RANSOM
Consulting
Engineers
and Scientists

Memo

400 Commercial Street, Suite 404, Portland, Maine 04101, Tel (207) 772-2891, Fax (207) 772-3248
Byfield, Massachusetts ☐Portsmouth, New Hampshire ☐ Hamilton, New Jersey ☐ Providence, Rhode Island
www.ransomenv.com

Date: June 22, 2020
To: Andrew Dorr, Town Manager, Town of Vinalhaven, Maine
From: Nathan Dill, P.E. and Scott Hayward
Subject: Review of Flood Insurance Rate mapping

INTRODUCTION

Ransom Consulting, LLC. (Ransom) has prepared this memorandum for the Town of Vinalhaven, Maine (Town) to describe our initial review of the Flood Insurance Study (FIS) and effective Flood Insurance Rate Maps (FIRMs) issued by the Federal Emergency Management Agency (FEMA). This memorandum has been prepared to provide the following:

- An explanation of the methods FEMA has applied to determine the Special Flood Hazard Area (SFHA) and Base Flood Elevations (BFE) [1] that are shown on the FIRM in the Town of Vinalhaven,
- Our opinion regarding the reasonableness of the methods and resultant mapping, and
- Recommendations for re-evaluating the coastal flood hazard to provide more accurate mapping for the Town.

This review is based upon information provided in FIS Report Number 23013CV000A for Knox County, Maine, Effective July 6, 2016 and supporting coastal analysis data for study 12-01-1051S provided as a digital download to the Town on Vinalhaven by Michael Baker International on behalf the FEMA Engineering Library on November 13, 2019 following a fee exempt request made by the Town for hydrologic and hydraulic backup data for the effective FIS[2].

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[1] SFHA is defined by FEMA as the land area that would be inundated by the "base flood". The Base Flood Elevation (BFE) is defined by FEMA as the computed elevation to which the flood water is expected to rise during the base flood event. The base flood event is the flood event that is expected to occur with 1% chance in a given year, also commonly known as the "100-year" flood. The "100-year" terminology can be misleading because it incorrectly suggests that a flood of this magnitude can only happen once a century. In fact, given a sufficiently long period of time (i.e. multiple centuries) it is possible to have zero 100-year events in some centuries and multiple 100-year events during other centuries. To avoid this confusion, and because future climate change is expected increase the magnitude of flood hazards as we move into the next century, it is better to characterize the flood hazard in terms of the probability of occurrence within the present year. Thus, we refer to the 1% annual chance flood event rather than a 100-year flood.

[2] The effective FIS report, FIRM panels, Flood Hazard Layer GIS data files, and an interactive flood hazard maps are available at the FEMA Map Services Center website: https://msc.fema.gov/portal/home.

The FIS and coastal engineering back-up data describe a county-wide study of the flood hazard for Knox County Maine. Because this is a county-wide study much of the information in these sources is not pertinent to the Town of Vinalhaven. To aid in our review of the information within the Town, we have extracted Town specific portions of the data tables from the FIS and engineering back-up calculations from the engineering library archive. These are provided as attachments to this memorandum.

- **Attachment A** provides excerpts from the Knox County FIS report that highlight the coastal transect data summary that is reported in the FIS for coastal flood hazard analysis transects in the Town of Vinalhaven.

- **Attachment B** provides annotated excerpts of coastal analysis calculations from the county-wide engineering library back-up data. These include MathCAD worksheets[3] showing wave setup and wave run-up calculations, output of fetch limited incident wave calculations from the Automated Coastal Engineering System (ACES) program, and overland wave model output files and wave crest elevation profile plots from the Wave Height Analysis for Flood Insurance Studies (WHAFIS) model.

- **Attachment C** provides an expanded summary table of the transect calculation data from the above sources with comments from our review.

- **Attachment D** provides a copy of the Annotated FIRM from LOMR case No. 20-01-0545P, which is currently under review by FEMA. If approved this LOMR would revise a portion of the FIRM at the head of Sand Cove and along a portion of the Old Harbor Pond shoreline as shown in the attachment.

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[3] MathCAD is a commercial engineering software sold by PTC Inc. that is commonly used to perform and document engineering calculations. FEMA's contractor, STARR, used MathCAD worksheets to calculate and document wave setup and wave runup calculations for the Knox County FIS.

FEMA COASTAL FLOOD MAPPING METHODOLOGY

FEMA's flood hazard mapping in Vinalhaven is based upon standard methods[4] that consider the flood hazard from a combination of high tide, storm surge, and damaging wave effects associated with a hypothetical 1% annual chance flood event. The hazard is characterized by the maximum floodwater elevation relative to a fixed vertical datum[5] and by a flood zone type that indicates the potential for severe damage to structures due to high velocity wave action. Flood zones are labeled as AE zones where the wave action during the 1% annual chance event is expected to be moderate or minimal, and VE zones where wave action has potential to cause severe erosion and/or damage to structures. In general, AE zones are delineated where wave heights over flooded land are expected to be less than 3 feet and wave runup is no more than 3 feet above the ground elevation. Figure 1 illustrates the various water level components that must be calculated to determine the flood zone type and BFE for a specific location. These components include:

- Still Water Elevation (SWEL) – The water level that results from a combination of high tide and storm surge driven by wind and atmospheric pressure, but neglecting contributions from wave action. FEMA has determined the SWEL for Vinalhaven from a combination of tide gauge data analysis and numerical modeling of a single representative 1% annual chance storm tide event using a hydrodynamic model called RMA2. Determination of the SWEL is described in a report by FEMA's contractor, the Strategic Alliance for Risk Reduction (STARR), that was provided in the digital archive downloaded from the FEMA Engineering Library[6].

- Wave Setup – Wave setup is an additional increase in the mean water level that occurs due to wave breaking processes. Wave setup can cause land above the SWEL to become inundated allowing wave action to propagate farther landward. The combination of the SWEL and maximum wave setup gives the Total stillWater Level (TWL). During the base flood condition, it is assumed that any ground below the TWL becomes inundated. The wave setup contribution to the flood hazard in Vinalhaven has been estimated using a simplification of the Direct Integration Method (DIM). An additional calculation based on geometric considerations described in the guidance has also been performed to estimate an additional contribution to the wave setup that may occur when coastal structures or steep natural slopes are present in the wave breaking zone. These calculations are documented in the MathCAD worksheets that are provided as pdf files in the data download from the engineering library. Annotated copies of the MathCAD sheets used for the Town are provided in Attachment B.

- Controlling Wave Height and Wave Crest Elevation – The wave height is the vertical distance between the peak and the trough of an ocean wave. The controlling wave height is the average height of the highest 1% of waves within a train of many waves. The wave crest elevation is determined by adding 70% of the controlling wave height to the TWL (i.e. waves are assumed to be asymmetrical with 70% of their height above mean water level). According to FEMA guidelines the controlling wave height and wave crest elevation must be computed with the Wave Height Analysis for Flood

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[4] FEMA, 2007. Guidelines and Specifications for Flood Hazard Mapping partners [February 2007]. Appendix D.2. Final Draft Atlantic Ocean and Gulf of Mexico Coastal Guidelines Update.

[5] All elevations in this memorandum refer to the North American Vertical Datum of 1988 (NAVD88) unless otherwise stated.

[6] *Undated report by STARR "Coastal Hydraulics and Hydrology Cumberland, York, Sagadahoc, Lincoln, Knox, Waldo, & Hancock Counties, Maine"*

Insurance Studies (WHAFIS) numerical model. The WHAFIS model is applied to calculate the wave crest elevation profile over land inundated by the TWL. Wave crest elevation profiles generated from the WHAFIS model output are provided in Appendix B. In areas where overland wave action is the dominant flood hazard, the BFE is determined by rounding the critical wave crest elevation to the nearest whole foot.

- Wave Run-up – Wave run-up is the vertical extent of the uprush of water on the shoreline. FEMA guidance requires the use of the 2% wave run-up to determine the BFE, which is the average wave run-up of the highest 2% of waves within a train of many waves. FEMA guidelines give various methods for calculating the wave run-up with the choice of methods dependent on the shoreline slope, shoreline type, and incident wave conditions. Wave run-up calculations for transects in Vinalhaven are documented in the MathCAD worksheets in Attachment B following the wave setup calculations.

Calculations to determine the components of the BFE are carried out at specific shoreline locations called “wave transects”. Transect calculations are based on shore perpendicular elevation profiles and site-specific estimates of the SWEL and incident wave conditions, as well as other factors that depend on the shoreline geology and the presence of coastal armoring structures. Generally coastal structures such as seawalls are assumed to provide no protection during the base flood and may be removed from the analysis or given an assumed failure profile in the analysis and evaluated for both intact and failed conditions. The BFE, which may vary along a transect, is determined by rounding the wave crest elevation or wave runup elevation to the nearest whole foot value, and taking the higher value as the BFE. Flood zones are drawn on the map covering areas adjacent to the wave transect where the shoreline conditions and wave exposure are assumed to be similar. Mapping of the flood zones between wave transects is performed by interpolation with professional judgement and must consider the results of the analysis, variations in shoreline conditions, and variations in topography between transects.

Typically, in areas where the land may be inundated by storm surge during the base flood, the BFE is determine by estimating the overland wave crest elevation. In areas where the storm surge would not inundate the land, but the shoreline is exposed to wave action, the BFE is determined by estimating the wave run-up elevation on the shoreline. Typically, wave run-up is the greater hazard on steeper bluff like shorelines that are naturally present in Vinalhaven and where the shoreline has been modified with structures or coastal armoring. If the wave run-up is higher than the crest of a bluff or structure, the potential for wave overtopping and wave splash beyond the crest is considered in determining the BFE and the landward extent of the flood zone. Figure 1 illustrates how the SWEL, wave setup, TWL, controlling wave height, and wave runup are combined to determine the BFE.

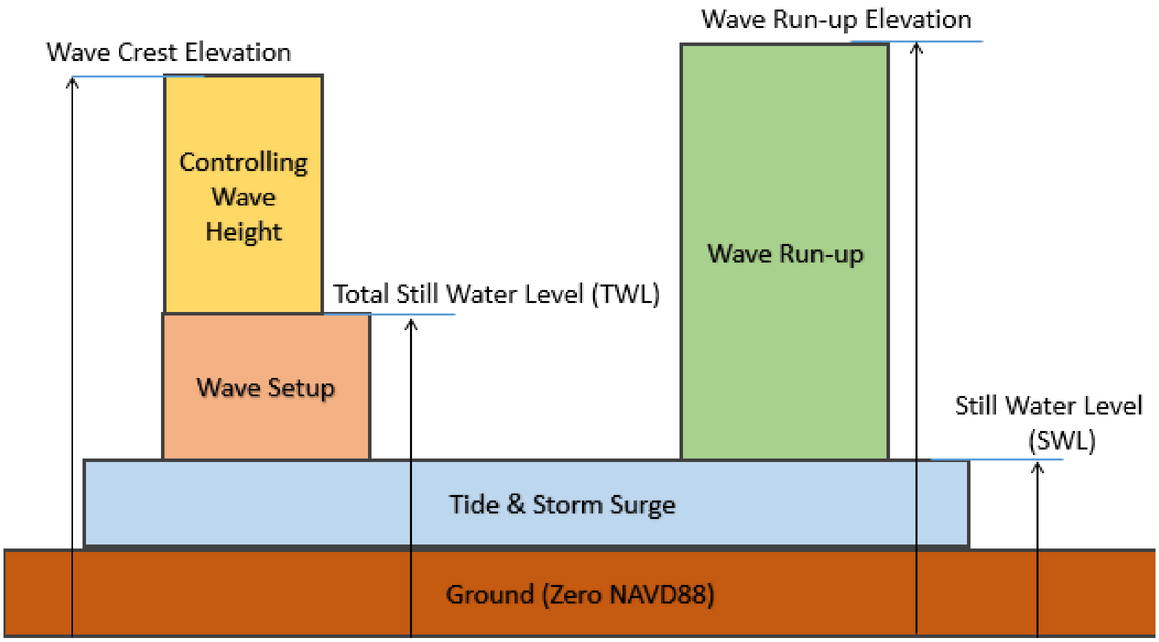

Figure 1. Illustration of the water level components that determine the Coastal BFE based on FEMA guidelines. The BFE is set to wave crest elevation or the wave run-up elevation, whichever is higher, then rounded to the nearest whole foot value.

GENERAL DEFICIENCIES IN MAPPING AND ANALYSIS FOR VINALHAVEN

Transect Spacing

To ensure accurate mapping of the flood hazard, FEMA guidance[7] suggests that coastal analysis transects should typically be spaced from a few hundred feet apart (where upland characteristics are highly variable or significantly developed) to a few thousand feet apart (where upland characteristics are uniform and development is sparse). However, FEMA has evaluated only 9 transects within the Town with transect spacing ranging from a minimum of 2700 feet to more than 5 miles spacing, roughly ten times the spacing recommended in the guidance. Considering the highly variable shoreline topography in the Town and the high variability in wave exposure as well as variations in the density of development along the shoreline, this spacing is too large to accurately assess the flood hazard for much of the Town. The large spacing means that flood mapping for many properties in the Town has been determined based on analyses that poorly represent the local shoreline condition and wave exposure. Evaluation of additional wave transects with closer spacing would improve the accuracy of flood mapping for the Town and could be used as a basis for revision of the FIRM.

Still Water Elevation

FEMA has utilized a SWEL ranging from 8.8 to 9.0 feet NAVD88 in transect analyses for Vinalhaven. FEMA determined the SWEL by applying a two-dimensional hydrodynamic finite-element model (RMA2) to simulate the propagation of a single representative 1% annual chance storm tide within Penobscot Bay. The hydrodynamic model was forced with an open ocean boundary condition in the Gulf of Maine that reached a peak storm tide elevation derived from a statistical analysis of observed water levels as described in FEMA's 2012 Updated Tidal Profiles for the New England Coastline[8]. Our review of the RMA2 modeling indicates that the model forcing did not include wind forcing, which could lead to under-estimation of the SWEL. In addition to the lack of wind forcing, this method is also crude compared to other SWEL methodology in common practice in flood hazard studies because it characterizes the hazard using a single representative storm surge event, rather than considering the statistical probability of surge from many possible storm events with potentially different combinations of meteorological forcing and coincidence with tides.

More advanced methods are available and have been commonly applied by FEMA for determining SWEL statistics in every FEMA Region along the Atlantic Coast of the United States except New England (FEMA Region I). In fact, the Town of Vinalhaven has available information based on more advanced 2-D hydrodynamic-wave modeling methods from the Town's 2017 resiliency planning study[9]. For example, Figure 2 shows the present day 1% annual chance TWL from the Town's resiliency planning. Information from the Town's resiliency planning study could be adapted and used as a basis to revise the FIRMs for the Town using the more detailed information.

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[7] FEMA, 2015. Guidance for Flood Risk Analysis and Mapping, Overland Wave Propagation, Guidance Document 41, November 2015.

[8] https://www.fema.gov/media-library-data/1383243270931-eed96b0ca96641e6c0200ac996b63b7a/220602416_New_England_Tide_Report_2012_0326_FINAL.pdf

[9] Ransom Consulting, 2017. Vinalhaven Resiliency Planning – Present and Future Coastal Flood Hazard, Memo prepared for the Town of Vinalhaven, August 30, 2017.

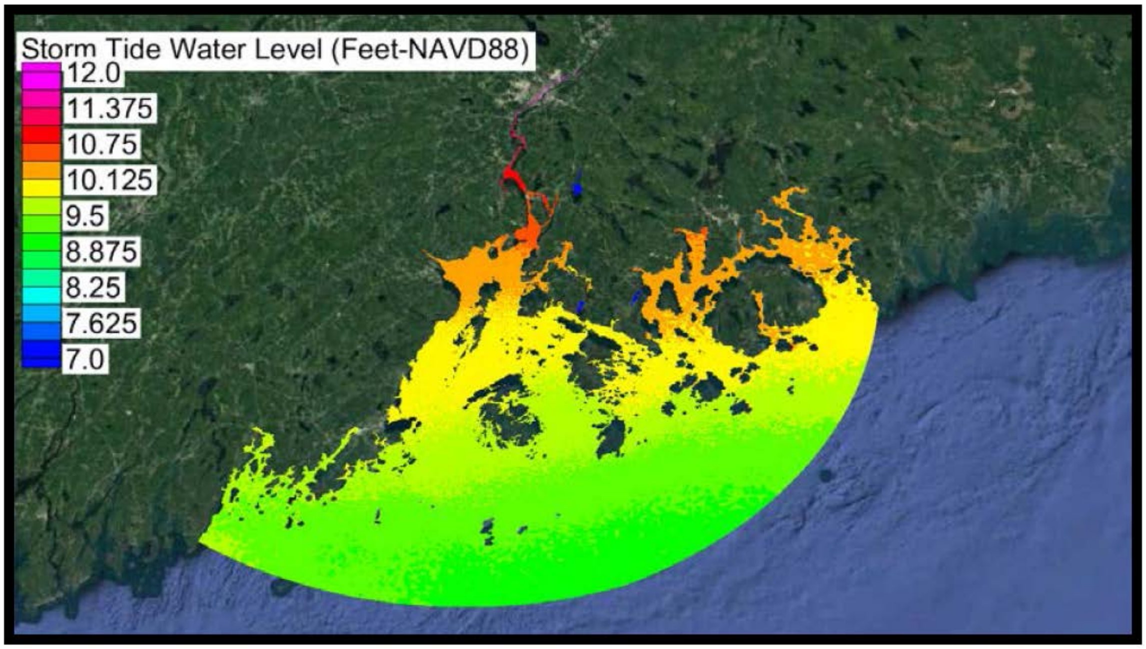

Figure 2. 1% annual chance water level statistics (including wave setup) for Penobscot Bay based on 2-D hydrodynamic-wave modeling from Vinalhaven's 2017 Resiliency planning study.

Incident Wave Conditions

To provide incident wave conditions at specific wave transects that are exposed to waves from the Gulf of Mexico FEMA developed a two-dimensional wave transformation model based on the Steady-State Spectral Wave Model version 6 (STWAVE). The STWAVE model computes how the offshore waves during the base flood event would transform as they grow with the wind and propagate toward land given the bathymetry and shoreline orientation around Vinalhaven. Output from this model was apparently used for input to the transect-based calculations on transects that have a south, southeast, and eastward exposure to the Gulf of Maine and East Penobscot Bay.

Figure 3 shows the 1% annual chance wave condition as presented in the STARR coastal hydraulics and hydrology report within the Knox County data archive[6]. However, we were unable to find STWAVE model data for this model domain in the engineering data archive for Knox County. The Knox County archive contains two files with STWAVE model outputs whose names indicate they are for Knox County and Hancock County. However, the file for Knox County[10] only has model data for the mainland shoreline of West Penobscot Bay. Similarly, the file for Hancock County provides data along the opposite side of East Penobscot Bay and doesn't include Vinalhaven. Thus, we cannot confirm the adequacy of STWAVE model data that were used for Vinalhaven because the only documentation we find in the archive is a relatively coarse image in the STARR coastal hydraulics and hydrology report. It appears the STWAVE data for Vinalhaven may have been inadvertently excluded from the engineering data archive.

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[10] located at: \Coastal Data from 12-01-1051S\Offshore_Wave_Models\STWAVE\Simulations\Production_Runs\OriginalFiles\Knox_100yr_results.txt

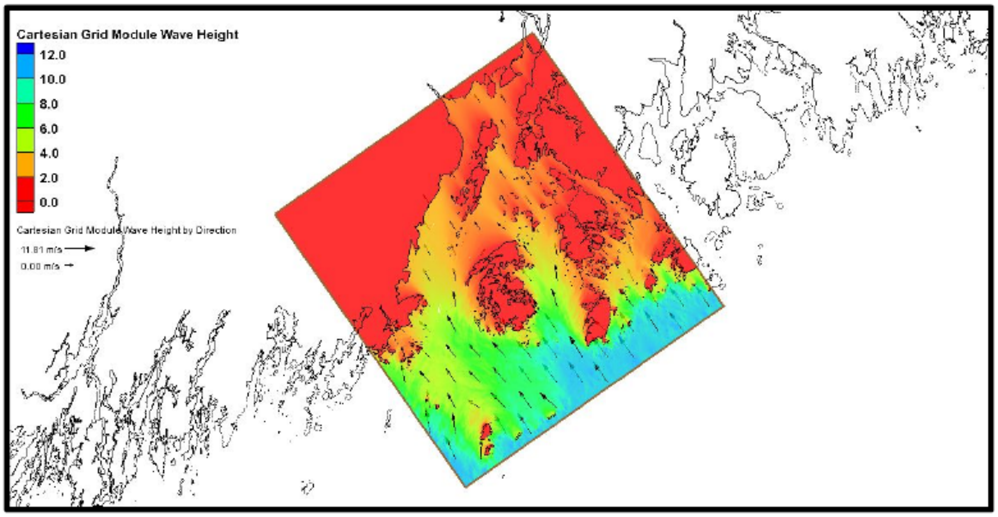

Figure 4-17 : Penobscot Bay STWAVE Grid Wave Heights (meters) and Direction Resulting From the 1-Percent-Annual-Chance Storm Simulation

Figure 3. Reproduction of Figure 4-17 from the STARR report "*Coastal Hydraulics and Hydrology Cumberland, York, Sagadahoc, Lincoln, Knox, Waldo, & Hancock Counties, Maine*" showing 1% annual chance wave heights for Penobscot Bay.

According to narrative reports in the engineering data archive FEMA's STWAVE model only considered wind and waves coming from the southeast for a single representative event. An additional report in the archive[11] explains that FEMA attempted to simulate wave conditions associated with wind and waves from a southwesterly direction as well but concluded that this did not significantly affect the model output. We disagree with this conclusion. We suspect that an undocumented configuration requirement for wind input in the STWAVE version 6 model prevented the wind forcing from being applied properly when FEMA attempted to simulate a southwesterly wind. If the model had applied wind forcing as expected, the model would have shown higher wave heights on open southwest facing shorelines in the Town[12]. This suggests that FEMA may have underestimated the severity of incident wave conditions on some of the southwest facing shorelines in the Town, and that FEMA's hazard mapping is biased toward events with southeasterly winds.

FEMA applied the Automated Coastal Engineering System (ACES) Fetch limited wave method to determine incident wave conditions for shorelines that are not directly exposed to waves from the Gulf of Maine. The wind speed applied for these models is reasonable and consistent with other flood hazard analysis for the Maine coast.

The more advanced numerical modeling approach taken in the Town of Vinalhaven 2017-2018 resiliency planning study also provides wave statistics that could be adapted and used as a basis of FIRM revisions in the Town. For example, Figure 4 shows the present day 1% significant

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[11] A pdf file labeled "FEMA RI_Knox_Waldo_Wave Height Methodology.pdf" included in the Knox County TSDN

[12] Our testing with STWAVE version 6 has discovered that in order to force the model with wind that has a directional component parallel to the offshore boundary, the wind forcing must be applied using the spatial grid input option. Our attempts to apply the wind as a constant value without using the spatial grid input option results in only the onshore component of the wind being included in the model simulation. This nuance is not explained in the user manual for the model, or is perhaps a bug in the program.

wave height from the Town's resiliency planning. It is noteworthy that this information considers incident waves statistics derived from the simulation of 40 historic storm events where wind and waves traveled toward the island from many different directions, not just the southeast. Wave hazard information from the Town's resiliency planning study could be adapted and used as a basis to revise the FIRMs for the Town using the more detailed information.

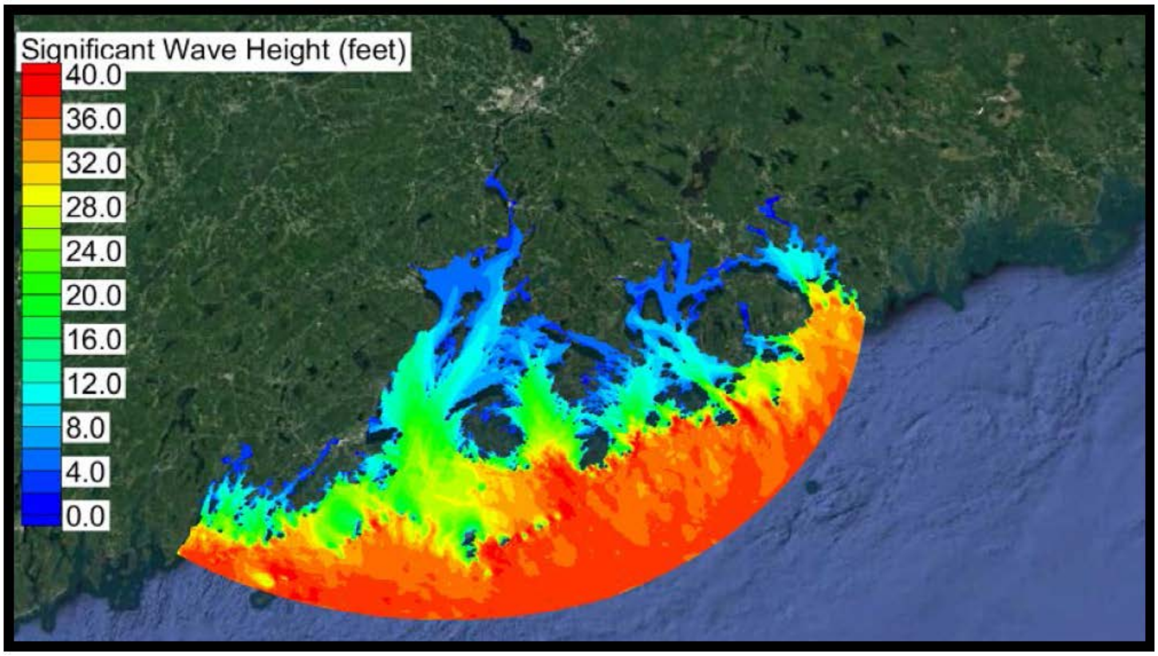

Figure 4. 1% annual chance wave statistics for Penobscot Bay based on 2-D hydrodynamic-wave modeling from Vinalhaven's 2017 Resiliency planning study.

<u>Open Coast Wave Setup (DIM method)</u>

The simplified DIM method, which was used to calculate open coast wave setup throughout this study, has not been validated for studies in this region and has been shown to over-estimate the wave setup compared to other more detailed methods. This method is based on a simple explicit formula that was developed for applications on the Pacific coast of the United States[13]. The DIM equation, shown below, uses wave conditions and shoreline slope to approximate the maximum wave setup at the shoreline, η.

$$\bar{\eta} / H_o' = 0.160 \frac{m^{0.2}}{(H_o' / L_o)^{0.2}} \qquad \text{(Eq. 2-1)}$$

Where $H_o{}'$ is the deep water significant wave height, L_o is the deep water wavelength, and m is the average shoreline slope (rise/run). This method is crude in comparison to other more detailed methods that are available and used practically for flood insurance studies in other regions. For example, the coupled 2-D hydrodynamic-wave modeling applied in the Vinalhaven resiliency

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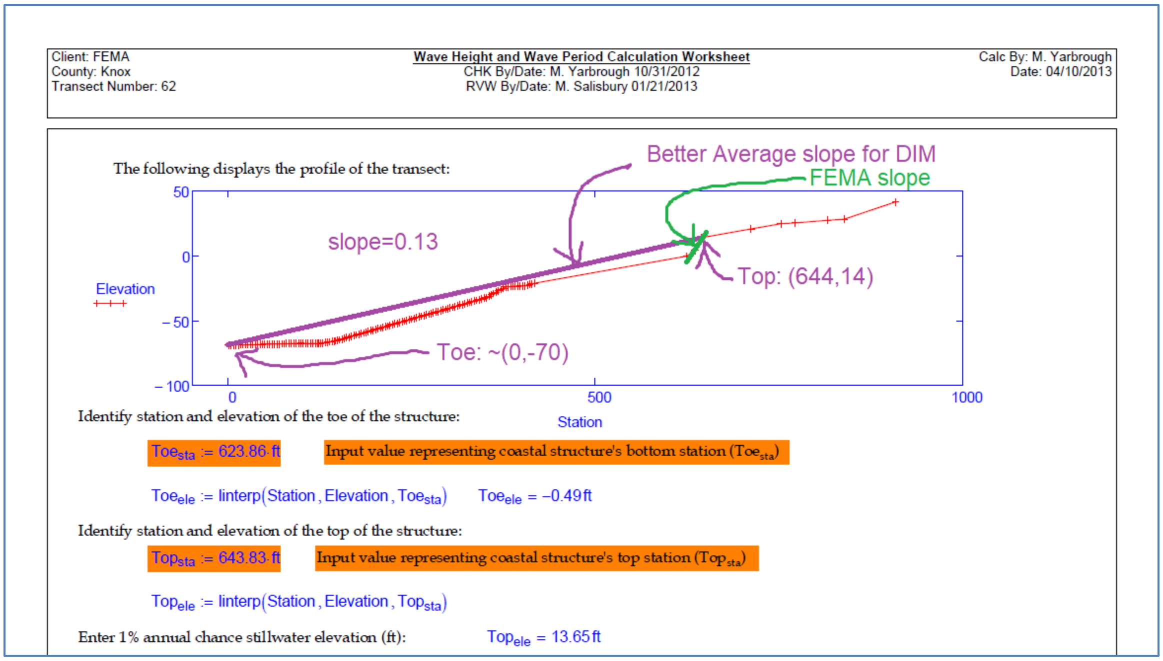
[13] FEMA, 2004 Final Draft Guidelines for Coastal Flood Hazard Analysis and Mapping for the Pacific Coast of the United States. A Joint Project by FEMA Region IX, FEMA Region X, FEMA Hedquarters, prepared by Northwest Hydraulic Consultants, Inc. November 2004

planning study calculates wave setup through the coupling of surge-wave model physics so that the model's water level outputs inherently include wave setup.

The DIM method is questionable for use in Vinalhaven because it requires that the shoreline slope can be represented by a single straight-line segment that extends from deep water to the landward extent of the flood level. While this assumption may be reasonable for the large planar beaches, it is not a reasonable assumption for the coastline in Maine, where shoreline profiles contain a range of slopes from level tidal flats to steep rocky banks within a single transect profile.

Furthermore, The MathCAD sheets in FEMA's Knox County TSDN show that slope values used in the DIM calculations are not representative of the average transect slope for the wave transects and there is no explicit documentation of how these slope values were determined (i.e. values for the average transect slope were simply input into the worksheets with no explanation of which points on the profile were used to estimate the slope). For many of the transects it appears that FEMA determined a profile slope that would be appropriate for the wave runup analysis, but then used that slope in the DIM equation as well as the wave run-up calculation.

For example, FEMA used a slope of 1.09 (rise/run) to calculate wave setup for transect 62, but the shoreline is only that steep over a relatively small section of the transect profile. In contrast, the average transect slope should be closer to 0.1, which is about ten times flatter, as shown in Figure 5. It is appropriate to use the steeper slope for calculating wave runup, but not for the wave setup calculation. Figure 6 shows the following section of MathCAD sheet where the larger slope was applied in the DIM equation. Review of the MathCAD sheets for all transects in Vinalhaven shows that similar unexplained slope values were used systematically for all transects in the Town.



Client: FEMA
County: Knox
Transect Number: 62

Wave Height and Wave Period Calculation Worksheet
CHK By/Date: M. Yarbrough 10/31/2012
RVW By/Date: M. Salisbury 01/21/2013

Calc By: M. Yarbrough
Date: 04/10/2013

The following displays the profile of the transect:

Identify station and elevation of the toe of the structure:

$Toe_{sta} := 623.86 \cdot ft$ Input value representing coastal structure's bottom station (Toe_{sta})

$Toe_{ele} := linterp(Station, Elevation, Toe_{sta})$ $Toe_{ele} = -0.49 ft$

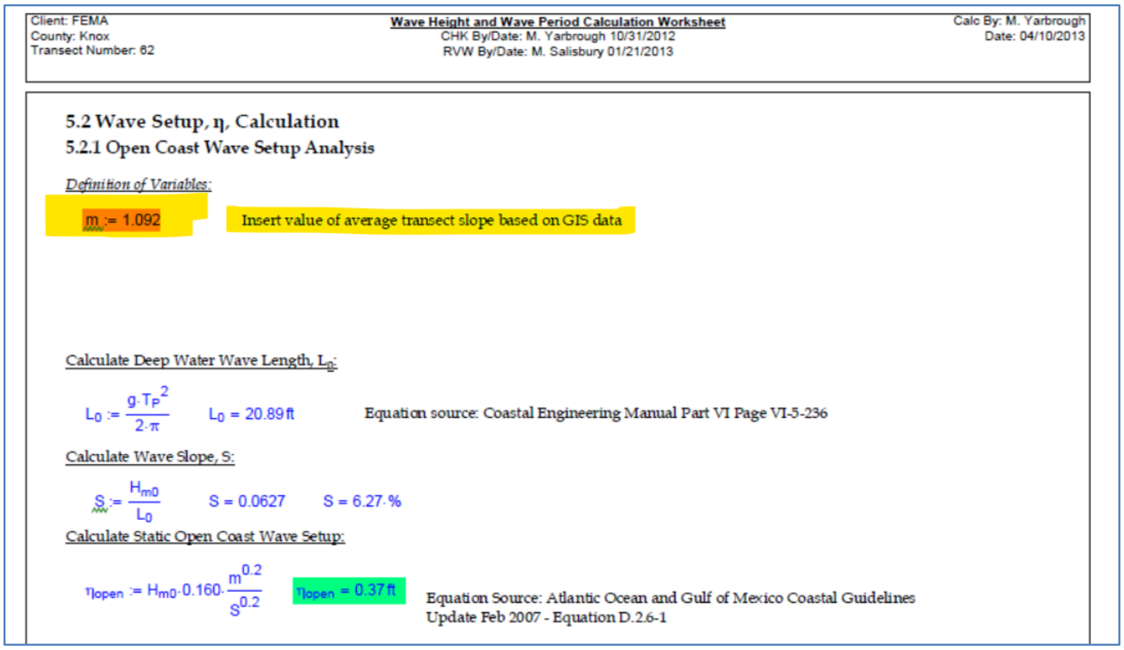
Identify station and elevation of the top of the structure:

$Top_{sta} := 643.83 \cdot ft$ Input value representing coastal structure's top station (Top_{sta})

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

Enter 1% annual chance stillwater elevation (ft): $Top_{ele} = 13.65 ft$

Figure 5. Elevation profile for Transect 62 in FEMA's MathCAD worksheet included in the Flood Insurance Study supporting data archive. (Note, FEMA used the steeper slope indicated with the green line rather than the flatter average slope indicated with the purple line)



Client: FEMA
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CHK By/Date: M. Yarbrough 10/31/2012
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Calc By: M. Yarbrough
Date: 04/10/2013

5.2 Wave Setup, η, Calculation

5.2.1 Open Coast Wave Setup Analysis

Definition of Variables:

$m := 1.092$ Insert value of average transect slope based on GIS data

Calculate Deep Water Wave Length, L_0:

$L_0 := \frac{g \cdot T_P^2}{2 \cdot \pi}$ $L_0 = 20.89 ft$ Equation source: Coastal Engineering Manual Part VI Page VI-5-236

Calculate Wave Slope, S:

$S := \frac{H_{m0}}{L_0}$ $S = 0.0627$ $S = 6.27 \cdot \%$

Calculate Static Open Coast Wave Setup:

$\eta_{open} := H_{m0} \cdot 0.160 \cdot \frac{m^{0.2}}{S^{0.2}}$ $\eta_{open} = 0.37 ft$ Equation Source: Atlantic Ocean and Gulf of Mexico Coastal Guidelines Update Feb 2007 - Equation D.2.6-1

Figure 6. DIM calculation for Transect 62 from FEMA's MathCAD sheet. The slope m=1.092 is not representative of the average transect profile slope that is appropriate for DIM.

Additional Wave Setup on Steep Slopes and Structures

In addition to calculating open coast wave setup with the DIM method, FEMA's MathCAD worksheets calculate an additional contribution to wave setup that can occur when the transect profile includes a relatively steep slope or sloping coastal structure. An error in this calculation that was programmed into FEMA's MathCADs sheets was discovered and appealed by the City of Rockland in 2014 and a proposed a correction to the error was accepted by FEMA. Although the City of Rockland's appeal informed FEMA that this error had occurred throughout their county-wide analysis, it was only corrected in communities that appealed the preliminary FIRMs prior to their adoption in 2016. We have confirmed that this error was also made in the calculations for Vinalhaven. This error effects the total wave setup values calculated for transects 60, 61, 62, and 63. A detailed explanation of this error and the proposed correction is provided as annotations to the MathCAD worksheet for transect 60 in Attachment B. Corrected calculations for transects 60 thru 63 are also given in Attachment B and the corrected structure wave setup values are listed in Attachment C. In general, this error leads to a 1-foot over-estimation of the BFE for these transects by overestimating the TWL that goes into the WHAFIS model input.

Overland Wave Height Analysis

FEMA Guidance requires application of the WHAFIS model to perform the overland wave height analysis. FEMA applied the Coastal Hazard Analysis and Mapping Program (CHAMP) to pre-process inputs for WHAFIS and execute the WHAFIS model. We did not find any general deficiencies with the application of WHAFIS for the Town of Vinalhaven. However, as discussed in the following section, FEMA used errant inputs to the WHAFIS model for some wave transects, resulting in incorrect wave crest elevations and mapped BFE in some areas in the Town.

Wave Runup Methodology

To calculate the 2% wave runup elevation during the 1% annual chance event, FEMA used the Technical Advisory Committee for Water Retaining Structures (TAW) method, which applies an empirical formula that estimates the wave runup as a function of the incident wave height, wave period, and shoreline slope at the intersection of the SWEL with the shoreline. FEMA's MathCAD worksheets apply a simplified version of this method. In most cases, the simplified method produces reasonable results. However, under some circumstances it is more suitable to use the more detailed iterative TAW method described in Van der Meer's guidance[14], which is the primary reference for this methodology. FEMA used the TAW method for all transects in the Town except transect 65 where the RUNUP 2.0 model was applied within the CHAMP program instead. Alternatively, other more detailed numerical model methods are available and accepted by FEMA for more accurate assessment of wave runup, such as the CSHORE model[15].

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[14] Van der Meer, J.W. 2002, Technical Report Wave Run-up and Wave Overtopping at Dikes. Technical Advisory Committee on Flood Defence. The Netherlands.

[15] Johnson, B.D., N. Kobayashi, and M.B. Graves. 2011. Cross-Shore numerical model CSHORE for waves, currents, sediment transport and beach profile evolution. ERDC/CHL Technical Report, in press, U.S. Army Engineer R&D Center, Vicksburg, MS.

TRANSECT-BY-TRANSECT DISCUSSION

In the following subsections we present a transect by transect discussion of FEMA's transect flood mapping for Vinalhaven. FEMA evaluated a total of 9 transects in the Town, identified as Transect 60 thru Transect 68 in the FIS report. The transect numbering starts at a transect near Youngs Cove along the Fox Islands Thoroughfare and proceeds counterclockwise around Vinalhaven Island. Figure 7, which is reproduced from the FIS, shows the transect locations in the Town. It is notable that Calderwood Neck and numerous smaller islands within the Town are not shown on the map in the FIS and that no wave transects were evaluated in these areas. However, the FIRMs do show mapped flood zones in these areas.

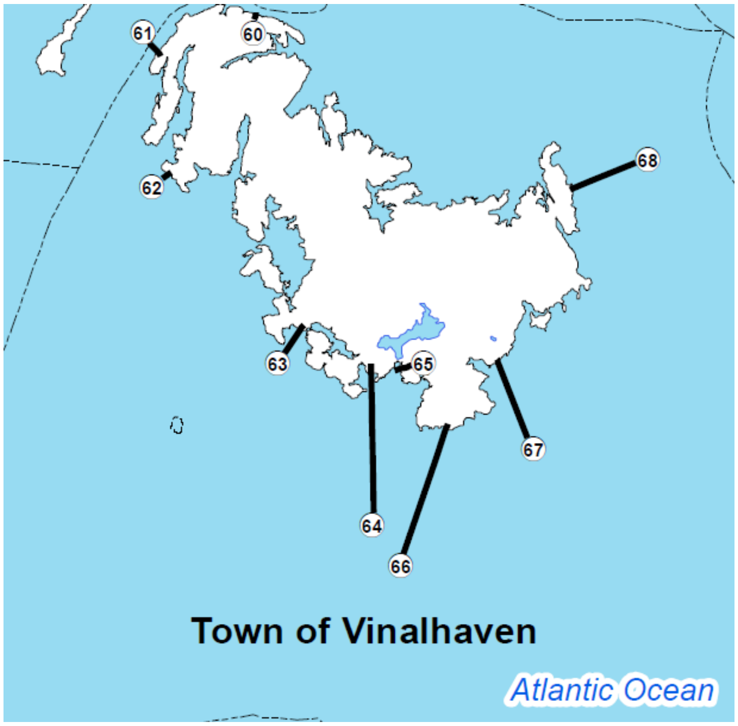

Figure 7. A portion of Figure 2 reproduced from the Knox County Flood Insurance Study report. Location of Transects 60-68 in the Town of Vinalhaven (note, Calderwood Neck and vicinity are shown as open water, numerous smaller islands in Town are also not shown on the map)

Transect 60:

Transect 60 is located about one half mile east of Youngs Cove on the north side of Vinalhaven Island along the Fox Islands Thoroughfare. The FIS reports a SWEL of 9.0 feet NAVD88. FEMA used the ACES fetch-limited wave generation method to determine incident wave conditions with a significant wave height 1.02 feet and a peak period of 1.6 seconds. The DIM method was used to calculate an open coast wave setup of 0.25 feet, and setup on a structure was determined to be 2.08 feet. Wave runup was calculated using the TAW method and yielded a runup height of 1.87 feet. FEMA has mapped the SFHA as an AE zone in this area with a BFE of 12 feet NAVD88. The BFE determination appears to be based on the maximum wave crest elevation from WHAFIS.

The calculation of wave setup on a structure for this transect is incorrect due to an error programed into the MathCAD sheet and is unrealistically large (e.g. it is not physically possible to have wave setup that is greater than the incident wave height). Correction of the wave setup error would reduce the TWL input to WHAFIS by more than 1 foot and likely lead to a reduction in the BFE for this transect.

Results from this transect have been used to delineate a large area extending from just east of Young's Cove along the Fox Islands Thoroughfare and including most of the sheltered area west, south and southeast of Calderwood Neck and in the vicinity of Penobscot Island. There appear to be multiple structures that are impacted by the flood zone delineation from this transect as shown in Figure 8. Analysis at this transect is only reasonable for mapping the shoreline along the Fox Island Thoroughfare. Analysis of additional transects should be considered to provide more accurate mapping in other areas. It is noteworthy that the flood zone drawn on the southeast side of Calderwood neck may under-estimate the flood hazard in areas where there is open fetch to East Penobscot Bay and likely overestimates the hazard on the numerous sheltered coves within the area due to the wave setup calculation error.

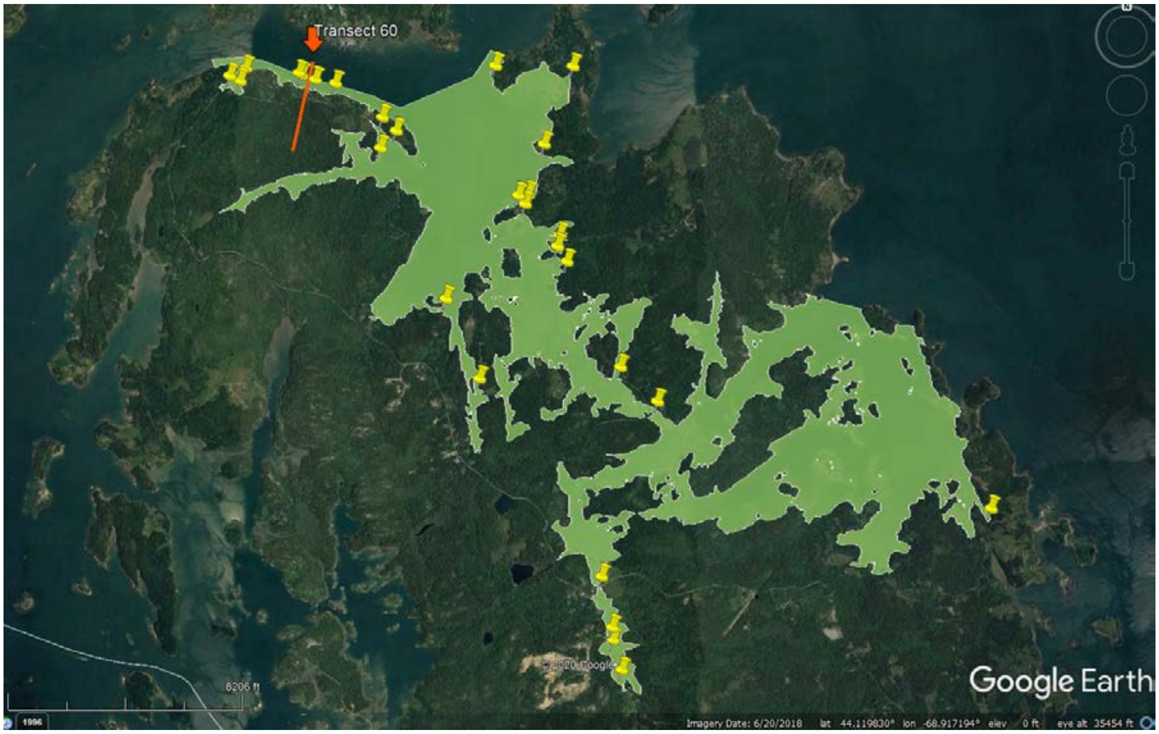

Figure 8. AE 12 Flood zone mapped based on Transect 60. Pushpins indicate buildings or roadways that are visible in the flood zone based on Google Earth imagery.

<u>Transect 61:</u>

Transect 61 is Located at Brown's Head on the northwest facing shoreline on Vinalhaven Island and was used to delineate the flood zones from the northernmost point of Vinalhaven Island to the end of Crockett Point and along the west facing shorelines of Dogfish Island and Leadbetter

Island as shown in Figure 9. We did not identify any structures within this zone from viewing in imagery available in Google Earth.

FEMA used the ACES fetch-limited wave generation method to calculate an incident wave height of 2.0 feet and period of 2.56 seconds. Wave setup of 0.46 feet was calculated using the DIM, and wave setup on a structure was determined to be 1.94 feet. Wave runup was calculated using TAW and yielded a runup height of 1.87 feet. FEMA has mapped the SFHA as a VE zone in this area with a BFE of 13 feet NAVD88. FEMA's mapping appears to be based on the maximum wave crest elevation from WHAFIS.

The calculation of wave setup on a structure is incorrect due to an error programed into the MathCAD sheet and an unrepresentative slope has been used in the DIM calculation. Correction of the wave setup would reduce the TWL input to WHAFIS by more than 1 foot and likely lead to a reduction in the BFE for this transect.

It is notable that the fetch length used to determine the incident wave conditions in the ACES calculation for this transect appears to be representative of the fetch between North Haven and Vinalhaven at the transect location where the fetch distance is only about 1 mile. This is reasonable for mapping the portion of the flood zone from the point of Brown's Head to the north, but it likely under-estimates the incident wave conditions along the west facing shoreline of Crockett Point and the islands to the south where the fetch extends more than 6 miles across West Penobscot Bay towards Owl's Head. FEMA's flood maps may under-estimate the flood hazard in these areas. The evaluation of additional wave transects in this area would likely call for an increase in the BFE and flood zone extent in some places.

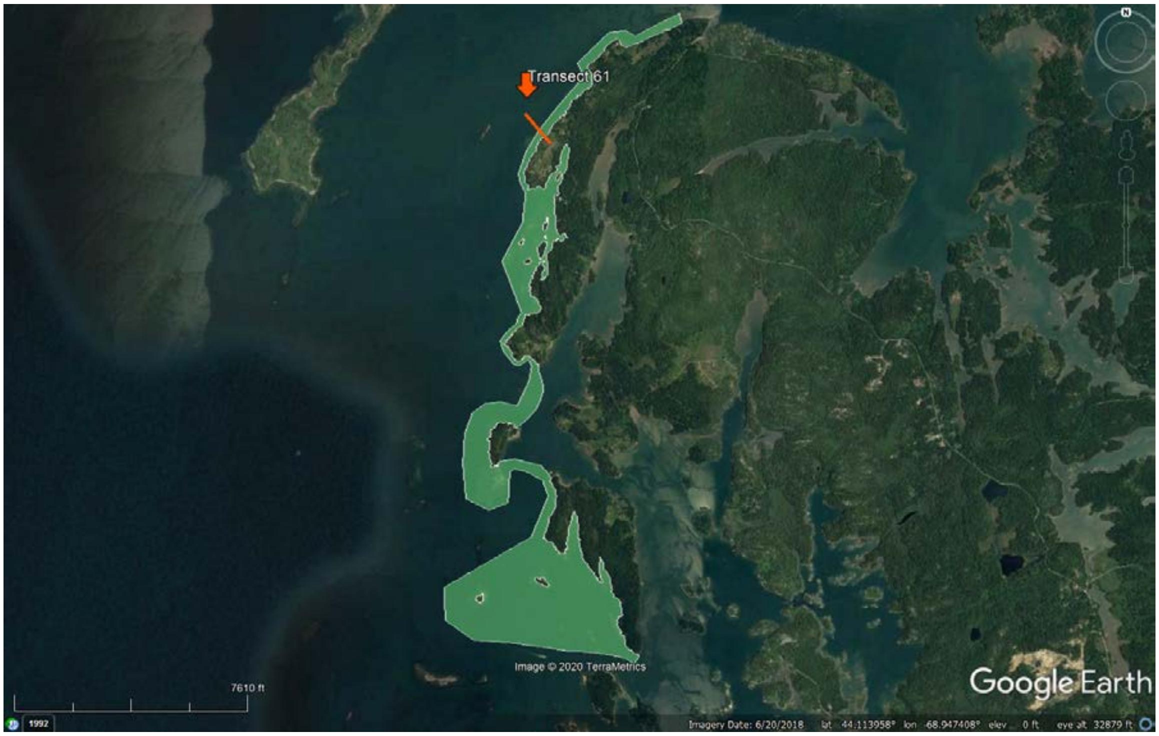

Figure 9. VE 13 Flood zone mapped based on Transect 60.

Transect 62:

Transect 62 is located south of Crockett Cove near the end of Crockett River Road. The shoreline in this area is partially sheltered by Dogfish Island and Leadbetter Island. The location of the transect is shown in Figure 10 along with the flood zone that has been mapped based on this transect and the location of buildings and roadways that show within the zone in Google Earth.

FEMA used the ACES fetch-limited wave generation method to calculate an incident wave height of 1.3 feet and wave period of 2.02 seconds. Wave setup of 0.37 feet was calculated using the DIM method and setup on a structure of was estimated to be 1.4 feet. Wave runup was calculated using TAW and yielded a runup height of 2.5 feet. The BFE in the vicinity of the transect is 12 feet NAVD88 and the SFHA has been mapped as an AE zone. FEMA's mapping appears to be based on the maximum wave crest elevation from WHAFIS.

The calculation of wave setup on a structure is incorrect due to an error programed into the MathCAD sheet and an unrepresentative slope has been used in the DIM calculation. Correction of these errors would reduce the TWL input to WHAFIS by 1 foot and likely lead to a reduction in the BFE for this transect.

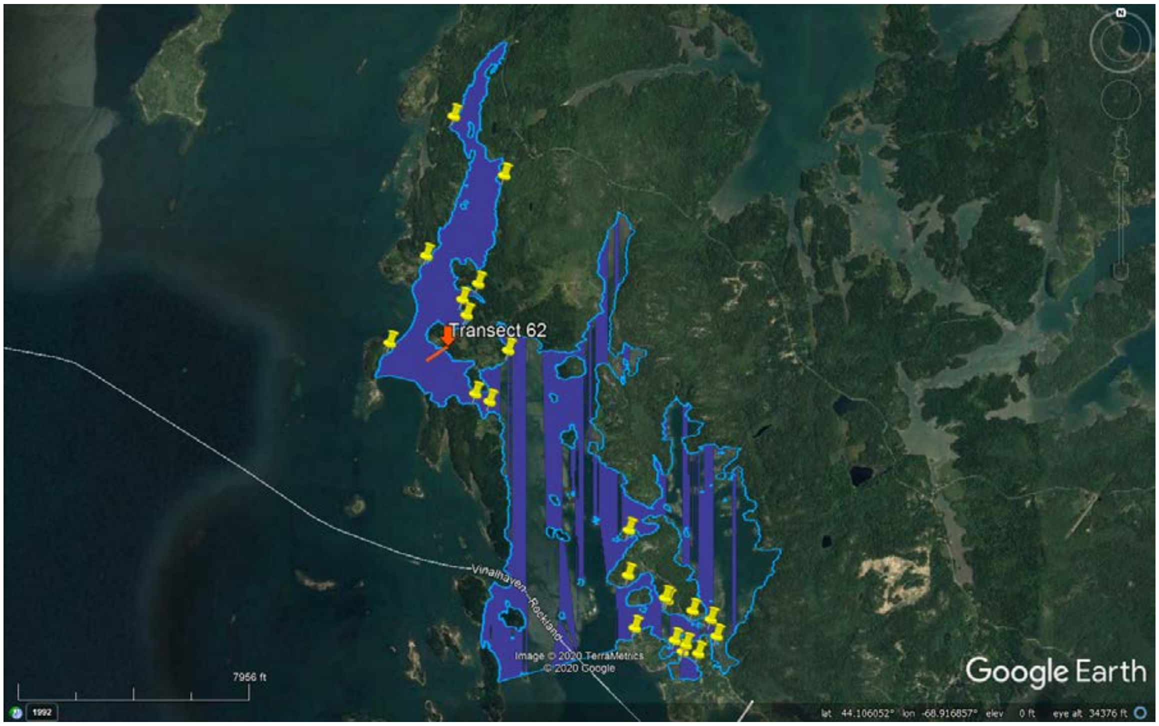

Figure 10. AE 12 Flood zone mapped based on Transect 62. Pushpins indicate buildings or roadways that are visible in the flood zone based on Google Earth imagery.

Transect 63:

Transect 63 is located on the southeast side of Vinalhaven Island where the shoreline is partially sheltered by Greens Island. The transect crosses Granite Point Road just north of the inlet to Old Harbor Pond. This transect was used to delineate the flood zone for shorelines along The Reach between Greens Island and Vinalhaven Island, and in Old Harbor Pond. Figure 11 shows the location of Transect 63, the flood zone mapped for this transect, and the location of buildings or roadways that are visible within the zone from our review in Google Earth.

FEMA used the ACES fetch-limited wave generation method to calculate an incident wave height of 1.51 feet and a wave period of 2.18 seconds. Wave setup of 0.59 feet was calculated using the DIM method and setup on a structure was estimated to be 1.24 feet. An unrealistic average transect slope of 5.29 (rise/run) was used in the DIM calculation. Wave runup was calculated using TAW and yielded a runup height of 1.66 feet. FEMA has mapped the SFHA in this as an AE zone with a BFE of 12 feet. FEMA's mapping appears to be based on the maximum wave crest elevation from WHAFIS.

The calculation of wave setup on a structure is incorrect due to an error programed into the MathCAD sheet and an unrealistic average transect slope has been used in the DIM calculation. Correction of these errors would reduce the TWL input to WHAFIS by at least 1 foot and likely lead to a reduction in the BFE for this transect.

Figure 11: AE 12 Flood zone mapped based on Transect 63. Pushpins indicate buildings or roadways that are visible in the flood zone based on Google Earth imagery.

<u>Transects 64:</u>

Transect 64 is located on a south facing shoreline on the north side of Sand Cove on Vinalhaven Island, approximately 1000 feet west of the Vinalhaven Ferry Terminal. It appears that FEMA used analysis from this transect to determine the flood mapping around Sand Cove and on the west facing shore of Lane Island. This transect crosses a rubble mound revetment, which FEMA considered might fail during the base flood event. Figure 12 shows the transect location, mapping from this transect and the location of buildings that show within the zone when viewed in Google Earth.

FEMA determined an incident wave height of 19.1 feet and wave period of 10.4 seconds, which were apparently based on the STWAVE model, although FEMA has not documented the location that this wave condition was extracted from the model. FEMA determined an open coast wave setup of 2.97 feet, and structure setup of 3.98 feet and 4.37 feet for the intact and failed structure profiles, respectively. Wave run-up calculations using the TAW method yield a 2% wave runup elevation of 16.9 and 17.7 feet for the intact and failed profiles, respectively. WHAFIS results for the intact case show a maximum wave crest elevation at the shoreline of 19 feet NAVD88 which quickly diminishes to a wave crest elevation of 13 feet or 14 feet NAVD88 where the ground would be inundated by the total water level.

It is unclear how FEMA determined the BFE and mapping for this transect based on these results. It is possible that FEMA simply used the maximum wave crest elevation from WHAFIS to determine the BFE of 19 feet-NAVD88, and then subjectively drew flood zones that transition to a BFE of 18 feet NAVD88 and from a VE zone to an AE zone. We can find no reasonable combination of the analysis results that suggest a BFE of 18 feet, or that the VE zone should extend so far inland.

A reasonable mapping based on FEMA's documented analyses would consider a combination of the wave run-up elevation and WHAFIS output. Following FEMA guidelines, the wave runup elevation should be limited to no more than 3 feet above the crest of the slope, which in this case is at 13 feet NAVD88 and would result in a VE zone with a BFE of 16 feet. Following the guidelines, the VE zone should extend up to 30 feet landward of the top of the failed profile slope, at which point the mapping should transition to WHAFIS results, which would be mapped as an AE zone with a BFE of 13 feet. In addition, re-evaluation of the incident wave condition and wave setup calculations would likely yield a further reduction in the BFE.

It is noteworthy that a recently submitted Letter of Map Revision (LOMR) application[16] for a property at the head of Sand Cove, if approved by FEMA, would considerably reduce the BFE by 7 to 9 feet in a portion of this area at the head of Sand Cove. The proposed revision for this LOMR request is shown in Attachment D.

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[16] LOMR case No. 20-01-0545P

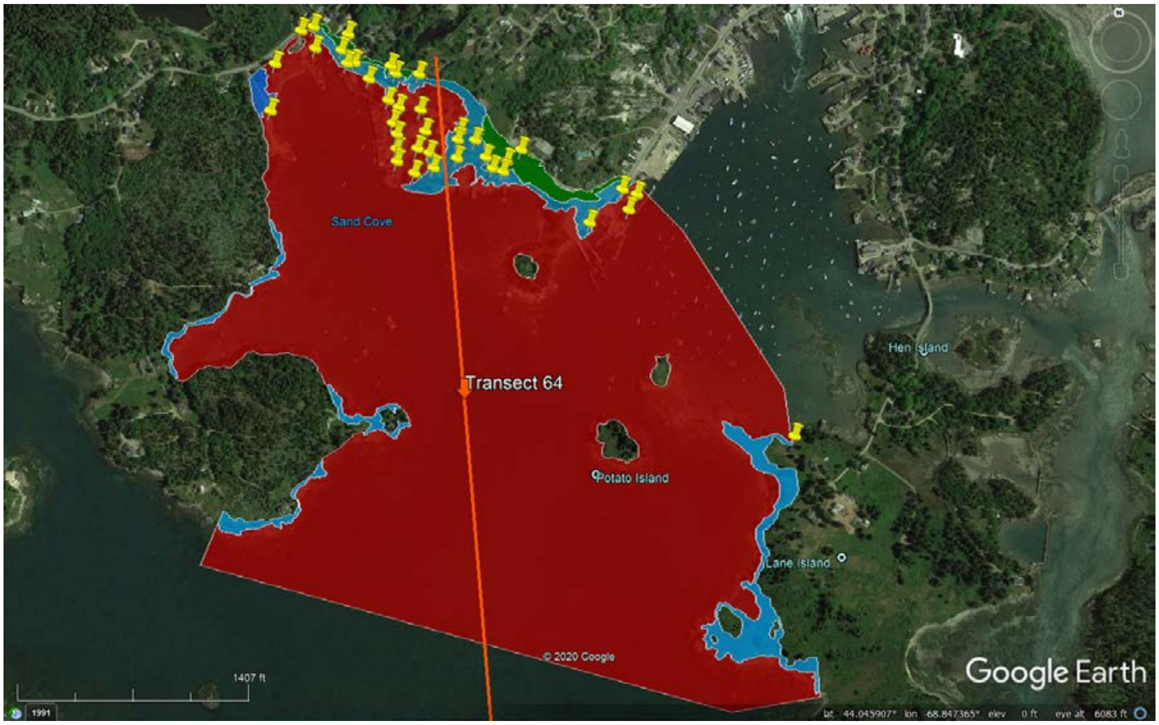


Figure 12. Flood zone mapped based on Transect 64, VE 19 (red), VE 18 (blue), AE 18 (green) Pushpins indicate buildings or roadways that are visible in the flood zone based on Google Earth imagery.

<u>Transects 65:</u>

Transect 65 is located within Carvers Harbor and crosses the shoreline on the east side of the harbor between Clamshell Alley and Leo Lane. Analysis from this transect was apparently used to delineate the flood zone along the shoreline around Carvers Harbor, the Carvers Pond Shoreline, the shoreline around Hen Island, the shoreline on the northeast side of Lane Island, and the Vinalhaven Island shoreline that faces Hen Island and Lane Island. This transect crosses a section of shoreline that is armored with riprap, and FEMA considered an intact profile as well as a partially failed profile condition. FEMA's failed profile assumes the ground would erode from an elevation of about 9 feet NAVD88 down to an elevation of 4 feet-NAVD88 for a distance of 45 feet landward of the existing armored shoreline as indicated by the WHAFIS profiles. The intact and failed ground elevation profiles are shown along with the WHAFIS model outputs in Attachment B. Figure 13 shows the transect location, the flood zones delineated based on this transect, and the location of buildings and roadways that are visible within the zone in Google Earth.

FEMA determined an incident wave height of 4.3 feet and wave period of 10.0 seconds based on the STWAVE model and an open coast wave setup of 1.23 feet for this transect. FEMA did not calculate a wave setup on structures or apply the TAW wave runup calculation for this transect. Instead wave runup was calculated with the RUNUP 2.0 model yielding 2% runup heights of 0.12 feet and 0.84 feet for the intact and failed conditions, respectively. WHAFIS results for the intact case show a maximum wave crest elevation of 14.8 feet NAVD88 that diminishes to an elevation of 10.3 feet (AE 10 zone) at the top of the riprap armoring. The WHAFIS results for the failed case show a similar starting condition, that transition to a VE 13 zone over the eroded portion of the profile, then to an AE 10 zone. FEMA's mapping of a VE 13 zone with fringes of AE 10 zones appears to be based on the WHAFIS results for the failed case.

FEMA's documentation does not explain where data were extracted from STWAVE model to provide wave conditions for the transect analysis. The wave height of 4.3 feet seems larger than expected for wave conditions in a sheltered harbor. A smaller incident wave height would likely be appropriate for most of the area that is mapped based on this wave transect. Furthermore, the failed analysis is highly specific to the shoreline at the transect location, which is not representative of the shoreline for most of the area that has been delineated based on this transect. Thus, for example, the mapping of the Carvers Pond shoreline is questionable and likely over-estimates the 1% annual chance flood hazard.

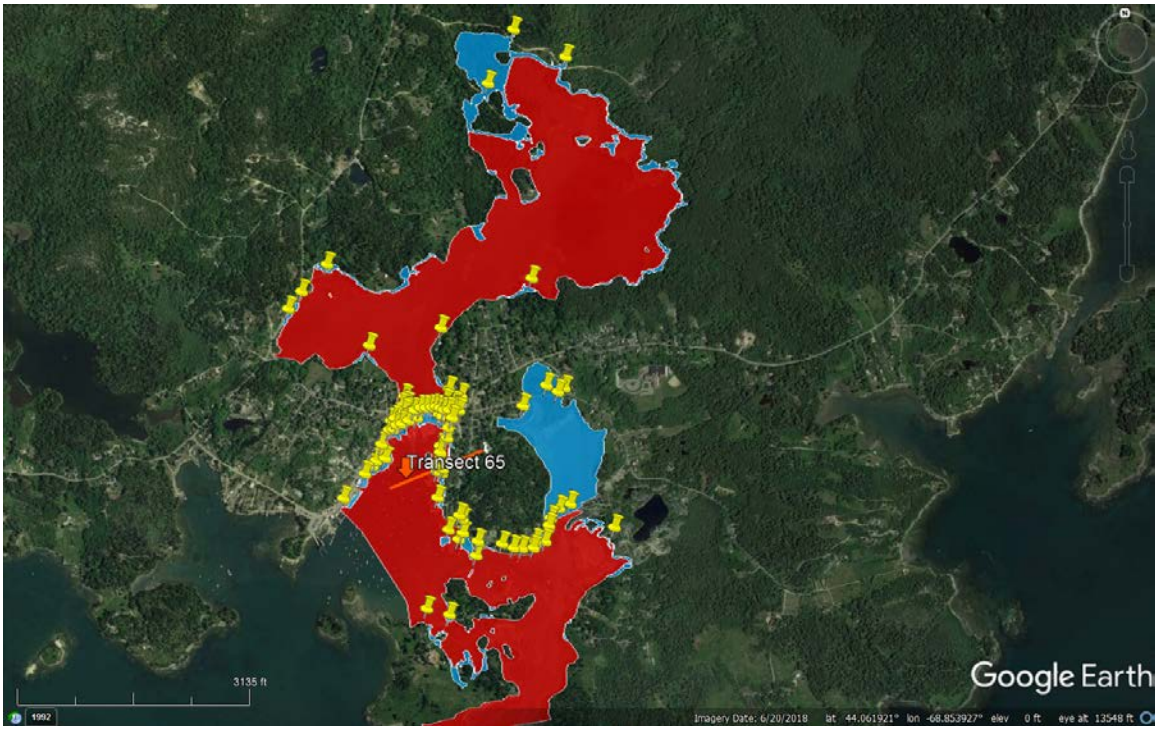


Figure 13. Flood zone mapped based on Transect 65, VE 13 (red), AE 10 (blue). Pushpins indicate buildings or roadways that are visible in the flood zone based on Google Earth imagery.

Transect 66:

Transect 66 is located near the southernmost point of Vinalhaven near the end of Cranberry Shores Road. The shoreline here has open exposure to waves from the Gulf of Maine to the south. FEMA used an incident wave height of 23.1 feet and wave period of 10.5 seconds derived from the STWAVE model. Wave setup calculated with the DIM method yields an open coast wave setup of 3.25ft and setup on a structure of 4.32ft. Wave runup was calculated using TAW and yielded a runup height of 10.6 feet, resulting in a 2% runup elevation of 19.4 feet NAVD88. FEMA has mapped the SFHA as a VE zone with BFE of 19, which is apparently based on the wave runup results. The transect location, flood zone, and structures that are visible within the zone are shown in Figure 14.

In general, the analysis and BFE for this transect are reasonable. However, it appears that FEMA delineated the landward extent of the zone by following the 19’ elevation contour. In portions of the zone where the shoreline slope is flatter than the slope at the transect location, this mapping can substantially over-estimate the landward extent of the SFHA. Re-evaluation for additional transects in this area where the shoreline slope is flatter might yield a lower BFE and/or reduction in the landward extent of the SFHA. Also, following FEMA guidelines, areas within this zone with ground elevation above 16’ NAVD88 could be mapped as AE zones if they are broad enough to show at the map scale.

Figure 14. VE 19 Flood zone mapped based on Transect 66. Pushpins indicate buildings that are visible in the flood zone based on Google Earth imagery.

Transect 67:

Transect 67 is located in Roberts Harbor and crosses Duchane Hill Road, between Narrows Island, and Carvers Cove. It is sheltered from waves coming from the southwest, and semi-sheltered from waves coming from the south, and east. FEMA used an incident wave height of 14.14 feet and a wave period of 11.05 seconds based on the STWAVE model. Wave setup was calculated using the DIM method yielding an open coast wave setup of 3.01ft, and setup on a structure of 4.35ft. Wave runup was calculated using TAW and yielded a runup height of 17.4 feet and runup elevation of 26.2 feet. FEMA determined the BFE based on the runup elevation of 26 feet NAV88 and appears to have mapped the inland extent of a VE zone by following the 26’ topographic contour. The transect location, flood zone, and structures that are visible within the zone are shown in Figure 15.

Although FEMA's determination of the BFE for this transect is appropriate given the results of the analysis, FEMA has not documented the location where the incident wave conditions were extracted from STWAVE, and the incident wave height used in the calculation appears larger than expected for the semi-sheltered shoreline in this location. It is possible that FEMA selected the incident wave height from their STWAVE model from outside Roberts Harbor, or that the STWAVE model did not adequately include the bathymetry and topography of the islands and shoals surrounding the Harbor that would block and refract wave energy reaching the shoreline at this location. The use of more representative incident wave conditions would likely reduce the wave runup and BFE in portions of this area.

Furthermore, FEMA's mapping, which follows the 26' elevation contour is not appropriate for mapping the hazard based on wave runup in much of this area where the slope is less steep. For example, wave run-up may be able to reach an elevation of 26 feet right at the transect location where the shoreline is steep, but it is unreasonable to assume waves could run-up more than 1000 feet horizontally past the limit of the SWL as the mapping shows for the portion of the zone that extends landward of Pequot Road at the head of Carvers Cove. This unrealistic mapping suggests that additional transects should be evaluated to more accurately determine the hazard zones and BFE.

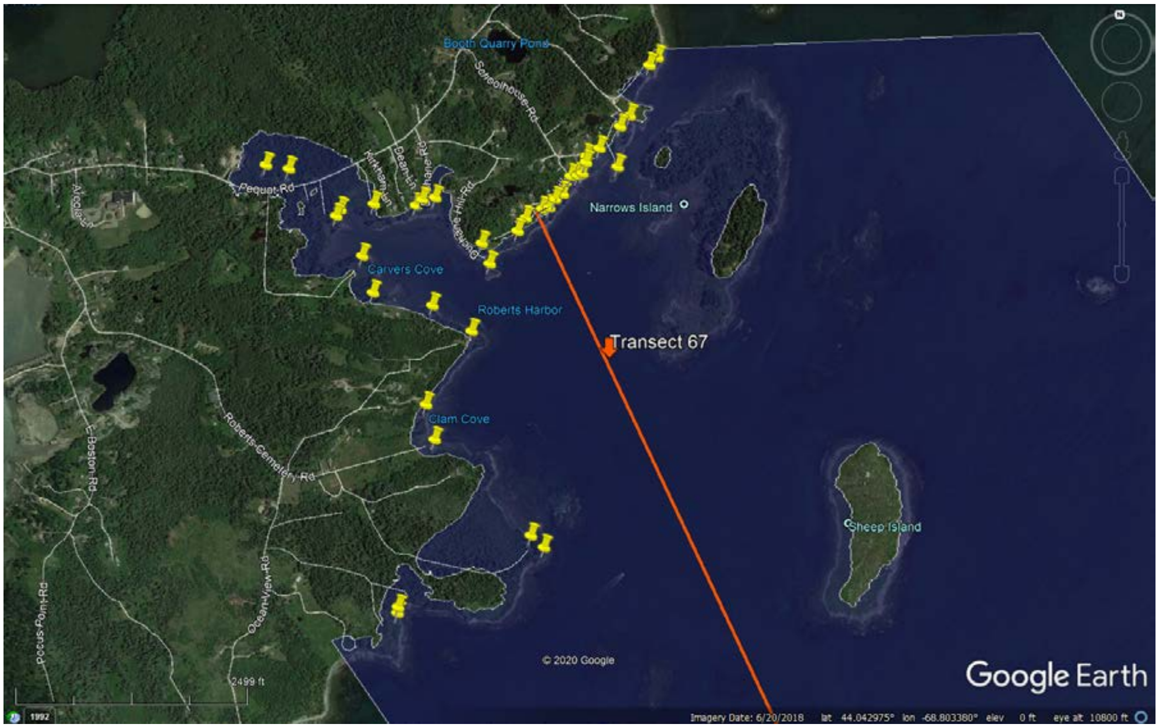


Figure 15. VE 26 Flood zone mapped based on Transect 67. Pushpins indicate buildings and roadways that are visible in the flood zone based on Google Earth imagery.

<u>Transect 68:</u>

Transect 68 is located near the easternmost point of Vinalhaven, on Coombs Neck where the shoreline faces east-northeast. It is semi-sheltered from waves coming from the south but exposed to waves coming from the Isle Au Haut Bay to the east and East Penobscot Bay to the northeast.

FEMA used an incident wave height of 15.26 feet and wave period of 9.71 seconds, apparently taken from the STWAVE model. Wave setup was calculated using the DIM method and yielded an open coast wave setup of 3.44ft, and setup on a structure of 4.43ft. Wave runup was calculated using TAW yielding a runup height of 13.11 feet and runup elevation of 22.0 feet. FEMA determined the BFE based on the runup elevation of 26 feet NAV88 and appears to have mapped the inland extent of a VE zone by approximately following the 22' topographic contour. The transect-based calculations from Transect 68 were used to delineate the flood mapping for approximately 7 miles of shoreline extending from Arey Cove at the southern end to Birch Island to the north. The transect location, flood zone, and structures that are visible within the zone are shown in Figure 16.

It is not clear where FEMA selected the incident wave conditions from the STWAVE model for this transect. Based on our understanding of the STWAVE model simulation with dominant southeasterly wind and wave direction it appears that FEMA may not have considered the wave directionality so that the incident wave height they selected may be more representative of waves traveling parallel to the shoreline at this location, rather than the waves incident on the shoreline from the east or northeast. Like transect 66 and 67, FEMA's practice of following the elevation contour at the wave run-up elevation also causes the zone to extend too far landward in many places. Furthermore, the zone that is mapped based on this transect is very large and includes many areas where shoreline and wave exposure are substantially different from the conditions at the transect location. Consideration of more appropriate incident wave conditions and additional transects in this area would improve the accuracy of the mapping and likely reduce the landward extent of the SFHA and/or BFE in much of this area.

Figure 16. VE 22 Flood zone mapped based on Transect 68. Pushpins indicate buildings and roadways that are visible in the flood zone based on Google Earth imagery.

SUMMARY AND RECOMMENDATIONS

FEMA's Flood mapping for the Town of Vinalhaven is coarse and based upon overly-simplified methodologies when compared to contemporary flood studies that FEMA has undertaken for other regions. The study's large transect spacing means that the flood hazard information assigned to most of the Town's shoreline is based upon analyses that are not representative of the local topography or exposure to coastal storm conditions.

There are systematic errors that over-estimate the wave setup affecting the BFE for nearly half of the coastal analysis transects in the Town (Transects 60 thru 63). Correction of the wave setup errors may reduce the BFE by one or two feet in more sheltered areas of the Town.

The modeling used to determine incident wave conditions for the transect analysis is poorly documented and possibly flawed. More detailed storm surge and wave modeling, to revise incident condition, would likely show the BFE has been under-estimated in some places, and over-estimated in others. Because of the coarse mapping and use of fetch-limited wave approximations with under-representative fetch lengths, the incident wave conditions may be under-estimated for portions of the Town that have west to southwest facing shorelines with open exposure to West Penobscot Bay. For portions of the Town with south to southeast facing shorelines with open exposure to the Gulf of Maine and for the east to northeast facing shorelines it is unclear how the locations were selected to extract output from the STWAVE model. More careful selection of incident wave condition would likely result in smaller wave heights and reduced BFE for more sheltered locations.

FEMA's practice of delineating the landward extent of the SHFA by following the topographic contour corresponding to the wave runup elevation for large distances away from the transect location results in overly conservative mapping in many areas. This puts many structures and properties within the SFHA where a more localized analysis of the flood hazard would likely show the flood hazard is minimal. Our review shows this is the predominant issue with the mapping along the south and eastern shorelines of the Town. This issue could be remedied by improving the offshore wave modeling, evaluating additional wave transects to better refine the wave runup results, and more carefully following FEMA's guidelines for mapping the landward extent of the flood zone.

FEMA provides the Letter of Map Revision (LOMR) process to allow communities to request revisions to the FIRM based on submission of improved flood hazard analysis data and proposed mapping for the community. A request for a LOMR can be made by an individual for a single property within the town, or requests can be made more broadly by the community for specific neighborhoods, or even for the entire town. To prepare a LOMR request, the supporting data, models, and proposed mapping must be developed by a qualified professional (i.e. survey data requires certification from a licensed surveyor, and calculations must be certified by a licensed engineer). This information is then provided to the community for review by the Town's official responsible for floodplain management for acknowledgment of the request. In cases where the revision would increase the BFE or SFHA the community is also required to publish notice of the requested revision in a local newspaper. Once those steps have been taken the application form and supporting documentation can be submitted to FEMA for review. FEMA will review the submission and typically make one or more request for additional data that require responses from the requestor before the revision is accepted. FEMA is allowed 90-days to review the submission after it is received, and additional 90-day review periods following any additional data requests. After FEMA makes a determination to accept the revision, FEMA will publish notice in the federal register and local newspaper to explain their intention to revise the effective flood hazard information and to initiate a 90-day appeal period during which anybody with interest in the revision may appeal if they oppose the revision. Once the appeal period passes and any appeals are resolved, the mapping determination becomes final and the proposed revision becomes the effective data for the Town. Overall, this process typically takes from nine months to one year from the time the application is submitted until the map revision becomes effective, but can take longer for larger and more complex revisions that require multiple additional data requests, or if the revision is appealed.

Table 1 provides a summary of our recommendation for correcting or re-evaluating each transect and where we suggest additional transects could be added to better refine the analysis. For Transects 60 thru 63, we recommend that the analysis be corrected for the additional wave setup calculation error described above. After the wave setup was corrected the WHAFIS model and mapping would have to be updated as well.

For the remaining transects and to support mapping of additional transects, we recommend performing improved and better documented offshore wave modeling, and then fully evaluating the transect calculations based on the improved wave inputs. Depending on the overall scope of a revision (e.g. town-wide vs. specific property) we recommend considering different approaches to the wave modeling. For example, for a town-wide revision it would be reasonable to consider using the wave model data from the Town's 2017 Resiliency planning study, which would require additional effort to update and document the analysis to meet FEMA's requirements for a revision. Whereas for a single property revision request it might be more practical to use simpler localized methods instead.

Due to the complex nature of the coastal flood hazard analysis, and without having a full understanding of the geographic scope of a proposed revision it is difficult to estimate the cost that would be required to get the FIRM revised. However, we can provide ballpark cost estimates based on our prior experiences with LOMR requests. Typical cost for a LOMR for a single transect/property, including modeling, preparation of the documentation, and follow-up correspondence to address FEMA's additional data requests is in the range of $10,000 to $20,000. In comparison, the typical cost to prepare a town-wide LOMR request and address follow-up correspondence with FEMA is in the $75,000 to $100,000 range.

Table 1. Summary of the transect-by-transect recommendations for revised and/or additional analysis of the flood zones in Vinalhaven.

Transect Number	Re-Evaluate Transect	Suggested Additional Transects
60	Correct wave setup	Possibly in select areas west of Calderwoodneck
61	Correct wave setup	One south of Browns Head
62	Correct wave setup	One between Gundell Is. and Dyer Is. where most buildings impacted and extending across The Basin
63	Correct wave setup	One near Reach Road extending across Old Harbor Pond
64	Revise Offshore Wave Model	One near ferry terminal, one near Bettys Way.
65	Revise Offshore Wave Model	One or two in Carvers Harbor, one in Carvers Pond
66	Revise Offshore Wave Model	None
67	Revise Offshore Wave Model	One in Carvers Cove, one in Clam Cove
68	Revise Offshore Wave Model	One near Arey Cove, one near Smith Harbor, one in Salt Works Cove, one in Carver Cove

Attachment A

Coastal Analysis Transcest Summary Data for the Town of Vinalhaven
from Knox County FIS 23013CV000A Effective July 6,2016

Memo to the Town of Vinalhaven
Review of Flood Insurance Rate Mapping
June 22, 2020

Ransom Consulting, LLC.
Project 191.06064

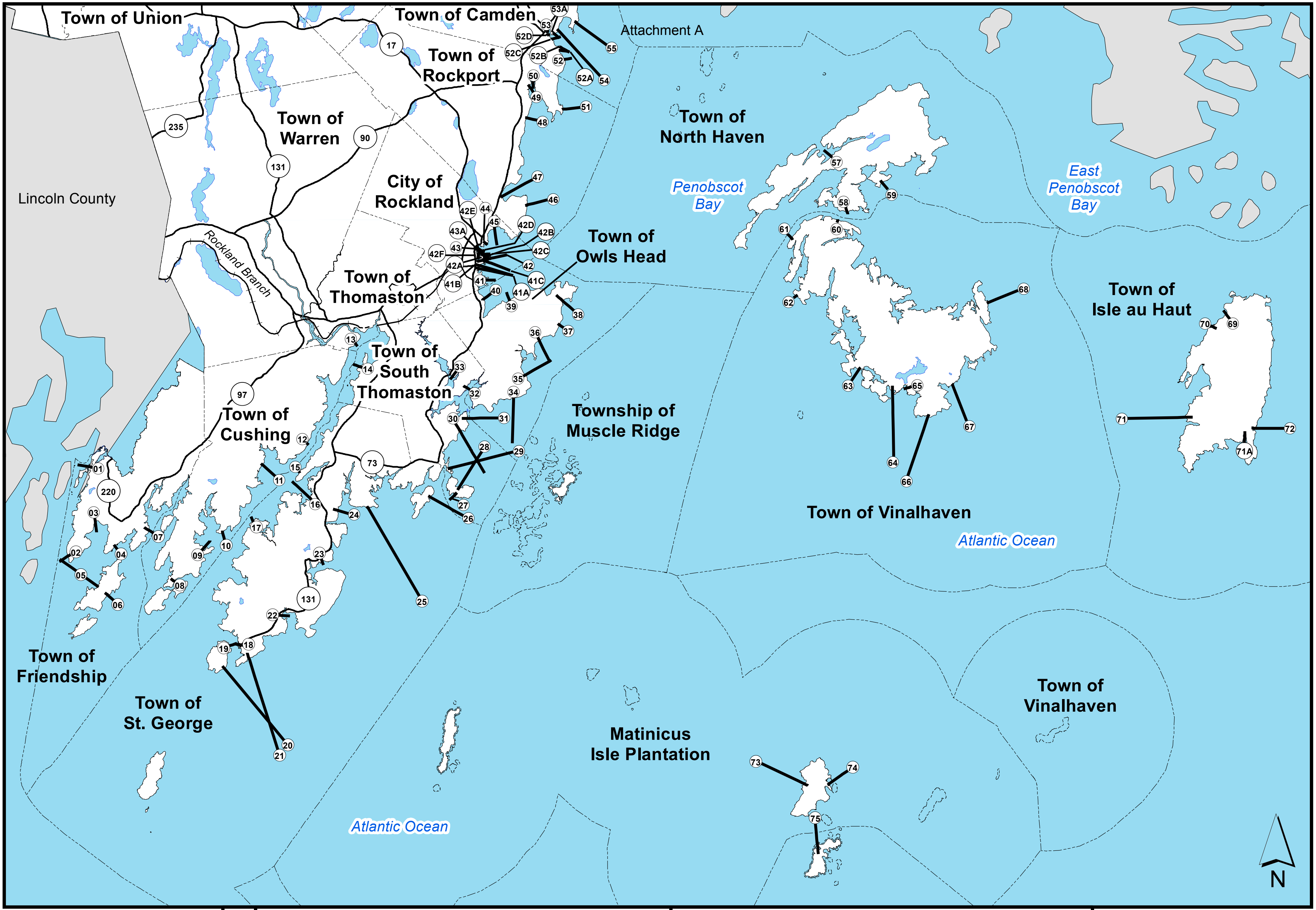


FIGURE 2

FEDERAL EMERGENCY MANAGEMENT AGENCY

KNOX COUNTY, ME

(ALL JURISDICTIONS)

APPROXIMATE SCALE

0 7,000 14,000 28,000 42,000 56,000 Feet

TRANSECT LOCATION MAP

Ransom Project 191.06064
nld 6-5-2020

Table 8 – Transect Data Location *(continued)*

	STILLWATER ELEVATION (FEET NAVD88[1])						
TRANSECT	10-PERCENT-ANNUAL-CHANCE	2-PERCENT-ANNUAL-CHANCE	1-PERCENT-ANNUAL-CHANCE	0.2-PERCENT-ANNUAL-CHANCE	TOTAL WATER LEVEL[2] 1-PERCENT-ANNUAL-CHANCE	ZONE	BASE FLOOD ELEVATION (FEET NAVD88[2,3])
46	*	*	9.0	*	10.8	VE	19
47	*	*	9.0	*	10.8	VE	14-16
48	*	*	9.0	*	11.1	VE	21
49	*	*	9.0	*	10.5	VE	12-14
50	*	*	9.0	*	11.3	VE	14
51	*	*	9.1	*	11.3	VE	16-17
52	*	*	9.1	*	11.1	VE	19
52A	*	*	9.2	*	11.5	VE	18
52B	*	*	9.2	*	12.1	VE	17
52C	*	*	9.2	*	12.0	VE	16
52D	*	*	9.2	*	10.9	AE	11-12
53	*	*	9.1	*	9.3	AE	10-11
53A	*	*	9.2	*	12.1	VE	16
54	*	*	9.1	*	11.4	VE	19
55	*	*	9.1	*	10.6	VE	17
56	*	*	9.2	*	10.7	VE	15
57	*	*	9.1	*	10.3	AE	12
58	*	*	9.0	*	10.8	AE	12
59	*	*	9.0	*	11.0	VE	14
60	*	*	9.0	*	11.1	AE	12
61	*	*	8.9	*	10.9	VE	13
62	*	*	8.9	*	10.3	AE	12
63	*	*	8.8	*	10.0	AE	12
64	*	*	8.8	*	13.1	AE/VE	18/18-19
65	*	*	8.8	*	10.0	AE/VE	10/13
66	*	*	8.8	*	13.1	VE	19
67	*	*	8.8	*	13.1	VE	26
68	*	*	8.9	*	13.3	VE	22
69	*	*	8.8	*	10.1	AE	12
70	*	*	8.8	*	10.1	AE	11
71	*	*	8.8	*	14.2	VE	18-20
71A	*	*	8.7		11.8	VE	14-18
72	*	*	8.7	*	14.1	VE	17-21
73	*	*	8.7	*	11.7	AE/VE	20/20
74	*	*	8.7	*	12.2	VE	15-18
75	*	*	8.7	*	11.2	AE/VE	12/14-17

[1] North American Datum of 1988

[2] Including stillwater elevation and effects of wave setup

[3] Due to map scale limitations, BFEs shown on the FIRM may represent average elevation for the zone depicted

*Data not available

Table 9 provides a description of the transect locations, the 1-percent-annual-chance coastal stillwater elevations, and the maximum 1-percent-annual-chance wave crest elevations.

Table 9 - Transect Descriptions *(continued)*

		Elevation (FEET NAVD88)[1]	
Transects	**Location**	**Stillwater 1-percent-annual-chance**	**Maximum Wave Crest 1-percent-annual-chance[2]**
53A	At the shoreline of the Atlantic Ocean, in the Town of Camden, extending 1,480 feet southeast from Sea Street	9.2	16
54	At the shoreline of the Atlantic Ocean, in the Town of Camden, extending approximately 10,666 feet southeast from Eaton Avenue	9.1	19
55	At the shoreline of the Atlantic Ocean, in the Town of Camden, extending approximately 6,809 feet southeast near Shermans Point Road	9.1	17
56	At the shoreline of the Atlantic Ocean, in the Town of Camden, extending approximately 1,513 feet southeast near Connemara Lane	9.2	15
57	At the shoreline of the Atlantic Ocean, in the Town of North Haven, extending approximately 1,896 feet northwest near Crabtree Point Road and Pulpit Harbor Road, in North Haven Island	9.1	12
58	At the shoreline of the Atlantic Ocean, in the Town of North Haven, extending approximately 1,313 feet southeast south near Church Street, in North Haven Island	9.0	12
59	At the shoreline of the Atlantic Ocean, in the Town of North Haven, extending approximately 1,995 feet southeast near Turner Farm Road, in North Haven Island	9.0	14
60	At the shoreline of the Atlantic Ocean, in the Town of Vinalhaven, extending approximately 629 feet northeast near Haven Road, in Red Lion Island	9.0	12

[1] North American Vertical Datum of 1988

[2] Because of map scale limitations, maximum wave elevations may not be shown on the FIRM

Table 9 - Transect Descriptions *(continued)*

		Elevation (FEET NAVD88)[1]	
Transects	**Location**	**Stillwater 1-percent-annual-chance**	**Maximum Wave Crest 1-percent-annual-chance[2]**
61	At the shoreline of the Atlantic Ocean, in the Town of Vinalhaven, extending approximately 1,292 feet northwest near Browns Head Light Road, in Red Lion Island	8.9	13
62	At the shoreline of the Atlantic Ocean, in the Town of Vinalhaven, extending approximately 909 feet southwest near Crockers River Road and Long Cove Road, in Red Lion Island	8.9	12
63	At the shoreline of the Atlantic Ocean, in the Town of Vinalhaven, extending approximately 2,680 feet southwest near Old Harbor Road and City Point Road, in Red Lion Island	8.8	12
64	At the shoreline of the Atlantic Ocean, in the Town of Vinalhaven, extending approximately 11,880 feet south near Skoog Park Road and Sands Road, in Red Lion Island	8.8	19
65	At the shoreline of the Atlantic Ocean, in the Town of Vinalhaven, extending approximately 1,352 feet southwest from the Medical Center Loop, in Red Lion Island	8.8	13
66	At the shoreline of the Atlantic Ocean, in the Town of Vinalhaven, extending approximately 10,929 feet southwest from Cranberry Shores Road and Balance Rock Road, in Red Lion Island	8.8	19
67	At the shoreline of the Atlantic Ocean, in the Town of Vinalhaven, extending approximately 6,678 feet from Narrow Island Road, in Red Lion Island	8.8	26

[1] North American Vertical Datum of 1988
[2] Because of map scale limitations, maximum wave elevations may not be shown on the FIRM

Table 9 - Transect Descriptions *(continued)*

		Elevation (FEET NAVD88)[1]	
Transects	**Location**	**Stillwater 1-percent-annual-chance**	**Maximum Wave Crest 1-percent-annual-chance[2]**
68	At the shoreline of the Atlantic Ocean, in the Town of Vinalhaven, extending approximately 5,696 feet from the northeast corner of Red Lion Island	8.9	22
69	At the shoreline of the Atlantic Ocean, in the Town of Isle au Haut, extending approximately 1,830 feet from Town Hill Road, in the Town of Isle au Haut	8.8	12
70	At the shoreline of the Atlantic Ocean, in the Town of Isle au Haut, extending approximately 1,160 feet from the northwest corner of Isle au Haut	8.8	11
71	At the shoreline of the Atlantic Ocean, in the Town of Isle au Haut, extending approximately 10,874 feet from the southwest corner of Isle au Haut	8.8	20
71A	At the shoreline of the Atlantic Ocean, in the Town of Isle au Haut, extending approximately 2,053 feet south from Island Main Loop Road and Eastern Head Road	8.7	14
72	At the shoreline of the Atlantic Ocean, in the Town of Isle au Haut, extending approximately 5,461 feet from the southeast corner of Isle au Haut	8.7	21
73	At the shoreline of the Atlantic Ocean, in the Matinicus Isle Plantation, extending approximately 8,711 feet from the west side of Matinicus Island	8.7	20
74	At the shoreline of the Atlantic Ocean, in the Matinicus Isle Plantation, extending approximately 4,134 feet from the east side of Matinicus Island	8.7	18

[1] North American Vertical Datum of 1988

[2] Because of map scale limitations, maximum wave elevations may not be shown on the FIRM

Attachment B

Backup Coastal engineering from 12-01-1051S.zip from FEMA Engineering Library
MathCAD wave setup and wave runup
ACES Fetch limited wave
WHAFIS profiles

Memo to the Town of Vinalhaven Review
of Flood Insurance Rate Mapping June
22, 2020

Ransom Consulting, LLC
Project 191.06064

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 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

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

Modeler Name: M. Yarbrough
Date: April 10, 2013
County: Knox, ME
Transect Number: 60
Airport: unknown
Years of Dataset: unknown
Associated Files: E:\Region I\Setup\Knox County\Profiles\60.csv

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

$FailTop_{Sta}$ - 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

$$U_{10} := 124.67 \frac{m}{s}$$

Wave speed based on:
Airport:
Taken from file:________________

$$U_{10} = 409.02 \cdot \frac{ft}{s}$$

This wind speed is preposterous, but doesn't get used in the calculations - nld 6/5/2020

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

Insert X, fetch in miles:

$$X := 12.84 \cdot mi \qquad X = 20663.98 \cdot m$$

Feature Class used:______________________
____

Calculate Coefficient of Drag, C_D:

$$C_D := 0.001 \cdot \left[1.1 + \left(0.035 \cdot U_{10} \cdot \frac{s}{m}\right)\right] \qquad C_D = 0.0055$$

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

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

Given

$$C_D = \frac{u_s^{\,2}}{U_{10}^{\,2}} \qquad u_s := \text{Find}(u_s) \qquad u_s = 9.22 \cdot \frac{m}{s}$$

Wave Height and Wave Period Calculation Worksheet

CHK By/Date: M. Yarbrough 10/31/2012
RVW By/Date: M. Salisbury 01/21/2013

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

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

$X = 20663.98 \cdot m$

Given

$u_s = 9.22 \cdot \frac{m}{s}$ $g = 9.81 \frac{1}{s} \cdot \frac{m}{s}$

$$\frac{g \cdot H_{m0}}{u_s^2} = 0.0413 \cdot \left(\frac{g \cdot X}{u_s^2} \right)^{0.5}$$

$H_{m0} := \text{Find}(H_{m0})$ $H_{m0} = 0 \cdot m$

$H_{m0} = 0 \, ft$

Calculate Wave Period, T_P (sec):

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

Given

$X = 20663.98 \cdot m$ $u_s = 9.22 \cdot \frac{m}{s}$ $g = 9.81 \frac{1}{s} \cdot \frac{m}{s}$

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

$T_P := \text{Find}(T_P)$ $T_P = 9.43 \cdot s$

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.

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

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

Feature Class:

Aces Output:

$H_{m0ACES} := 1.02 \cdot ft$ $T_{PACES} := 1.76 \cdot sec$

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

ACES result file:

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

$H_{m0STWAVE} := -9999 \cdot m$ $T_{PSTWAVE} := -9999 \cdot sec$

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

5.2 Wave Setup, η, Calculation

5.2.1 Open Coast Wave Setup Analysis

Definition of Variables:

$m := 0.526192$ Insert value of average transect slope based on GIS data

It is not clear how this slope value was determined.
This slope is not representative of the average transect slope. See figure 3 pages down. -nld 6/5/2020

Calculate Deep Water Wave Length, L_0:

$L_0 := \frac{g \cdot T_P^{2}}{2 \cdot \pi}$ $L_0 = 15.86\,ft$ Equation source: Coastal Engineering Manual Part VI Page VI-5-236

Calculate Wave Slope, S:

$S := \frac{H_{m0}}{L_0}$ $S = 0.0643$ $S = 6.43 \cdot \%$

Calculate Static Open Coast Wave Setup:

$\eta_{open} := H_{m0} \cdot 0.160 \cdot \frac{\cancel{m}^{0.2}}{S^{0.2}}$ $\eta_{open} = \cancel{0.25}\,ft$

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

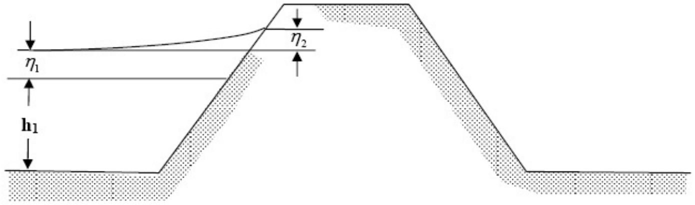


Figure D.2.6-6. Definition Sketch for Nonovertopped Levee

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("E:\Region I\Setup\Knox County\Profiles\60.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:

Profile =

	0	1
0	0	-19.91
1	3.28	-19.63
2	6.55	-19.35
3	9.83	-19.07
4	13.1	-18.78
5	16.38	-18.5
6	19.65	-18.22
7	22.93	...

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

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

Array of horizontal distance from the shoreline

Station =

	0
0	0
1	3.28
2	6.55
3	...

ft

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

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

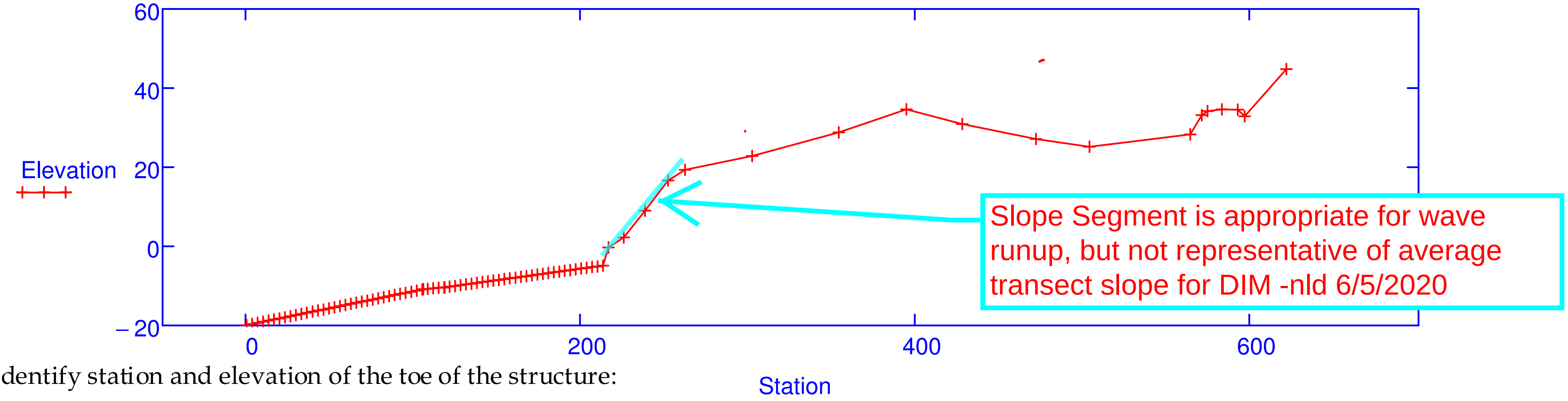
Array of Elevations associated with each horizontal distance from the shoreline:

Elevation =

	0
0	-19.91
1	-19.63
2	-19.35
3	...

ft

The following displays the profile of the transect:



Slope Segment is appropriate for wave runup, but not representative of average transect slope for DIM -nld 6/5/2020

Identify station and elevation of the toe of the structure:

$Toe_{sta} := 212.91 \cdot ft$ Input value representing coastal structure's bottom station (Toe_{sta})

$Toe_{ele} := linterp(Station, Elevation, Toe_{sta})$ $Toe_{ele} = -4.86\,ft$

Identify station and elevation of the top of the structure:

$Top_{sta} := 251.6 \cdot ft$ Input value representing coastal structure's top station (Top_{sta})

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

Enter 1% annual chance stillwater elevation (ft): $Top_{ele} = 16.67\,ft$

$SWEL := 8.97 \cdot ft$ Associated excel file for calculation of 1% annual chance stillwater elevation (SWEL): __________

Calculate Water Depth at Structure, h

$h := SWEL - Toe_{ele}$ $h = 13.83\,ft$

Calculate the Breaking Wave Height, H_b:

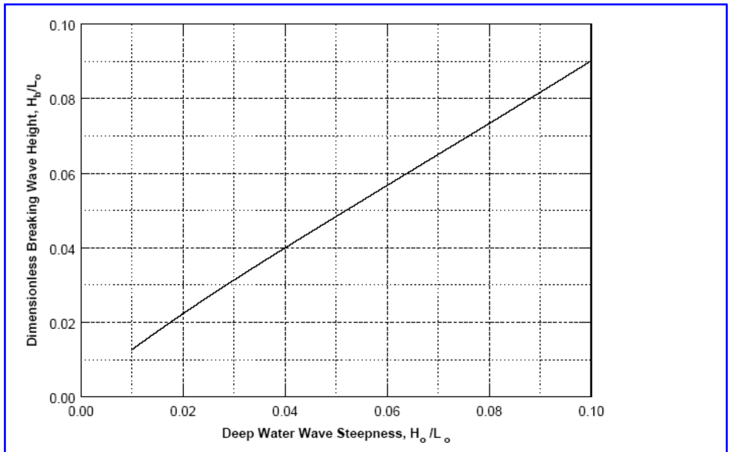


Figure D.2.6-7. Dimensionless Breaking Wave Height vs. Deepwater Wave Steepness

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

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

$H_b := b_h \cdot L_0$ $\quad H_b = 0.96\,\text{ft}$

Calculate the Breaking Wave Depth, H_d:

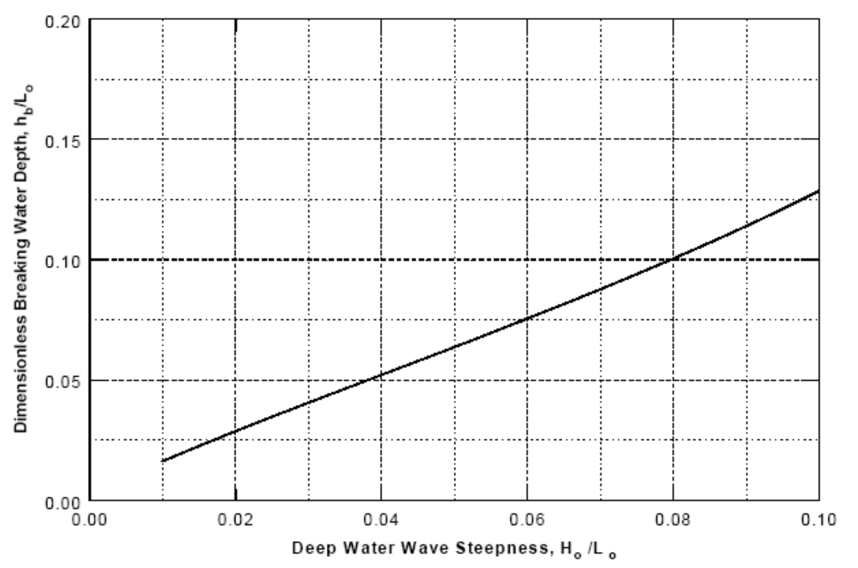


Figure D.2.6-8. Dimensionless Breaking Water Depth vs. Deepwater Wave Steepness.

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

$H_d := b_d \cdot L_0$ $H_d = 1.3\ \text{ft}$

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

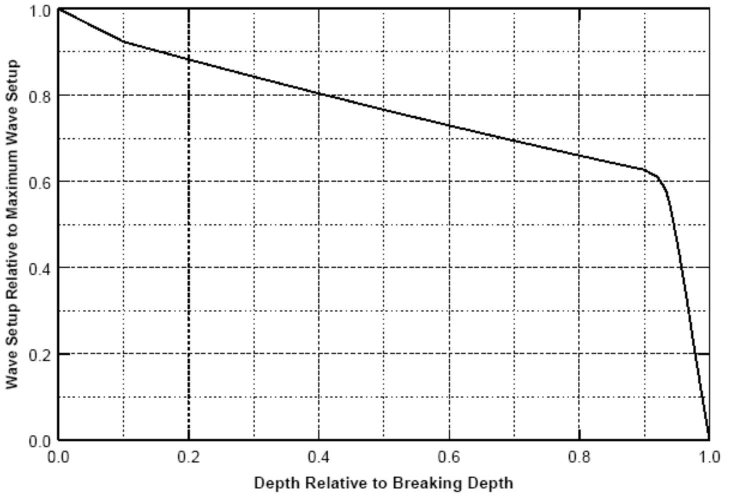


Figure D.2.6-9. Proportion of Maximum Wave Setup that Has Occurred vs. a Proportion of the Breaking Depth.

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

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

A zero value for R indicates that incipient wave breaking is landward of the toe of the slope. which means this calculation is invalid because R is outside the range of data in Figure D.2.6-9. Continuing the calculation in this case makes the setup equal to fifteen percent of the depth at the toe of the slope (Toe_elev), regardless of the incident wave conditions.
A proposed correction given in City of Rockland, ME 2014 appeal replaces h with Hd in this case, so that the setup becomes equal to fifteen percent of the breaking wave depth, rather than fifteen percent of the depth at the toe.
-nld 6/5/2020

$R = 0$ $\qquad \frac{h}{H_d} = 10.66$

$\eta_1 := R\cdot\eta_{open}$ $\qquad \eta_1 = 0\,ft$ $\qquad \eta_2 := 0.15\cdot(h+\eta_1)$ $\qquad \eta_2 = 2.08\,ft$

This can lead to a large over-estimation of the wave setup.

In this case, resulting in setup that is more than double the wave height, which obviously is incorrect.
-nld 6/5/2020

$\eta_{Structure} := \eta_1 + \eta_2$ $\qquad \eta_{Structure} = \cancel{2.08\,ft}$ Total Setup against a coastal structure without considering overtopping

Correction yields
n = 0.15*Hd = 0.15*1.3 = 0.195 feet

Check Overtopping if Coastal Structure Exists:

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

$$\text{Overtopped} = \text{"No"}$$

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

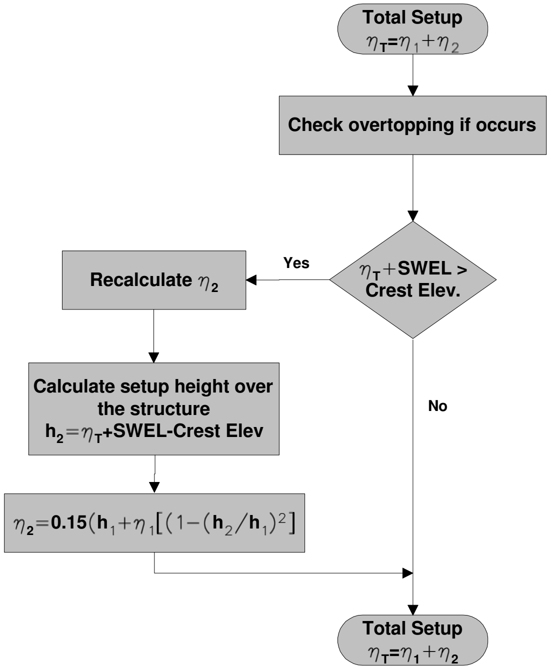
Equation D.2.6-12 for η_2 from Atlantic Ocean and Gulf of Mexico Coastal Guidelines Update

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

$$\eta_{Structure} := \eta_1 + \eta_2$$

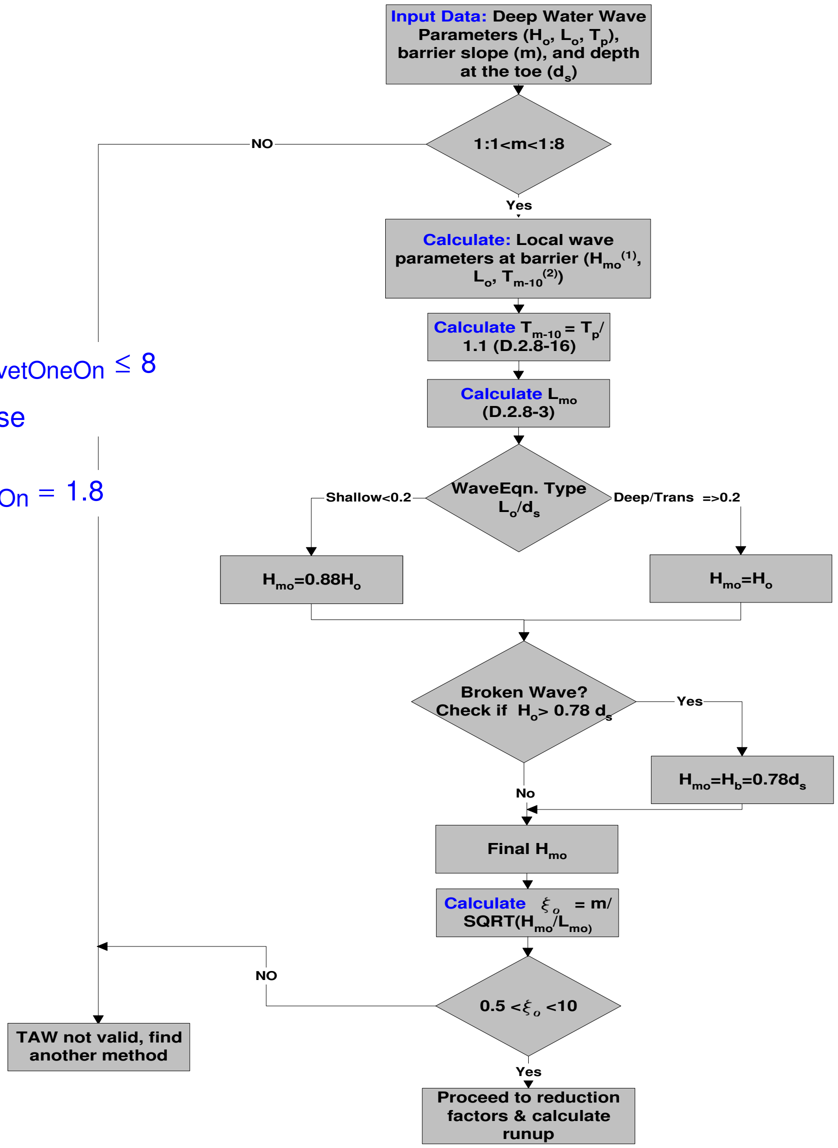
~~$\eta_{Structure} = 2.08\,ft$~~

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:

$$\text{Slope}_{\text{Revet}} := \frac{(\text{Top}_{\text{ele}} - \text{Toe}_{\text{ele}})}{(\text{Top}_{\text{sta}} - \text{Toe}_{\text{sta}})} \qquad \text{Slope}_{\text{Revet}} = 55.65 \cdot \%$$

$$\text{Slope}_{\text{RevetOneOn}} := \frac{1}{\text{Slope}_{\text{Revet}}}$$

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

$$\text{Slope}_{\text{Check}} = \text{"TAW Method of Runup Calculation Applies"} \qquad \text{Slope}_{\text{RevetOneOn}} = 1.8$$

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

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

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

$$\text{Depth}_{\text{Limited}} = \text{"Not Limited"}$$

Determine Wave Type:

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

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

Determine Significant Wave Height Depending on Wave Type and DepthLimited Condition:

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

$H_{m0runup1} = 1.02\,ft$

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

$H_{m0runup} = 1.02\,ft$

Calculate the Spectral Wave Period, T_{m10}

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

$T_{m10} = 1.6\,s$

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

$L_{m0} = 13.11\,ft$

Calculate the Iribarren Number, ξ_{0m}:

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

$\xi_{om} = 2$

Check TAW Method for Validity based on Iribarren Number:

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

$Iribarren_{Check} =$ "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

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

$\gamma_r = 0.58$

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

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

$\gamma_p = 1$

Summary of Reduction Factors:

$\gamma_p = 1$

$\gamma_\beta = 1$

$\gamma_b = 1$

$\gamma_r = 0.58$

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

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

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

$R_{2\%} = 1.87\,\text{ft}$

Check for Overtopping:

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

$\text{OVERTOPPED}_{\text{Runup}}$ = "NO Overtopping"

6.0 Conclusions/Results

Wave Height, H_{m0} H_{m0} = 1.02 ft FetchStatus = "Restricted Fetch Input from ACES (Hmo, Tp)"

Wave Period, T_P T_P = 1.76 s FetchStatus = "Restricted Fetch Input from ACES (Hmo, Tp)"

Wave Setup on an open coast, η_{open} η_{open} = ~~0.25 ft~~

Wave Setup on a revetment, $\eta_{Structure}$ $\eta_{Structure}$ = ~~2.08 ft~~

Wave Runup on a revetment, $R_{2\%}$ $R_{2\%}$ = 1.87 ft

$\text{OVERTOPPED}_{\text{Runup}}$ = "NO Overtopping"

NOTES:

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 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

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

Modeler Name: M. Yarbrough
Date: April 10, 2013
County: Knox, ME
Transect Number: 61
Airport: unknown
Years of Dataset: unknown
Associated Files: E:\Region I\Setup\Knox County\Profiles\61.csv

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

$FailTop_{Sta}$ - 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

$U_{10} := 124.67 \frac{m}{s}$

Wave speed based on:
Airport:
Taken from file:________________

$U_{10} = 409.02 \cdot \frac{ft}{s}$

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

Insert X, fetch in miles:

$X := 12.84 \cdot mi$

$X = 20663.98 \cdot m$

Feature Class used:_____________________
____

Calculate Coefficient of Drag, C_D:

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

$C_D = 0.0055$

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

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

Given

$C_D = \frac{u_s^{\,2}}{U_{10}^{\,2}}$

$u_s := \text{Find}(u_s)$

$u_s = 9.22 \cdot \frac{m}{s}$

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

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

$X = 20663.98 \cdot m$

Given

$u_s = 9.22 \cdot \frac{m}{s}$ $g = 9.81 \frac{1}{s} \cdot \frac{m}{s}$

$$\frac{g \cdot H_{m0}}{u_s^2} = 0.0413 \cdot \left(\frac{g \cdot X}{u_s^2}\right)^{0.5}$$

$H_{m0} := \mathrm{Find}(H_{m0})$ $H_{m0} = 0 \cdot m$ $H_{m0} = 0\,ft$

Calculate Wave Period, T_P (sec):

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

Given

$X = 20663.98 \cdot m$ $u_s = 9.22 \cdot \frac{m}{s}$ $g = 9.81 \frac{1}{s} \cdot \frac{m}{s}$

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

$T_P := \mathrm{Find}(T_P)$ $T_P = 9.43 \cdot s$

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.

$$\mathrm{ACESInput}_{Ang} := \begin{pmatrix} \blacksquare \\ \blacksquare \\ \blacksquare \\ \blacksquare \\ \blacksquare \\ \blacksquare \\ \blacksquare \\ \blacksquare \\ \blacksquare \end{pmatrix} \qquad \mathrm{ACESInput}_{Fetch} := \begin{pmatrix} \blacksquare \\ \blacksquare \\ \blacksquare \\ \blacksquare \\ \blacksquare \\ \blacksquare \\ \blacksquare \\ \blacksquare \\ \blacksquare \end{pmatrix}$$

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

Feature Class:

Aces Output:

$H_{m0ACES} := 2 \cdot ft$ $\qquad T_{PACES} := 2.56 \cdot sec$

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

ACES result file:

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

$H_{m0STWAVE} := -9999 \cdot m$ $\qquad T_{PSTWAVE} := -9999 \cdot sec$

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

5.2 Wave Setup, η, Calculation

5.2.1 Open Coast Wave Setup Analysis

Definition of Variables:

$m := 0.371473$ Insert value of average transect slope based on GIS data

Calculate Deep Water Wave Length, L_0:

$L_0 := \frac{g \cdot T_P^2}{2 \cdot \pi}$ $L_0 = 33.56\,\mathrm{ft}$ Equation source: Coastal Engineering Manual Part VI Page VI-5-236

Calculate Wave Slope, S:

$S := \frac{H_{m0}}{L_0}$ $S = 0.0596$ $S = 5.96 \cdot \%$

Calculate Static Open Coast Wave Setup:

$\eta_{open} := H_{m0} \cdot 0.160 \cdot \frac{m^{0.2}}{S^{0.2}}$ $\eta_{open} = 0.46\,\mathrm{ft}$

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

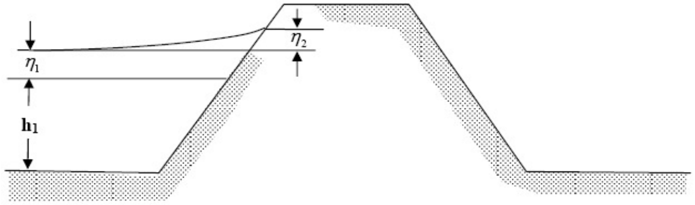


Figure D.2.6-6. Definition Sketch for Nonovertopped Levee

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("E:\Region I\Setup\Knox County\Profiles\61.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:

Profile =

	0	1
0	0	-44.86
1	3.28	-44.89
2	6.56	-44.93
3	9.84	-44.96
4	13.12	-44.99
5	16.4	-45.03
6	19.68	-45.06
7	22.96	...

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

$\text{Station} := \text{Station} \cdot 1 \cdot \text{ft}$

Array of horizontal distance from the shoreline

Station =

	0
0	0
1	3.28
2	6.56
3	...

ft

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

$\text{Elevation} := \text{Elevation} \cdot 1 \cdot \text{ft}$

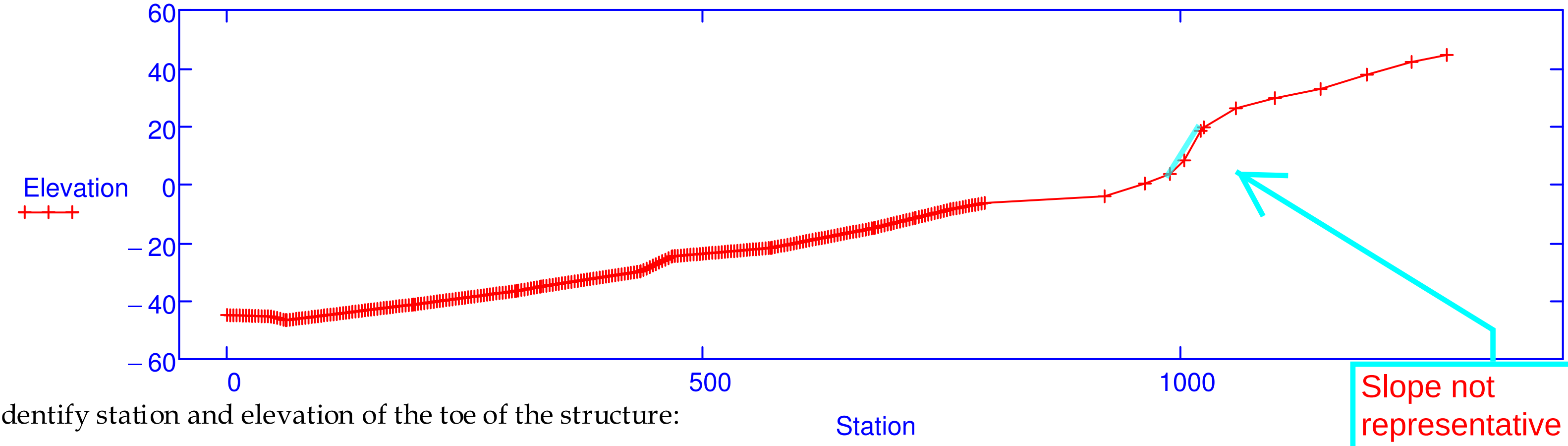
Array of Elevations associated with each horizontal distance from the shoreline:

Elevation =

	0
0	-44.86
1	-44.89
2	-44.93
3	...

ft

The following displays the profile of the transect:



Slope not representative of average transect slope for DIM -nld 6/5/2020

Identify station and elevation of the toe of the structure:

$Toe_{sta} := 919.59 \cdot ft$ Input value representing coastal structure's bottom station (Toe_{sta})

$Toe_{ele} := \text{linterp}(Station, Elevation, Toe_{sta})$ $Toe_{ele} = -4.03\,ft$

Identify station and elevation of the top of the structure:

$Top_{sta} := 1020.12 \cdot ft$ Input value representing coastal structure's top station (Top_{sta})

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

Enter 1% annual chance stillwater elevation (ft): $Top_{ele} = 18.44\,ft$

$SWEL := 8.91 \cdot ft$ Associated excel file for calculation of 1% annual chance stillwater elevation (SWEL): __________

Calculate Water Depth at Structure, h

$h := SWEL - Toe_{ele}$ $h = 12.94\,ft$

Calculate the Breaking Wave Height, H_b:

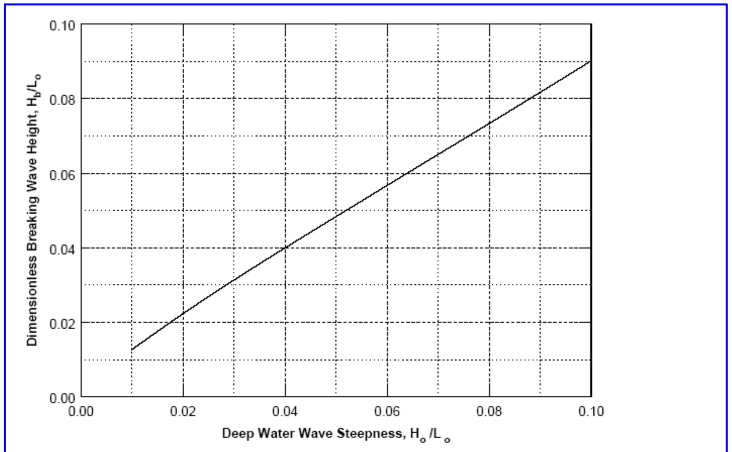


Figure D.2.6-7. Dimensionless Breaking Wave Height vs. Deepwater Wave Steepness

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

$H_b := b_h \cdot L_0$ $H_b = 1.89\,\text{ft}$

Calculate the Breaking Wave Depth, H_d:

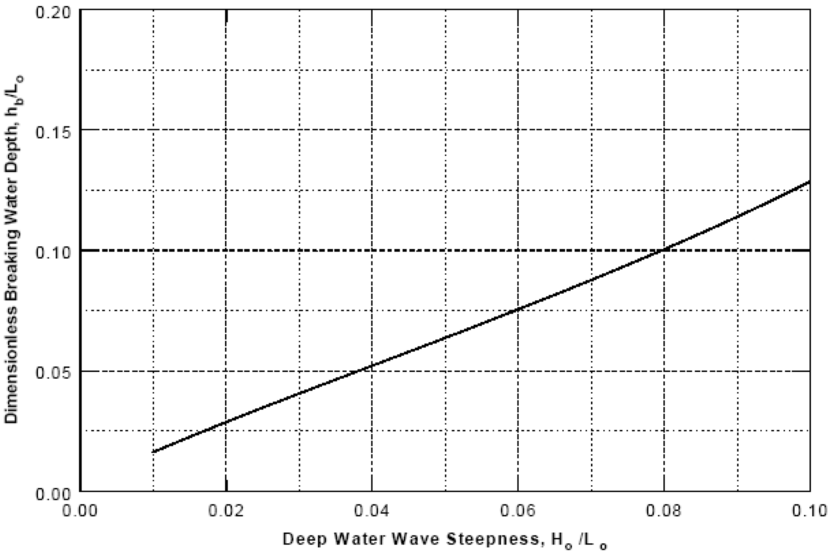


Figure D.2.6-8. Dimensionless Breaking Water Depth vs. Deepwater Wave Steepness.

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

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

$H_d := b_d \cdot L_0$ $\quad H_d = 2.55\,\mathrm{ft}$

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

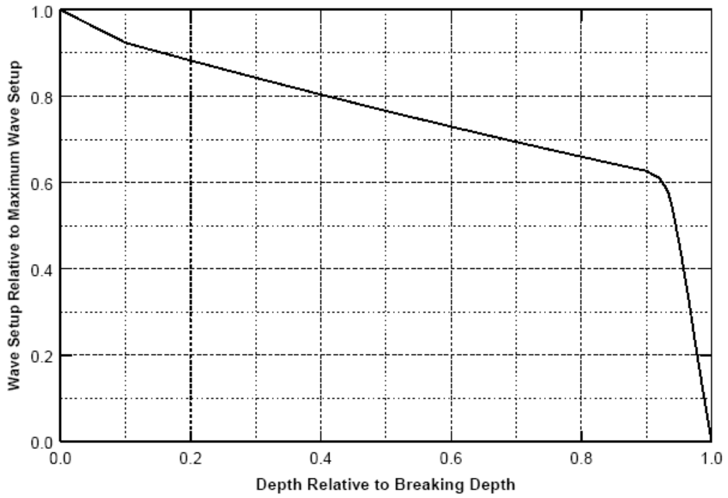


Figure D.2.6-9. Proportion of Maximum Wave Setup that Has Occurred vs. a Proportion of the Breaking Depth.

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

See programming error described for transect 60

$R = 0$ $\quad \frac{h}{H_d} = 5.07$

$\eta_1 := R\cdot\eta_{open}$ $\quad \eta_1 = 0\,ft$ $\quad \eta_2 := 0.15\cdot(h+\eta_1)$ $\quad \eta_2 = 1.94\,ft$

$\eta_{Structure} := \eta_1 + \eta_2$ $\quad \eta_{Structure} =$ ~~1.94 ft~~ Total Setup against a coastal structure without considering overtopping

Corrected
Nstructure = 0.15 * Hd
= 0.15 *2.55 = 0.3825 ft
-nld 6/5/2020

Check Overtopping if Coastal Structure Exists:

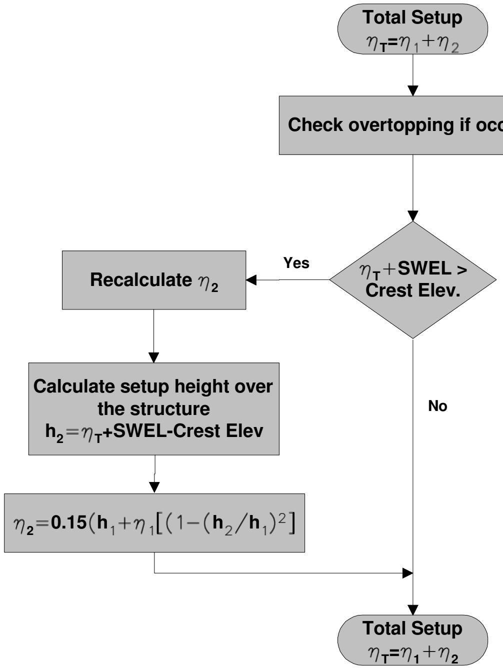
$$Overtopped := \begin{cases} \text{"Yes"} & \text{if } (\eta_{Structure} + SWEL) > Top_{ele} \\ \text{"No"} & \text{otherwise} \end{cases} \qquad Overtopped = \text{"No"}$$

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

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

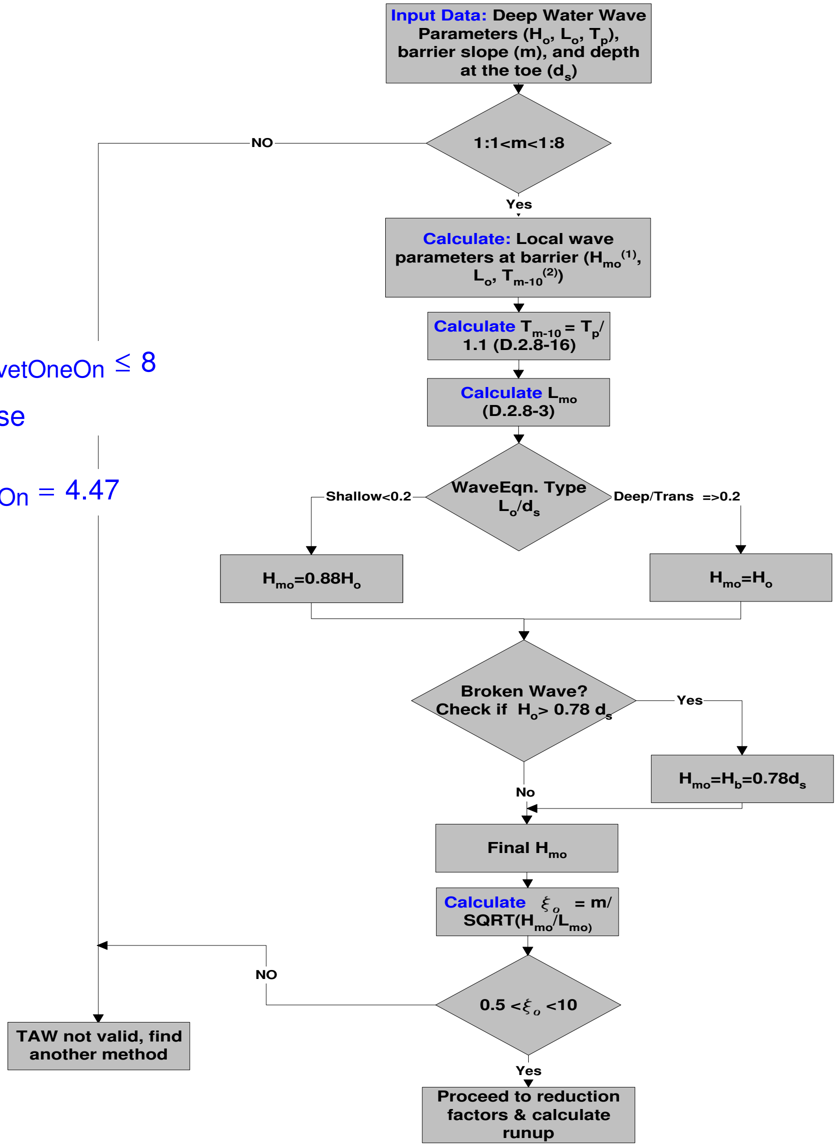
$$\eta_2 := \begin{cases} 0.15 \cdot (h + \eta_1) \cdot \left[1 - \left(\frac{h_2}{h}\right)^2\right] & \text{if } Overtopped = \text{"Yes"} \\ \eta_2 & \text{otherwise} \end{cases}$$

$\eta_{Structure} := \eta_1 + \eta_2$ ~~$\eta_{Structure} = 1.94\,ft$~~ 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:

$$\text{Slope}_{\text{Revet}} := \frac{(\text{Top}_{\text{ele}} - \text{Toe}_{\text{ele}})}{(\text{Top}_{\text{sta}} - \text{Toe}_{\text{sta}})} \qquad \text{Slope}_{\text{Revet}} = 22.35 \cdot \%$$

$$\text{Slope}_{\text{RevetOneOn}} := \frac{1}{\text{Slope}_{\text{Revet}}}$$

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

$$\text{Slope}_{\text{Check}} = \text{"TAW Method of Runup Calculation Applies"} \qquad \text{Slope}_{\text{RevetOneOn}} = 4.47$$

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

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

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

$$\text{Depth}_{\text{Limited}} = \text{"Not Limited"}$$

Determine Wave Type:

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

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

Determine Significant Wave Height Depending on Wave Type and DepthLimited Condition:

$$H_{m0runup1} := \begin{array}{|l} 0.88\cdot H_{m0} \ \ \text{if} \ \ WaveType = \text{"Shallow"} \\ H_{m0} \ \ \text{otherwise} \end{array}$$

$H_{m0runup1} = 2\,ft$

$$H_{m0runup} := \begin{array}{|l} 0.78\cdot h \ \ \text{if} \ \ Depth_{Limited} = \text{"Limited"} \\ H_{m0runup1} \ \ \text{otherwise} \end{array}$$

$H_{m0runup} = 2\,ft$

Calculate the Spectral Wave Period, T_{m10}

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

Equation D.2.8-16

$T_{m10} = 2.33\,s$

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

$L_{m0} = 27.73\,ft$

Calculate the Iribarren Number, ξ_{0m}:

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

$\xi_{om} = 0.83$

Check TAW Method for Validity based on Iribarren Number:

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

$Iribarren_{Check} =$ "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

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

$\gamma_r = 0.58$

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

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

$\gamma_p = 1$

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:

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

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

$R_{2\%} = 1.71 \text{ ft}$

Check for Overtopping:

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

$\mathrm{OVERTOPPED}_{\mathrm{Runup}} = \text{"NO Overtopping"}$

6.0 Conclusions/Results

Wave Height, H_{m0} $H_{m0} = 2\,\mathrm{ft}$ $\mathrm{FetchStatus} = \text{"Restricted Fetch Input from ACES (Hmo, Tp)"}$

Wave Period, T_P $T_P = 2.56\,\mathrm{s}$ $\mathrm{FetchStatus} = \text{"Restricted Fetch Input from ACES (Hmo, Tp)"}$

Wave Setup on an open coast, η_{open} $\eta_{open} = 0.\cancel{46}\,\mathrm{ft}$

Wave Setup on a revetment, $\eta_{Structure}$ $\eta_{Structure} = \cancel{1.94}\,\mathrm{ft}$

Wave Runup on a revetment, $R_{2\%}$ $R_{2\%} = 1.71\,\mathrm{ft}$

$\mathrm{OVERTOPPED}_{\mathrm{Runup}} = \text{"NO Overtopping"}$

NOTES:

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 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

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

Modeler Name: M. Yarbrough
Date: April 10, 2013
County: Knox, ME
Transect Number: 62
Airport: unknown
Years of Dataset: unknown
Associated Files: E:\Region I\Setup\Knox County\Profiles\62.csv

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

$FailTop_{Sta}$ - 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:

$U_{10} := 124.67 \frac{m}{s}$

$U_{10} = 409.02 \cdot \frac{ft}{s}$

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

Wave speed based on:
Airport:
Taken from file:________________

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

Insert X, fetch in miles:

$X := 12.84 \cdot mi$

$X = 20663.98 \cdot m$

Feature Class used:______________________
____

Calculate Coefficient of Drag, C_D:

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

$C_D = 0.0055$

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

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

Given

$$C_D = \frac{u_s^{\,2}}{U_{10}^{\,2}}$$

$u_s := \text{Find}(u_s)$

$u_s = 9.22 \cdot \frac{m}{s}$

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

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

$X = 20663.98 \cdot m$

Given

$u_s = 9.22 \cdot \frac{m}{s}$ $g = 9.81 \frac{1}{s} \cdot \frac{m}{s}$

$$\frac{g \cdot H_{m0}}{u_s^{\,2}} = 0.0413 \cdot \left(\frac{g \cdot X}{u_s^{\,2}}\right)^{0.5}$$

$H_{m0} := \mathrm{Find}(H_{m0})$ $H_{m0} = 0 \cdot m$

$H_{m0} = 0\,ft$

Calculate Wave Period, T_P (sec):

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

Given

$X = 20663.98 \cdot m$ $u_s = 9.22 \cdot \frac{m}{s}$ $g = 9.81 \frac{1}{s} \cdot \frac{m}{s}$

$$\frac{g \cdot T_P}{u_s} = 0.751 \cdot \left(\frac{g \cdot X}{u_s^{\,2}}\right)^{\frac{1}{3}}$$

$T_P := \mathrm{Find}(T_P)$ $T_P = 9.43 \cdot s$

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:

Aces Output:

$H_{m0ACES} := 1.31 \cdot ft$ $\qquad T_{PACES} := 2.02 \cdot sec$

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

ACES result file:

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

$H_{m0STWAVE} := -9999 \cdot m$ $\qquad T_{PSTWAVE} := -9999 \cdot sec$

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

5.2 Wave Setup, η, Calculation

5.2.1 Open Coast Wave Setup Analysis

Definition of Variables:

$m := 1.092$

Insert value of average transect slope based on GIS data

Not clear where this slope comes from. seems too steep for DIM -nld 6/5/2020

Calculate Deep Water Wave Length, L_0:

$L_0 := \frac{g\cdot T_P^{\,2}}{2\cdot\pi}$ $L_0 = 20.89\,ft$

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

Calculate Wave Slope, S:

$S := \frac{H_{m0}}{L_0}$ $S = 0.0627$ $S = 6.27\cdot\%$

Calculate Static Open Coast Wave Setup:

$\eta_{open} := H_{m0}\cdot 0.160\cdot\frac{\cancel{m}^{0.2}}{S^{0.2}}$ $\eta_{open} = \cancel{0.37\,ft}$

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

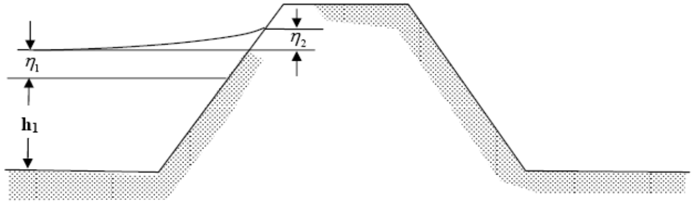


Figure D.2.6-6. Definition Sketch for Nonovertopped Levee

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("E:\Region I\Setup\Knox County\Profiles\62.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:

Profile =

	0	1
0	0	-69.32
1	3.28	-69.27
2	6.56	-69.22
3	9.84	-69.17
4	13.12	-69.12
5	16.4	-69.07
6	19.68	-69.02
7	22.96	...

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

$\text{Station} := \text{Station} \cdot 1 \cdot \text{ft}$

Array of horizontal distance from the shoreline

Station =

	0
0	0
1	3.28
2	6.56
3	...

ft

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

$\text{Elevation} := \text{Elevation} \cdot 1 \cdot \text{ft}$

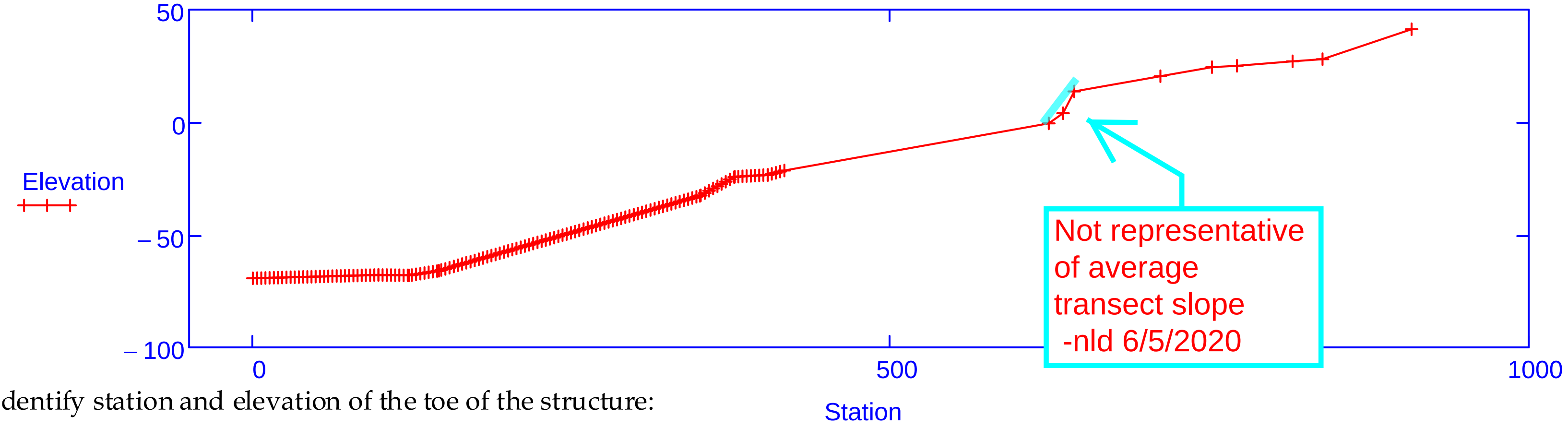
Array of Elevations associated with each horizontal distance from the shoreline:

Elevation =

	0
0	-69.32
1	-69.27
2	-69.22
3	...

ft

The following displays the profile of the transect:



Not representative
of average
transect slope
 -nld 6/5/2020

Identify station and elevation of the toe of the structure:

$Toe_{sta} := 623.86 \cdot ft$ Input value representing coastal structure's bottom station (Toe_{sta})

$Toe_{ele} := linterp(Station, Elevation, Toe_{sta})$ $Toe_{ele} = -0.49\,ft$

Identify station and elevation of the top of the structure:

$Top_{sta} := 643.83 \cdot ft$ Input value representing coastal structure's top station (Top_{sta})

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

Enter 1% annual chance stillwater elevation (ft): $Top_{ele} = 13.65\,ft$

$SWEL := 8.86 \cdot ft$ Associated excel file for calculation of 1% annual chance stillwater elevation (SWEL): __________

Calculate Water Depth at Structure, h

$h := SWEL - Toe_{ele}$ $h = 9.35\,ft$

Calculate the Breaking Wave Height, H_b:

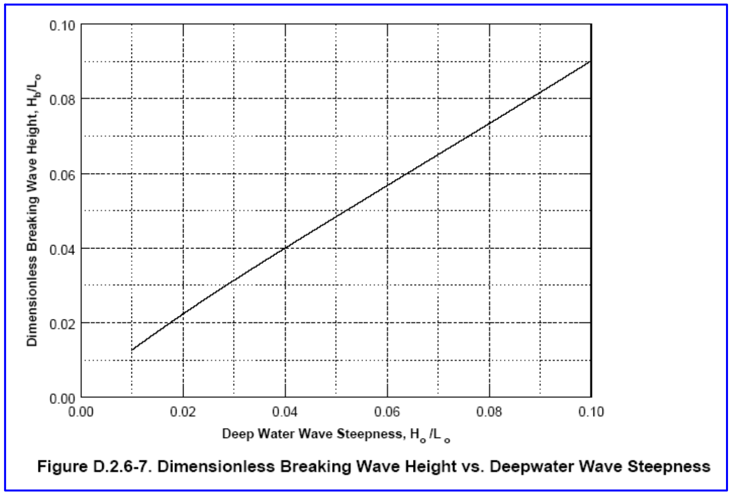


Figure D.2.6-7. Dimensionless Breaking Wave Height vs. Deepwater Wave Steepness

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

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

$H_b := b_h \cdot L_0$ $\quad H_b = 1.23\,\text{ft}$

Calculate the Breaking Wave Depth, H_d:

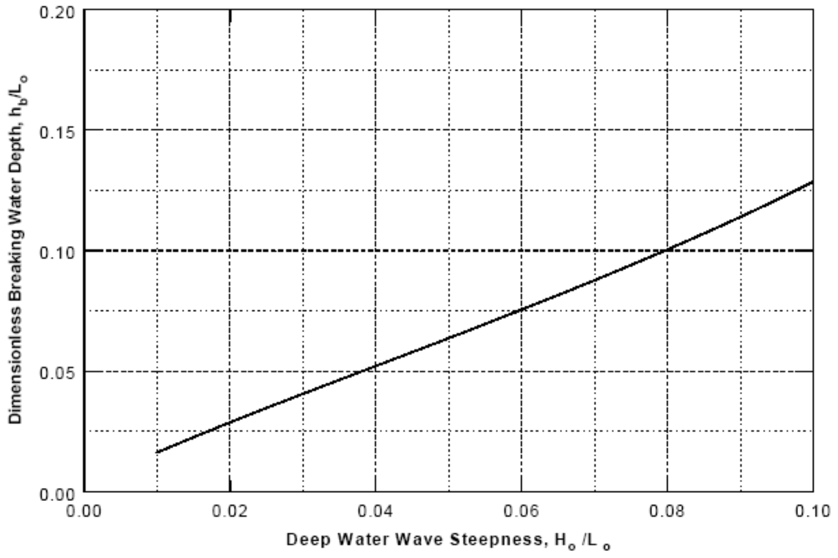


Figure D.2.6-8. Dimensionless Breaking Water Depth vs. Deepwater Wave Steepness.

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

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

$H_d := b_d \cdot L_0$ $\qquad H_d = 1.67\,\text{ft}$

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

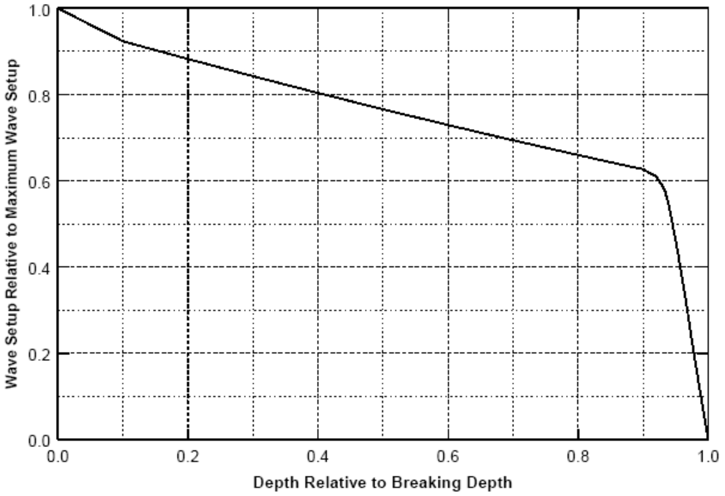


Figure D.2.6-9. Proportion of Maximum Wave Setup that Has Occurred vs. a Proportion of the Breaking Depth.

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

See programing error described for transect 60 -nld 6/6/2020

$R = 0$ $\qquad \frac{h}{H_d} = 5.61$

$\eta_1 := R\cdot\eta_{open}$ $\qquad \eta_1 = 0\,\text{ft}$ $\qquad \eta_2 := 0.15\cdot(h+\eta_1)$ $\qquad \eta_2 = 1.4\,\text{ft}$

$\eta_{Structure} := \eta_1 + \eta_2$ $\qquad \eta_{Structure} =$ ~~1.4 ft~~ Total Setup against a coastal structure without considering overtopping

Corrected is
0.15*Hd =
0.15*1.67 = 0.25 ft
-nld 6/6/2020

Check Overtopping if Coastal Structure Exists:

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

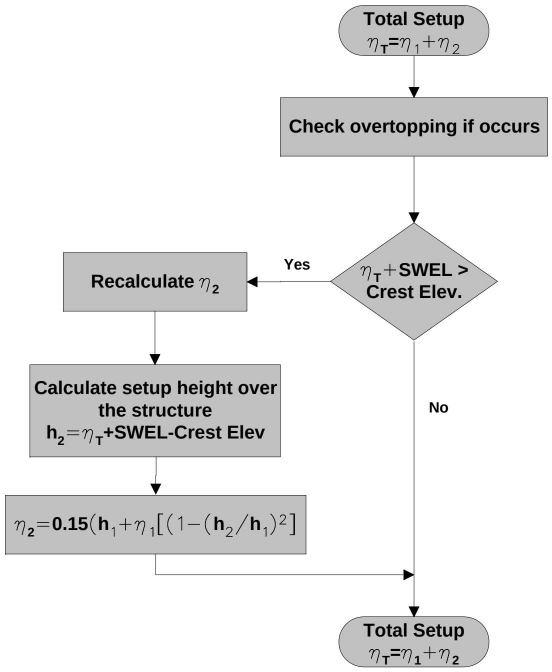
$$h_2 := \begin{cases} (\eta_{Structure} + SWEL - Top_{ele}) & \text{if Overtopped} = \text{"Yes"} \\ 0 & \text{otherwise} \end{cases}$$

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

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

$$\eta_{Structure} := \eta_1 + \eta_2 \qquad \eta_{Structure} = \cancel{1.4\,ft}$$

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:

$$\text{Slope}_{\text{Revet}} := \frac{(\text{Top}_{\text{ele}} - \text{Toe}_{\text{ele}})}{(\text{Top}_{\text{sta}} - \text{Toe}_{\text{sta}})} \qquad \text{Slope}_{\text{Revet}} = 70.8 \cdot \%$$

$$\text{Slope}_{\text{RevetOneOn}} := \frac{1}{\text{Slope}_{\text{Revet}}}$$

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

$\text{Slope}_{\text{Check}} = \text{"TAW Method of Runup Calculation Applies"}$ $\qquad \text{Slope}_{\text{RevetOneOn}} = 1.41$

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

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

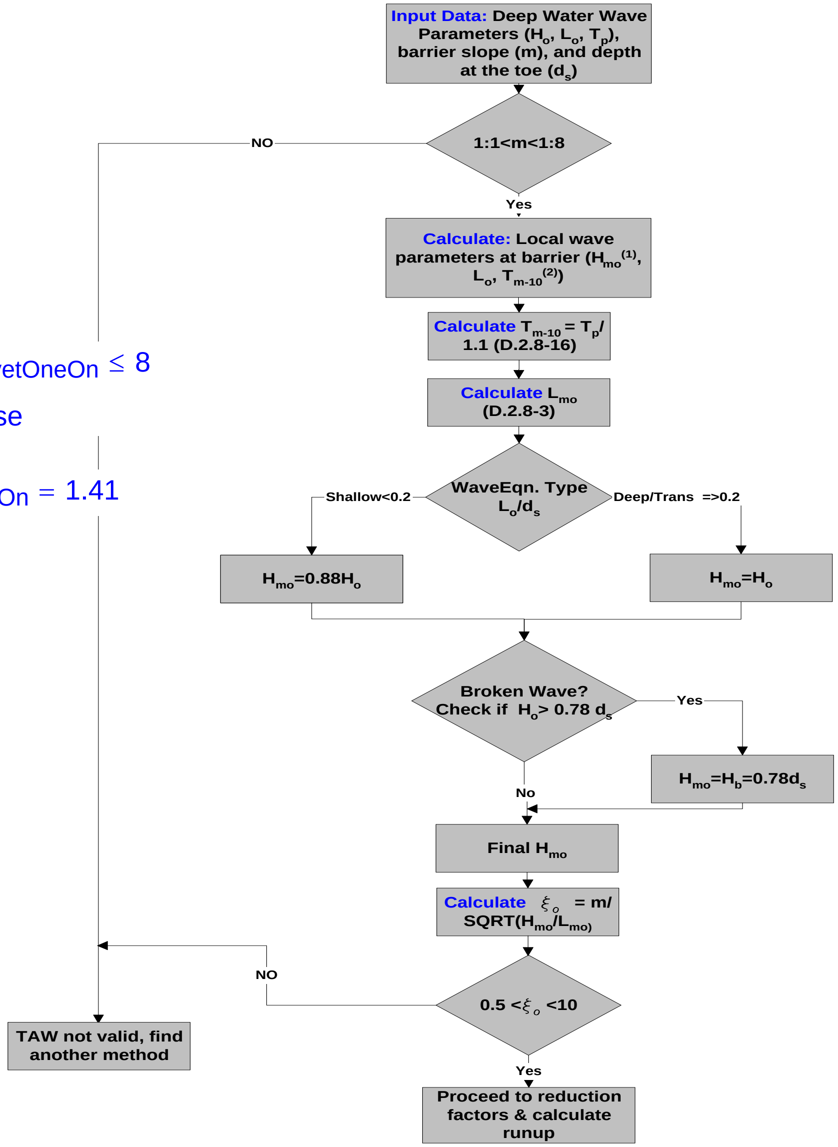
If wave is depth limited, H_b *will be used rather than* H_{m0}

$$\text{Depth}_{\text{Limited}} = \text{"Not Limited"}$$

Determine Wave Type:

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

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



Determine Significant Wave Height Depending on Wave Type and DepthLimited Condition:

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

$H_{m0runup1} = 1.31\,ft$

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

$H_{m0runup} = 1.31\,ft$

Calculate the Spectral Wave Period, T_{m10}

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

Equation D.2.8-16

$T_{m10} = 1.84\,s$

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

$L_{m0} = 17.27\,ft$

Calculate the Iribarren Number, ξ_{0m}:

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

$\xi_{om} = 2.57$

Check TAW Method for Validity based on Iribarren Number:

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

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

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

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

$\gamma_r = 0.58$

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

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

$\gamma_\beta = 1$

Select Porosity Factor, γ_P:

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:

$\gamma_p = 1$

$\gamma_\beta = 1$

$\gamma_b = 1$

$\gamma_r = 0.58$

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

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

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

$R_{2\%} = 2.51\,\text{ft}$

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"

6.0 Conclusions/Results

Wave Height, H_{m0} $H_{m0} = 1.31\,ft$ FetchStatus = "Restricted Fetch Input from ACES (Hmo, Tp)"

Wave Period, T_P $T_P = 2.02\,s$ FetchStatus = "Restricted Fetch Input from ACES (Hmo, Tp)"

Wave Setup on an open coast, η_{open} η_{open} = ~~0.37 ft~~

Wave Setup on a revetment, $\eta_{Structure}$ $\eta_{Structure}$ = ~~1.4 ft~~

Wave Runup on a revetment, $R_{2\%}$ $R_{2\%} = 2.51\,ft$

$OVERTOPPED_{Runup}$ = "NO Overtopping"

NOTES:

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 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

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

Modeler Name: M. Yarbrough
Date: April 10, 2013
County: Knox, ME
Transect Number: 63
Airport: unknown
Years of Dataset: unknown
Associated Files: E:\Region I\Setup\Knox County\Profiles\63.csv

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

$FailTop_{Sta}$ - 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

$U_{10} := 124.67 \frac{m}{s}$

Wave speed based on:
Airport:
Taken from file:_______________

$U_{10} = 409.02 \cdot \frac{ft}{s}$

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

Insert X, fetch in miles:

$X := 12.84 \cdot mi$ $X = 20663.98 \cdot m$

Feature Class used:_____________________
____

Calculate Coefficient of Drag, C_D:

$$C_D := 0.001 \cdot \left[1.1 + \left(0.035 \cdot U_{10} \cdot \frac{s}{m}\right)\right] \qquad C_D = 0.0055$$

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

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

Given

$$C_D = \frac{u_s^2}{U_{10}^2} \qquad u_s := \text{Find}(u_s) \qquad u_s = 9.22 \cdot \frac{m}{s}$$

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

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

$X = 20663.98 \cdot m$

Given

$u_s = 9.22 \cdot \frac{m}{s}$

$g = 9.81 \frac{1}{s} \cdot \frac{m}{s}$

$$\frac{g \cdot H_{m0}}{u_s^2} = 0.0413 \cdot \left(\frac{g \cdot X}{u_s^2}\right)^{0.5}$$

$H_{m0} := \mathrm{Find}(H_{m0})$ $H_{m0} = 0 \cdot m$

$H_{m0} = 0\,\mathrm{ft}$

Calculate Wave Period, T_P (sec):

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

Given

$X = 20663.98 \cdot m$

$u_s = 9.22 \cdot \frac{m}{s}$

$g = 9.81 \frac{1}{s} \cdot \frac{m}{s}$

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

$T_P := \mathrm{Find}(T_P)$ $T_P = 9.43 \cdot s$

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.

$$\mathrm{ACESInput}_{\mathrm{Ang}} := \begin{pmatrix} \blacksquare \\ \blacksquare \\ \blacksquare \\ \blacksquare \\ \blacksquare \\ \blacksquare \\ \blacksquare \\ \blacksquare \\ \blacksquare \end{pmatrix} \qquad \mathrm{ACESInput}_{\mathrm{Fetch}} := \begin{pmatrix} \blacksquare \\ \blacksquare \\ \blacksquare \\ \blacksquare \\ \blacksquare \\ \blacksquare \\ \blacksquare \\ \blacksquare \\ \blacksquare \end{pmatrix}$$

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

Feature Class:

Aces Output:

$H_{\mathrm{m0ACES}} := 1.51 \cdot \mathrm{ft}$ $\qquad$ $T_{\mathrm{PACES}} := 2.18 \cdot \mathrm{sec}$

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

ACES result file:

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

$H_{\mathrm{m0STWAVE}} := -9999 \cdot \mathrm{m}$ $\qquad$ $T_{\mathrm{PSTWAVE}} := -9999 \cdot \mathrm{sec}$

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

5.2 Wave Setup, η, Calculation

5.2.1 Open Coast Wave Setup Analysis

Definition of Variables:

$m := 5.29$ Insert value of average transect slope based on GIS data

It is not clear where this slope comes from, this is nearly vertical and is clearly not the average transect slope
-nld 6/6/2020

Calculate Deep Water Wave Length, L_0:

$$L_0 := \frac{g \cdot T_P^{\,2}}{2 \cdot \pi} \qquad L_0 = 24.34\,\text{ft}$$

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

Calculate Wave Slope, S:

$$S := \frac{H_{m0}}{L_0} \qquad S = 0.062 \qquad S = 6.2 \cdot \%$$

Calculate Static Open Coast Wave Setup:

$$\eta_{open} := H_{m0} \cdot 0.160 \cdot \frac{m^{0.2}}{S^{0.2}} \qquad \cancel{\eta_{open} = 0.59\,\text{ft}}$$

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

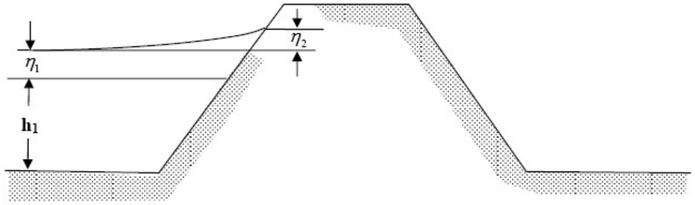


Figure D.2.6-6. Definition Sketch for Nonovertopped Levee

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("E:\Region I\Setup\Knox County\Profiles\63.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:

Profile =

	0	1
0	0	-37.06
1	3.28	-36.99
2	6.56	-36.92
3	9.84	-36.85
4	13.12	-36.78
5	13.21	-36.78
6	16.4	-36.69
7	19.68	...

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

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

Array of horizontal distance from the shoreline

Station =

	0
0	0
1	3.28
2	6.56
3	...

ft

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

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

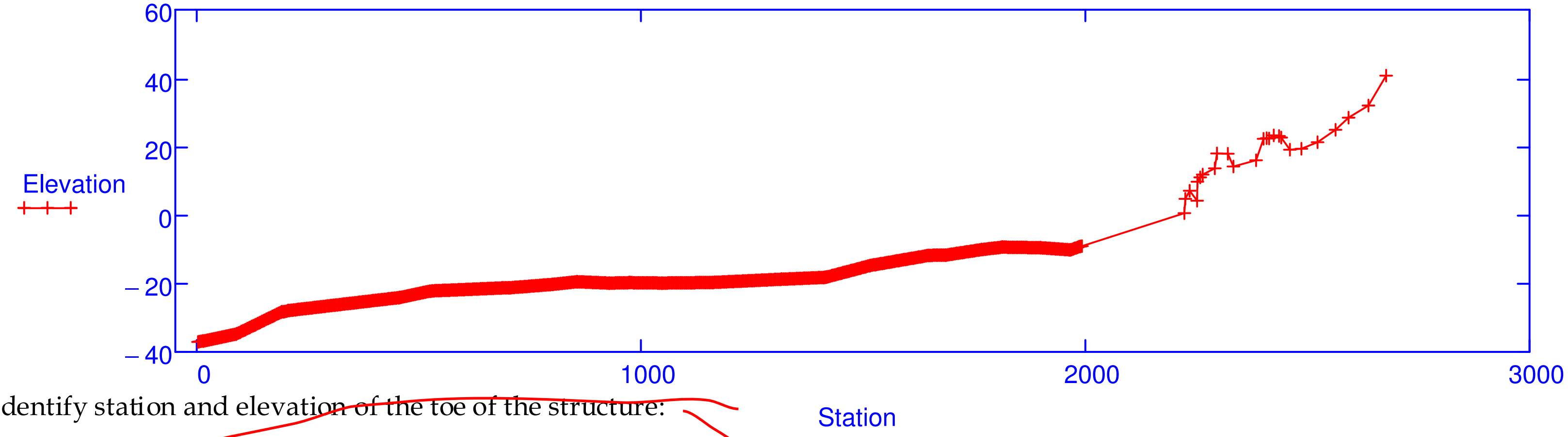
Array of Elevations associated with each horizontal distance from the shoreline:

Elevation =

	0
0	-37.06
1	-36.99
2	-36.92
3	...

ft

The following displays the profile of the transect:



Identify station and elevation of the toe of the structure:

$Toe_{sta} := 2222.29 \cdot ft$ Input value representing coastal structure's bottom station (Toe_{sta})

$Toe_{ele} := linterp(Station, Elevation, Toe_{sta})$ $Toe_{ele} = 0.52\,ft$

Toe and Top points give here yeild a slope of about 0.3, but 5.29 has been used in the DIM calculation
-nld 6/6/2020

Identify station and elevation of the top of the structure:

$Top_{sta} := 2257.91 \cdot ft$ Input value representing coastal structure's top station (Top_{sta})

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

Enter 1% annual chance stillwater elevation (ft): $Top_{ele} = 11\,ft$

$SWEL := 8.80 \cdot ft$ Associated excel file for calculation of 1% annual chance stillwater elevation (SWEL): __________

Calculate Water Depth at Structure, h

$h := SWEL - Toe_{ele}$ $h = 8.28\,ft$

Calculate the Breaking Wave Height, H_b:

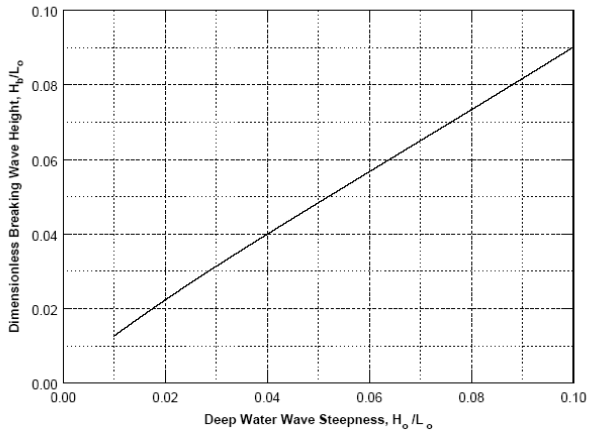


Figure D.2.6-7. Dimensionless Breaking Wave Height vs. Deepwater Wave Steepness

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

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

$H_b := b_h \cdot L_0$ $\quad H_b = 1.42\,\mathrm{ft}$

Calculate the Breaking Wave Depth, H_d:

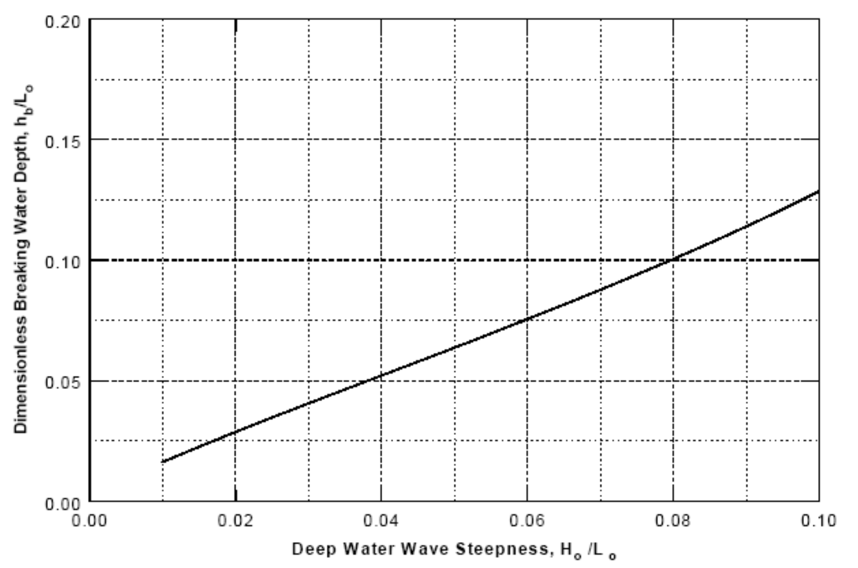


Figure D.2.6-8. Dimensionless Breaking Water Depth vs. Deepwater Wave Steepness.

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

$H_d := b_d \cdot L_0$ $H_d = 1.92\,ft$

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

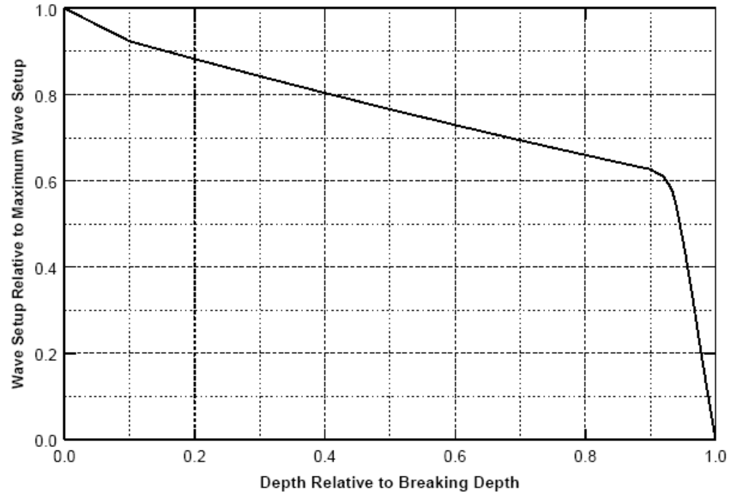


Figure D.2.6-9. Proportion of Maximum Wave Setup that Has Occurred vs. a Proportion of the Breaking Depth.

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

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

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

See comment for Transect 60
Correct nStructure = 0.15*Hd
= 0.15*1.92
= 0.29 feet

$R = 0$ $\qquad \frac{h}{H_d} = 4.31$

$\eta_1 := R\cdot\eta_{open}$ $\qquad \eta_1 = 0\,ft$ $\qquad \eta_2 := 0.15\cdot(h+\eta_1)$ $\qquad \eta_2 = 1.24\,ft$

$\eta_{Structure} := \eta_1 + \eta_2$ $\qquad \eta_{Structure} = \cancel{1.24}\,ft$ Total Setup against a coastal structure without considering overtopping

Check Overtopping if Coastal Structure Exists:

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

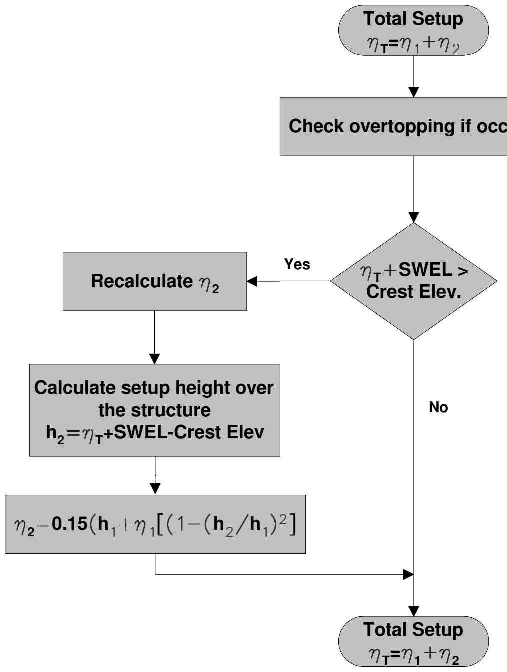
$$h_2 := \begin{cases} (\eta_{Structure} + SWEL - Top_{ele}) & \text{if Overtopped = "Yes"} \\ 0 & \text{otherwise} \end{cases}$$

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

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

$$\eta_{Structure} := \eta_1 + \eta_2 \qquad \eta_{Structure} = 1.\xcancel{24}\ \text{ft}$$

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:

$$Slope_{Revet} := \frac{(Top_{ele} - Toe_{ele})}{(Top_{sta} - Toe_{sta})} \qquad Slope_{Revet} = 29.42 \cdot \%$$

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

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

$$Slope_{Check} = \text{"TAW Method of Runup Calculation Applies"} \qquad Slope_{RevetOneOn} = 3.4$$

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

$$Depth_{Limited} := \begin{array}{|l} \text{"Limited"} \quad \text{if} \quad H_{m0} \ge 0.78 \cdot h \\ \text{"Not Limited"} \quad \text{otherwise} \end{array}$$

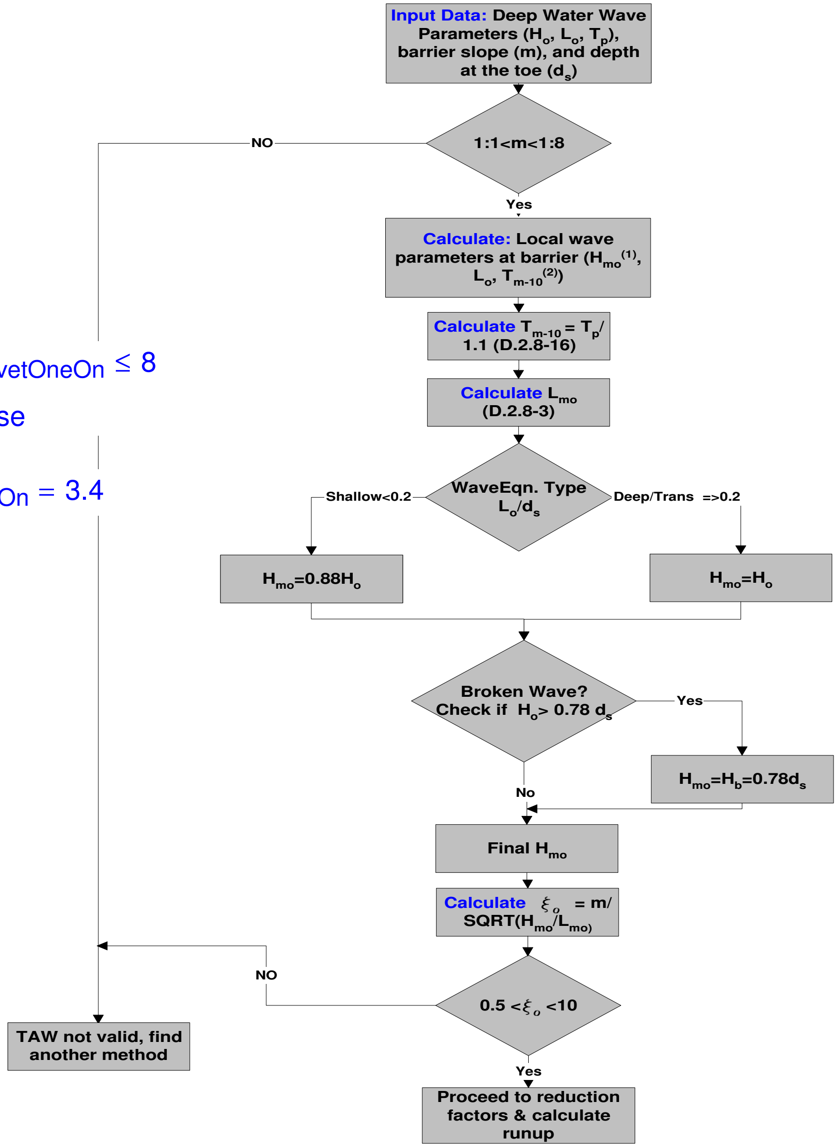
If wave is depth limited, H_b *will be used rather than* H_{m0}

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

Determine Wave Type:

$$WaveType := \begin{array}{|l} \text{"Shallow"} \quad \text{if} \quad \frac{h}{L_0} < 0.2 \\ \text{"Transitional"} \quad \text{if} \quad 0.2 \le \frac{h}{L_0} < 0.5 \\ \text{"Deep"} \quad \text{otherwise} \end{array}$$

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



Determine Significant Wave Height Depending on Wave Type and DepthLimited Condition:

$$H_{m0runup1} := \begin{vmatrix} 0.88 \cdot H_{m0} \ \text{ if } \ WaveType = \text{"Shallow"} \\ H_{m0} \ \text{ otherwise} \end{vmatrix}$$

$H_{m0runup1} = 1.51\,\text{ft}$

$$H_{m0runup} := \begin{vmatrix} 0.78 \cdot h \ \text{ if } \ Depth_{Limited} = \text{"Limited"} \\ H_{m0runup1} \ \text{ otherwise} \end{vmatrix}$$

$H_{m0runup} = 1.51\,\text{ft}$

Calculate the Spectral Wave Period, T_{m10}

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

$T_{m10} = 1.98\,\text{s}$

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

$L_{m0} = 20.11\,\text{ft}$

Calculate the Iribarren Number, ξ_{0m}:

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

$\xi_{om} = 1.07$

Check TAW Method for Validity based on Iribarren Number:

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

$Iribarren_{Check} =$ "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

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

$\gamma_r = 0.58$

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

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

$\gamma_\beta = 1$

Select Porosity Factor, γ_P:

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:

$\gamma_p = 1$

$\gamma_\beta = 1$

$\gamma_b = 1$

$\gamma_r = 0.58$

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

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

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

$R_{2\%} = 1.66\,\text{ft}$

Check for Overtopping:

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

$OVERTOPPED_{Runup}$ = "NO Overtopping"

6.0 Conclusions/Results

Wave Height, H_{m0} $H_{m0} = 1.51\,ft$ FetchStatus = "Restricted Fetch Input from ACES (Hmo, Tp)"

Wave Period, T_P $T_P = 2.18\,s$ FetchStatus = "Restricted Fetch Input from ACES (Hmo, Tp)"

Wave Setup on an open coast, η_{open} $\eta_{open} = 0.59\,ft$

Wave Setup on a revetment, $\eta_{Structure}$ $\eta_{Structure} = 1.24\,ft$

Wave Runup on a revetment, $R_{2\%}$ $R_{2\%} = 1.66\,ft$

$OVERTOPPED_{Runup}$ = "NO Overtopping"

NOTES:

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: M. Yarbrough
Date: May 14 2013
County: Knox, ME
Transect Number: 64
Airport: unknown
Years of Dataset: unknown
Associated Files: E:\Region I\Setup\Knox County\Profiles\64.csv

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

$$U_{10} := 124.67 \cdot \frac{m}{s}$$

Wave speed based on:
Airport:
Taken from file:_________________

$$U_{10} = 409.02 \cdot \frac{ft}{s}$$

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

Insert X, fetch in miles:

$$X := 12.84 \cdot mi \qquad X = 20663.98 \cdot m$$

Feature Class used:______________________
____

Calculate Coefficient of Drag, C_D:

$$C_D := 0.001 \cdot \left[1.1 + \left(0.035 \cdot U_{10} \cdot \frac{s}{m}\right)\right] \qquad C_D = 0.0055$$

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

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

Given

$$C_D = \frac{u_s^2}{U_{10}^2} \qquad u_s := \mathrm{Find}(u_s) \qquad u_s = 9.22 \cdot \frac{m}{s}$$

Client: FEMA
County: Knox
Transect Number: 64

Wave Height and Wave Period Calculation Worksheet

CHK By/Date: M. Yarbrough 10/31/2012
RVW By/Date: M. Salisbury 01/21/2013

Calc By: M. Yarbrough
Date: 05/14/2013

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

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

$X = 20663.98 \cdot m$ $u_s = 9.22 \cdot \frac{m}{s}$ $g = 9.81 \frac{1}{s} \cdot \frac{m}{s}$

Given

$$\frac{g \cdot H_{m0}}{{u_s}^2} = 0.0413 \cdot \left(\frac{g \cdot X}{{u_s}^2}\right)^{0.5} \qquad H_{m0} := \text{Find}(H_{m0}) \qquad H_{m0} = 17.47 \cdot m \qquad H_{m0} = 57.32\,ft$$

Calculate Wave Period, T_P (sec):

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

$X = 20663.98 \cdot m$ $u_s = 9.22 \cdot \frac{m}{s}$ $g = 9.81 \frac{1}{s} \cdot \frac{m}{s}$

Given

$$\frac{g \cdot T_P}{u_s} = 0.751 \cdot \left(\frac{g \cdot X}{{u_s}^2}\right)^{\frac{1}{3}} \qquad T_P := \text{Find}(T_P) \qquad T_P = 9.43 \cdot s$$

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.

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

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

Feature Class:

Aces Output:

$H_{m0ACES} := -9999 \cdot ft$ $T_{PACES} := -9999 \cdot sec$

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

ACES result file:

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

$H_{m0STWAVE} := 5.83 \cdot m$ $T_{PSTWAVE} := 10.41 \cdot sec$

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:

5.2 Wave Setup, η, Calculation

5.2.1 Open Coast Wave Setup Analysis

Definition of Variables:

$m := 0.029904$ Insert value of average transect slope based on GIS data

This slope may be reasonable for DIM, but is not reasonable for TAW and is probably the TAW calculation below is invalid
-nld 6/6/2020

Calculate Deep Water Wave Length, L_0:

$$L_0 := \frac{g \cdot T_P^{\,2}}{2 \cdot \pi} \qquad L_0 = 554.92\,\text{ft}$$

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

Calculate Wave Slope, S:

$$S := \frac{H_{m0}}{L_0} \qquad S = 0.0345 \qquad S = 3.45 \cdot \%$$

Calculate Static Open Coast Wave Setup:

$$\eta_{open} := H_{m0} \cdot 0.160 \cdot \frac{m^{0.2}}{S^{0.2}} \qquad \eta_{open} = 2.97\,\text{ft}$$

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

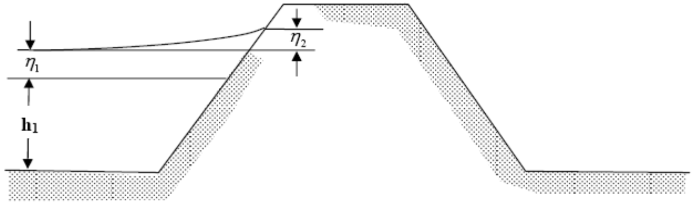


Figure D.2.6-6. Definition Sketch for Nonovertopped Levee

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("C:\Users\21677\Desktop\Knox Drafts\64.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:

$\text{Profile} =$

	0	1
0	0	-104.6
1	3.28	-104.44
2	6.56	-104.28
3	9.84	-104.13
4	13.12	-103.97
5	16.4	-103.81
6	19.68	-103.66
7	22.96	...

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

$\text{Station} := \text{Station} \cdot 1 \cdot \text{ft}$

Array of horizontal distance from the shoreline

$\text{Station} =$

	0
0	0
1	3.28
2	6.56
3	...

ft

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

$\text{Elevation} := \text{Elevation} \cdot 1 \cdot \text{ft}$

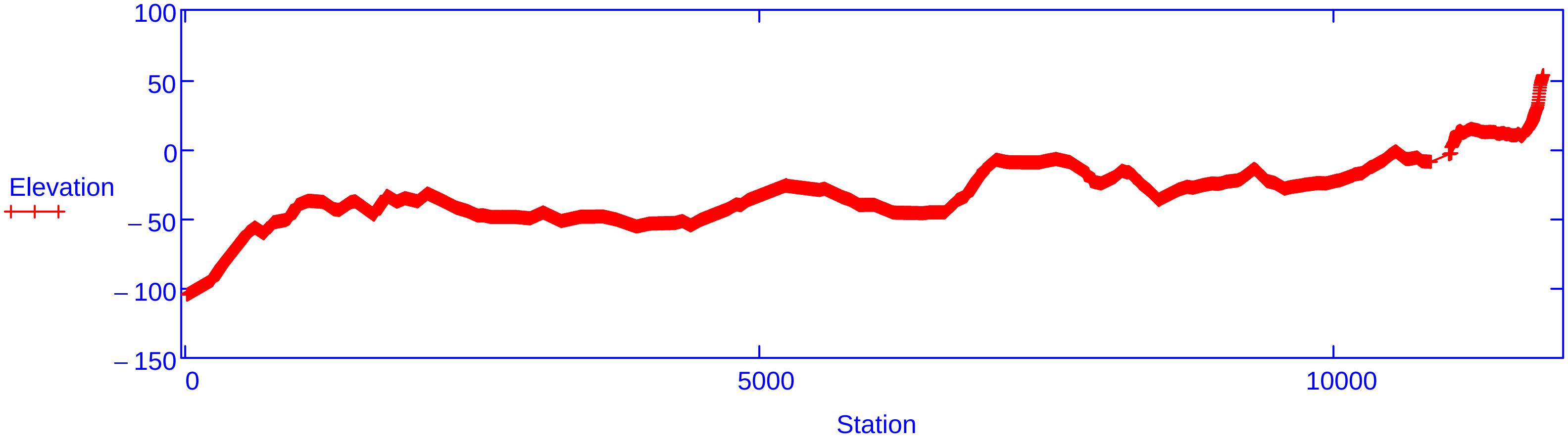
Array of Elevations associated with each horizontal distance from the shoreline:

$\text{Elevation} =$

	0
0	-104.6
1	-104.44
2	-104.28
3	...

ft

The following displays the profile of the transect:



Identify station and elevation of the toe of the structure:

$Toe_{sta} := 11025.24 \cdot ft$ Input value representing coastal structure's bottom station (Toe_{sta})

$Toe_{ele} := linterp(Station, Elevation, Toe_{sta})$ $Toe_{ele} = 1.46\,ft$

Identify station and elevation of the top of the structure:

$Top_{sta} := 11100.59 \cdot ft$ Input value representing coastal structure's top station (Top_{sta})

$Top_{ele} := linterp(Station, Elevation, Top_{sta})$ $Top_{ele} = 13.08\,ft$

Enter 1% annual chance stillwater elevation (ft):

$SWEL := 8.76 \cdot ft$ Associated excel file for calculation of 1% annual chance stillwater elevation (SWEL): __________

Calculate Water Depth at Structure, h

$h := SWEL - Toe_{ele}$ $h = 7.3\,ft$

Calculate the Breaking Wave Height, H_b:

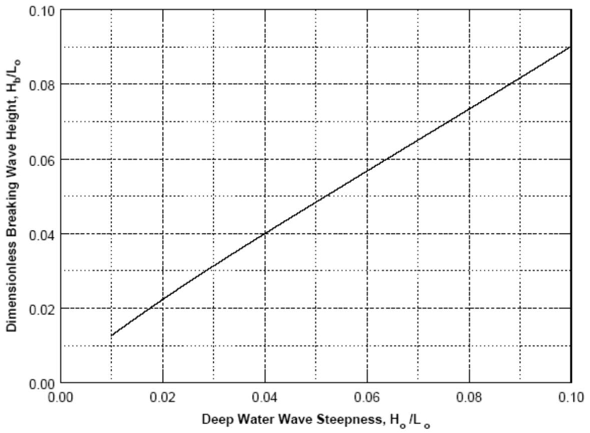


Figure D.2.6-7. Dimensionless Breaking Wave Height vs. Deepwater Wave Steepness

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

$b_h := 0.8481 \cdot S + 0.0057$ $b_h = 0.03$ Estimated curve equation in Figure D.2.6-7

$H_b := b_h \cdot L_0$ $H_b = 19.38\,\text{ft}$

Calculate the Breaking Wave Depth, H_d:

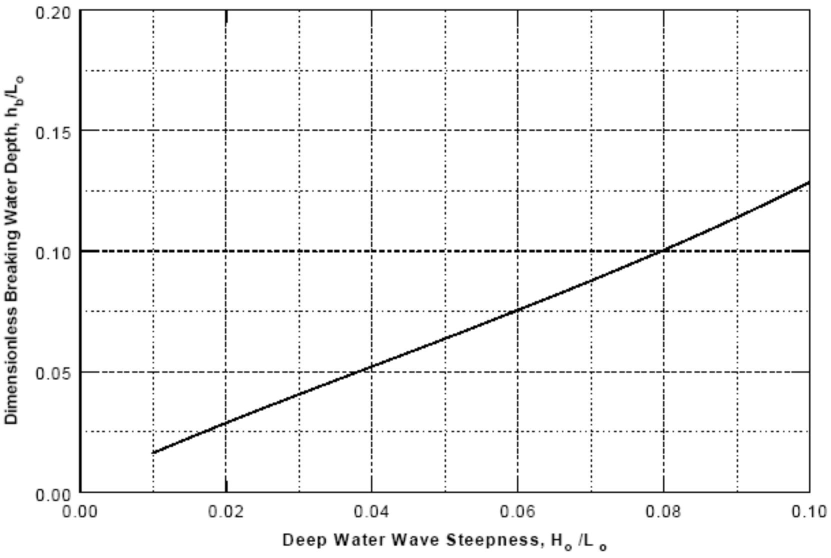


Figure D.2.6-8. Dimensionless Breaking Water Depth vs. Deepwater Wave Steepness.

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

$b_d := 1.2205 \cdot S + 0.0033$ $\quad b_d = 0.05$ Estimated curve equation from Figure D.2.6-8

$H_d := b_d \cdot L_0$ $\quad H_d = 25.18\,\text{ft}$

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

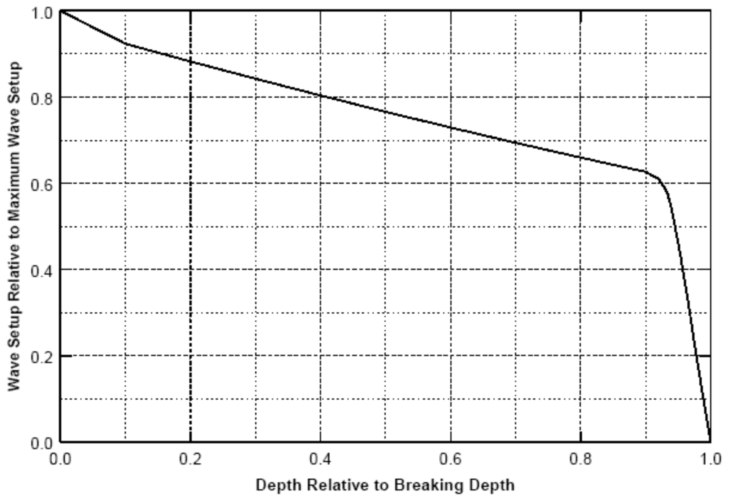


Figure D.2.6-9. Proportion of Maximum Wave Setup that Has Occurred vs. a Proportion of the Breaking Depth.

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

Calc is ok if R > 0
-nld 6/6/2020

$R = 0.84 \qquad \frac{h}{H_d} = 0.29$

$\eta_1 := R\cdot\eta_{open} \qquad \eta_1 = 2.51\,ft \qquad \eta_2 := 0.15\cdot(h+\eta_1) \qquad \eta_2 = 1.47\,ft$

$\eta_{Structure} := \eta_1 + \eta_2 \qquad \eta_{Structure} = 3.98\,ft$ Total Setup against a coastal structure without considering overtopping

Check Overtopping if Coastal Structure Exists:

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

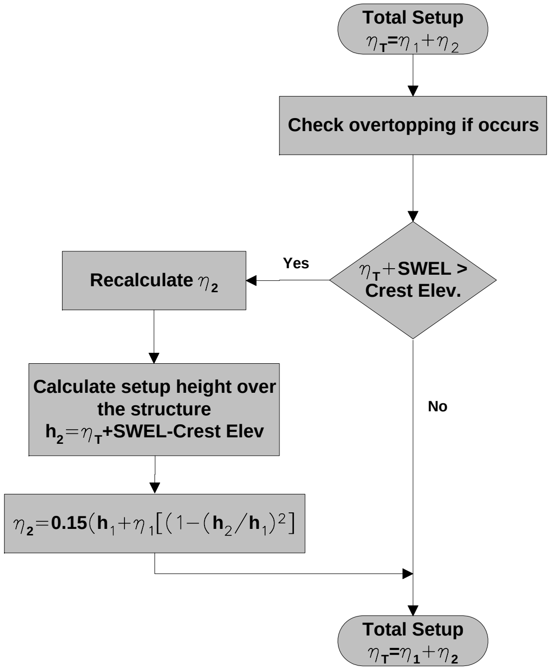
$$h_2 := \begin{cases} (\eta_{Structure} + \text{SWEL} - \text{Top}_{ele}) & \text{if Overtopped} = \text{"Yes"} \\ 0 & \text{otherwise} \end{cases}$$

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

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

$$\eta_{Structure} := \eta_1 + \eta_2 \qquad \eta_{Structure} = 3.98 \text{ ft}$$

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:

$$Slope_{Revet} := \frac{(Top_{ele} - Toe_{ele})}{(Top_{sta} - Toe_{sta})} \qquad Slope_{Revet} = 15.42\cdot\%$$

$$Slope_{RevetOneOn} := \frac{1}{Slope_{Revet}} \qquad Slope_{RevetOneOn} = 6.48$$

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

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

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

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

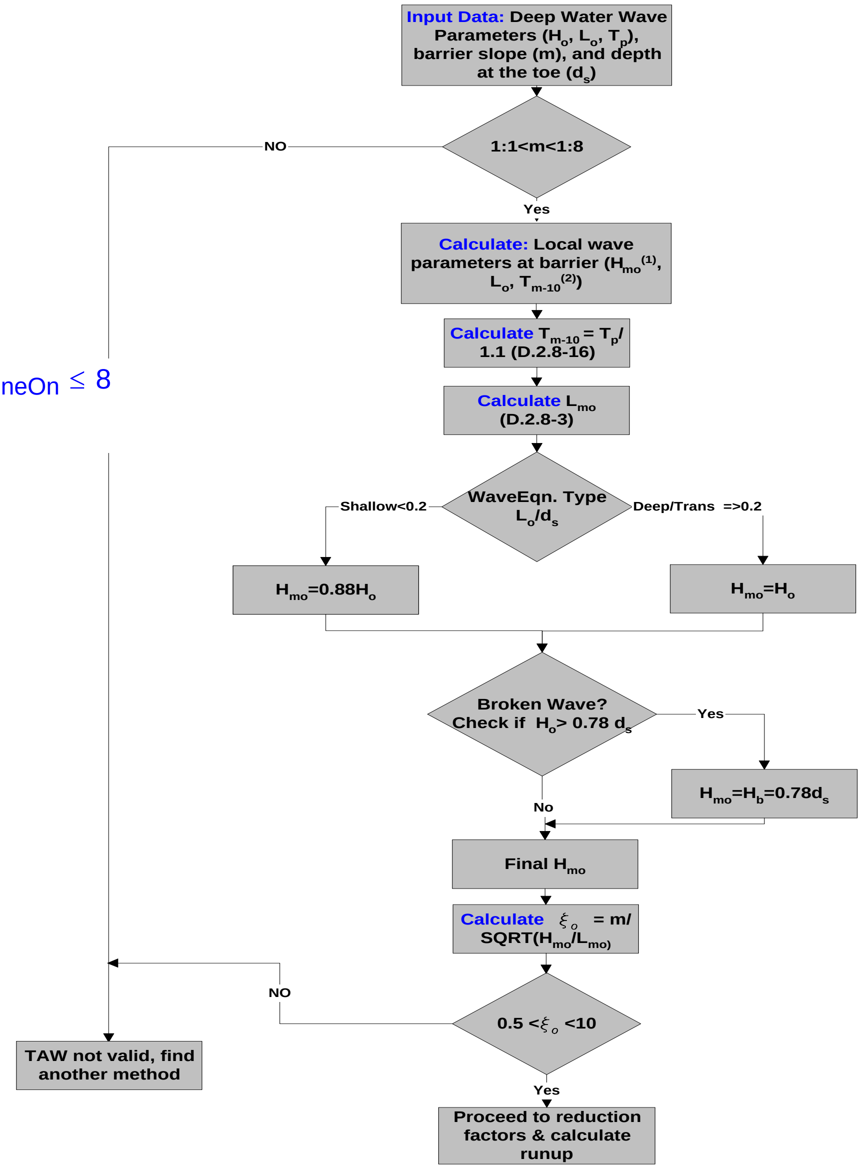
If wave is depth limited, H_b will be used rather than H_{m0}

$$Depth_{Limited} = \text{"Limited"}$$

Determine Wave Type:

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

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



Determine Significant Wave Height Depending on Wave Type and DepthLimited Condition:

$$H_{m0runup1} := \left| \begin{array}{l} 0.88 \cdot H_{m0} \quad \text{if} \quad WaveType = \text{"Shallow"} \\ H_{m0} \quad \text{otherwise} \end{array} \right.$$

$$H_{m0runup1} = 16.83\,\text{ft}$$

$$H_{m0runup} := \left| \begin{array}{l} 0.78 \cdot h \quad \text{if} \quad Depth_{Limited} = \text{"Limited"} \\ H_{m0runup1} \quad \text{otherwise} \end{array} \right.$$

$$H_{m0runup} = 5.69\,\text{ft}$$

Calculate the Spectral Wave Period, T_{m10}

$$T_{m10} := \frac{T_P}{1.1}$$ Equation D.2.8-16 $$T_{m10} = 9.46\,\text{s}$$

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 $$L_{m0} = 458.61\,\text{ft}$$

Calculate the Iribarren Number, ξ_{0m}:

$$\xi_{om} := \frac{Slope_{Revet}}{\sqrt{\frac{H_{m0runup}}{L_{m0}}}}$$ $$\xi_{om} = 1.38$$

Check TAW Method for Validity based on Iribarren Number:

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

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

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

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

$\gamma_r = 0.58$

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

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

$\gamma_p = 1$

Summary of Reduction Factors:

$\gamma_p = 1$

$\gamma_\beta = 1$

$\gamma_b = 1$

$\gamma_r = 0.58$

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

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

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

$R_{2\%} = 8.09\,\text{ft}$

Check for Overtopping:

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

$$\mathrm{OVERTOPPED}_{\mathrm{Runup}} = \text{"Overtopped... Please consider 3 foot rule"}$$

Top is 13', would
yeild BFE = 16'
-nld 6/6/2020

5.4 Failed Revetment Structure Analysis

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

Calculate Slope of the Revetment:

$$Slope := \frac{(Top_{ele} - Toe_{ele})}{(Top_{sta} - Toe_{sta})} \qquad Slope = 0.15$$

Calculate the Midpoint of the Revetment:

$$Length := \sqrt{(Top_{sta} - Toe_{sta})^2 + (Top_{ele} - Toe_{ele})^2} \qquad Length = 76.24\,ft$$

$$Midpoint := \frac{Length}{2} \qquad Midpoint = 38.12\,ft$$

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

$$Mid_{sta} := \left[\left(\frac{Midpoint}{Length}\right)\cdot(Top_{sta} - Toe_{sta})\right] + Toe_{sta} \qquad Mid_{sta} = 11062.91\,ft$$

Determine the Elevation of the Midpoint of the Revetment:

$$Mid_{ele} := linterp(Station, Elevation, Mid_{sta}) \qquad Mid_{ele} = 8.44\,ft$$

Calculate the Upper Quarter of the Revetment:

$$\text{Quarter} := \frac{\text{Length}\cdot 3}{4} \qquad \text{Quarter} = 57.18\,\text{ft}$$

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

$$\text{Quarter}_{\text{sta}} := \left[\left(\frac{\text{Quarter}}{\text{Length}}\right)\cdot\left(\text{Top}_{\text{sta}} - \text{Toe}_{\text{sta}}\right)\right] + \text{Toe}_{\text{sta}} \qquad \text{Quarter}_{\text{sta}} = 11081.75\,\text{ft}$$

Determine the Elevation of the Upper Quadrant of the Revetment:

$$\text{Quarter}_{\text{ele}} := \text{linterp}\left(\text{Station}, \text{Elevation}, \text{Quarter}_{\text{sta}}\right) \qquad \text{Quarter}_{\text{ele}} = 12.35\,\text{ft}$$

Calculate Scour at the Toe of the Revetment:

$$\text{ToeR}_{\text{scour}} := \text{Toe}_{\text{ele}} - \text{Armor}_{\text{D}} \qquad \text{ToeR}_{\text{scour}} = -2.54\,\text{ft}$$

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

$\mathrm{Toe}_{location} := \mathrm{match}(\mathrm{Toe}_{sta}, \mathrm{Station})$ $\mathrm{Toe}_{location} = \begin{pmatrix} 3463 \\ 3464 \end{pmatrix}$ $\mathrm{Toe}_{location_0} = 3463$

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

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

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

$\mathrm{Toe}_{Staloc} = 3464$

Determine if station of the midpoint of th ... he Station array and if not, add a data point

$\mathrm{Mid}_{location} := \mathrm{match}(\mathrm{Mid}_{sta}, \mathrm{Station})$ $\mathrm{Mid}_{location} = \begin{pmatrix} 3475 \\ 3476 \\ 3477 \end{pmatrix}$ $\mathrm{Mid}_{location_0} = 3475$ $\mathrm{Mid}_{sta} = 11062.91\,\mathrm{ft}$

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

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

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

$\mathrm{Mid}_{Staloc} = 3477$ $\mathrm{FailRevetSta}_{\mathrm{Mid}_{Staloc}} := \mathrm{Mid}_{sta}$

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

$\mathrm{Quarter}_{location} := \mathrm{match}(\mathrm{Quarter}_{sta}, \mathrm{Station})$ $\mathrm{Quarter}_{location} = (3482)$ $\mathrm{Quarter}_{location_0} = 3482$ $\mathrm{Quarter}_{sta} = 11081.75\,\mathrm{ft}$

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

$Offset_{qua} = 1$

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

$Quarter_{Staloc} = 3485$ $\quad FailRevetSta_{Quarter_{Staloc}} := Quarter_{sta}$

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

$Top_{location} := match(Top_{sta}, Station)$ $\quad Top_{location} = (3488)$ $\quad Top_{location_0} = 3488$ $\quad Top_{sta} = 11100.59\,ft$

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

$Offset_{top} = 1$

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

$Top_{Staloc} = 3492$ $\quad FailRevetSta_{Top_{Staloc}} := Top_{sta}$

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

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

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

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

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

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

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

$$\mathrm{FailRevetSta}_{\mathrm{Quarter}_{\mathrm{Staloc}}} := \mathrm{Quarter}_{\mathrm{sta}}$$

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

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

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

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

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

$$\mathrm{end} := \mathrm{last}(\mathrm{Station}) + \mathrm{Offset}_{\mathrm{toe}} + \mathrm{Offset}_{\mathrm{mid}} + \mathrm{Offset}_{\mathrm{qua}} + \mathrm{Offset}_{\mathrm{top}} \qquad \mathrm{end} = 3714$$

$$w := \left(\mathrm{Top}_{\mathrm{Staloc}} + 1\right) .. \mathrm{end} \qquad \mathrm{FailRevet}_{\mathrm{Sta}_w} := \mathrm{Station}_{w-\mathrm{Offset}_{\mathrm{toe}}-\mathrm{Offset}_{\mathrm{mid}}-\mathrm{Offset}_{\mathrm{qua}}-\mathrm{Offset}_{\mathrm{top}}}$$

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

$$\mathrm{FailRevet}_{\mathrm{Ele}_i} := \mathrm{Elevation}_i$$

$$\mathrm{FailRevet}_{\mathrm{Ele}_i} := \left| \begin{array}{l} \left[\left[\left[\left(\mathrm{Toe}_{\mathrm{sta}} - \mathrm{FailRevet}_{\mathrm{Sta}_i}\right)\cdot\left(\frac{1}{3}\right)\right] + \mathrm{ToeR}_{\mathrm{scour}}\right]\right] \ \text{if} \ \left[\left[\left(\mathrm{Toe}_{\mathrm{sta}} - \mathrm{FailRevet}_{\mathrm{Sta}_i}\right)\cdot\left(\frac{1}{3}\right)\right] + \mathrm{ToeR}_{\mathrm{scour}}\right] \le \mathrm{Elevation}_i \\ \text{break} \quad \text{otherwise} \end{array} \right.$$

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

$$\mathrm{FailRevet}_{\mathrm{Ele}_{\mathrm{Toe}_{\mathrm{Staloc}}}} := \mathrm{ToeR}_{\mathrm{scour}}$$

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

$$\mathrm{FailRevet}_{\mathrm{Ele}_x} := \left| \begin{array}{l} \mathrm{Elevation}_{x-\mathrm{Offset}_{\mathrm{toe}}} - \mathrm{Armor}_D \ \text{ if } \ x \ne \mathrm{Toe}_{\mathrm{Staloc}} \\ \mathrm{ToeR}_{\mathrm{scour}} \ \text{ otherwise} \end{array} \right.$$

Sets the elevation of the middle of the revetment

$$\mathrm{FailRevet}_{\mathrm{Ele}_{\mathrm{Mid}_{\mathrm{Staloc}}}} := \left(\mathrm{Mid}_{\mathrm{ele}} - \mathrm{Armor}_D\right)$$

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.

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

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.

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

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

$$failed := last\left(FailRevet_{Ele}\right) \qquad failed = 3490$$

Finds the intersection point of failed profile and intact profile:

$$Station_{failed-Offset_{toe}-Offset_{mid}-Offset_{qua}+1} = 11100.59\,ft \qquad Station_{failed-Offset_{toe}-Offset_{mid}-Offset_{qua}} = 11097.31\,ft$$

$$Land_{slope} := \frac{Elevation_{failed-Offset_{toe}-Offset_{mid}-Offset_{qua}+1} - Elevation_{failed-Offset_{toe}-Offset_{mid}-Offset_{qua}}}{Station_{failed-Offset_{toe}-Offset_{mid}-Offset_{qua}+1} - Station_{failed-Offset_{toe}-Offset_{mid}-Offset_{qua}}}$$

$Land_{slope} = 0.02$

Given

$$Elevation_{failed-Offset_{toe}-Offset_{mid}-Offset_{qua}+1} = Station_{failed-Offset_{toe}-Offset_{mid}-Offset_{qua}+1} \cdot Land_{slope} + b_{land}$$

$b_{land} := Find(b_{land}) = -219.75\,ft$

$$Failed_{slope} := \frac{1}{1.5}$$

Given

$$FailRevet_{Ele_{failed}} = FailRevet_{Sta_{failed}} \cdot Failed_{slope} + b_{failed}$$

$b_{failed} := Find(b_{failed}) = -7386.3\,ft$

Given

$$X \cdot Failed_{slope} + b_{failed} = X \cdot Land_{slope} + b_{land}$$

$X := Find(X) = 11099.03\,ft$

$Y := X \cdot Failed_{slope} + b_{failed} = 13.05\,ft$

$FailTop_{Sta} := X$ $FailTop_{Sta} = 11099.03\,ft$

$FailTop_{Ele} := Y$ $FailTop_{Ele} = 13.05\,ft$

$$Offset_{intersect} := \begin{vmatrix} 0 \text{ if } FailTop_{Sta} = Station_{failed-Offset_{toe}-Offset_{mid}-Offset_{qua}} \\ 1 \end{vmatrix}$$

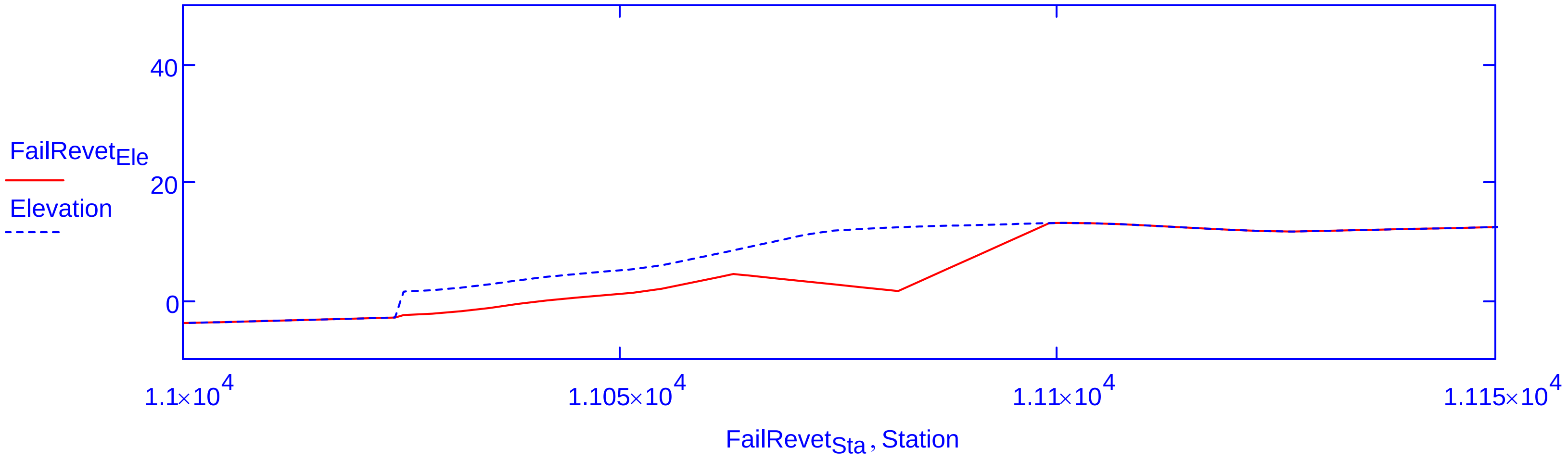
$Offset_{intersect} = 1$

$\mathrm{FailRevet}_{\mathrm{Sta}_{\mathrm{failed}+\mathrm{Offset}_{\mathrm{intersect}}}} := X$ $\mathrm{FailRevet}_{\mathrm{Ele}_{\mathrm{failed}+\mathrm{Offset}_{\mathrm{intersect}}}} := Y$

$a := \left(\mathrm{failed} + \mathrm{Offset}_{\mathrm{intersect}} + 1\right) .. \mathrm{end}$

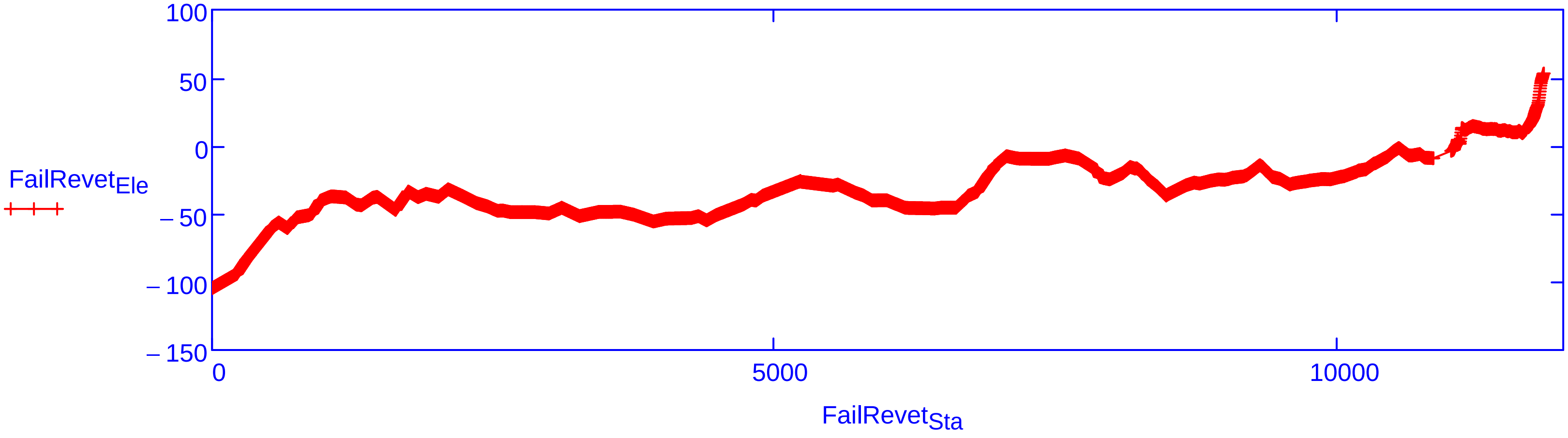
$\mathrm{FailRevet}_{\mathrm{Sta}_a} := \mathrm{Station}_{a-\mathrm{Offset}_{\mathrm{toe}}-\mathrm{Offset}_{\mathrm{mid}}-\mathrm{Offset}_{\mathrm{qua}}-\mathrm{Offset}_{\mathrm{intersect}}}$

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



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

$h := SWEL - ToeR_{scour}$ $h = 11.3\,ft$

$H_b := b_h \cdot L_0$ $H_b = 19.38\,ft$ $H_d := b_d \cdot L_0$ $H_d = 25.18\,ft$

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

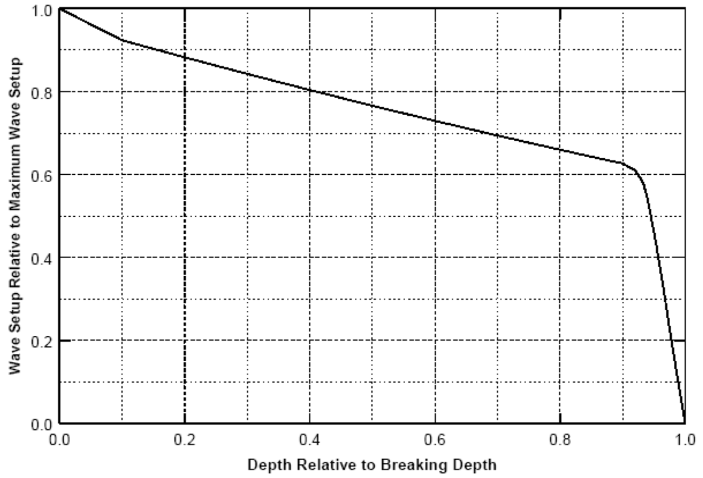


Figure D.2.6-9. Proportion of Maximum Wave Setup that Has Occurred vs. a Proportion of the Breaking Depth.

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

Ok -nld 6/6/2020

$R = 0.78$

$\frac{h}{H_d} = 0.45$

$\eta_1 := R\cdot\eta_{open}$ $\eta_1 = 2.33\,ft$ $\eta_2 := 0.15\cdot(h+\eta_1)$ $\eta_2 = 2.04\,ft$

$\eta_{FailedStructure} := \eta_1 + \eta_2$ $\eta_{FailedStructure} = 4.37\,ft$

Total Setup against a coastal structure without considering overtopping

Check Overtopping if Coastal Structure Exists:

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

$$\text{Overtopped} = \text{"Yes"}$$

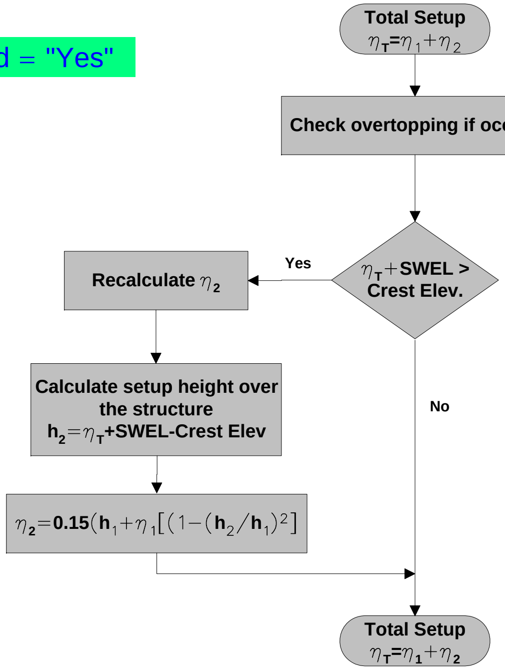
$$h_2 := \begin{cases} \left(\eta_{FailedStructure} + SWEL - Top_{ele}\right) & \text{if Overtopped} = \text{"Yes"} \\ 0 & \text{otherwise} \end{cases}$$

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

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

$$\eta_{FailedStructure} := \eta_1 + \eta_2 \qquad \eta_{FailedStructure} = 4.37\,\text{ft}$$

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:

$$\text{Slope}_{\text{FAILRevet}} := \frac{\left(\text{FailTop}_{\text{Ele}} - \text{ToeR}_{\text{scour}}\right)}{\left(\text{FailTop}_{\text{Sta}} - \text{Toe}_{\text{sta}}\right)} \qquad \text{Slope}_{\text{FAILRevet}} = 21.12\cdot\%$$

$$\text{Slope}_{\text{FAILRevetOneOn}} := \frac{1}{\text{Slope}_{\text{FAILRevet}}} \qquad \text{Slope}_{\text{FAILRevetOneOn}} = 4.73$$

$$\text{FAILSlope}_{\text{Check}} := \begin{array}{|l} \text{"TAW Method of Runup Calculation Applies"} \quad \text{if} \quad 0 < \text{Slope}_{\text{RevetOneOn}} \le 8 \\ \text{"TAW Method Does Not Apply, Switch to Runup-2.0"} \quad \text{otherwise} \end{array}$$

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

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

$$\text{Depth}_{\text{Limited}} := \begin{array}{|l} \text{"Limited"} \quad \text{if} \quad H_{m0} \ge 0.78\cdot h \\ \text{"Not Limited"} \quad \text{otherwise} \end{array}$$

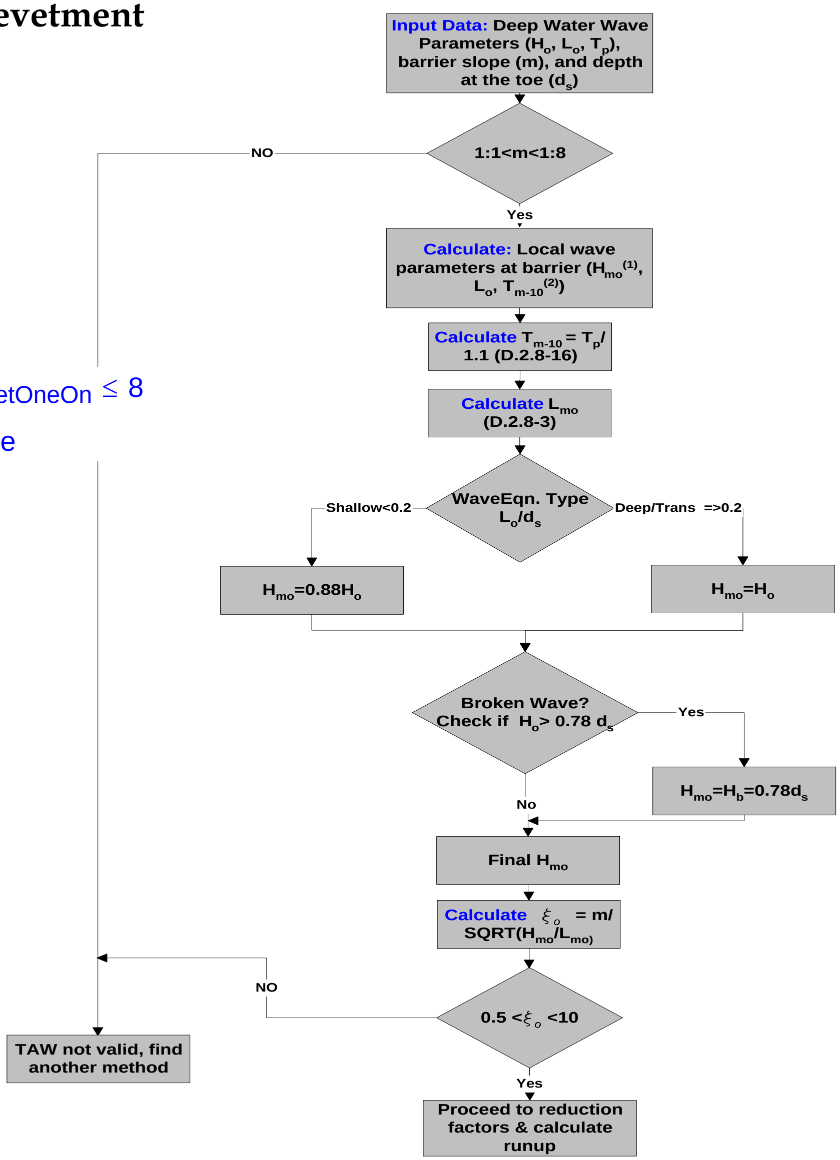
If wave is depth limited, H_b will be used rather than H_{m0}

$$\text{Depth}_{\text{Limited}} = \text{"Limited"}$$

Determine Wave Type:

$$\text{WaveType} := \begin{array}{|l} \text{"Shallow"} \quad \text{if} \quad \frac{h}{L_0} < 0.2 \\ \text{"Transitional"} \quad \text{if} \quad 0.2 \le \frac{h}{L_0} < 0.5 \\ \text{"Deep"} \quad \text{otherwise} \end{array}$$

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



Determine Significant Wave Height Depending on WaveType and DepthLimited Condition:

$$H_{m0runupFAIL1} := \begin{cases} 0.88 \cdot H_{m0} & \text{if } WaveType = \text{"Shallow"} \\ H_{m0} & \text{otherwise} \end{cases} \qquad H_{m0runupFAIL1} = 16.83\,\text{ft}$$

$$H_{m0runupFAIL} := \begin{cases} 0.78 \cdot h & \text{if } Depth_{Limited} = \text{"Limited"} \\ H_{m0runupFAIL1} & \text{otherwise} \end{cases} \qquad H_{m0runupFAIL} = 8.81\,\text{ft}$$

Calculate the Iribarren Number, ξ_{0m}:

$$\xi_{om} := \frac{Slope_{FAILRevet}}{\sqrt{\dfrac{H_{m0runupFAIL}}{L_{m0}}}} \qquad \xi_{om} = 1.52$$

Check TAW Method for Validity based on Iribarren Number:

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

$FAILIribarren_{Check} =$ "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

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

$\gamma_r = 0.58$

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

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

$\gamma_\beta = 1$

Select Porosity Factor, γ_P:

Porosity :=
○ 0.1
○ 0.4
● 0.5
○ 0.6

Default Porosity = 0.5

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

$\gamma_p = 1$

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:

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

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

$R_{FAIL2\%} = 8.9\,ft$

Check for Overtopping:

$$\text{OVERTOPPEDFAIL}_{\text{Runup}} := \begin{cases} \text{"Overtopped... Please consider 3 foot rule"} & \text{if } \left(R_{\text{FAIL2\%}} + \text{SWEL}\right) > \text{FailTop}_{\text{Ele}} \\ \text{"NO Overtopping"} & \text{otherwise} \end{cases}$$

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

6.0 Conclusions/Results

Wave Height, H_{m0} $H_{m0} = 19.13\,\text{ft}$ $\text{FetchStatus} = \text{"STWAVE Input (Hmo, Tp)"}$

Wave Period, T_P $T_P = 10.41\,\text{s}$ $\text{FetchStatus} = \text{"STWAVE Input (Hmo, Tp)"}$

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16'
-nld 6/6/2020

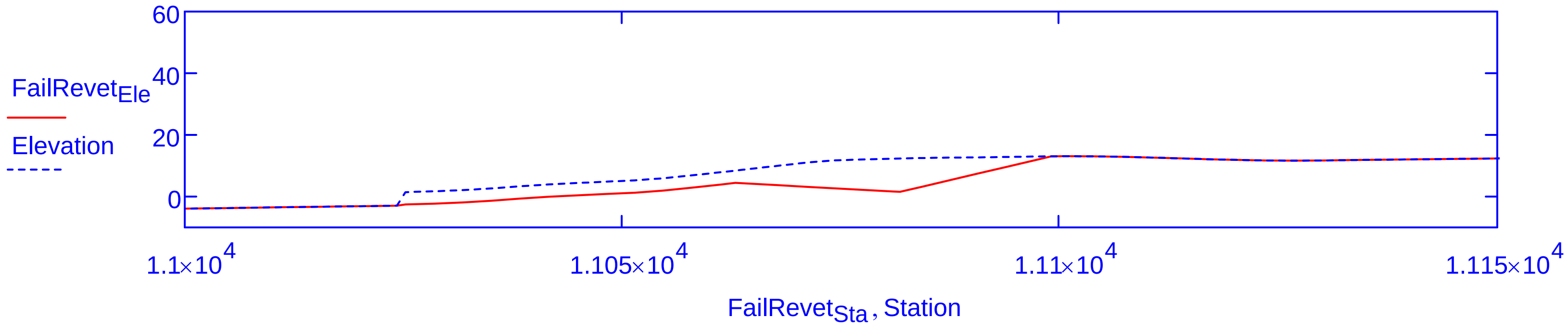
Wave Setup on an open coast, η_{open} $\eta_{open} = 2.97\,\text{ft}$

Wave Setup on a revetment, $\eta_{Structure}$ $\eta_{Structure} = 3.98\,\text{ft}$

Wave Runup on a revetment, $R_{2\%}$ $R_{2\%} = 8.09\,\text{ft}$

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

Failed Structure Profile:



Wave Setup on a Failed Structure, η $\eta_{FailedStructure} = 4.37\,ft$

Wave Runup on a Failed Structure, $R_{FAIL2\%}$ $R_{FAIL2\%} = 8.9\,ft$

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

Top of Failed Revetment Station and Elevation: $FailTop_{Sta} = 11099.03\,ft$ $FailTop_{Ele} = 13.05\,ft$

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

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

Out_1 := WRITEPRN("E:\Region I\Setup\Knox County\Failure Profiles\FAILED_REVETMENT_Station_REV64.prn" , $Fail_{Sta}$)

Out_2 := WRITEPRN("E:\Region I\Setup\Knox County\Failure Profiles\FAILED_REVETMENT_Elev_REV64.prn" , $Fail_{Ele}$)

NOTES:

Wave Height, Wave Period and Wave Setup Worksheet Without Structures

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.

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. For Restricted fetches, an additional ACES analysis was performed. 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 if fetch length is unrestricted 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 5.2 - Wave Setup

Section 5.2.1 - Open Coast Wave Setup Calculation

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

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 Calculations:

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 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 Height, Wave Period and Wave Setup Calculation Worksheet Without Structures

Modeler Name: M. Yarbrough
Date: March 28, 2013
County: Knox, ME
Transect Number: 65
Airport: unknown
Years of Data set: unknown
Associated Files: E:\Region I\Setup\Knox County\Profiles\65.csv

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)

m - Average slope of transect (dimensionless)

H_{m0ACES} - Energy-based significant deepwater wave height from ACES analysis (ft)

T_{PACES} - Limiting Wave Period from ACES analysis (ft)

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

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

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)

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

η_{open} - Wave setup (ft)

○ 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:

$$U_{10} := 124.67 \frac{m}{s}$$

Wind speed based on:
Airport:
Taken from file:

$$U_{10} = 409.02 \cdot \frac{ft}{s}$$

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

Insert X, fetch in miles:

$$X := 13.68 \cdot mi \qquad X = 22015.83 \cdot m$$

Feature class used:

Calculate Coefficient of Drag, C_D:

$$C_D := 0.001 \cdot \left[1.1 + \left(0.035 \cdot U_{10} \cdot \frac{s}{m}\right)\right] \qquad C_D = 0.0055$$

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

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

Given

$$C_D = \frac{u_s^{\,2}}{U_{10}^{\,2}} \qquad u_s := \text{Find}(u_s) \qquad u_s = 9.22 \cdot \frac{m}{s}$$

Wave Height and Wave Period Calculation Worksheet
CHK By/Date: M. Yarbrough 10/31/2012
RVW By/Date: M. Salisbury 01/21/2013

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

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

$X = 22015.83 \cdot m$ $u_s = 9.22 \cdot \frac{m}{s}$ $g = 9.81 \frac{1}{s} \cdot \frac{m}{s}$

Given

$$\frac{g \cdot H_{m0}}{{u_s}^2} = 0.0413 \cdot \left(\frac{g \cdot X}{{u_s}^2}\right)^{0.5}$$

$H_{m0} := \text{Find}(H_{m0})$ $H_{m0} = 18.03 \cdot m$ $H_{m0} = 59.16\,ft$

Calculate Wave Period, T_P (sec):

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

$X = 22015.83 \cdot m$ $u_s = 9.22 \cdot \frac{m}{s}$ $g = 9.81 \frac{1}{s} \cdot \frac{m}{s}$

Given

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

$T_P := \text{Find}(T_P)$ $T_P = 9.63 \cdot s$

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.

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

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

Feature Class File:

ACES Output:

$H_{m0ACES} := 1.16 \cdot ft$

$T_{PACES} := 1.95 \cdot sec$

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

ACES result file:

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

$H_{m0STWAVE} := 1.31 \cdot m$

$T_{PSTWAVE} := 10.04 \cdot sec$

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

5.2 Wave Setup on an Open Coast, η, Calculation

Definition of Variables:

$m := 0.150421$

Insert value of average transect slope based on GIS data

Calculate Deep Water Wave Length, L_0:

$$L_0 := \frac{g \cdot T_P^{\,2}}{2 \cdot \pi} \qquad L_0 = 516.17\,\text{ft}$$

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

Calculate Wave Slope, S:

$$S := \frac{H_{m0}}{L_0} \qquad S = 0.0083 \qquad S = 0.83 \cdot \%$$

Calculate Static Open Coast Wave Setup:

$$\eta_{open} := H_{m0} \cdot 0.160 \cdot \frac{m^{0.2}}{S^{0.2}} \qquad \eta_{open} = 1.23\,\text{ft}$$

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

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

`Profile := READFILE("E:\Region I\Setup\Knox County\Profiles\65.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:

Profile =

	0
0	0
1	3.27
2	6.55
3	9.82
4	13.09
5	15
6	16.37
7	19.64
8	22.92
9	26.19
10	...

Array of horizontal distance from the shoreline

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

$\mathrm{Station} := \mathrm{Station} \cdot 1 \cdot \mathrm{ft}$

Station = ft

	0
0	0
1	3.27
2	6.55
3	...

Array of Elevations associated with each horizontal distance from the shoreline:

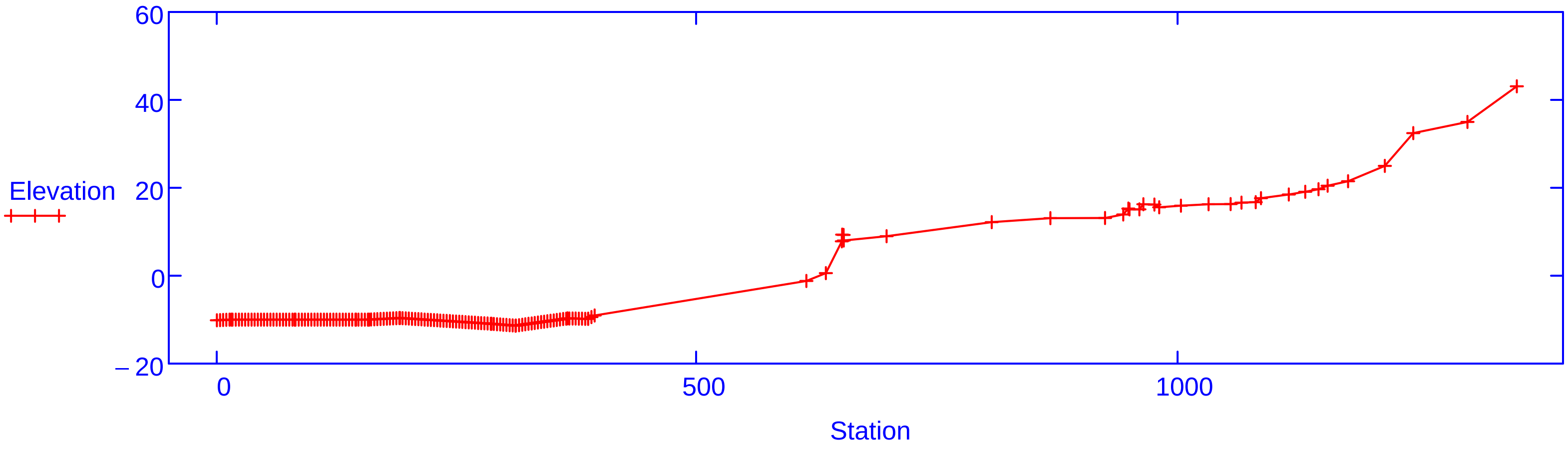
$\mathrm{Elevation} := \mathrm{Profile}^{\langle 1 \rangle}$

$\mathrm{Elevation} := \mathrm{Elevation} \cdot 1 \cdot \mathrm{ft}$

Elevation = ft

	0
0	-10.13
1	-10.1
2	-10.07
3	...

The following displays the profile of the transect:



6.0 Conclusions/Results

Wave Height, H_{m0} $H_{m0} = 4.3\,ft$ FetchStatus = "STWAVE Input (Hmo, Tp)"

Wave Period, T_P $T_P = 10.04\,s$ FetchStatus = "STWAVE Input (Hmo, Tp)"

Wave Setup, η $\eta_{open} = 1.23\,ft$

NOTES:

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 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

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

Modeler Name: M. Yarbrough
Date: March 29, 2013
County: Knox, ME
Transect Number: 66
Airport: unknown
Years of Dataset: unknown
Associated Files: E:\Region I\Setup\Knox County\Profiles\66.csv

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

$FailTop_{Sta}$ - 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:

$U_{10} := 124.67 \frac{m}{s}$

$U_{10} = 409.02 \cdot \frac{ft}{s}$

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

Wave speed based on:
Airport:
Taken from file:_______________

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

Insert X, fetch in miles:

$X := 12.84 \cdot mi$

$X = 20663.98 \cdot m$

Feature Class used:____________________
____

Calculate Coefficient of Drag, C_D:

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

$C_D = 0.0055$

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

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

Given

$C_D = \frac{{u_s}^2}{{U_{10}}^2}$

$u_s := \text{Find}(u_s)$

$u_s = 9.22 \cdot \frac{m}{s}$

Wave Height and Wave Period Calculation Worksheet
CHK By/Date: M. Yarbrough 10/31/2012
RVW By/Date: M. Salisbury 01/21/2013

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

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

$X = 20663.98 \cdot m$

Given

$u_s = 9.22 \cdot \frac{m}{s}$

$g = 9.81 \frac{1}{s} \cdot \frac{m}{s}$

$$\frac{g \cdot H_{m0}}{u_s^2} = 0.0413 \cdot \left(\frac{g \cdot X}{u_s^2}\right)^{0.5}$$

$H_{m0} := \mathrm{Find}(H_{m0})$ $H_{m0} = 0 \cdot m$

$H_{m0} = 0\,ft$

Calculate Wave Period, T_P (sec):

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

Given

$X = 20663.98 \cdot m$

$u_s = 9.22 \cdot \frac{m}{s}$

$g = 9.81 \frac{1}{s} \cdot \frac{m}{s}$

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

$T_P := \mathrm{Find}(T_P)$ $T_P = 9.43 \cdot s$

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 0º facing North.

Feature Class:

Aces Output:

$H_{m0ACES} := -9999 \cdot ft$ $\qquad$ $T_{PACES} := -9999 \cdot sec$

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

ACES result file:

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

not clear where this comes from

$H_{m0STWAVE} := 6.44 \cdot m$ $\qquad$ $T_{PSTWAVE} := 10.54 \cdot sec$

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

5.2 Wave Setup, η, Calculation

5.2.1 Open Coast Wave Setup Analysis

Definition of Variables:

$m := 0.030452$ Insert value of average transect slope based on GIS data

Calculate Deep Water Wave Length, L_0:

$L_0 := \dfrac{g \cdot T_P^{\,2}}{2 \cdot \pi}$ $L_0 = 568.86\,\text{ft}$ Equation source: Coastal Engineering Manual Part VI Page VI-5-236

Calculate Wave Slope, S:

$S := \dfrac{H_{m0}}{L_0}$ $S = 0.0371$ $S = 3.71 \cdot \%$

Calculate Static Open Coast Wave Setup:

$\eta_{open} := H_{m0} \cdot 0.160 \cdot \dfrac{m^{0.2}}{S^{0.2}}$ $\eta_{open} = 3.25\,\text{ft}$

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

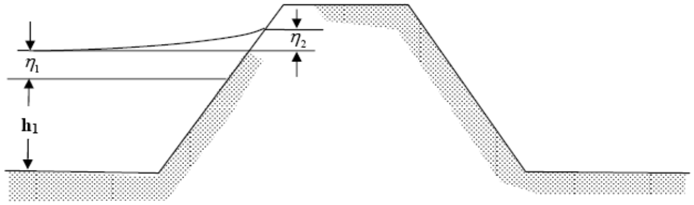


Figure D.2.6-6. Definition Sketch for Nonovertopped Levee

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("E:\Region I\Setup\Knox County\Profiles\66.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:

Profile =

	0	1
0	0	-141.8
1	3.28	-141.68
2	6.56	-141.57
3	9.84	-141.45
4	13.12	-141.34
5	16.4	-141.22
6	19.68	-141.11
7	22.96	...

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

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

Array of horizontal distance from the shoreline

Station =

	0
0	0
1	3.28
2	6.56
3	...

ft

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

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

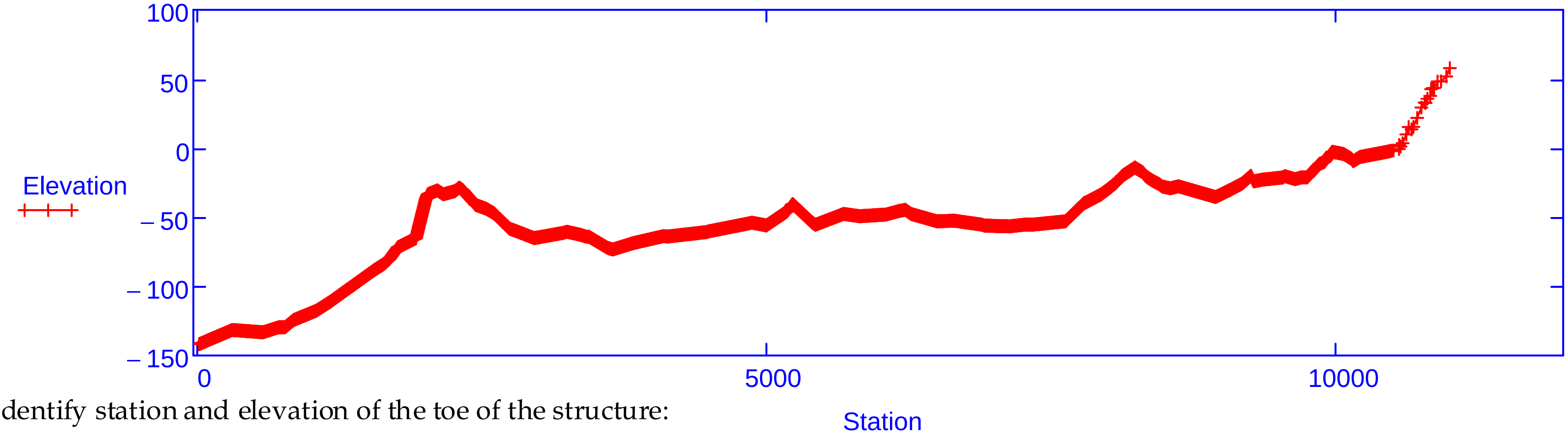
Array of Elevations associated with each horizontal distance from the shoreline:

Elevation =

	0
0	-141.8
1	-141.68
2	-141.57
3	...

ft

The following displays the profile of the transect:



Identify station and elevation of the toe of the structure:

$Toe_{sta} := 10569.14 \cdot ft$ Input value representing coastal structure's bottom station (Toe_{sta})

$Toe_{ele} := linterp(Station, Elevation, Toe_{sta})$ $Toe_{ele} = 1.12\,ft$

Identify station and elevation of the top of the structure:

$Top_{sta} := 10641.44 \cdot ft$ Input value representing coastal structure's top station (Top_{sta})

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

Enter 1% annual chance stillwater elevation (ft): $Top_{ele} = 15.24\,ft$

$SWEL := 8.75 \cdot ft$ Associated excel file for calculation of 1% annual chance stillwater elevation (SWEL): __________

Calculate Water Depth at Structure, h

$h := SWEL - Toe_{ele}$ $h = 7.63\,ft$

Calculate the Breaking Wave Height, H_b:

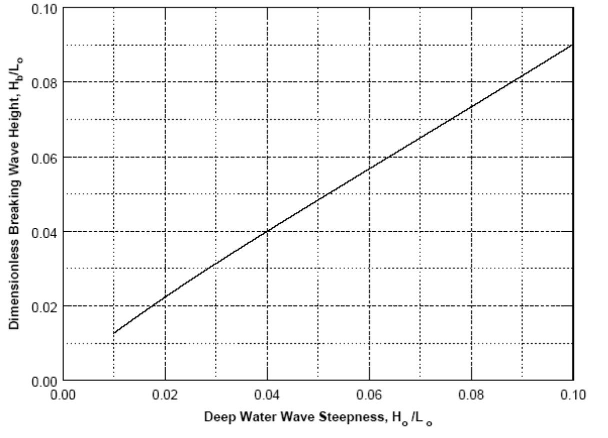


Figure D.2.6-7. Dimensionless Breaking Wave Height vs. Deepwater Wave Steepness

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

$b_h := 0.8481 \cdot S + 0.0057$ $b_h = 0.04$ Estimated curve equation in Figure D.2.6-7

$H_b := b_h \cdot L_0$ $H_b = 21.16\,\mathrm{ft}$

Calculate the Breaking Wave Depth, H_d:

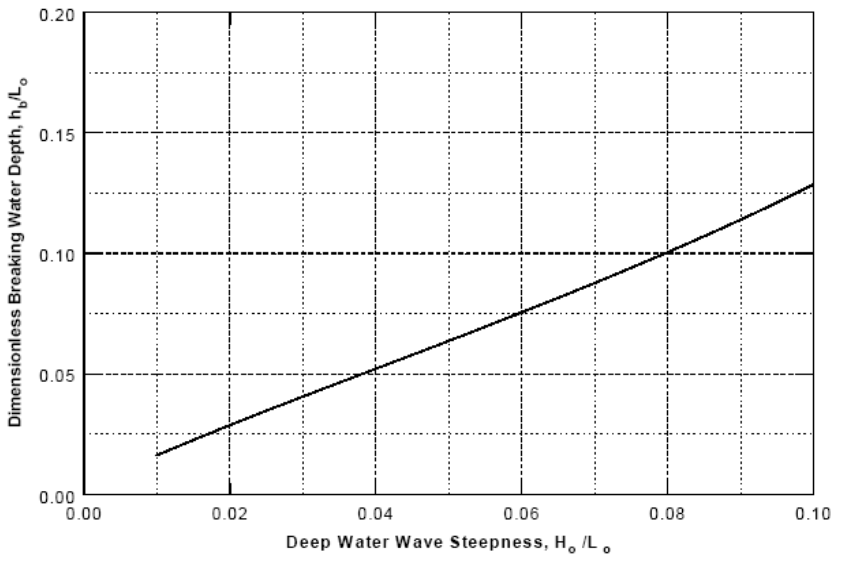


Figure D.2.6-8. Dimensionless Breaking Water Depth vs. Deepwater Wave Steepness.

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

$b_d := 1.2205 \cdot S + 0.0033$ $b_d = 0.05$ Estimated curve equation from Figure D.2.6-8

$H_d := b_d \cdot L_0$ $H_d = 27.66\,\text{ft}$

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

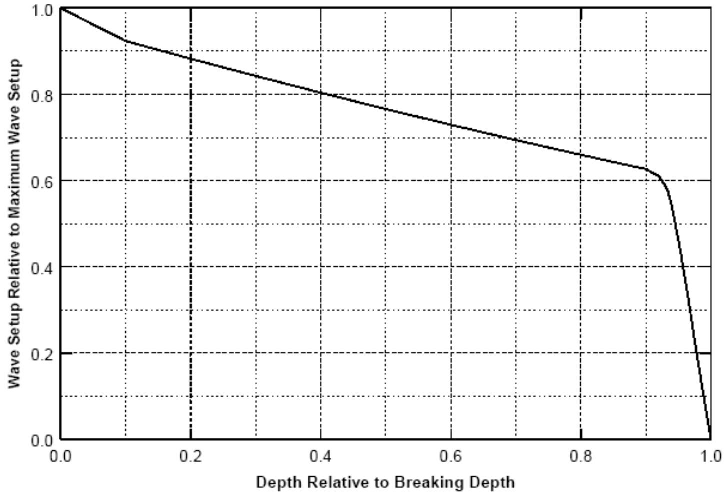


Figure D.2.6-9. Proportion of Maximum Wave Setup that Has Occurred vs. a Proportion of the Breaking Depth.

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

Ok when R > 0
-nld 6/6/2020

$R = 0.85$ $\frac{h}{H_d} = 0.28$

$\eta_1 := R\cdot\eta_{open}$ $\eta_1 = 2.76\,ft$ $\eta_2 := 0.15\cdot(h+\eta_1)$ $\eta_2 = 1.56\,ft$

$\eta_{Structure} := \eta_1 + \eta_2$ $\eta_{Structure} = 4.32\,ft$ Total Setup against a coastal structure without considering overtopping

Check Overtopping if Coastal Structure Exists:

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

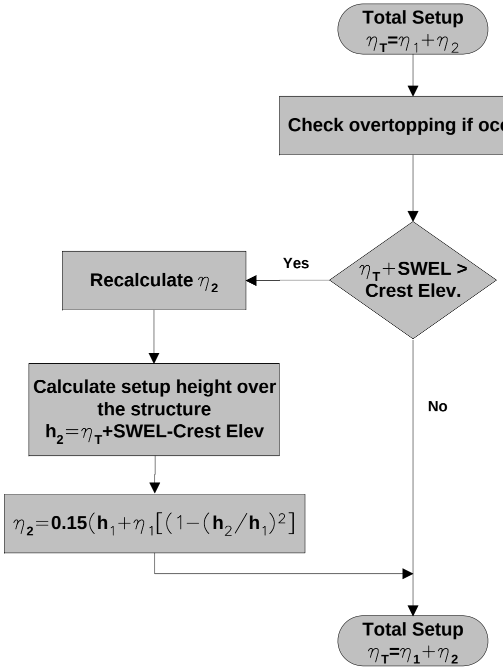
$$h_2 := \begin{cases} (\eta_{Structure} + SWEL - Top_{ele}) & \text{if Overtopped} = \text{"Yes"} \\ 0 & \text{otherwise} \end{cases}$$

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

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

$$\eta_{Structure} := \eta_1 + \eta_2 \qquad \eta_{Structure} = 4.32\,ft$$

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:

$$\mathrm{Slope}_{\mathrm{Revet}} := \frac{(\mathrm{Top}_{\mathrm{ele}} - \mathrm{Toe}_{\mathrm{ele}})}{(\mathrm{Top}_{\mathrm{sta}} - \mathrm{Toe}_{\mathrm{sta}})} \qquad \mathrm{Slope}_{\mathrm{Revet}} = 19.53 \cdot \%$$

$$\mathrm{Slope}_{\mathrm{RevetOneOn}} := \frac{1}{\mathrm{Slope}_{\mathrm{Revet}}}$$

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

$$\mathrm{Slope}_{\mathrm{Check}} = \text{"TAW Method of Runup Calculation Applies"} \qquad \mathrm{Slope}_{\mathrm{RevetOneOn}} = 5.12$$

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

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

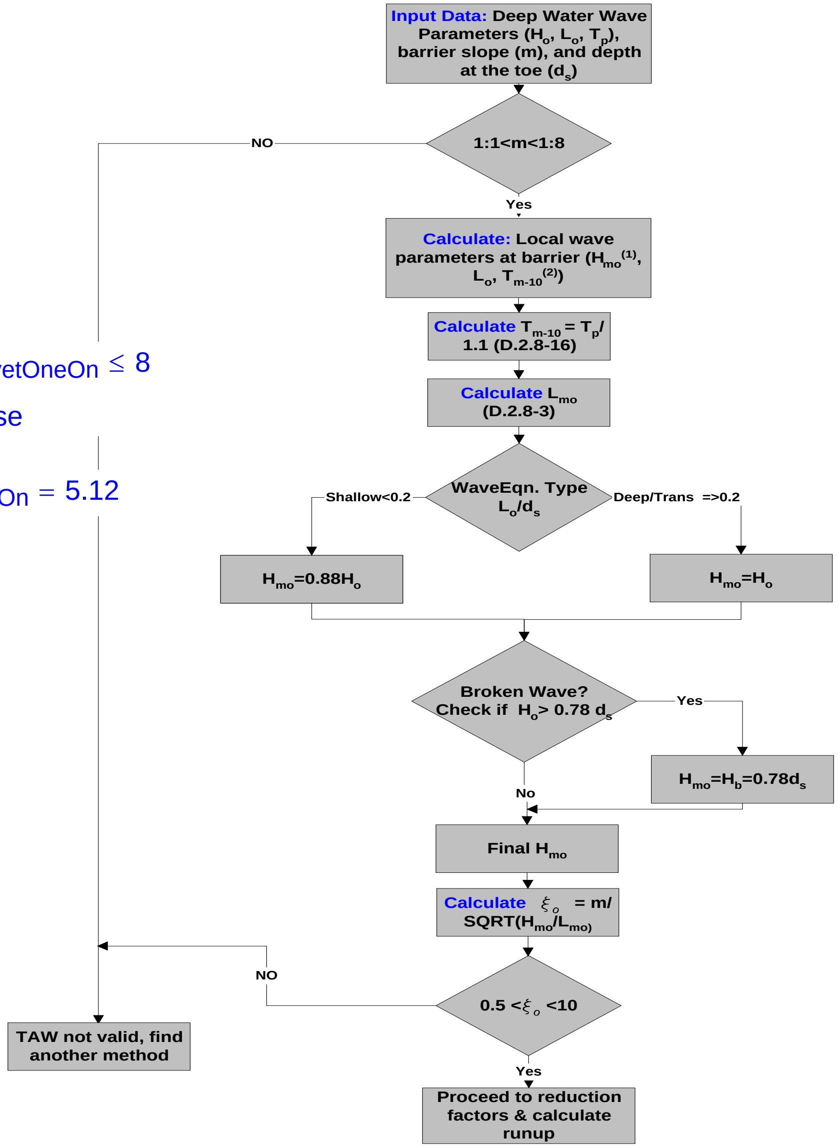
If wave is depth limited, H_b will be used rather than H_{m0}

$$\mathrm{Depth}_{\mathrm{Limited}} = \text{"Limited"}$$

Determine Wave Type:

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

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



Determine Significant Wave Height Depending on Wave Type and DepthLimited Condition:

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

$H_{m0runup1} = 18.59\,ft$

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

$H_{m0runup} = 5.95\,ft$

Calculate the Spectral Wave Period, T_{m10}

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

Equation D.2.8-16

$T_{m10} = 9.58\,s$

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

$L_{m0} = 470.13\,ft$

Calculate the Iribarren Number, ξ_{0m}:

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

$\xi_{om} = 1.74$

Check TAW Method for Validity based on Iribarren Number:

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

$Iribarren_{Check} = $ "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

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

$\gamma_r = 0.58$

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:

$\beta := 0$ 0º 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

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

$\gamma_p = 1$

Summary of Reduction Factors:

$\gamma_p = 1$

$\gamma_\beta = 1$

$\gamma_b = 1$

$\gamma_r = 0.58$

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

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

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

$R_{2\%} = 10.6\,\text{ft}$

Check for Overtopping:

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

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

6.0 Conclusions/Results

Wave Height, H_{m0} $H_{m0} = 21.13\,\mathrm{ft}$ FetchStatus = "STWAVE Input (Hmo, Tp)"

Wave Period, T_P $T_P = 10.54\,\mathrm{s}$ FetchStatus = "STWAVE Input (Hmo, Tp)"

Wave Setup on an open coast, η_{open} $\eta_{open} = 3.25\,\mathrm{ft}$

Wave Setup on a revetment, $\eta_{Structure}$ $\eta_{Structure} = 4.32\,\mathrm{ft}$

Wave Runup on a revetment, $R_{2\%}$ $R_{2\%} = 10.6\,\mathrm{ft}$

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

NOTES:

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 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

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

Modeler Name: M. Yarbrough
Date: March 29, 2013
County: Knox, ME
Transect Number: 67
Airport: unknown
Years of Dataset: unknown
Associated Files: E:\Region I\Setup\Knox County\Profiles\67.csv

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

$FailTop_{Sta}$ - 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

$$U_{10} := 124.67\frac{m}{s}$$

Wave speed based on:
Airport:
Taken from file:________________

$$U_{10} = 409.02\cdot\frac{ft}{s}$$

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

Insert X, fetch in miles:

$X := 12.84\cdot mi$ $\quad$ $X = 20663.98\cdot m$

Feature Class used:______________________
____

Calculate Coefficient of Drag, C_D:

$$C_D := 0.001\cdot\left[1.1 + \left(0.035\cdot U_{10}\cdot\frac{s}{m}\right)\right] \qquad C_D = 0.0055$$

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

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

Given

$$C_D = \frac{{u_s}^2}{{U_{10}}^2} \qquad u_s := \text{Find}(u_s) \qquad u_s = 9.22\cdot\frac{m}{s}$$

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

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

$X = 20663.98 \cdot m$

Given

$u_s = 9.22 \cdot \frac{m}{s}$ $g = 9.81 \frac{1}{s} \cdot \frac{m}{s}$

$$\frac{g \cdot H_{m0}}{u_s^2} = 0.0413 \cdot \left(\frac{g \cdot X}{u_s^2}\right)^{0.5}$$

$H_{m0} := \text{Find}(H_{m0})$ $H_{m0} = 0 \cdot m$

$H_{m0} = 0\,ft$

Calculate Wave Period, T_P (sec):

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

Given

$X = 20663.98 \cdot m$ $u_s = 9.22 \cdot \frac{m}{s}$ $g = 9.81 \frac{1}{s} \cdot \frac{m}{s}$

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

$T_P := \text{Find}(T_P)$ $T_P = 9.43 \cdot s$

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.

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

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

Feature Class:

Aces Output:

$H_{m0ACES} := -9999 \cdot ft$ $\qquad$ $T_{PACES} := -9999 \cdot sec$

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

ACES result file:

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

Not Clear where
this comes from
-nld 6/6/2020

$H_{m0STWAVE} := 4.31 \cdot m$ $\qquad$ $T_{PSTWAVE} := 11.05$

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

5.2 Wave Setup, η, Calculation

5.2.1 Open Coast Wave Setup Analysis

Definition of Variables:

$m := 0.094218$ Insert value of average transect slope based on GIS data

Not Clear where this comes from
-nld 6/6/2020

Calculate Deep Water Wave Length, L_0:

$$L_0 := \frac{g \cdot T_P^2}{2 \cdot \pi} \qquad L_0 = 625.25\,\text{ft}$$

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

Calculate Wave Slope, S:

$$S := \frac{H_{m0}}{L_0} \qquad S = 0.0226 \qquad S = 2.26 \cdot \%$$

Calculate Static Open Coast Wave Setup:

$$\eta_{open} := H_{m0} \cdot 0.160 \cdot \frac{m^{0.2}}{S^{0.2}} \qquad \eta_{open} = 3.01\,\text{ft}$$

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

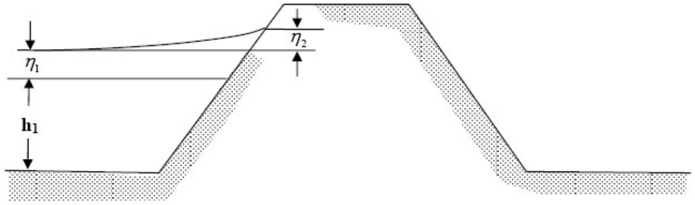


Figure D.2.6-6. Definition Sketch for Nonovertopped Levee

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("E:\Region I\Setup\Knox County\Profiles\67.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:

Profile =

	0	1
0	0	-26.1
1	3.28	-26.13
2	6.56	-26.15
3	9.84	-26.17
4	13.12	-26.2
5	16.4	-26.22
6	19.68	-26.25
7	22.96	...

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

$\text{Station} := \text{Station} \cdot 1 \cdot \text{ft}$

Array of horizontal distance from the shoreline

Station =

	0
0	0
1	3.28
2	6.56
3	...

ft

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

$\text{Elevation} := \text{Elevation} \cdot 1 \cdot \text{ft}$

Array of Elevations associated with each horizontal distance from the shoreline:

Elevation =

	0
0	-26.1
1	-26.13
2	-26.15
3	...

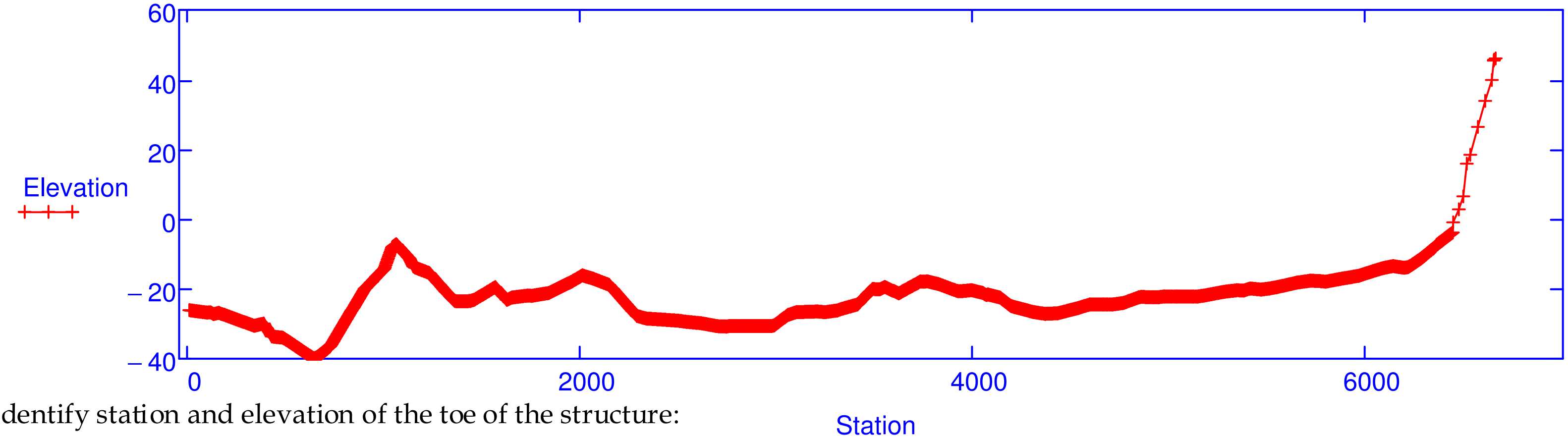
ft

Client: FEMA
County: Knox
Transect Number: 67

Wave Height and Wave Period Calculation Worksheet
CHK By/Date: M. Yarbrough 10/31/2012
RVW By/Date: M. Salisbury 01/21/2013

Calc By: M. Yarbrough
Date: 03/29/2013

The following displays the profile of the transect:



Identify station and elevation of the toe of the structure:

$\text{Toe}_{\text{sta}} := 6438.43 \cdot \text{ft}$ Input value representing coastal structure's bottom station (Toe_{sta})

$\text{Toe}_{\text{ele}} := \text{linterp}(\text{Station}, \text{Elevation}, \text{Toe}_{\text{sta}})$ $\text{Toe}_{\text{ele}} = -3.78\,\text{ft}$

Identify station and elevation of the top of the structure:

$\text{Top}_{\text{sta}} := 6565.17 \cdot \text{ft}$ Input value representing coastal structure's top station (Top_{sta})

$\text{Top}_{\text{ele}} := \text{linterp}(\text{Station}, \text{Elevation}, \text{Top}_{\text{sta}})$

Enter 1% annual chance stillwater elevation (ft): $\text{Top}_{\text{ele}} = 26.45\,\text{ft}$

$\text{SWEL} := 8.75 \cdot \text{ft}$ Associated excel file for calculation of 1% annual chance stillwater elevation (SWEL): __________

Calculate Water Depth at Structure, h

$h := \text{SWEL} - \text{Toe}_{\text{ele}}$ $h = 12.53\,\text{ft}$

Calculate the Breaking Wave Height, H_b:

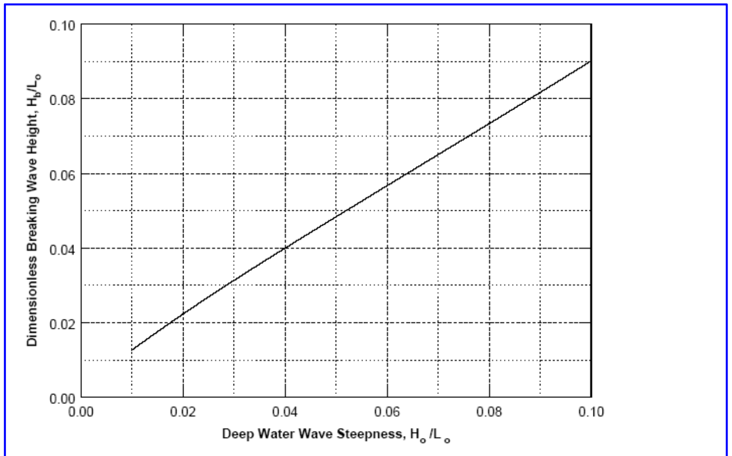


Figure D.2.6-7. Dimensionless Breaking Wave Height vs. Deepwater Wave Steepness

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

$b_h := 0.8481 \cdot S + 0.0057$ $\quad b_h = 0.02$ Estimated curve equation in Figure D.2.6-7

$H_b := b_h \cdot L_0$ $\quad H_b = 15.56\,\text{ft}$

Calculate the Breaking Wave Depth, H_d:

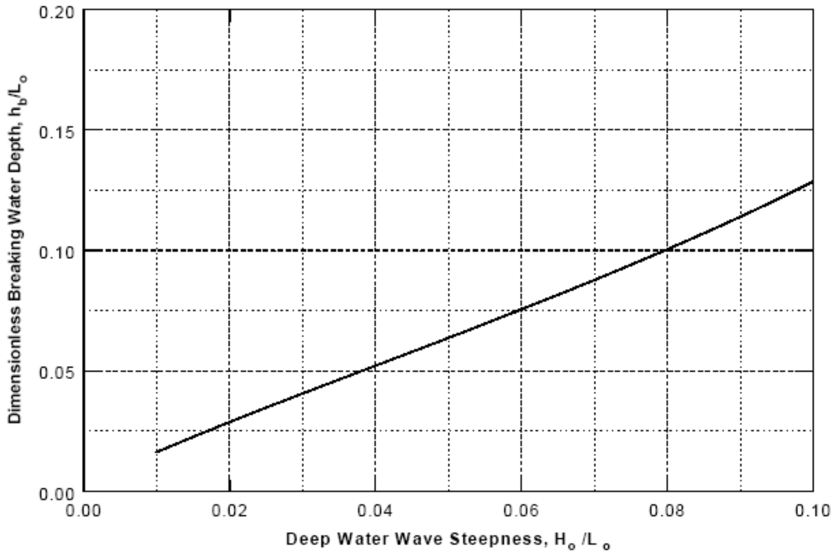


Figure D.2.6-8. Dimensionless Breaking Water Depth vs. Deepwater Wave Steepness.

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

$b_d := 1.2205 \cdot S + 0.0033$ $b_d = 0.03$ Estimated curve equation from Figure D.2.6-8

$H_d := b_d \cdot L_0$ $H_d = 19.32\,\text{ft}$

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

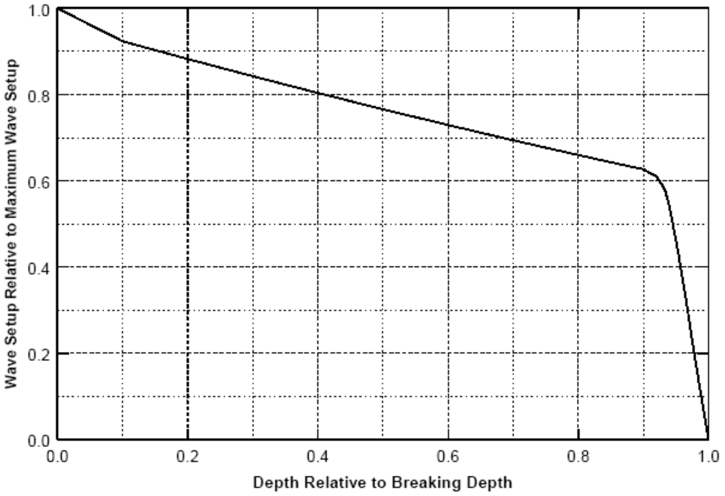


Figure D.2.6-9. Proportion of Maximum Wave Setup that Has Occurred vs. a Proportion of the Breaking Depth.

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

$R = 0.71$ $\frac{h}{H_d} = 0.65$

$\eta_1 := R\cdot\eta_{open}$ $\eta_1 = 2.14\,\text{ft}$ $\eta_2 := 0.15\cdot(h+\eta_1)$ $\eta_2 = 2.2\,\text{ft}$

$\eta_{Structure} := \eta_1 + \eta_2$ $\eta_{Structure} = 4.35\,\text{ft}$ Total Setup against a coastal structure without considering overtopping

Check Overtopping if Coastal Structure Exists:

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

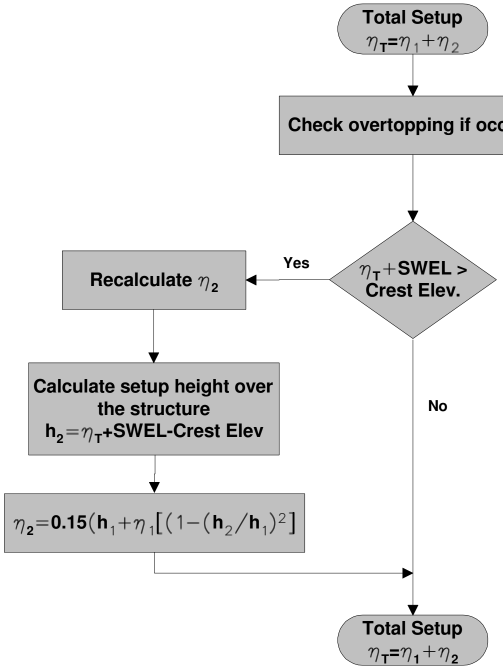
$$h_2 := \begin{cases} (\eta_{Structure} + SWEL - Top_{ele}) & \text{if Overtopped} = \text{"Yes"} \\ 0 & \text{otherwise} \end{cases}$$

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

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

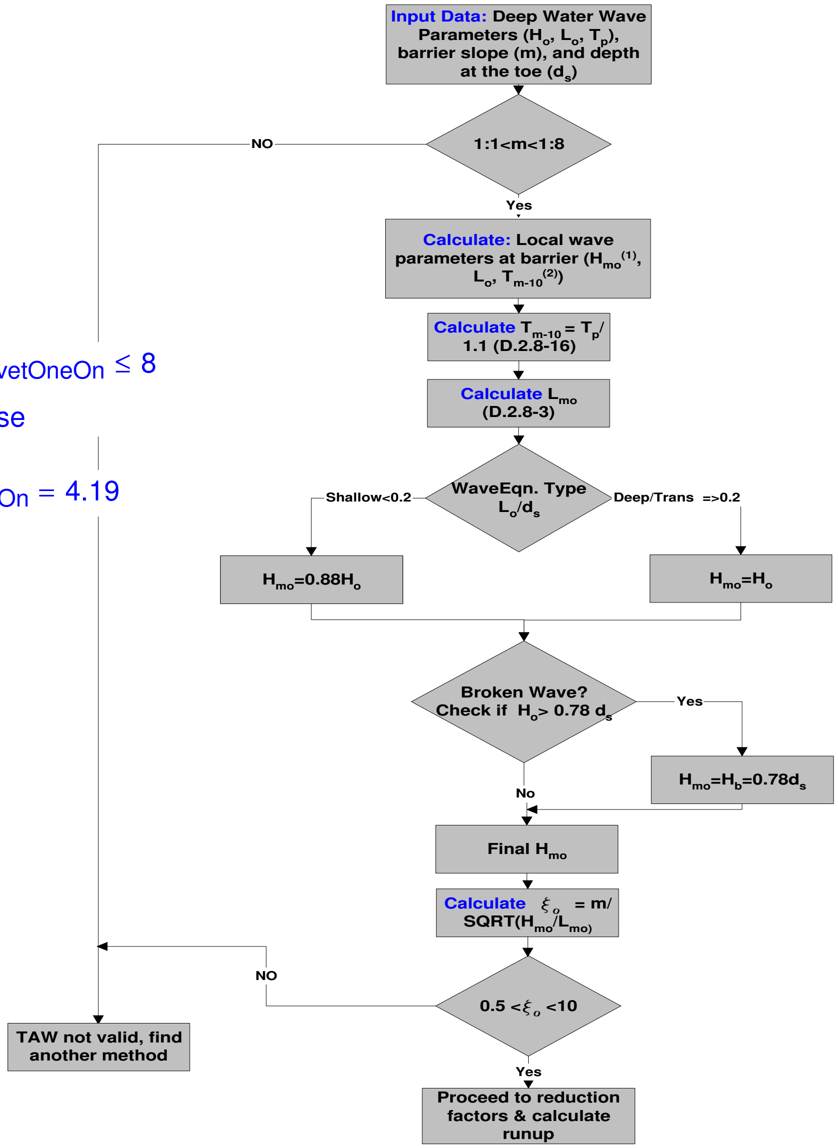
$$\eta_{Structure} := \eta_1 + \eta_2 \qquad \eta_{Structure} = 4.35\,\text{ft}$$

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:

$$\text{Slope}_{\text{Revet}} := \frac{(\text{Top}_{\text{ele}} - \text{Toe}_{\text{ele}})}{(\text{Top}_{\text{sta}} - \text{Toe}_{\text{sta}})} \qquad \text{Slope}_{\text{Revet}} = 23.85 \cdot \%$$

$$\text{Slope}_{\text{RevetOneOn}} := \frac{1}{\text{Slope}_{\text{Revet}}}$$

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

$$\text{Slope}_{\text{Check}} = \text{"TAW Method of Runup Calculation Applies"} \qquad \text{Slope}_{\text{RevetOneOn}} = 4.19$$

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

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

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

$$\text{Depth}_{\text{Limited}} = \text{"Limited"}$$

Determine Wave Type:

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

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

Determine Significant Wave Height Depending on Wave Type and DepthLimited Condition:

$$H_{m0runup1} := \begin{cases} 0.88 \cdot H_{m0} & \text{if } \; WaveType = \text{"Shallow"} \\ H_{m0} & \text{otherwise} \end{cases} \qquad H_{m0runup1} = 12.44\,\text{ft}$$

$$H_{m0runup} := \begin{cases} 0.78 \cdot h & \text{if } \; Depth_{Limited} = \text{"Limited"} \\ H_{m0runup1} & \text{otherwise} \end{cases} \qquad H_{m0runup} = 9.77\,\text{ft}$$

Calculate the Spectral Wave Period, T_{m10}

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

Equation D.2.8-16

$$T_{m10} = 10.05\,\text{s}$$

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

$$L_{m0} = 516.73\,\text{ft}$$

Calculate the Iribarren Number, ξ_{0m}:

$$\xi_{om} := \frac{Slope_{Revet}}{\sqrt{\dfrac{H_{m0runup}}{L_{m0}}}} \qquad \xi_{om} = 1.73$$

Check TAW Method for Validity based on Iribarren Number:

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

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

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

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

$\gamma_r = 0.58$

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

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

$\gamma_p = 1$

Summary of Reduction Factors:

$\gamma_p = 1$

$\gamma_\beta = 1$

$\gamma_b = 1$

$\gamma_r = 0.58$

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

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

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

$R_{2\%} = 17.4\,\text{ft}$

Check for Overtopping:

$$\text{OVERTOPPED}_{\text{Runup}} := \left| \begin{array}{l} \text{"Overtopped... Please consider 3 foot rule"} \quad \text{if } \left(R_{2\%} + \text{SWEL}\right) > \text{Top}_{\text{ele}} \\ \text{"NO Overtopping"} \quad \text{otherwise} \end{array} \right.$$

$\text{OVERTOPPED}_{\text{Runup}} = \text{"NO Overtopping"}$

6.0 Conclusions/Results

Wave Height, H_{m0} $H_{m0} = 14.14\,\text{ft}$ $\text{FetchStatus} = \text{"STWAVE Input (Hmo, Tp)"}$

Wave Period, T_P $T_P = 11.05\,\text{s}$ $\text{FetchStatus} = \text{"STWAVE Input (Hmo, Tp)"}$

Wave Setup on an open coast, η_{open} $\eta_{open} = 3.01\,\text{ft}$

Wave Setup on a revetment, $\eta_{Structure}$ $\eta_{Structure} = 4.35\,\text{ft}$

Wave Runup on a revetment, $R_{2\%}$ $R_{2\%} = 17.4\,\text{ft}$

$\text{OVERTOPPED}_{\text{Runup}} = \text{"NO Overtopping"}$

NOTES:

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 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

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

Modeler Name: M. Yarbrough
Date: May 14, 2013
County: Knox, ME
Transect Number: 68
Airport: unknown
Years of Dataset: unknown
Associated Files: E:\Region I\Setup\Knox County\Profiles\68.csv

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

$FailTop_{Sta}$ - 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:

$$U_{10} := 124.67\,\frac{m}{s}$$

$$U_{10} = 409.02\cdot\frac{ft}{s}$$

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

Wave speed based on:
Airport:
Taken from file:_______________

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

Insert X, fetch in miles:

$$X := 12.84\cdot mi \qquad X = 20663.98\cdot m$$

Feature Class used:_____________________
____

Calculate Coefficient of Drag, C_D:

$$C_D := 0.001\cdot\left[1.1 + \left(0.035\cdot U_{10}\cdot\frac{s}{m}\right)\right] \qquad C_D = 0.0055$$

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

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

Given

$$C_D = \frac{u_s^{\,2}}{U_{10}^{\,2}} \qquad u_s := \mathrm{Find}(u_s) \qquad u_s = 9.22\cdot\frac{m}{s}$$

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

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

$X = 20663.98 \cdot m$

Given

$u_S = 9.22 \cdot \frac{m}{s}$ $g = 9.81 \frac{1}{s} \cdot \frac{m}{s}$

$$\frac{g \cdot H_{m0}}{u_S^{\,2}} = 0.0413 \cdot \left(\frac{g \cdot X}{u_S^{\,2}}\right)^{0.5}$$

$H_{m0} := \text{Find}(H_{m0})$ $H_{m0} = 0 \cdot m$

$H_{m0} = 0\,ft$

Calculate Wave Period, T_P (sec):

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

Given

$X = 20663.98 \cdot m$ $u_S = 9.22 \cdot \frac{m}{s}$ $g = 9.81 \frac{1}{s} \cdot \frac{m}{s}$

$$\frac{g \cdot T_P}{u_S} = 0.751 \cdot \left(\frac{g \cdot X}{u_S^{\,2}}\right)^{\frac{1}{3}}$$

$T_P := \text{Find}(T_P)$ $T_P = 9.43 \cdot s$

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.

$\mathrm{ACESInput}_{Ang} := \begin{pmatrix} \blacksquare \\ \blacksquare \\ \blacksquare \\ \blacksquare \\ \blacksquare \\ \blacksquare \\ \blacksquare \\ \blacksquare \\ \blacksquare \end{pmatrix}$

$\mathrm{ACESInput}_{Fetch} := \begin{pmatrix} \blacksquare \\ \blacksquare \\ \blacksquare \\ \blacksquare \\ \blacksquare \\ \blacksquare \\ \blacksquare \\ \blacksquare \\ \blacksquare \end{pmatrix}$

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

Feature Class:

Aces Output:

$H_{m0ACES} := -9999 \cdot ft$

$T_{PACES} := -9999 \cdot sec$

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

ACES result file:

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

Not Clear where this comes from -nld 6/6/2020

$H_{m0STWAVE} := 4.65 \cdot m$

$T_{PSTWAVE} :=$

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

5.2 Wave Setup, η, Calculation

5.2.1 Open Coast Wave Setup Analysis

Definition of Variables:

$m := 0.174525$ Insert value of average transect slope based on GIS data

Not clear where this comes from. Seems too steep for average transect slope based on figure below
-nld 6/6/2020

Calculate Deep Water Wave Length, L_0:

$L_0 := \frac{g \cdot T_P^2}{2 \cdot \pi}$ $L_0 = 482.8\,ft$ Equation source: Coastal Engineering Manual Part VI Page VI-5-236

Calculate Wave Slope, S:

$S := \frac{H_{m0}}{L_0}$ $S = 0.0316$ $S = 3.16 \cdot \%$

Calculate Static Open Coast Wave Setup:

$\eta_{open} := H_{m0} \cdot 0.160 \cdot \frac{m^{0.2}}{S^{0.2}}$ $\eta_{open} = 3.44\,ft$ 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

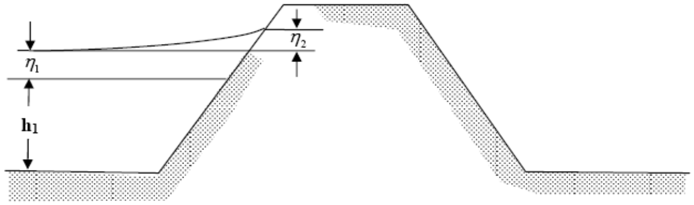


Figure D.2.6-6. Definition Sketch for Nonovertopped Levee

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("C:\Users\21677\Desktop\Knox Drafts\68.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:

Profile =

	0	1
0	0	-140.41
1	3.28	-140.55
2	6.56	-140.69
3	9.84	-140.83
4	13.12	-140.97
5	16.4	-141.11
6	19.68	-141.25
7	22.96	...

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

$$\text{Station} := \text{Station} \cdot 1 \cdot \text{ft}$$

Array of horizontal distance from the shoreline

Station =

	0
0	0
1	3.28
2	6.56
3	...

ft

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

$$\text{Elevation} := \text{Elevation} \cdot 1 \cdot \text{ft}$$

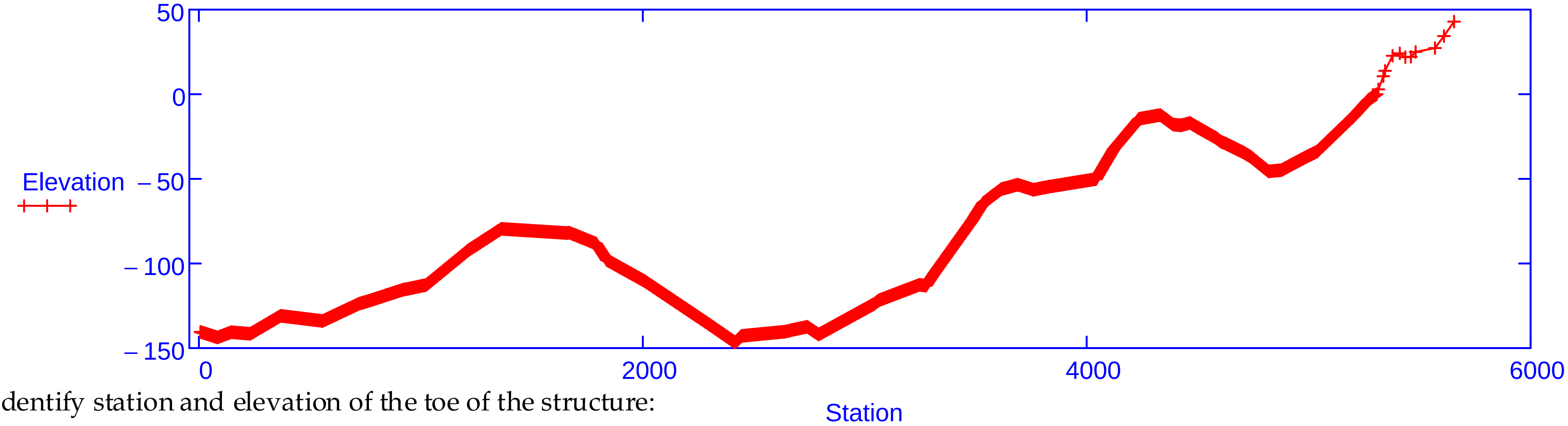
Array of Elevations associated with each horizontal distance from the shoreline:

Elevation =

	0
0	-140.41
1	-140.55
2	-140.69
3	...

ft

The following displays the profile of the transect:



Identify station and elevation of the toe of the structure:

$Toe_{sta} := 5304.68 \cdot ft$ Input value representing coastal structure's bottom station (Toe_{sta})

$Toe_{ele} := \text{linterp}(Station, Elevation, Toe_{sta})$ $Toe_{ele} = -0\,ft$

Identify station and elevation of the top of the structure:

$Top_{sta} := 5377.23 \cdot ft$ Input value representing coastal structure's top station (Top_{sta})

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

Enter 1% annual chance stillwater elevation (ft): $Top_{ele} = 22.74\,ft$

$SWEL := 8.88 \cdot ft$ Associated excel file for calculation of 1% annual chance stillwater elevation (SWEL): __________

Calculate Water Depth at Structure, h

$h := SWEL - Toe_{ele}$ $h = 8.88\,ft$

Calculate the Breaking Wave Height, H_b:

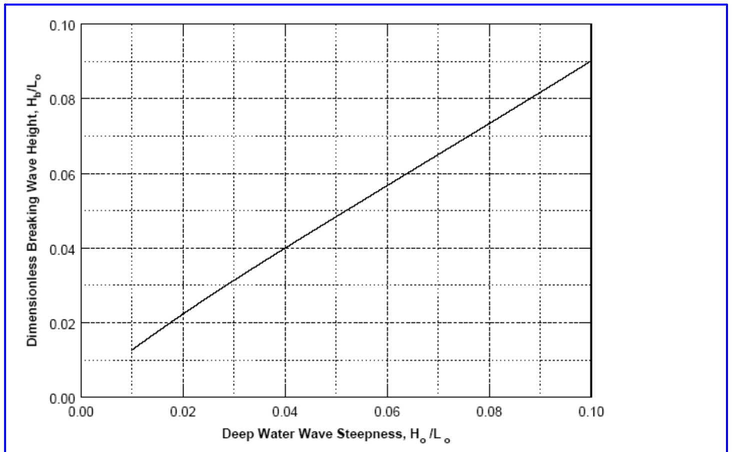


Figure D.2.6-7. Dimensionless Breaking Wave Height vs. Deepwater Wave Steepness

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

$b_h := 0.8481 \cdot S + 0.0057$ $b_h = 0.03$ Estimated curve equation in Figure D.2.6-7

$H_b := b_h \cdot L_0$ $H_b = 15.69\,\text{ft}$

Calculate the Breaking Wave Depth, H_d:

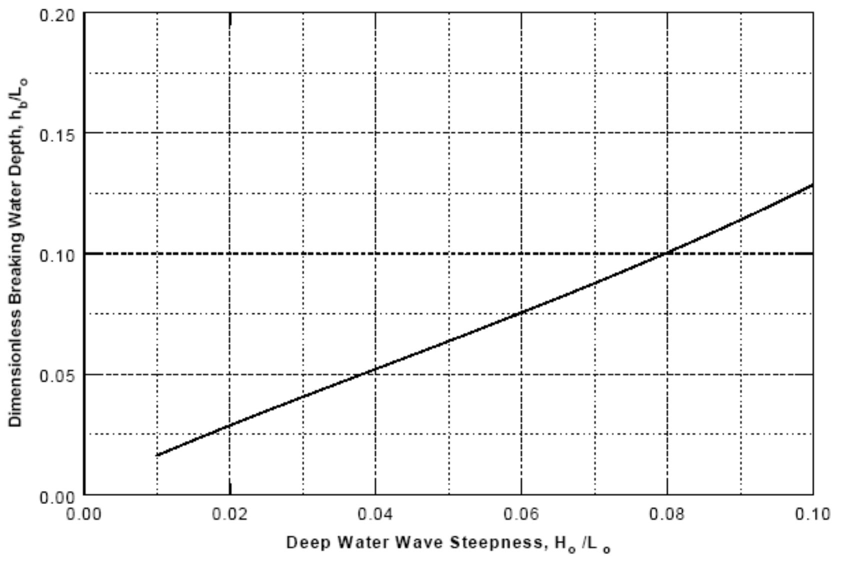


Figure D.2.6-8. Dimensionless Breaking Water Depth vs. Deepwater Wave Steepness.

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

$b_d := 1.2205 \cdot S + 0.0033$ $b_d = 0.04$ Estimated curve equation from Figure D.2.6-8

$H_d := b_d \cdot L_0$ $H_d = 20.21\,\text{ft}$

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

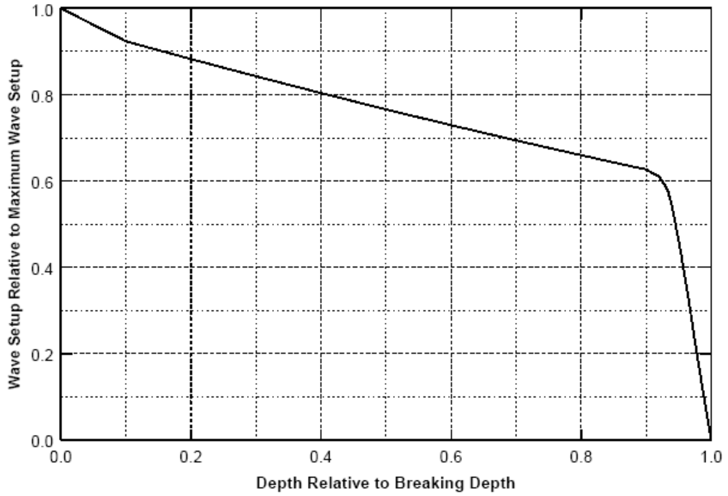


Figure D.2.6-9. Proportion of Maximum Wave Setup that Has Occurred vs. a Proportion of the Breaking Depth.

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

$R = 0.79$ $\frac{h}{H_d} = 0.44$

$\eta_1 := R\cdot\eta_{open}$ $\eta_1 = 2.7\,ft$ $\eta_2 := 0.15\cdot(h+\eta_1)$ $\eta_2 = 1.74\,ft$

$\eta_{Structure} := \eta_1 + \eta_2$ $\eta_{Structure} = 4.43\,ft$ Total Setup against a coastal structure without considering overtopping

Check Overtopping if Coastal Structure Exists:

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

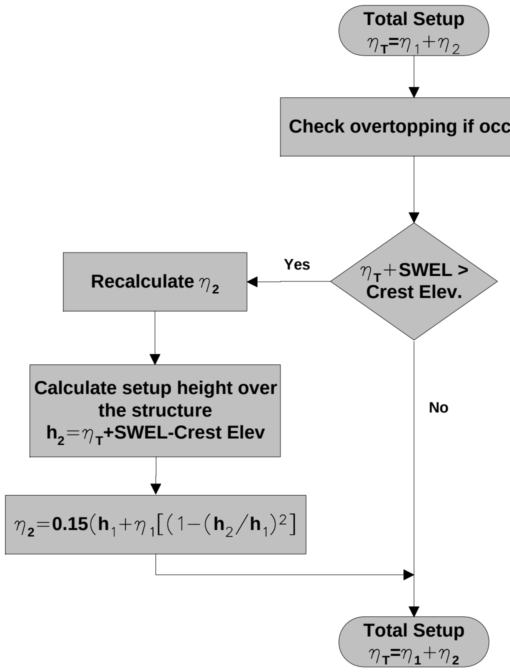
$$h_2 := \begin{cases} (\eta_{Structure} + SWEL - Top_{ele}) & \text{if Overtopped} = \text{"Yes"} \\ 0 & \text{otherwise} \end{cases}$$

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

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

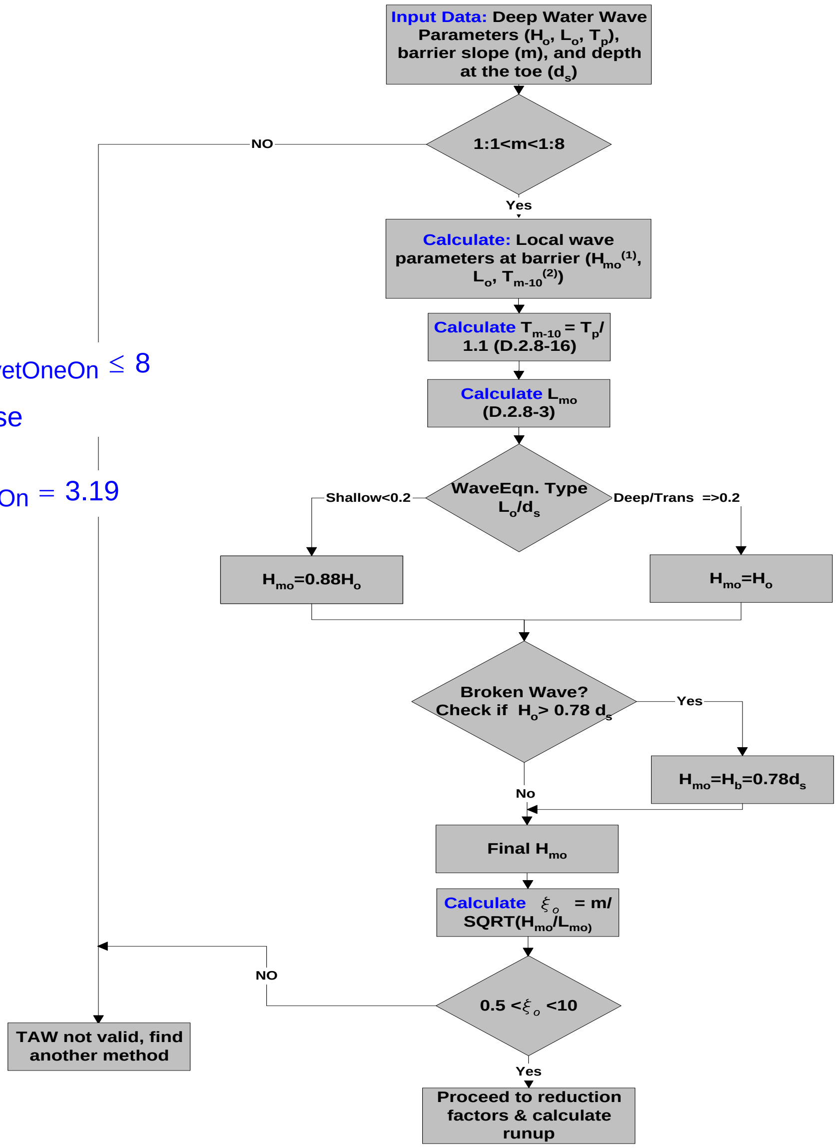
$$\eta_{Structure} := \eta_1 + \eta_2 \qquad \eta_{Structure} = 4.43\,\text{ft}$$

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:

$$Slope_{Revet} := \frac{(Top_{ele} - Toe_{ele})}{(Top_{sta} - Toe_{sta})} \qquad Slope_{Revet} = 31.34 \cdot \%$$

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

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

$$Slope_{Check} = \text{"TAW Method of Runup Calculation Applies"} \qquad Slope_{RevetOneOn} = 3.19$$

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}

$$Depth_{Limited} = \text{"Limited"}$$

Determine Wave Type:

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

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

Determine Significant Wave Height Depending on Wave Type and DepthLimited Condition:

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

$$H_{m0runup1} = 13.43\,\text{ft}$$

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

$$H_{m0runup} = 6.93\,\text{ft}$$

Calculate the Spectral Wave Period, T_{m10}

$$T_{m10} := \frac{T_P}{1.1}$$ Equation D.2.8-16 $$T_{m10} = 8.83\,\text{s}$$

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 $$L_{m0} = 399.01\,\text{ft}$$

Calculate the Iribarren Number, ξ_{0m}:

$$\xi_{om} := \frac{Slope_{Revet}}{\sqrt{\frac{H_{m0runup}}{L_{m0}}}}$$ $$\xi_{om} = 2.38$$

Check TAW Method for Validity based on Iribarren Number:

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

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

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

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

$\gamma_r = 0.58$

Select Berm Section in Breakwater, γ_b:

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

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

$\gamma_b = 1$

Select Wave Direction Factor, γ_β:

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

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

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

$\gamma_\beta = 1$

Select Porosity Factor, γ_P:

Porosity :=
○ 0.1
○ 0.4
● 0.5
○ 0.6

Default Porosity = 0.5

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

$\gamma_p = 1$

Summary of Reduction Factors:

$\gamma_p = 1$

$\gamma_\beta = 1$

$\gamma_b = 1$

$\gamma_r = 0.58$

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

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

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

$R_{2\%} = 13.11\,\text{ft}$

Check for Overtopping:

$$\mathrm{OVERTOPPED}_{\mathrm{Runup}} := \left| \begin{array}{l} \text{"Overtopped... Please consider 3 foot rule"} \quad \text{if} \quad (R_{2\%} + \mathrm{SWEL}) > \mathrm{Top}_{\mathrm{ele}} \\ \text{"NO Overtopping"} \quad \text{otherwise} \end{array} \right.$$

$\mathrm{OVERTOPPED}_{\mathrm{Runup}}$ = "NO Overtopping"

6.0 Conclusions/Results

Wave Height, H_{m0} — $H_{m0} = 15.26\,\mathrm{ft}$ — FetchStatus = "STWAVE Input (Hmo, Tp)"

Wave Period, T_P — $T_P = 9.71\,\mathrm{s}$ — FetchStatus = "STWAVE Input (Hmo, Tp)"

Wave Setup on an open coast, η_{open} — $\eta_{open} = 3.44\,\mathrm{ft}$

Wave Setup on a revetment, $\eta_{Structure}$ — $\eta_{Structure} = 4.43\,\mathrm{ft}$

Wave Runup on a revetment, $R_{2\%}$ — $R_{2\%} = 13.11\,\mathrm{ft}$

$\mathrm{OVERTOPPED}_{\mathrm{Runup}}$ = "NO Overtopping"

NOTES:

Project: FEMA RI - KNOX ACES
Group: ACES_KNOX

Case: KN-60

Windspeed Adjustment and Wave Growth

Breaking criteria 0.780

Item	Value	Units
El of Observed Wind (Zobs)	33.00	feet
Observed Wind Speed (Uobs)	56.10	mph
Air Sea Temp. Diff. (dT)	0.00	deg F
Dur of Observed Wind (DurO)	3.00	hours
Dur of Final Wind (DurF)	3.00	hours
Lat. of Observation (LAT)	44.50	deg
Results		
Wind Fetch Length (F)	0.23	MILES
Wind Direction (WDIR)	14.00	deg
Eq Neutral Wind Speed (Ue)	50.48	mph
Adjusted Wind Speed (Ua)	75.92	mph
Mean Wave Direction (THETA)	14.00	deg
Wave Height (Hmo)	1.02	feet
Wave Period (Tp)	1.76	sec

Wind Obs Type	Wind Fetch Options
Overwater	Deep restricted

Restricted Fetch Geometry

#	Fetch Angle (deg)	Fetch Length (miles)
1	9.00	0.32
2	14.00	0.30
3	19.00	0.32

Wave Growth: Deep

Project: FEMA RI - KNOX ACES
Group: ACES_KNOX

Case: KN-61

Windspeed Adjustment and Wave Growth

Breaking criteria 0.780

Item	Value	Units
El of Observed Wind (Zobs)	33.00	feet
Observed Wind Speed (Uobs)	56.10	mph
Air Sea Temp. Diff. (dT)	0.00	deg F
Dur of Observed Wind (DurO)	3.00	hours
Dur of Final Wind (DurF)	3.00	hours
Lat. of Observation (LAT)	44.50	deg
Results		
Wind Fetch Length (F)	0.86	MILES
Wind Direction (WDIR)	320.30	deg
Eq Neutral Wind Speed (Ue)	50.48	mph
Adjusted Wind Speed (Ua)	75.92	mph
Mean Wave Direction (THETA)	320.00	deg
Wave Height (Hmo)	1.99	feet
Wave Period (Tp)	2.56	sec

Wind Obs Type	Wind Fetch Options
Overwater	Deep restricted

Restricted Fetch Geometry

#	Fetch Angle (deg)	Fetch Length (miles)
1	315.30	1.23
2	320.30	1.18
3	325.30	1.11

Wave Growth: Deep

Project: FEMA RI - KNOX ACES
Group: ACES_KNOX

Case: KN-62

Windspeed Adjustment and Wave Growth

Breaking criteria 0.780

Item	Value	Units
El of Observed Wind (Zobs)	33.00	feet
Observed Wind Speed (Uobs)	56.10	mph
Air Sea Temp. Diff. (dT)	0.00	deg F
Dur of Observed Wind (DurO)	3.00	hours
Dur of Final Wind (DurF)	3.00	hours
Lat. of Observation (LAT)	44.50	deg
Results		
Wind Fetch Length (F)	0.37	MILES
Wind Direction (WDIR)	236.10	deg
Eq Neutral Wind Speed (Ue)	50.48	mph
Adjusted Wind Speed (Ua)	75.92	mph
Mean Wave Direction (THETA)	236.00	deg
Wave Height (Hmo)	1.30	feet
Wave Period (Tp)	2.02	sec

Wind Obs Type	Wind Fetch Options
Overwater	Deep restricted

Restricted Fetch Geometry

#	Fetch Angle (deg)	Fetch Length (miles)
1	231.10	0.50
2	236.10	0.51
3	241.10	0.50

Wave Growth: Deep

Project: FEMA RI - KNOX ACES
Group: ACES_KNOX

Case: KN-63

Windspeed Adjustment and Wave Growth

Breaking criteria 0.780

Item	Value	Units
El of Observed Wind (Zobs)	33.00	feet
Observed Wind Speed (Uobs)	56.10	mph
Air Sea Temp. Diff. (dT)	0.00	deg F
Dur of Observed Wind (DurO)	3.00	hours
Dur of Final Wind (DurF)	3.00	hours
Lat. of Observation (LAT)	44.50	deg
Results		
Wind Fetch Length (F)	0.49	MILES
Wind Direction (WDIR)	214.70	deg
Eq Neutral Wind Speed (Ue)	50.48	mph
Adjusted Wind Speed (Ua)	75.92	mph
Mean Wave Direction (THETA)	215.00	deg
Wave Height (Hmo)	1.50	feet
Wave Period (Tp)	2.18	sec

Wind Obs Type	Wind Fetch Options
Overwater	Deep restricted

Restricted Fetch Geometry

#	Fetch Angle (deg)	Fetch Length (miles)
1	209.70	0.65
2	214.70	0.70
3	219.70	0.63

Wave Growth: Deep

Project: FEMA RI - KNOX ACES
Group: ACES_KNOX

Case: KN-68_Validation

Windspeed Adjustment and Wave Growth

Breaking criteria 0.780

Item	Value	Units
El of Observed Wind (Zobs)	33.00	feet
Observed Wind Speed (Uobs)	56.10	mph
Air Sea Temp. Diff. (dT)	0.00	deg F
Dur of Observed Wind (DurO)	3.00	hours
Dur of Final Wind (DurF)	3.00	hours
Lat. of Observation (LAT)	44.50	deg
Results		
Wind Fetch Length (F)	5.25	MILES
Wind Direction (WDIR)	67.60	deg
Eq Neutral Wind Speed (Ue)	50.48	mph
Adjusted Wind Speed (Ua)	75.92	mph
Mean Wave Direction (THETA)	68.00	deg
Wave Height (Hmo)	4.90	feet
Wave Period (Tp)	4.24	sec

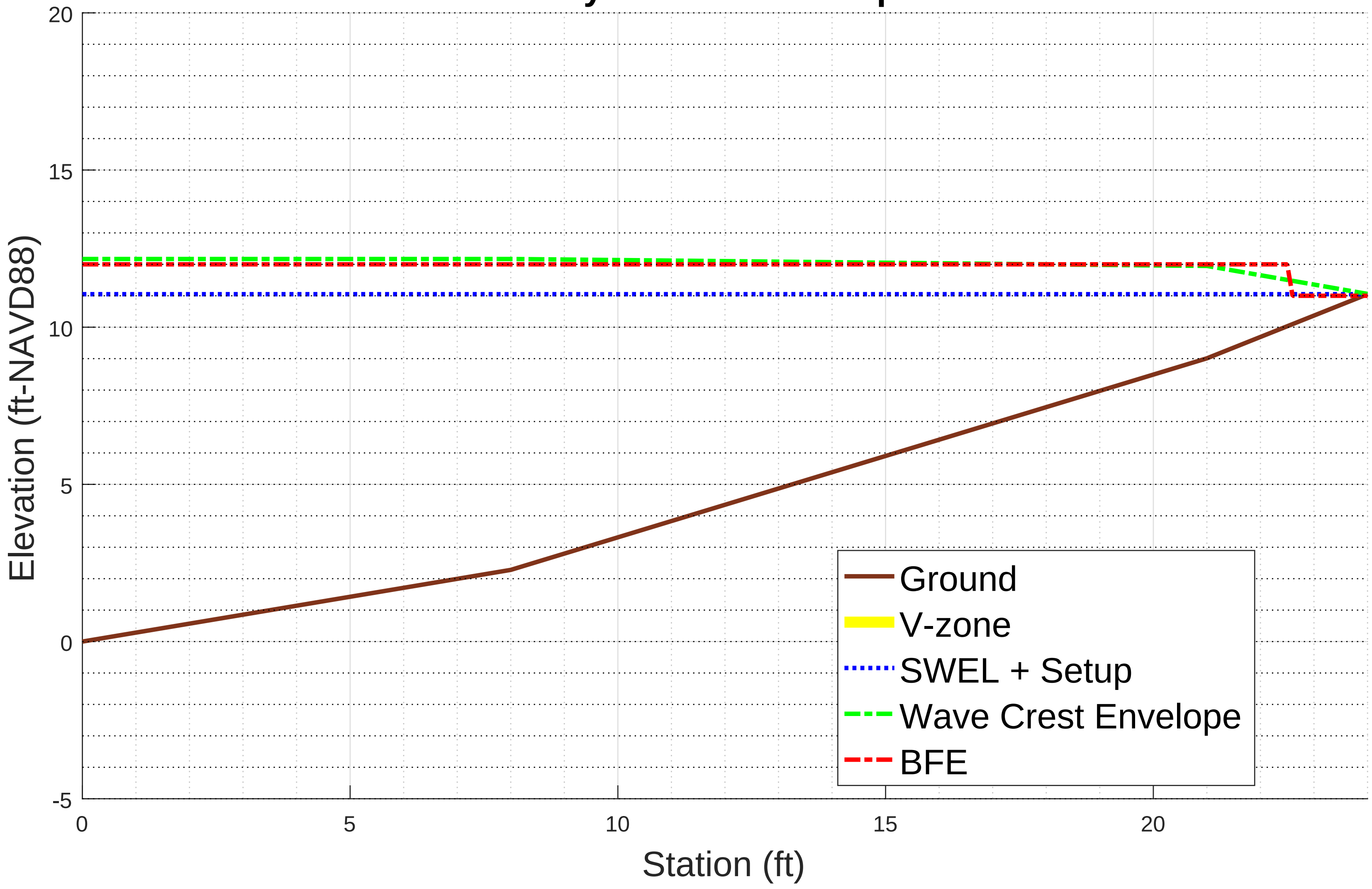
Wind Obs Type	Wind Fetch Options
Overwater	Deep restricted

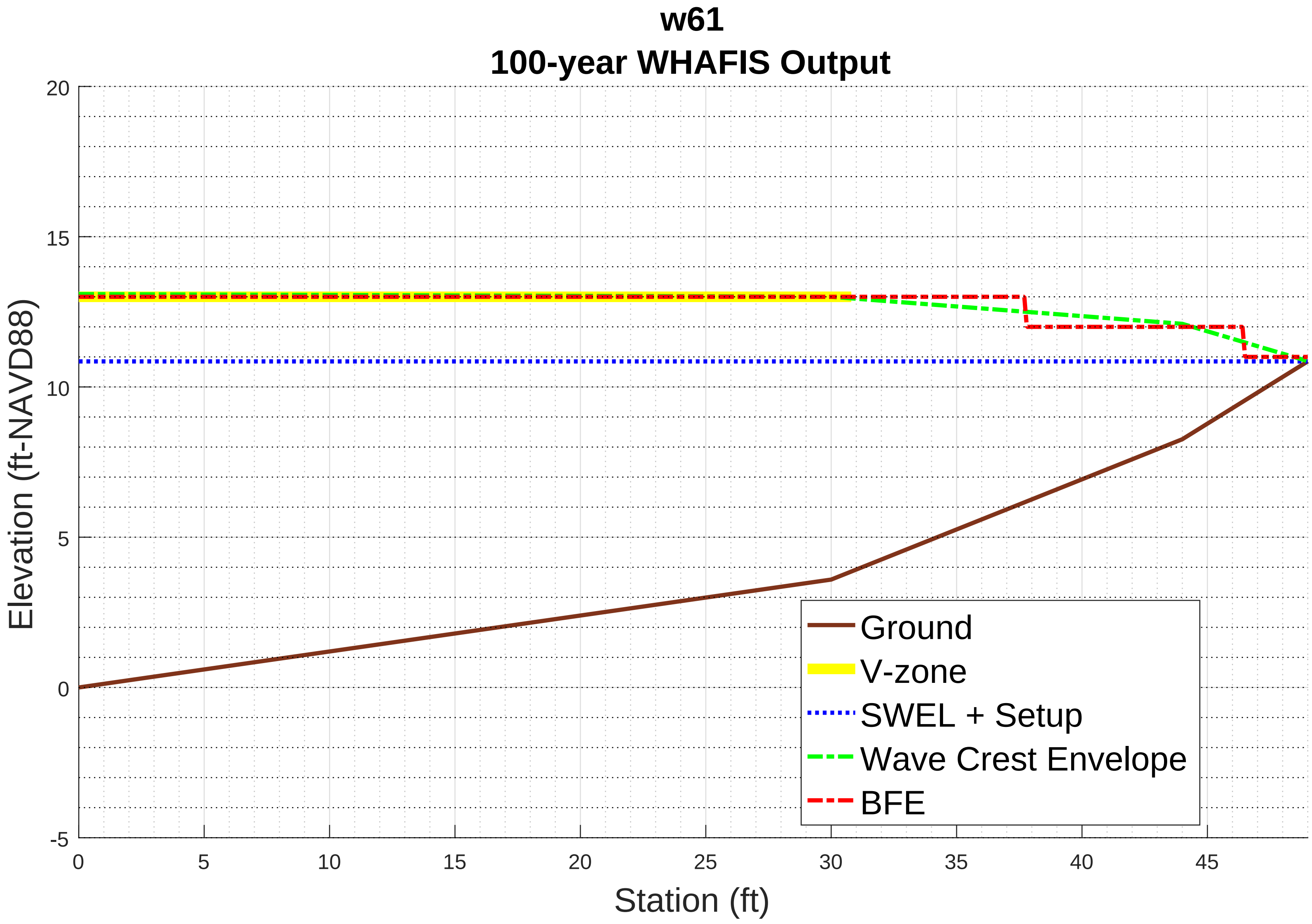
Restricted Fetch Geometry

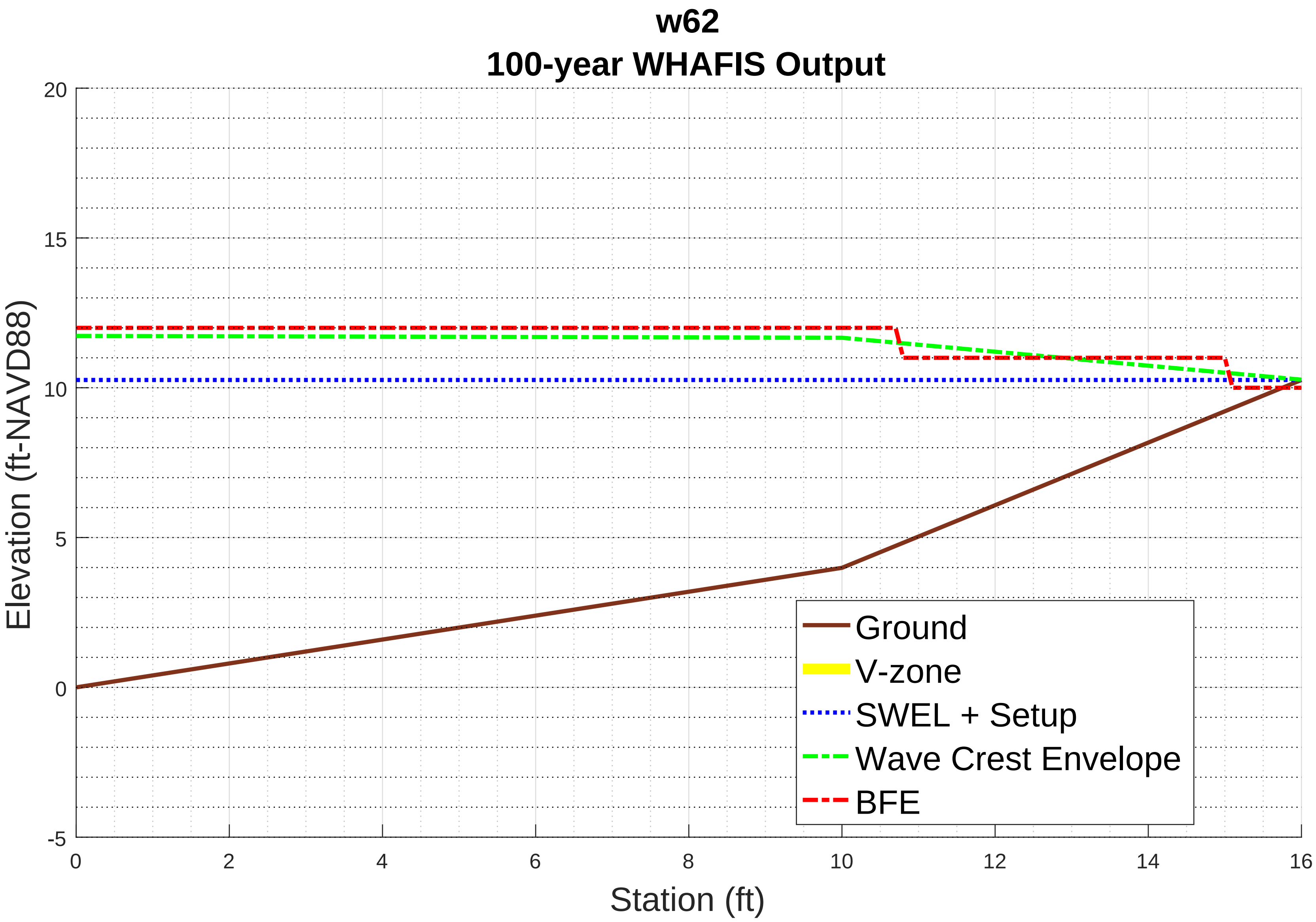
#	Fetch Angle (deg)	Fetch Length (miles)
1	62.60	4.69
2	67.60	7.66
3	72.60	8.30

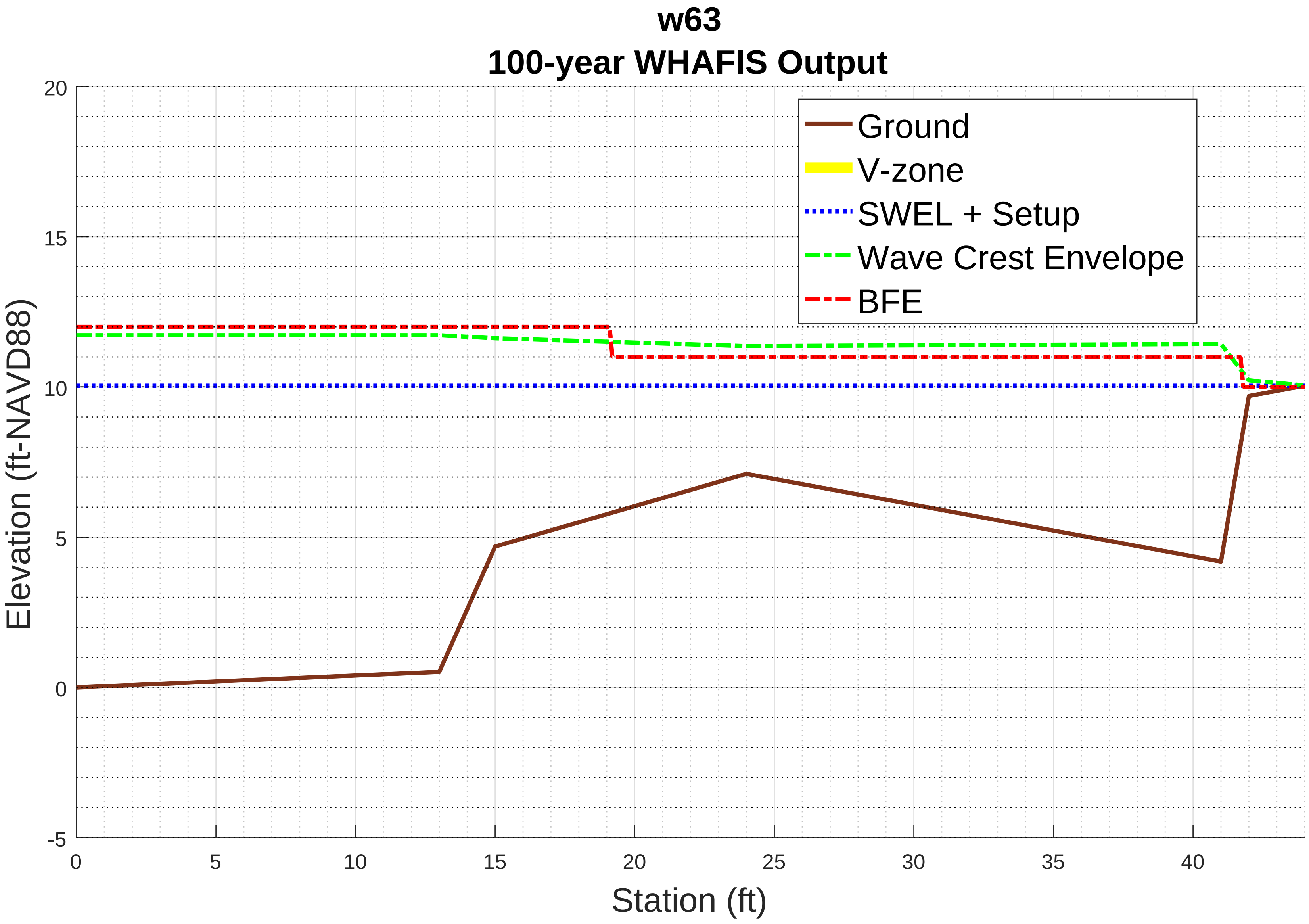
Wave Growth: Deep

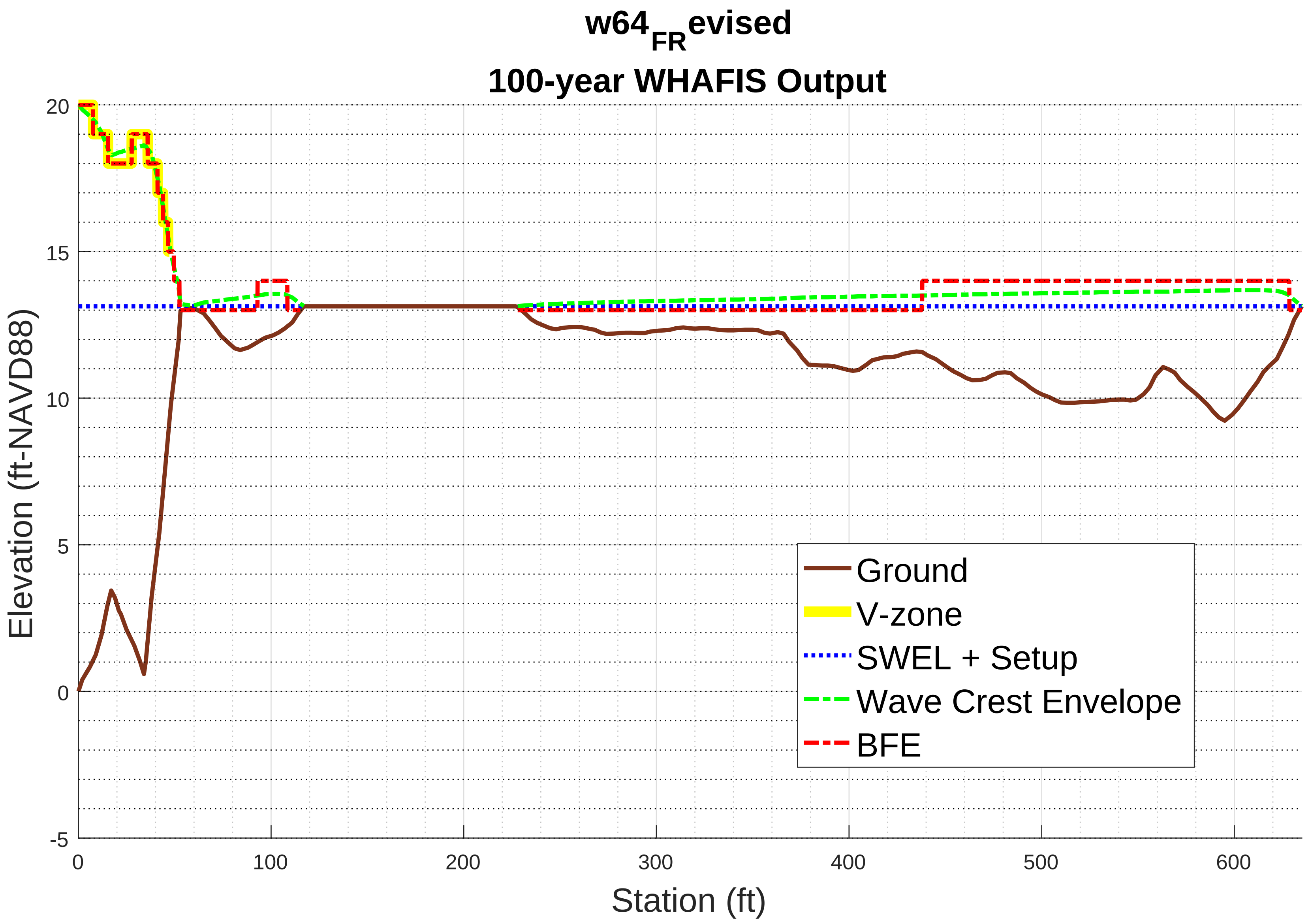
w60
100-year WHAFIS Output

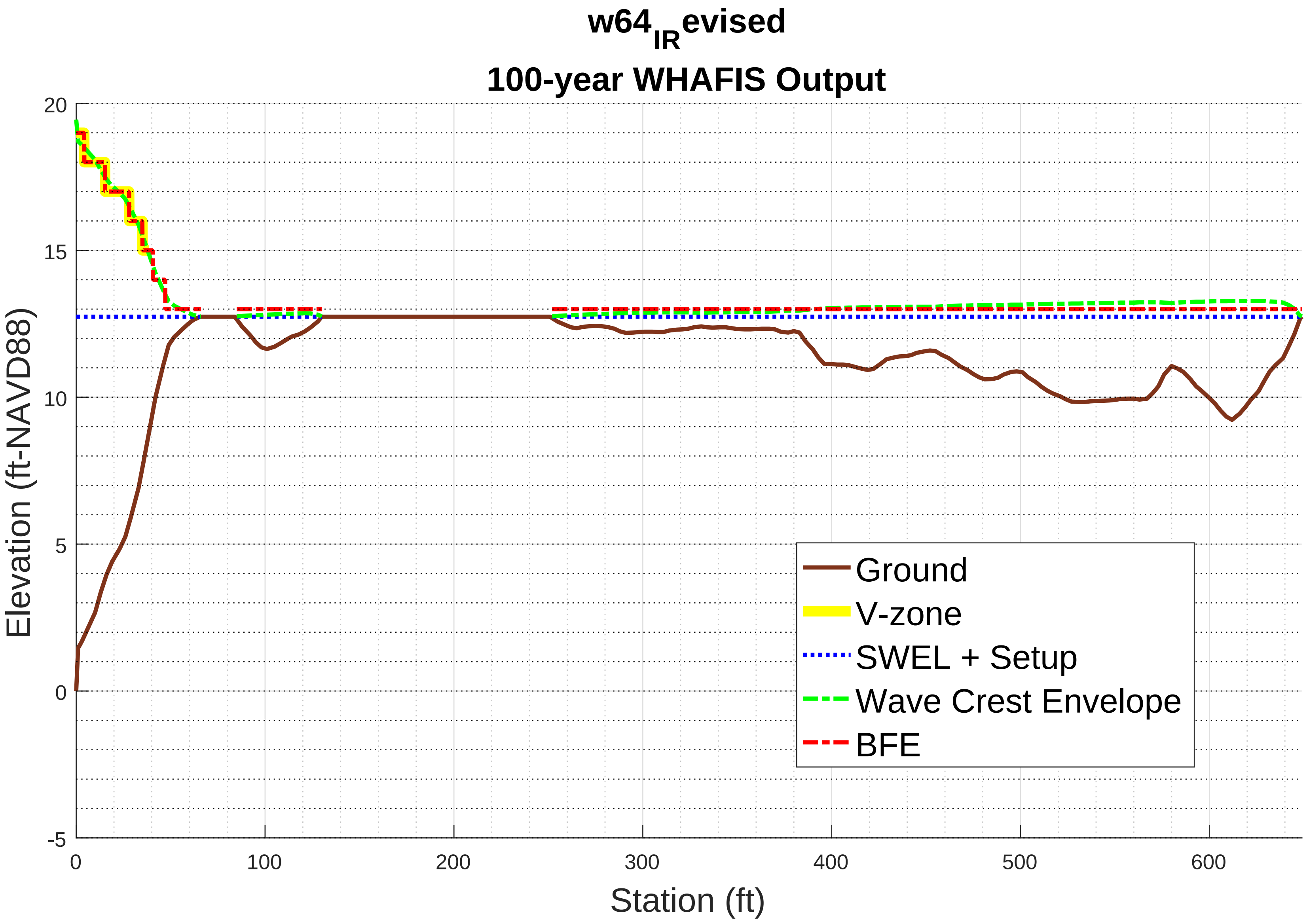



w61
100-year WHAFIS Output
Elevation (ft-NAVD88)
20
15
10
5
0
-5
Station (ft)
0
5
10
15
20
25
30
35
40
45
Ground
V-zone
SWEL + Setup
Wave Crest Envelope
BFE


w62
100-year WHAFIS Output
Elevation (ft-NAVD88)
20
15
10
5
0
-5
0
2
4
6
8
10
12
14
16
Station (ft)
Ground
V-zone
SWEL + Setup
Wave Crest Envelope
BFE


w63
100-year WHAFIS Output
Ground
V-zone
SWEL + Setup
Wave Crest Envelope
BFE
Elevation (ft-NAVD88)
20
15
10
5
0
-5
0
5
10
15
20
25
30
35
40
Station (ft)

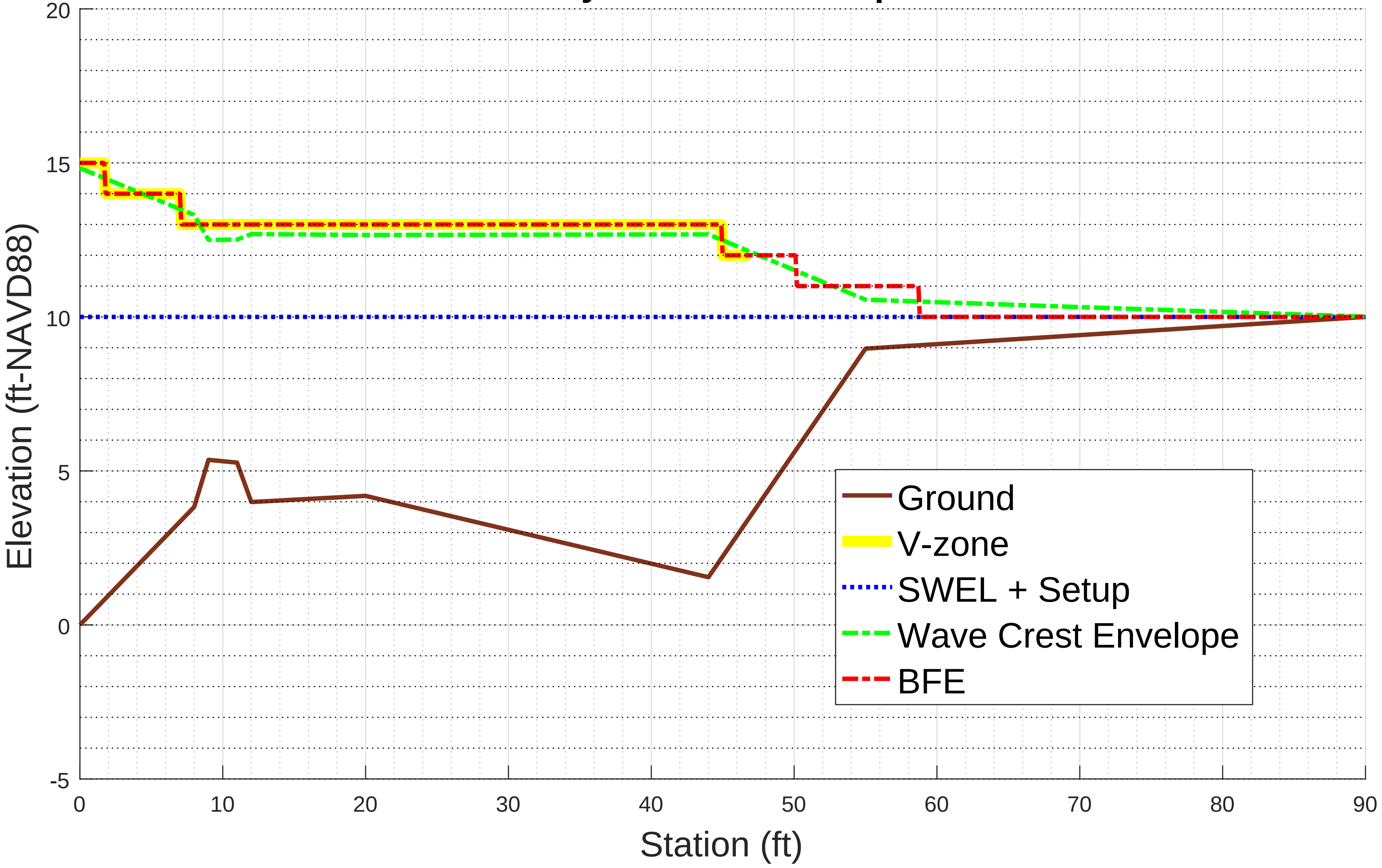

w64$_{FR}$evised
100-year WHAFIS Output
Elevation (ft-NAVD88)
20
15
10
5
0
-5
Station (ft)
0
100
200
300
400
500
600
Ground
V-zone
SWEL + Setup
Wave Crest Envelope
BFE



w64$_{IR}$evised
100-year WHAFIS Output
Elevation (ft-NAVD88)
20
15
10
5
0
-5
0
100
200
300
400
500
600
Station (ft)
Ground
V-zone
SWEL + Setup
Wave Crest Envelope
BFE

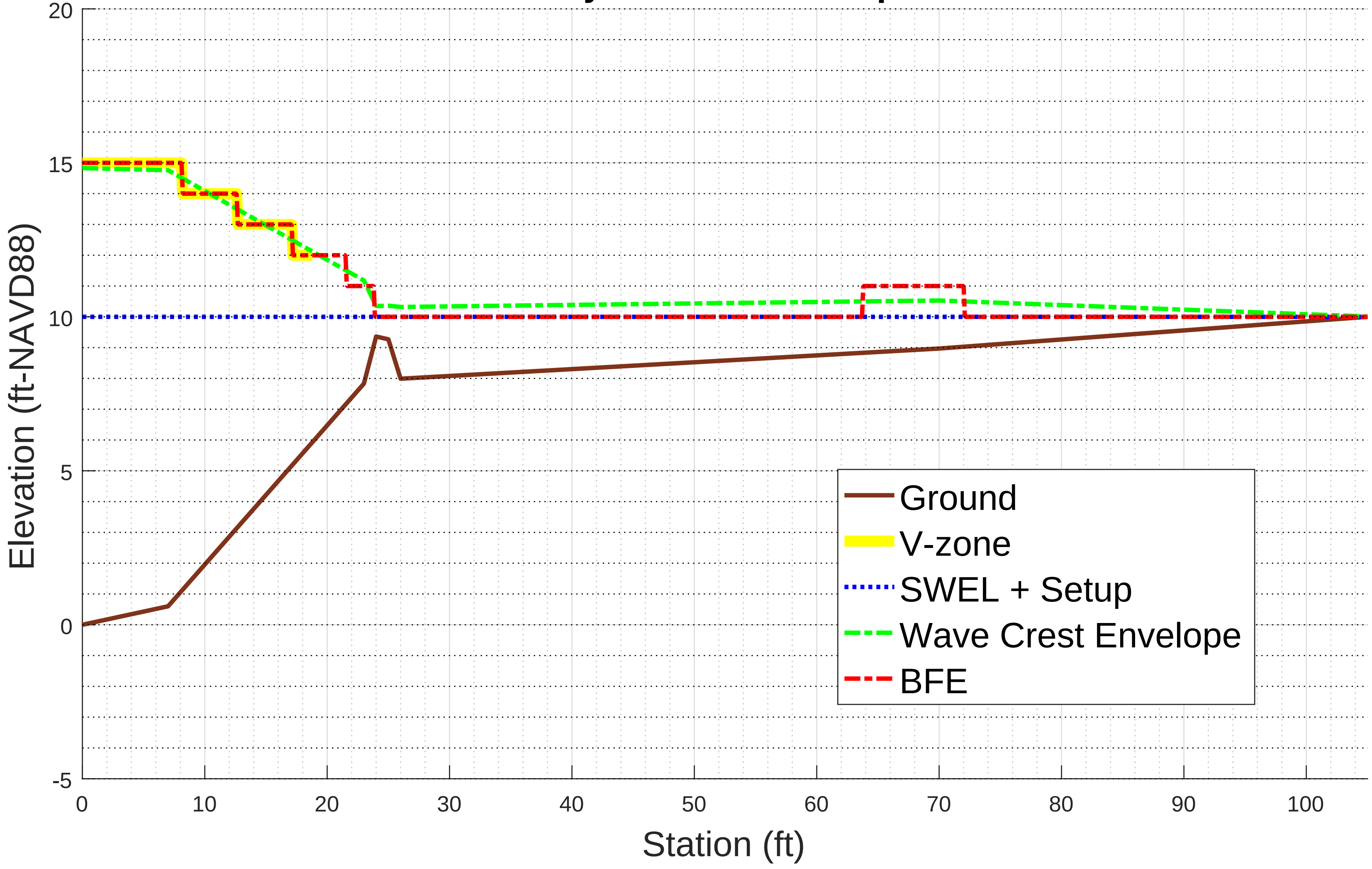
$w65_F$

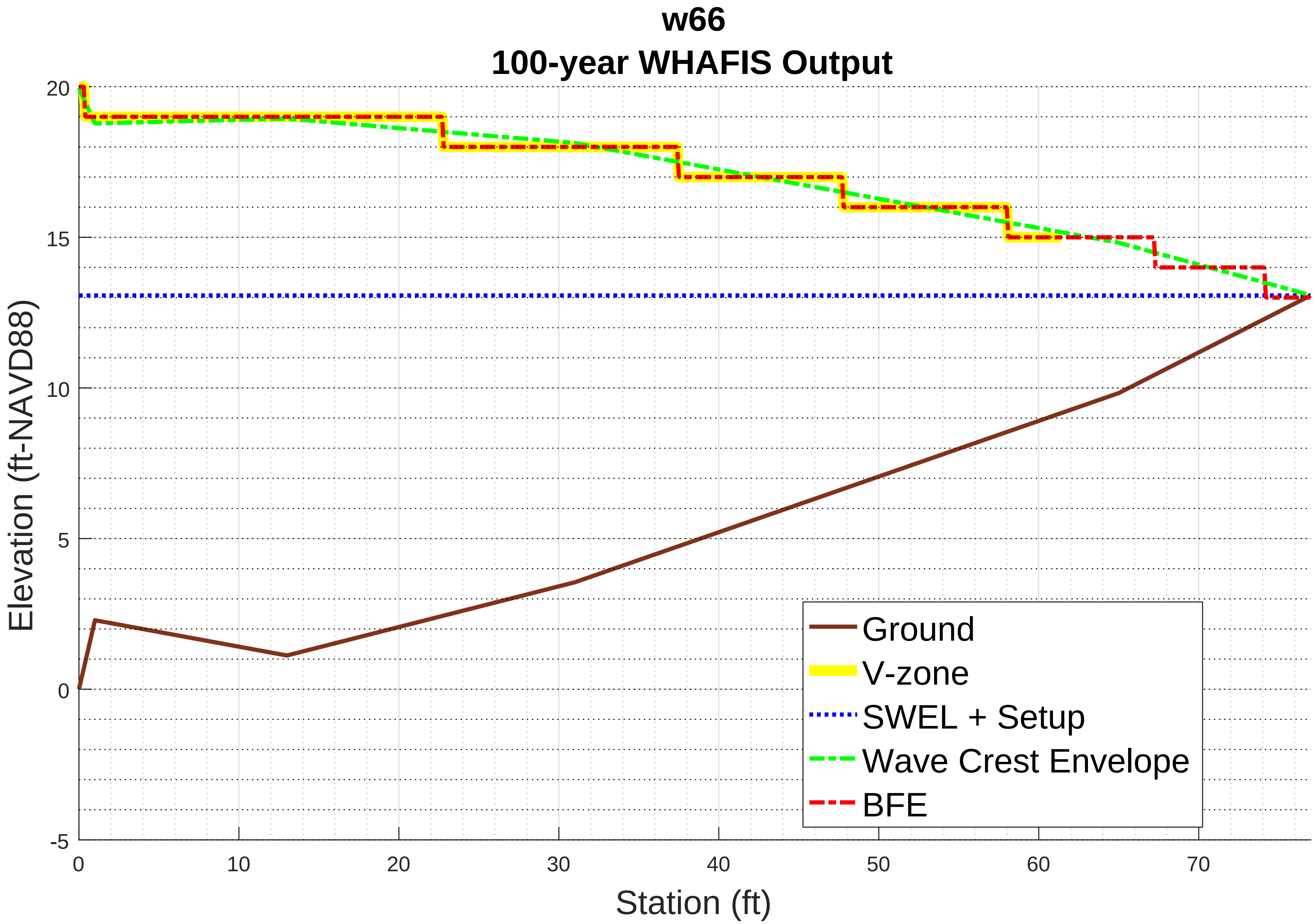
100-year WHAFIS Output



w65$_l$

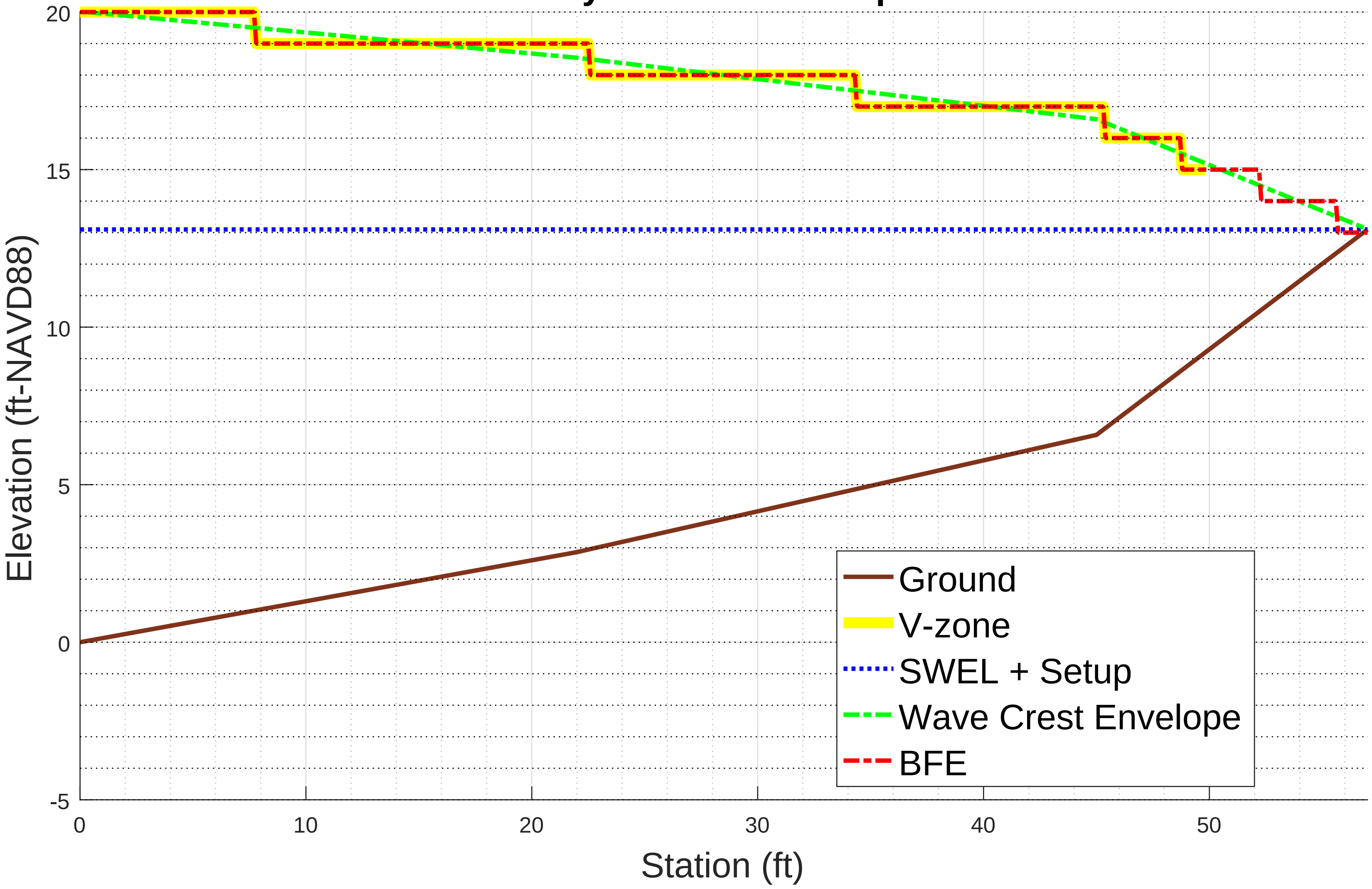
100-year WHAFIS Output

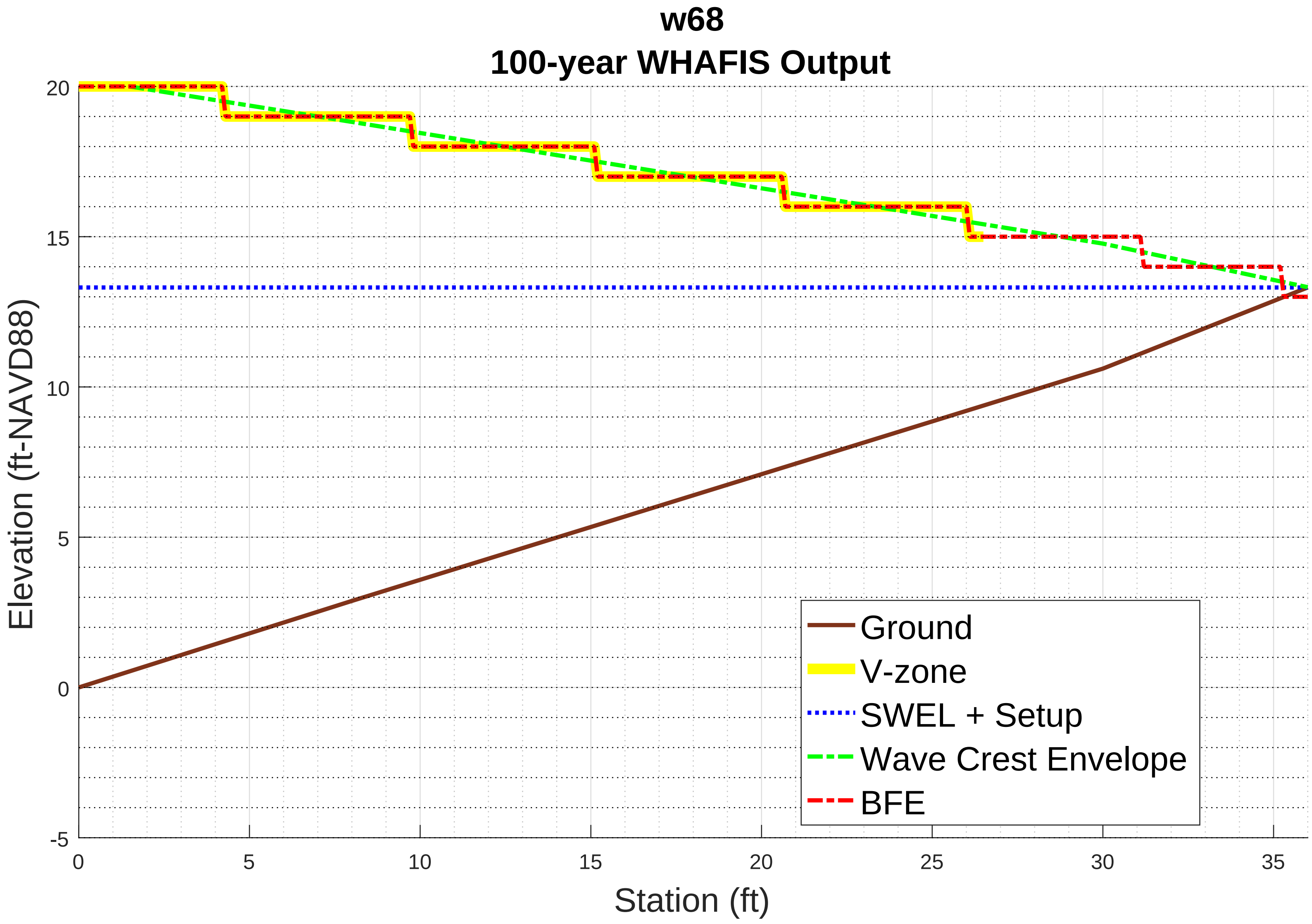




w66
100-year WHAFIS Output

w67
100-year WHAFIS Output




w68
100-year WHAFIS Output
Elevation (ft-NAVD88)
Station (ft)
20
15
10
5
0
-5
0
5
10
15
20
25
30
35
Ground
V-zone
SWEL + Setup
Wave Crest Envelope
BFE

Attachment C
Coastal Analysis Transect Data Summary Table

Memo to the Town of Vinalhaven
Review of Flood Insurance Rate Mapping
June 22, 2020

Ransom Consulting, LLC
Project 191.06064

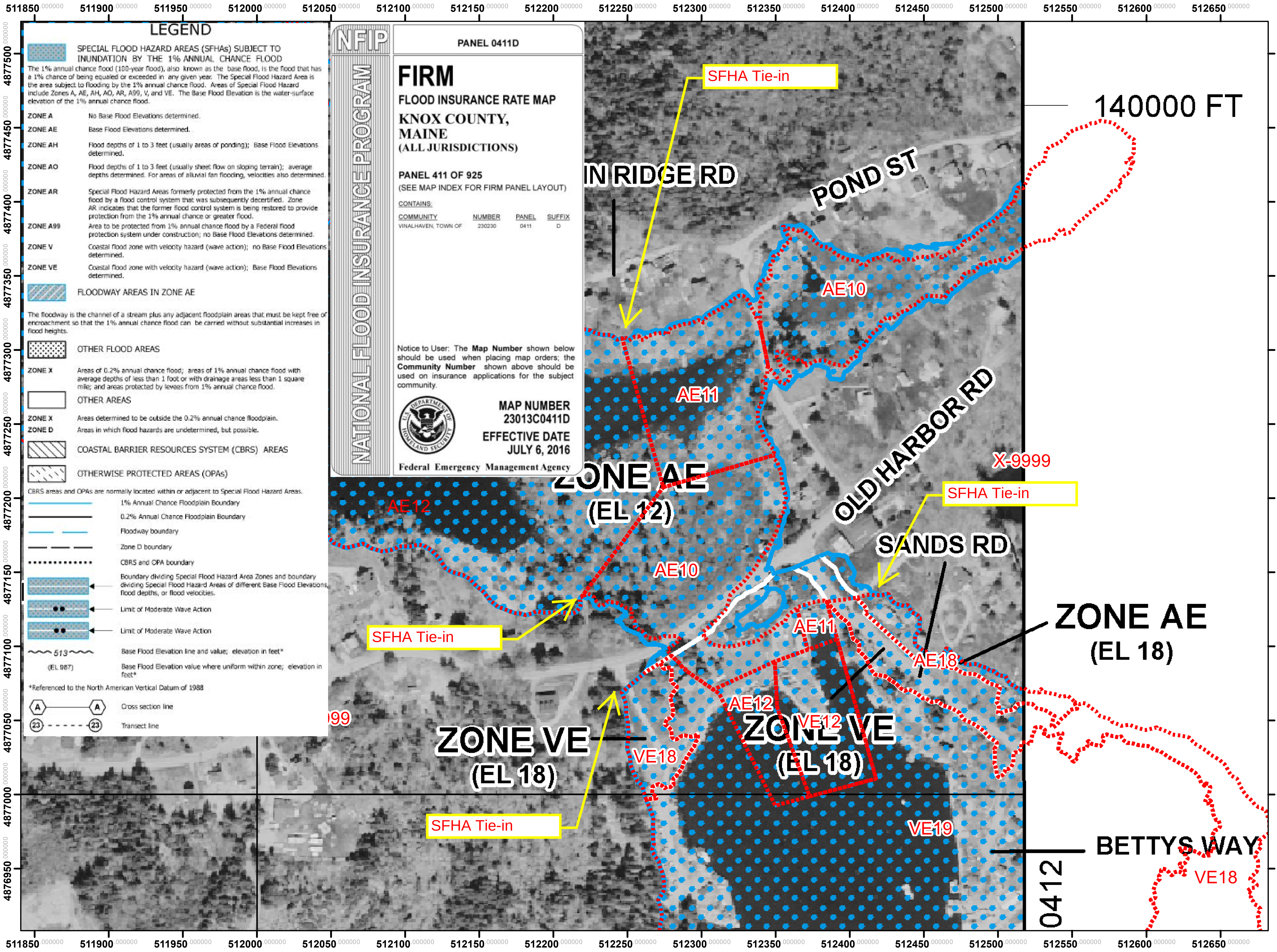
Transect ID	Still Water Level (ft-NAVD88)	Significant wave height (ft)	Peak Wave Period (s)	Wave Source	Slope	Open Coast Wave Setup (ft)	FEMA Coastal Structure Wave Setup (ft)	Corrected Coastal Structure Setup (ft)	FEMA Total Water Level (ft-NAVD88)	Corrected Total Water Level (ft-NAVD88)	2% Runup Height (ft)	2% Runup elevation (ft-NAVD88)	WHAFIS Max Wave Crest Elev. (ft-NAVD88)	FEMA Mapped Zone	Decision	Ransom Comment
60	9.0	1.02	1.76	ACES	0.53	0.25	2.08	0.20	11.08	9.25	1.87	10.87	12.17	AE 12	WHAFIS	Correction to wave setup and TWL might reduce BFE 1 ft
61	8.9	2.00	2.56	ACES	0.37	0.46	1.94	0.38	10.84	9.36	1.71	10.61	13.09	VE 13	WHAFIS	Correction to wave setup and TWL might reduce BFE 1 ft
62	8.9	1.31	2.02	ACES	1.09	0.37	1.40	0.25	10.30	9.27	2.51	11.41	11.73	AE 12	WHAFIS	Correction to wave setup and TWL might reduce BFE 1 ft
63	8.8	1.51	2.18	ACES	5.29	0.59	1.24	0.29	10.04	9.39	1.66	10.46	11.72	AE 12	WHAFIS	Correction to wave setup and TWL might reduce BFE 1-2 ft
64	8.8	19.13	10.41	STWAVE	0.03	2.97	3.98	NA	12.78	NA	8.09	16.89	19.45	VE 19, VE 18, AE 18	Unclear	Wave height possibly too large, unclear where values were taken from STWAVE, mapping is inconsistent with analysis results
64 Failed	8.8	19.13	10.41	STWAVE	0.03	2.97	4.37	NA	13.17	NA	8.90	17.70	20.04	Unclear	Unclear	Wave height possibly too large, unclear where values were taken from STWAVE, mapping is inconsistent with analysis results
65	8.8	4.30	10.04	STWAVE	0.15	1.23	NA	NA	10.03	NA	0.12	8.92	14.83	VE 13, AE 10	WHAFIS	Wave height possibly too large, unclear where values were taken from STWAVE, Transect location and profile is unrepresentative of most of the mapped area, VE zone is not reasonable for Carvers Pond
65 Failed	8.8	4.30	10.04	STWAVE	0.15	1.23	NA	NA	10.03	NA	0.84	9.64	14.83	above	above	above
66	8.8	21.13	10.54	STWAVE	0.03	3.25	4.32	NA	13.12	NA	10.60	19.40	19.96	VE 19	Runup	Not clear where wave data come from. BFE appears to be based runup and is reasonable, but extending zone extent to 19' contour may not be appropriate in some portions of the zone where the shoreline slope is flatter and
67	8.8	14.14	11.05	STWAVE	0.09	3.01	4.35	NA	13.15	NA	17.40	26.20	20.02	VE 26	Runup	Not clear where wave data come from. wave height seems large considering partial sheltering here and attenuation that would occur in Carvers Cove, zone based on runup should not extend so far landward
68	8.9	15.26	9.71	STWAVE	0.17	3.44	4.43	NA	13.33	NA	13.11	22.01	20.27	VE 22	Runup	Not clear where wave data come from. The transect location is not representative of sheltered shoreline, zone based on runup should not extend so far landward

Attachment D

Annotated FIRM from LOMR case 20-01-0545P (under review)

Memo to the Town of Vinalhaven
Review of Flood Insurance Rate Mapping
June 22, 2020

Ransom Consulting, LLC.
Project 191.06064



LEGEND

▨ SPECIAL FLOOD HAZARD AREAS (SFHAs) SUBJECT TO INUNDATION BY THE 1% ANNUAL CHANCE FLOOD

The 1% annual chance flood (100-year flood), also known as the base flood, is the flood that has a 1% chance of being equaled or exceeded in any given year. The Special Flood Hazard Area is the area subject to flooding by the 1% annual chance flood. Areas of Special Flood Hazard include Zones A, AE, AH, AO, AR, A99, V, and VE. The Base Flood Elevation is the water-surface elevation of the 1% annual chance flood.

ZONE A	No Base Flood Elevations determined.
ZONE AE	Base Flood Elevations determined.
ZONE AH	Flood depths of 1 to 3 feet (usually areas of ponding); Base Flood Elevations determined.
ZONE AO	Flood depths of 1 to 3 feet (usually sheet flow on sloping terrain); average depths determined. For areas of alluvial fan flooding, velocities also determined.
ZONE AR	Special Flood Hazard Areas formerly protected from the 1% annual chance flood by a flood control system that was subsequently decertified. Zone AR indicates that the former flood control system is being restored to provide protection from the 1% annual chance or greater flood.
ZONE A99	Area to be protected from 1% annual chance flood by a Federal flood protection system under construction; no Base Flood Elevations determined.
ZONE V	Coastal flood zone with velocity hazard (wave action); no Base Flood Elevations determined.
ZONE VE	Coastal flood zone with velocity hazard (wave action); Base Flood Elevations determined.

▨ FLOODWAY AREAS IN ZONE AE

The floodway is the channel of a stream plus any adjacent floodplain areas that must be kept free of encroachment so that the 1% annual chance flood can be carried without substantial increases in flood heights.

▨ OTHER FLOOD AREAS

ZONE X	Areas of 0.2% annual chance flood; areas of 1% annual chance flood with average depths of less than 1 foot or with drainage areas less than 1 square mile; and areas protected by levees from 1% annual chance flood.

☐ OTHER AREAS

ZONE X	Areas determined to be outside the 0.2% annual chance floodplain.
ZONE D	Areas in which flood hazards are undetermined, but possible.

▨ COASTAL BARRIER RESOURCES SYSTEM (CBRS) AREAS

▨ OTHERWISE PROTECTED AREAS (OPAs)

CBRS areas and OPAs are normally located within or adjacent to Special Flood Hazard Areas.

———	1% Annual Chance Floodplain Boundary
———	0.2% Annual Chance Floodplain Boundary
— —	Floodway boundary
— — —	Zone D boundary
••••••••••••••	CBRS and OPA boundary
▨ ◀—	Boundary dividing Special Flood Hazard Area Zones and boundary dividing Special Flood Hazard Areas of different Base Flood Elevations, flood depths, or flood velocities.
▨ ●● ◀—	Limit of Moderate Wave Action
▨ ●● ◀—	Limit of Moderate Wave Action
~~ 513 ~~~	Base Flood Elevation line and value; elevation in feet*
(EL 987)	Base Flood Elevation value where uniform within zone; elevation in feet*

*Referenced to the North American Vertical Datum of 1988

(A)——(A)	Cross section line
(23) - - - - (23)	Transect line

NFIP

NATIONAL FLOOD INSURANCE PROGRAM

PANEL 0411D

FIRM
FLOOD INSURANCE RATE MAP
KNOX COUNTY, MAINE
(ALL JURISDICTIONS)

PANEL 411 OF 925
(SEE MAP INDEX FOR FIRM PANEL LAYOUT)

CONTAINS:

COMMUNITY	NUMBER	PANEL	SUFFIX
VINALHAVEN, TOWN OF	230230	0411	D

Notice to User: The **Map Number** shown below should be used when placing map orders; the **Community Number** shown above should be used on insurance applications for the subject community.

MAP NUMBER
23013C0411D

EFFECTIVE DATE
JULY 6, 2016

Federal Emergency Management Agency

RANSOM
Consulting
Engineers
and Scientists

Legend & Notes

AE10	Proposed Flood Zone

Notes

1. Background image is the effective FIRM panel 230130411D.
2. The map project and grid are UTM Zone 19 North.
3. The vertical datum is NAVD88.

Scale & Orientation

N

0 100 200 Feet

1 inch = 200 feet

Prepared For

Mr. Gregory Nelson
8 Hickory St,
Hudson, NH 03051

Drawn By: SJH
Checked By: NLD
Date: 6/19/2020

181.06110 June 2020

Annotated FIRM

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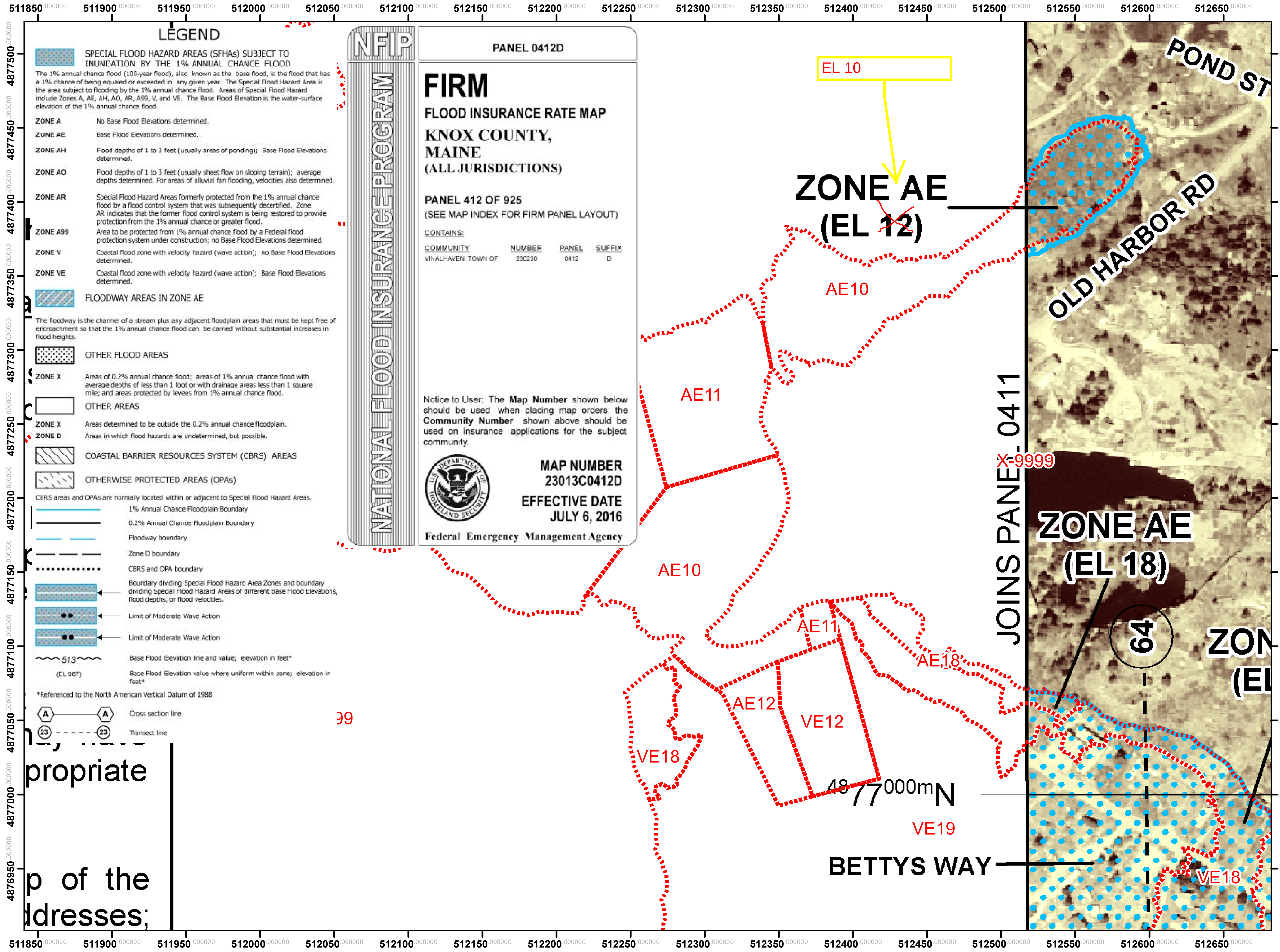

LEGEND

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ZONE V	Coastal flood zone with velocity hazard (wave action); no Base Flood Elevations determined.
ZONE VE	Coastal flood zone with velocity hazard (wave action); Base Flood Elevations determined.

▨ FLOODWAY AREAS IN ZONE AE

The floodway is the channel of a stream plus any adjacent floodplain areas that must be kept free of encroachment so that the 1% annual chance flood can be carried without substantial increases in flood heights.

▨ OTHER FLOOD AREAS

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☐ OTHER AREAS

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———	0.2% Annual Chance Floodplain Boundary
— —	Floodway boundary
— — —	Zone D boundary
•••••••••••••	CBRS and OPA boundary
▨	Boundary dividing Special Flood Hazard Area Zones and boundary dividing Special Flood Hazard Areas of different Base Flood Elevations, flood depths, or flood velocities.
▨ ••	Limit of Moderate Wave Action
▨ ••	Limit of Moderate Wave Action
~~ 513 ~~~	Base Flood Elevation line and value; elevation in feet*
(EL 987)	Base Flood Elevation value where uniform within zone; elevation in feet*

*Referenced to the North American Vertical Datum of 1988

(A)———(A)	Cross section line
(23)- - - - -(23)	Transect line

NFIP

NATIONAL FLOOD INSURANCE PROGRAM

PANEL 0412D

FIRM

FLOOD INSURANCE RATE MAP

KNOX COUNTY,
MAINE
(ALL JURISDICTIONS)

PANEL 412 OF 925

(SEE MAP INDEX FOR FIRM PANEL LAYOUT)

CONTAINS:

COMMUNITY	NUMBER	PANEL	SUFFIX
VINALHAVEN, TOWN OF	230230	0412	D

Notice to User: The **Map Number** shown below should be used when placing map orders; the **Community Number** shown above should be used on insurance applications for the subject community.

MAP NUMBER
23013C0412D

EFFECTIVE DATE
JULY 6, 2016

Federal Emergency Management Agency

RANSOM
Consulting
Engineers
and Scientists

Legend & Notes

AE10	Proposed Flood Zone

Notes

1. Background image is the effective FIRM panel 230130412D.
2. The map project and grid are UTM Zone 19 North.
3. The vertical datum is NAVD88.

Scale & Orientation

N

0 100 200 Feet

1 inch = 200 feet

Prepared For

Mr. Gregory Nelson
8 Hickory St,
Hudson, NH 03051

Drawn By: SJH
Checked By: NLD
Date: 6/19/2020

181.06110 | June 2020

Annotated FIRM

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