

Calculate the Midpoint of the Revetment:

$$Length := \sqrt{(Top_{sta} - Toe_{sta})^2 + (Top_{ele} - Toe_{ele})^2} \qquad Length = 77.1\,ft$$

$$Midpoint := \frac{Length}{2} \qquad Midpoint = 38.55\,ft$$

Determine the Distance from the Shoreline to the Midpoint of the Revetment:

$$Mid_{sta} := \left[\left(\frac{Midpoint}{Length}\right) \cdot (Top_{sta} - Toe_{sta})\right] + Toe_{sta} \qquad Mid_{sta} = 48\,ft$$

Determine the Elevation of the Midpoint of the Revetment:

$$Mid_{ele} := linterp(Station, Elevation, Mid_{sta}) \qquad Mid_{ele} = 9.21\,ft$$

Calculate the Upper Quarter of the Revetment:

$$\text{Quarter} := \frac{\text{Length}\cdot 3}{4} \qquad \text{Quarter} = 57.82\,\text{ft}$$

Determine the Distance from the Shoreline to the Upper Quadrant of the Revetment:

$$\text{Quarter}_{\text{sta}} := \left[\left(\frac{\text{Quarter}}{\text{Length}}\right)\cdot\left(\text{Top}_{\text{sta}} - \text{Toe}_{\text{sta}}\right)\right] + \text{Toe}_{\text{sta}} \qquad \text{Quarter}_{\text{sta}} = 67\,\text{ft}$$

Determine the Elevation of the Upper Quadrant of the Revetment:

$$\text{Quarter}_{\text{ele}} := \text{linterp}\left(\text{Station}, \text{Elevation}, \text{Quarter}_{\text{sta}}\right) \qquad \text{Quarter}_{\text{ele}} = 13.03\,\text{ft}$$

Calculate Scour at the Toe of the Revetment:

$$\text{ToeR}_{\text{scour}} := \text{Toe}_{\text{ele}} - \text{Armor}_{\text{D}} \qquad \text{ToeR}_{\text{scour}} = -3.37\,\text{ft}$$

Adjusting the Existing Profile:

The following calculations determine the index values in the array Station which identify the toe, midpoint, upper quadrant, and top of the revetment. If the value of $\text{Toe}_{\text{location}}$, $\text{Mid}_{\text{location}}$, $\text{Quarter}_{\text{location}}$, or $\text{Top}_{\text{location}}$ exists within the Station array, then only one value should appear for Toe location. If two values appear, then the station location is between two points in the Station array. If more than two value appears, adjust the TOL, convergence tolerance, in Tools > Worksheet Options... to be lower until only 2 values appear for Toelocation, $\text{Mid}_{\text{location}}$, $\text{Quarter}_{\text{location}}$, and $\text{Top}_{\text{location}}$.

$\text{Offset}_{\text{toe}}$, $\text{Offset}_{\text{mid}}$, $\text{Offset}_{\text{qua}}$, and $\text{Offset}_{\text{top}}$ are equal to 0 if the horizontal distance from the shoreline to the bottom of the vertical structure already exists in the station array, otherwise, offset is set to 1. If no data point exists to represent the station of these locations, a data point is created in the FailSta array, which is the array of horizontal distances from the shoreline along the transect which is used to generate a profile of the failed structures.

Determine if station of the toe of the revetment is within the Station array and if not, add a data point

$$\text{Toe}_{\text{location}} := \text{match}\left(\text{Toe}_{\text{sta}}, \text{Station}\right) \qquad \text{Toe}_{\text{location}} = (\,1\,) \qquad \text{Toe}_{\text{location}_0} = 1$$

$$\mathrm{Offset}_{toe} := \left| \begin{array}{ll} 0 & \text{if } \ \mathrm{Station}_{\left(\mathrm{Toe}_{location_0}\right)} = \mathrm{Toe}_{sta} \\ 1 & \text{otherwise} \end{array} \right.$$

$$\mathrm{Offset}_{toe} = 0$$

$$\mathrm{Toe}_{Staloc} := \left| \begin{array}{ll} \mathrm{Toe}_{location_0} + \mathrm{Offset}_{toe} & \text{if } \ \mathrm{Toe}_{sta} \geq \mathrm{Station}_{\left(\mathrm{Toe}_{location_0}\right)} \\ \mathrm{Toe}_{location_0} & \text{otherwise} \end{array} \right.$$

$$\mathrm{Toe}_{Staloc} = 1$$

Determine if station of the midpoint of the revetment is within the Station array and if not, add a data point

$$\mathrm{Mid}_{sta} = 48\,\mathrm{ft}$$

$$\mathrm{Mid}_{location} := \mathrm{match}\left(\mathrm{Mid}_{sta}, \mathrm{Station}\right) \qquad \mathrm{Mid}_{location} := ■ \qquad \mathrm{Mid}_{location_0} = 14$$

$$\mathrm{Offset}_{mid} := \left| \begin{array}{ll} 0 & \text{if } \ \mathrm{Station}_{\left(\mathrm{Mid}_{location_0}\right)} = \mathrm{Mid}_{sta} \\ 1 & \text{otherwise} \end{array} \right.$$

$$\mathrm{Offset}_{mid} = 0$$

$$\mathrm{Mid}_{Staloc} := \left| \begin{array}{ll} \mathrm{Mid}_{location_0} + \mathrm{Offset}_{toe} + \mathrm{Offset}_{mid} & \text{if } \ \mathrm{Mid}_{sta} \geq \mathrm{Station}_{\left(\mathrm{Mid}_{location_0}\right)} \\ \left(\mathrm{Mid}_{location_0} + \mathrm{Offset}_{toe}\right) & \text{otherwise} \end{array} \right.$$

$$\mathrm{Mid}_{Staloc} = 14 \qquad \mathrm{FailRevetSta}_{\mathrm{Mid}_{Staloc}} := \mathrm{Mid}_{sta}$$

Determine if station of the upper quadrant of the revetment is within the Station array and if not, add a data point

$$\mathrm{Quarter}_{location} := \mathrm{match}\left(\mathrm{Quarter}_{sta}, \mathrm{Station}\right) \qquad \mathrm{Quarter}_{location} := ■ \qquad \mathrm{Quarter}_{location_0} = 20$$

$$\mathrm{Offset}_{qua} := \left| \begin{array}{ll} 0 & \text{if } \ \mathrm{Station}_{\left(\mathrm{Quarter}_{location_0}\right)} = \mathrm{Quarter}_{sta} \\ 1 & \text{otherwise} \end{array} \right.$$

$$\mathrm{Offset}_{qua} = 1$$

$$\mathrm{Quarter}_{\mathrm{Staloc}} := \begin{cases} \mathrm{Quarter}_{\mathrm{location}_0} + \mathrm{Offset}_{\mathrm{toe}} + \mathrm{Offset}_{\mathrm{mid}} + \mathrm{Offset}_{\mathrm{qua}} & \text{if } \mathrm{Quarter}_{\mathrm{sta}} \geq \mathrm{Station}_{\left(\mathrm{Quarter}_{\mathrm{location}_0}\right)} \\ \left(\mathrm{Quarter}_{\mathrm{location}_0} + \mathrm{Offset}_{\mathrm{toe}} + \mathrm{Offset}_{\mathrm{mid}}\right) & \text{otherwise} \end{cases}$$

$\mathrm{Quarter}_{\mathrm{Staloc}} = 20$ $\mathrm{FailRevet}_{\mathrm{Sta}_{\mathrm{Quarter}_{\mathrm{Staloc}}}} := \mathrm{Quarter}_{\mathrm{sta}}$

Determine if station of the top of the revetment is within the Station array and if not, add a data point

$\mathrm{Top}_{\mathrm{location}} := \mathrm{match}\left(\mathrm{Top}_{\mathrm{sta}}, \mathrm{Station}\right)$ $\mathrm{Top}_{\mathrm{location}} = (\ 24\ )$ $\mathrm{Top}_{\mathrm{location}_0} = 24$ $\mathrm{Top}_{\mathrm{sta}} = 86\,\mathrm{ft}$

$$\mathrm{Offset}_{\mathrm{top}} := \begin{cases} 0 & \text{if } \mathrm{Station}_{\left(\mathrm{Top}_{\mathrm{location}_0}\right)} = \mathrm{Top}_{\mathrm{sta}} \\ 1 & \text{otherwise} \end{cases}$$

$\mathrm{Offset}_{\mathrm{top}} = 0$

$$\mathrm{Top}_{\mathrm{Staloc}} := \begin{cases} \mathrm{Top}_{\mathrm{location}_0} + \mathrm{Offset}_{\mathrm{toe}} + \mathrm{Offset}_{\mathrm{mid}} + \mathrm{Offset}_{\mathrm{qua}} + \mathrm{Offset}_{\mathrm{top}} & \text{if } \mathrm{Top}_{\mathrm{sta}} \geq \mathrm{Station}_{\left(\mathrm{Top}_{\mathrm{location}_0}\right)} \\ \left(\mathrm{Top}_{\mathrm{location}_0} + \mathrm{Offset}_{\mathrm{toe}} + \mathrm{Offset}_{\mathrm{mid}} + \mathrm{Offset}_{\mathrm{qua}}\right) & \text{otherwise} \end{cases}$$

$\mathrm{Top}_{\mathrm{Staloc}} = 25$ $\mathrm{FailRevet}_{\mathrm{Sta}_{\mathrm{Top}_{\mathrm{Staloc}}}} := \mathrm{Top}_{\mathrm{sta}}$

Sets the station of the failed profile to be equal to the existing profile station from the shore to the toe of the revetment

$i := \mathrm{Toe}_{\mathrm{location}_0} .. 0$ $\mathrm{FailRevet}_{\mathrm{Sta}_i} := \mathrm{Station}_i$ $\mathrm{FailRevet}_{\mathrm{Sta}_{\mathrm{Toe}_{\mathrm{Staloc}}}} := \mathrm{Toe}_{\mathrm{sta}}$

Sets the station of the failed profile to be equal to the existing profile station from the toe of the revetment to the midpoint of the revetment, offsetting if a data point was added to represent the toe of the revetment

$$x := \left|\begin{array}{l} \left(\text{Toe}_{\text{Staloc}} + 1\right) .. \left(\text{Mid}_{\text{Staloc}} - 1\right) \;\; \text{if} \;\; \left(\text{Toe}_{\text{Staloc}} + 1\right) \le \left(\text{Mid}_{\text{Staloc}} - 1\right) \\ \text{Toe}_{\text{Staloc}} \;\; \text{otherwise} \end{array}\right.$$

$$\text{FailRevet}_{\text{Sta}_x} := \left|\begin{array}{l} \text{Station}_{x-\text{Offset}_{\text{toe}}} \;\; \text{if} \;\; x \ne \text{Toe}_{\text{Staloc}} \\ \text{Toe}_{\text{sta}} \;\; \text{otherwise} \end{array}\right.$$

$$\text{FailRevet}_{\text{Sta}_{\text{Mid}_{\text{Staloc}}}} := \text{Mid}_{\text{sta}}$$

Sets the station of the failed profile to be equal to the existing profile station from the midpoint of the revetment to the upper quadrant of the revetment, offsetting values if a data point was added to represent the midpoint of the revetment

$$y := \left|\begin{array}{l} \left(\text{Mid}_{\text{Staloc}} + 1\right) .. \left(\text{Quarter}_{\text{Staloc}} - 1\right) \;\; \text{if} \;\; \left(\text{Mid}_{\text{Staloc}} + 1\right) \le \left(\text{Quarter}_{\text{Staloc}} - 1\right) \\ \text{Mid}_{\text{Staloc}} \;\; \text{otherwise} \end{array}\right.$$

$$\text{FailRevet}_{\text{Sta}_y} := \left|\begin{array}{l} \text{Station}_{y-\text{Offset}_{\text{toe}}-\text{Offset}_{\text{mid}}} \;\; \text{if} \;\; y \ne \text{Mid}_{\text{Staloc}} \\ \text{Mid}_{\text{sta}} \;\; \text{otherwise} \end{array}\right.$$

$$\text{FailRevet}_{\text{Sta}_{\text{Quarter}_{\text{Staloc}}}} := \text{Quarter}_{\text{sta}}$$

Sets the station of the failed profile to be equal to the existing profile station from the upper quadrant of the revetment to the top of the revetment, offsetting values if a data point was added to represent the upper quadrant of the revetment

$$z := \left|\begin{array}{l} \left(\text{Quarter}_{\text{Staloc}} + 1\right) .. \left(\text{Top}_{\text{Staloc}} - 1\right) \;\; \text{if} \;\; \left(\text{Quarter}_{\text{Staloc}} + 1\right) \le \left(\text{Top}_{\text{Staloc}} - 1\right) \\ \text{Quarter}_{\text{Staloc}} \;\; \text{otherwise} \end{array}\right.$$

$$\text{FailRevet}_{\text{Sta}_z} := \left|\begin{array}{l} \text{Station}_{z-\text{Offset}_{\text{toe}}-\text{Offset}_{\text{mid}}-\text{Offset}_{\text{qua}}} \;\; \text{if} \;\; z \ne \text{Quarter}_{\text{Staloc}} \\ \text{Quarter}_{\text{sta}} \end{array}\right.$$

$$FailRevet_{Sta_{Top_{Staloc}}} := Top_{sta}$$

Sets the station of the failed profile to be equal to the existing profile station from the top of the revetment to the end of the transect, offsetting values to compensate for any added data points

$$end := last(Station) + Offset_{toe} + Offset_{mid} + Offset_{qua} + Offset_{top} \qquad end = 415$$

$$w := \left(Top_{Staloc} + 1\right) .. end \qquad FailRevet_{Sta_w} := Station_{w-Offset_{toe}-Offset_{mid}-Offset_{qua}-Offset_{top}}$$

Sets the elevation of the failed profile to be equal to the existing profile from the shore to the toe of the revetment and then slopes towards the shoreline at a 3h:1v slope from the toe of the revetment

$$FailRevet_{Ele_i} := Elevation_i$$

$$FailRevet_{Ele_i} := \left| \begin{array}{l} \left[\left[\left[\left(Toe_{sta} - FailRevet_{Sta_i}\right)\cdot\left(\frac{1}{3}\right)\right] + ToeR_{scour}\right]\right] \text{ if } \left[\left[\left[\left(Toe_{sta} - FailRevet_{Sta_i}\right)\cdot\left(\frac{1}{3}\right)\right] + ToeR_{scour}\right]\right] \le Elevation_i \\ \text{break} \quad \text{otherwise} \end{array} \right.$$

Sets the elevation at the toe of the revetment to the elevation after failure occurs:

$$FailRevet_{Ele_{Toe_{Staloc}}} := ToeR_{scour}$$

Sets the elevation of the failed revetment from the toe to the midpoint of the revetment based on armor depth if points exist between the toe and midpoint of the revetment

$$FailRevet_{Ele_x} := \left| \begin{array}{ll} Elevation_{x-Offset_{toe}} - Armor_D & \text{if } x \ne Toe_{Staloc} \\ ToeR_{scour} & \text{otherwise} \end{array} \right.$$

Sets the elevation of the middle of the revetment

$$FailRevet_{Ele_{Mid_{Staloc}}} := \left(Mid_{ele} - Armor_D\right)$$

Sets the elevation of the failed revetment from the midpoint to the upper quadrant of the revetment assuming a constant slope equal to the slope of the original revetment, only sloping downwards instead.

$$FailRevet_{Ele_y} := \left| \begin{array}{l} \left(Station_{y-Offset_{toe}-Offset_{mid}} - Mid_{sta}\right)\cdot(Slope\cdot -1) + \left(Mid_{ele} - Armor_D\right) \quad \text{if} \quad y \neq Mid_{Staloc} \\ \left(\left(Mid_{ele} - Armor_D\right)\right) \quad \text{otherwise} \end{array} \right.$$

Sets the elevation of the upper quadrant of the revetment

$$FailRevet_{Ele_{Quarter_{Staloc}}} := \left(Quarter_{sta} - Mid_{sta}\right)\cdot(Slope\cdot -1) + \left(Mid_{ele} - Armor_D\right)$$

Sets the elevation of the failed revetment from the upper quadrant to the top of the failed revetment assuming a constant slope of 1v:1.5h until it reaches the existing elevation, or the top of the revetment.

$$j := \left(Quarter_{Staloc} + 1\right) .. end$$

$$FailRevet_{Ele_j} := \left| \begin{array}{l} \left[\left(FailRevet_{Sta_j} - Quarter_{sta}\right)\cdot\left(\frac{1}{1.5}\right)\right] + FailRevet_{Ele_{Quarter_{Staloc}}} \quad \text{if} \quad \left[\left(FailRevet_{Sta_j} - Quarter_{sta}\right)\cdot\left(\frac{1}{1.5}\right)\right] + FailRevet_{Ele_{Quarter_{Staloc}}} \le \\ \text{break} \quad \text{otherwise} \end{array} \right.$$

$$failed := last\left(FailRevet_{Ele}\right) \qquad failed = 24$$

$$Offset_{failTop} := \left| \begin{array}{l} 0 \quad \text{if} \quad FailRevet_{Sta_{failed}} = Station_{failed-Offset_{toe}-Offset_{mid}-Offset_{qua}} \\ 1 \end{array} \right.$$

$$Offset_{failTop} = 1$$

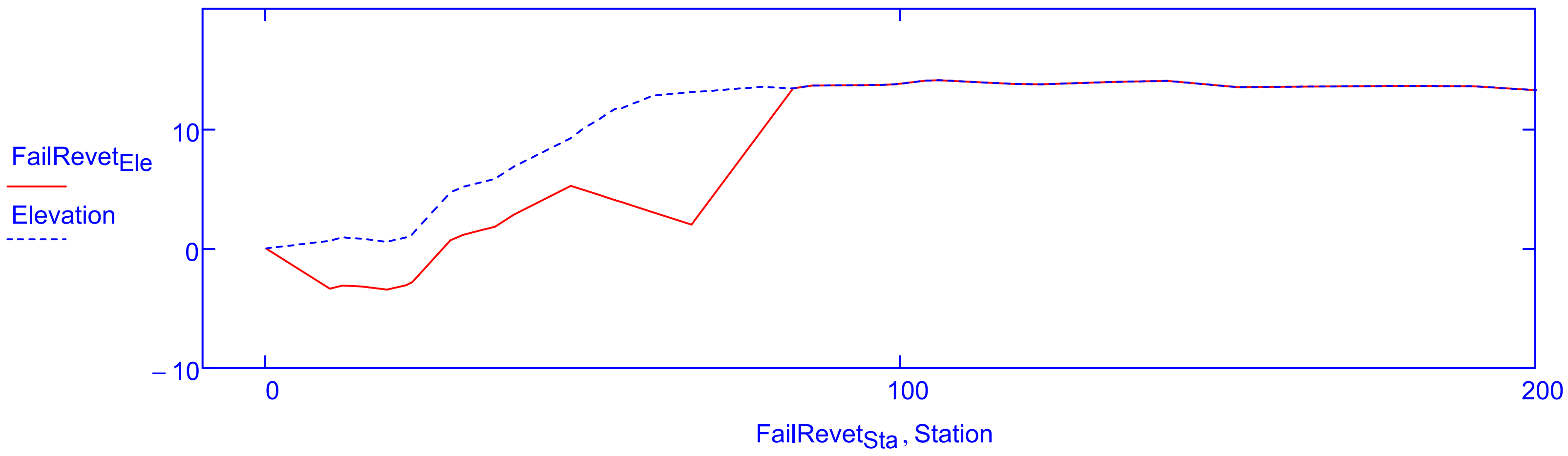
$$FailTop_{Sta} := Station_{failed-Offset_{toe}-Offset_{mid}-Offset_{qua}+Offset_{failTop}} \qquad FailTop_{Sta} = 86\,ft$$

$$FailTop_{Ele} := Elevation_{failed-Offset_{toe}-Offset_{mid}-Offset_{qua}+Offset_{failTop}} \qquad FailTop_{Ele} = 13.59\,ft$$

$$a := \left(failed + Offset_{failTop}\right) .. end$$

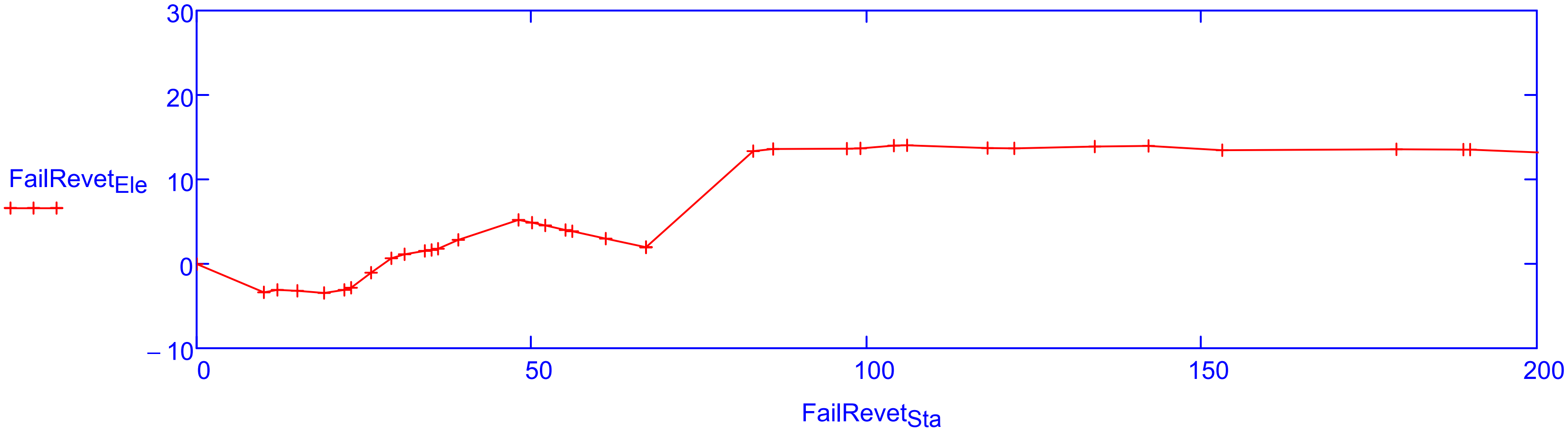
$$FailRevet_{Sta_a} := Station_{a-Offset_{toe}-Offset_{mid}-Offset_{qua}-Offset_{failTop}}$$

$\text{FailRevet}_{\text{Ele}_a} := \text{Elevation}_{a-\text{Offset}_{\text{toe}}-\text{Offset}_{\text{mid}}-\text{Offset}_{\text{qua}}-\text{Offset}_{\text{failTop}}}$



5.5 Wave Setup, η, Calculation on Failed Revetment

The following displays the failed profile of the transect:



Calculate Water Depth at Failed Structure, h

$h := SWEL - ToeR_{scour}$ $h = 13.95\,ft$

$H_b := b_h \cdot L_0$ $H_b = 5.06\,ft$ $H_d := b_d \cdot L_0$ $H_d = 6.88\,ft$

Calculate Wave Setup on a FailedStructure, $\eta_{structure}$:

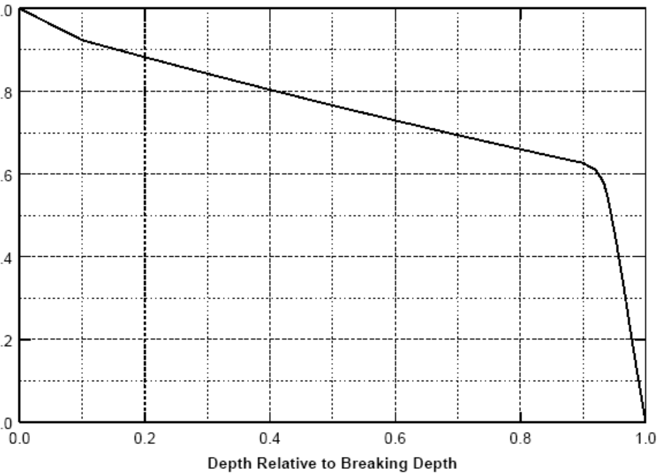


Figure D.2.6-9. Proportion of Maximum Wave Setup that Has Occurred vs. a Proportion of the Breaking Depth.

Figure from: Atlantic Ocean and Gulf of Mexico Coastal Guidelines Update Feb 2007

$$R := \begin{cases} \left[-0.8\cdot\left(\frac{h}{H_d}\right)+1\right] & \text{if } \left(\frac{h}{H_d}\right) \le 0.092 \\ \left[-0.3919\cdot\left(\frac{h}{H_d}\right)+0.9585\right] & \text{if } 0.092 < \frac{h}{H_d} \le 0.4 \\ \left[-0.3475\cdot\left(\frac{h}{H_d}\right)+0.9379\right] & \text{if } 0.4 < \frac{h}{H_d} \le 0.9 \\ \left[-33.312\cdot\left(\frac{h}{H_d}\right)^2+59.811\cdot\left(\frac{h}{H_d}\right)-26.223\right] & \text{if } 0.9 < \left(\frac{h}{H_d}\right) \le 0.94444 \\ \left[-9.8703\cdot\left(\frac{h}{H_d}\right)+9.8703\right] & \text{if } 0.94444 < \left(\frac{h}{H_d}\right) \le 1 \\ 0 & \text{otherwise} \end{cases}$$

Equation based on estimated curve from Figure D.2.6-9

$R = 0$

$\frac{h}{H_d} = 2.03$

$\eta_1 := R \cdot \eta_{open} \qquad \eta_1 = 0\,ft \qquad \eta_2 := 0.15 \cdot (h + \eta_1) \qquad \eta_2 = 2.09\,ft$

$\eta_{FailedStructure} := \eta_1 + \eta_2 \qquad \eta_{FailedStructure} = 2.09\,ft$

Total Setup against a coastal structure without considering overtopping

Check Overtopping if Coastal Structure Exists:

$$Overtopped := \begin{cases} \text{"Yes"} & \text{if } (\eta_{FailedStructure} + SWEL) > Top_{ele} \\ \text{"No"} & \text{otherwise} \end{cases}$$

$Overtopped = \text{"No"}$

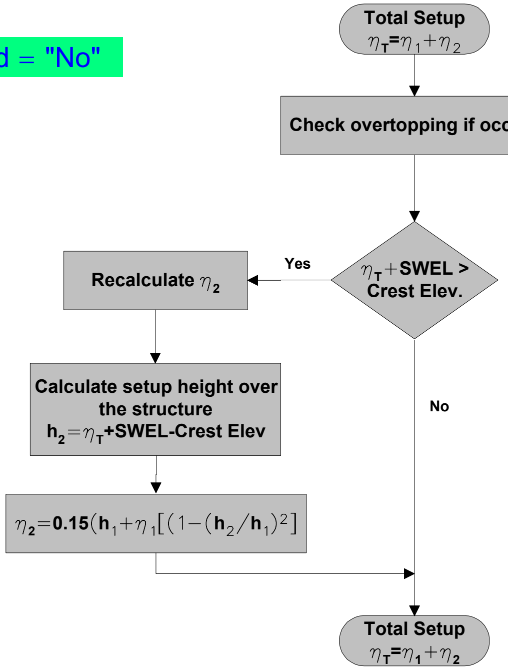
$$h_2 := \begin{cases} (\eta_{FailedStructure} + SWEL - Top_{ele}) & \text{if } Overtopped = \text{"Yes"} \\ 0 & \text{otherwise} \end{cases}$$

Equation D.2.6-12 for η_2 from Atlantic Ocean and Gulf of Mexico Coastal Guidelines Update

$$\eta_2 := \begin{cases} 0.15 \cdot (h + \eta_1) \cdot \left[1 - \left(\frac{h_2}{h}\right)^2\right] & \text{if } Overtopped = \text{"Yes"} \\ \eta_2 & \text{otherwise} \end{cases}$$

$\eta_{FailedStructure} := \eta_1 + \eta_2 \qquad \eta_{FailedStructure} = 2.09\,ft$

Total Setup with a failed coastal structure



5.6 Wave Runup Analysis (Using TAW Method) on a Failed Revetment

Flow Chart of Process of Calculating Wave Runup:

Checking Slope of Revetment to determine if it is between 1:0 and 1:8:

$$Slope_{FAILRevet} := \frac{(FailTop_{Ele} - ToeR_{scour})}{(FailTop_{Sta} - Toe_{sta})} \qquad Slope_{FAILRevet} = 22.32 \cdot \%$$

$$Slope_{FAILRevetOneOn} := \frac{1}{Slope_{FAILRevet}} \qquad Slope_{FAILRevetOneOn} = 4.48$$

$$FAILSlope_{Check} := \left| \begin{array}{ll} \text{"TAW Method of Runup Calculation Applies"} & \text{if } 0 < Slope_{RevetOneOn} \le 8 \\ \text{"TAW Method Does Not Apply, Switch to Runup-2.0"} & \text{otherwise} \end{array} \right.$$

$$FAILSlope_{Check} = \text{"TAW Method of Runup Calculation Applies"}$$

Check if Wave is Depth Limited at the Toe of the Revetment / Barrier:

$$Depth_{Limited} := \left| \begin{array}{ll} \text{"Limited"} & \text{if } H_{m0} \ge 0.78 \cdot h \\ \text{"Not Limited"} & \text{otherwise} \end{array} \right.$$

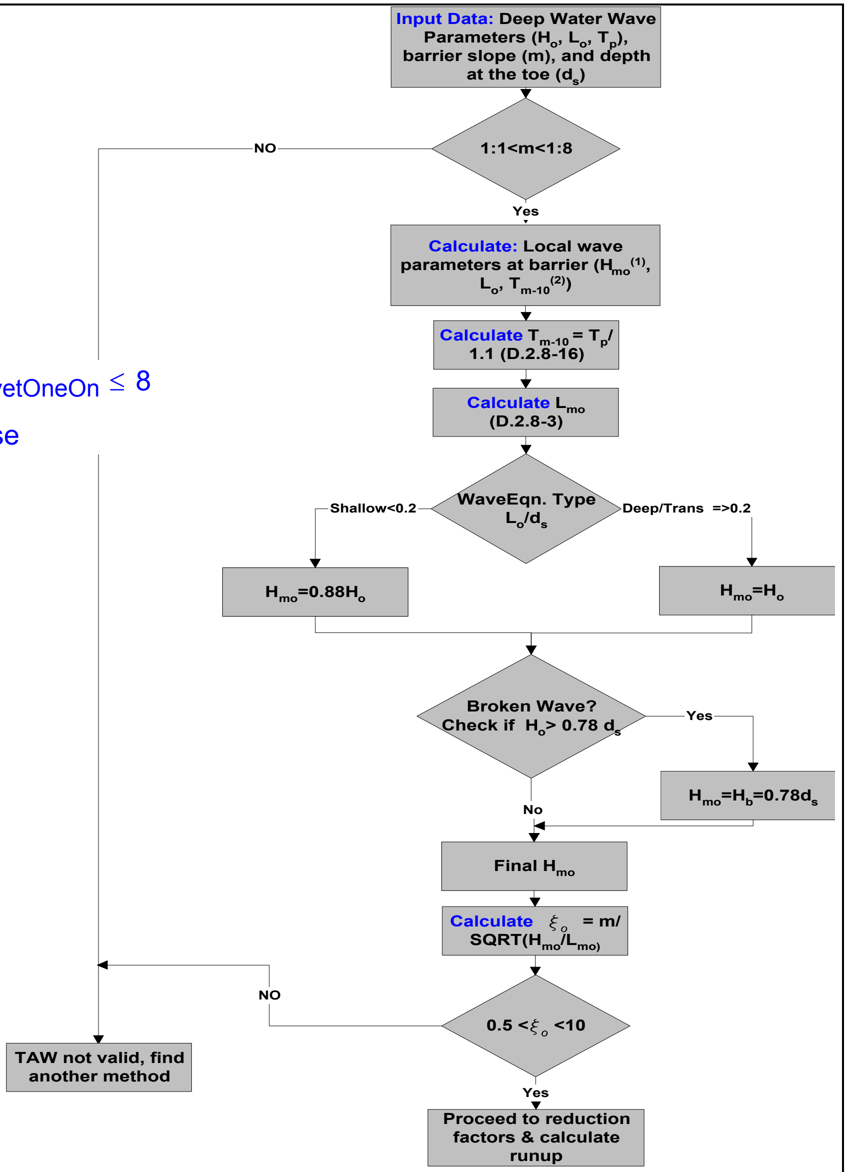
If wave is depth limited, H_b *will be used rather than* H_{m0}

$$Depth_{Limited} = \text{"Not Limited"}$$

Determine Wave Type:

$$WaveType := \left| \begin{array}{ll} \text{"Shallow"} & \text{if } \frac{h}{L_0} < 2 \\ \text{"Transitional"} & \text{if } 0.2 \le \frac{h}{L_0} < 0.5 \\ \text{"Deep"} & \text{otherwise} \end{array} \right.$$

$$WaveType = \text{"Shallow"}$$



Determine Significant Wave Height Depending on WaveType and DepthLimited Condition:

$$H_{m0runupFAIL1} := \begin{cases} 0.88 \cdot H_{m0} & \text{if } WaveType = \text{"Shallow"} \\ H_{m0} & \text{otherwise} \end{cases} \qquad H_{m0runupFAIL1} = 4.76\,ft$$

$$H_{m0runupFAIL} := \begin{cases} 0.78 \cdot h & \text{if } Depth_{Limited} = \text{"Limited"} \\ H_{m0runupFAIL1} & \text{otherwise} \end{cases} \qquad H_{m0runupFAIL} = 4.76\,ft$$

Calculate the Iribarren Number, ξ_{0m}:

$$\xi_{om} := \frac{Slope_{FAILRevet}}{\sqrt{\dfrac{H_{m0runupFAIL}}{L_{m0}}}} \qquad \xi_{om} = 0.84$$

Check TAW Method for Validity based on Iribarren Number:

$$FAILIribarren_{Check} := \begin{cases} \text{"TAW method is Valid"} & \text{if } 0.5 < \xi_{om} < 10 \\ \text{"TAW method is NOT vaild for this Irbarren value. Please seek alternative method."} & \text{otherwise} \end{cases}$$

$$FAILIribarren_{Check} = \text{"TAW method is Valid"}$$

Calculate Runup Reduction Factors in Accordance with Table D.2.8-5 of Guidelines and Specifications for Flood Hazard Mapping:

Select Roughness Reduction Factor, γ_r:

$\gamma_r :=$

○ Smooth Concrete, Asphalt, and Smooth Block Revetment
● 1 Layer of Rock with Diameter, D, where Hs/D = 1 to 3
○ 2 or More Layers of Rock where Hs/D = 1.5 to 6
○ Quadratic Blocks

$$\gamma_r := \begin{cases} \gamma_r & \text{if } \gamma_r \geq 0.53 \\ \text{"Please Select Radio Button"} & \text{otherwise} \end{cases}$$

○ Quadratic Blocks

$\gamma_r = 0.58$

Select Berm Section in Breakwater, γ_b:

$\gamma_b :=$
○ Berm Present
● No Berm Present

$$\gamma_b := \begin{cases} \gamma_b & \text{if } \gamma_b > 0.5 \\ \text{"Please Select Radio Button"} & \text{otherwise} \end{cases}$$

$\gamma_b = 1$

Select Wave Direction Factor, γ_β:

$\beta := 0$ 0º for normally incident wave

$\gamma_\beta :=$
○ Short-Crested Wave
● Long-Crested Wave

$$\gamma_\beta := \begin{cases} (1 - 0.0022 \cdot \beta) & \text{if } |\beta| \le 80 \wedge \gamma_\beta = 1 \\ (1 - 0.0022 \cdot |80|) & \text{if } (|\beta| \ge 80) \wedge \gamma_\beta = 1 \\ 1 & \text{if } 0 \le |\beta| < 10 \wedge \gamma_\beta = 2 \\ \cos\left[(|\beta| - 10) \cdot \left(\frac{\pi}{180}\right)\right] & \text{if } (10 < |\beta| < 63 \wedge \gamma_\beta = 2) \\ 0.63 & \text{if } |\beta| > 63 \wedge \gamma_\beta = 2 \\ \text{"Please Select Radio Button"} & \text{otherwise} \end{cases}$$

$\gamma_\beta = 1$

Select Porosity Factor, γ_P:

$Porosity :=$
○ 0.1
○ 0.4
● 0.5
○ 0.6

Default Porosity = 0.5

$$\gamma_p := \begin{cases} 1 & \text{if } (Porosity = 0.5) \wedge \xi_{om} \le 3.3 \\ \left(\left(\frac{2}{1.17 \cdot \xi_{om}^{\;0.46}}\right)\right) & \text{if } (Porosity = 0.5) \wedge \xi_{om} > 3.3 \\ 0.5 & \text{otherwise} \end{cases}$$

$\gamma_p = 1$

Summary of Reduction Factors:

$\gamma_p = 1$

$\gamma_\beta = 1$

$\gamma_b = 1$

$\gamma_r = 0.58$

Calculate Runup Reduction Factors in Accordance with Table D.2.8-5 of Guidelines and Specifications for Flood Hazard Mapping:

$$R_{FAIL2\%} := \left| \begin{array}{ll} H_{m0runup} \cdot \left(1.77 \cdot \gamma_r \cdot \gamma_b \cdot \gamma_\beta \cdot \gamma_p \cdot \xi_{om}\right) & \text{if } 0.5 \le \gamma_b \cdot \xi_{om} < 1.8 \\ H_{m0runup} \cdot \left[\gamma_r \cdot \gamma_b \cdot \gamma_\beta \cdot \gamma_p \cdot \left(4.3 - \frac{1.6}{\sqrt{\xi_{om}}}\right)\right] & \text{if } 1.8 \le \gamma_b \cdot \xi_{om} \\ 0 & \text{otherwise} \end{array} \right.$$

$$R_{FAIL2\%} := \left| \begin{array}{ll} \text{"TAW Not Valid"} & \text{if } FAILSlope_{Check} = \text{"TAW Method Does Not Apply, Switch to Runup-2.0"} \\ \text{"TAW Not Valid"} & \text{if } FAILIribarren_{Check} = \text{"TAW method is NOT vaild for this Irbarren value. Please seek alternative me} \\ R_{FAIL2\%} & \text{otherwise} \end{array} \right.$$

$R_{FAIL2\%} = 4.11\,\text{ft}$

Check for Overtopping:

$$OVERTOPPEDFAIL_{Runup} := \left| \begin{array}{ll} \text{"Overtopped... Please consider 3 foot rule"} & \text{if } \left(R_{FAIL2\%} + SWEL\right) > Top_{ele} \\ \text{"NO Overtopping"} & \text{otherwise} \end{array} \right.$$

$OVERTOPPEDFAIL_{Runup} =$ "Overtopped... Please consider 3 foot rule"

6.0 Conclusions/Results

Wave Height, H_{m0}	$H_{m0} = 5.41\,\text{ft}$	FetchStatus = "STWAVE Input (Hmo, Tp)"
Wave Period, T_P	$T_P = 4\,\text{s}$	FetchStatus = "STWAVE Input (Hmo, Tp)"

Wave Setup on an open coast, η_{open}

$\eta_{open} = 0.67\,ft$

Wave Setup on a revetment, $\eta_{Structure}$

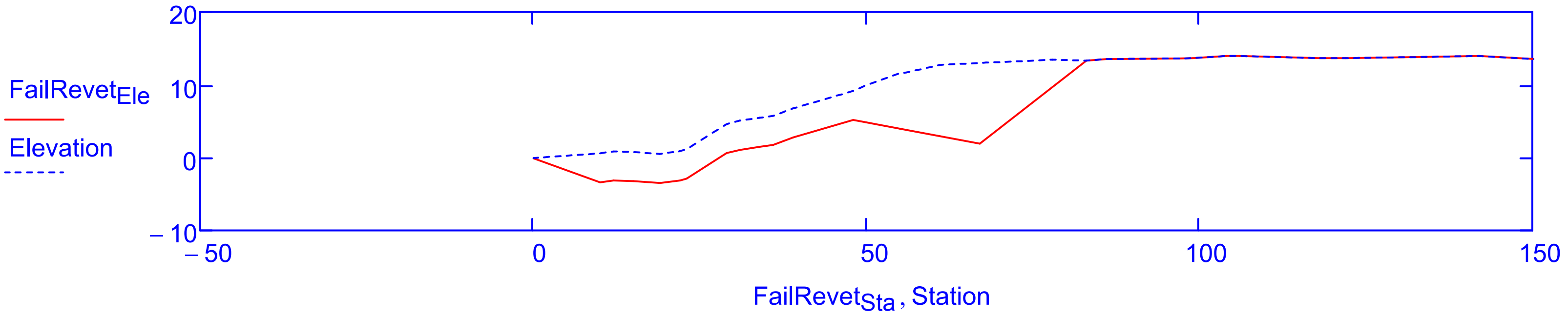
$\eta_{Structure} = 0$

Wave Runup on a revetment, $R_{2\%}$

$R_{2\%} = 2.87\,ft$

$OVERTOPPED_{Runup}$ = "NO Overtopping"

Failed Structure Profile:



Wave Setup on a Failed Structure, η

$\eta_{FailedStructure} = 2.09\,ft$

Wave Runup on a Failed Structure, $R_{FAIL2\%}$

$R_{FAIL2\%} = 4.11\,ft$

$OVERTOPPEDFAIL_{Runup}$ = "Overtopped... Please consider 3 foot rule"

$Fail_{Sta} := FailRevet_{Sta} \cdot 1 \cdot \frac{1}{ft}$ $Fail_{Ele} := FailRevet_{Ele} \cdot 1 \cdot \frac{1}{ft}$

Input a path and file name for failed profile station and elevation data