Town of Marshfield, MA, Appeal to FEMA Preliminary Coastal Flood Maps

I. Introduction

This is an appeal to a portion of the Preliminary Flood Insurance Rating Maps for Plymouth County, Massachusetts, as released on May 1, 2013, and as documented by Flood Insurance Study Number 25023CV001B, and supplemented by electronic files provided to us by STARR[1], the consultant that prepared the study for FEMA. This appeal is being filed by the Town of Marshfield, Massachusetts, on behalf of itself, specifically for the detailed studies (VE- and AE-designated) areas near Wave Transects PL-64 and PL-66 identified in **Attachment 1. Attachment 2** contains FEMA STWAVE model significant wave height contours of the 1% annual chance coastal storm. **Attachment 3** shows the contouring of the Peak Wave Period of the 1% annual chance coastal storm. The FEMA Preliminary Map for the area of interest is shown in **Attachment 4**. These areas are included within the FEMA Preliminary panels 25023C0231K, 25023C0232K, 25023C0233K, and 25023C0234K, respectively. This appeal is focused only on the boundaries and Base Flood Elevations (BFE) for the area near Wave Transects PL-64 and PL-66, and deals only with the 1% annual chance flood as determined by detailed studies. However, these transects were done to illustrate a general principle that wave setup, which largely determines the BFE on the inland side of the outer coast, is overstated and would be lower by several feet if the incident wave height as determined by the STWAVE model were used instead of the deepwater offshore wave height of 30.65'.

As explained in detail below, the wave setups as we calculated them, would result in a reduction of the inland BFE from 16-17' to 13-15' NAVD88 for Wave Transects PL-64 and PL-66 in the area of detailed studies compared with the BFEs calculated by FEMA through the WHAFIS program.

II. Legal Basis for Appeal

FEMA has issued a Guidance Document dated November 30, 2011, called "Criteria for Appeals of Flood Insurance Rate Maps." In that document several different criteria are identified as valid bases for appealing Preliminary FIRMs. The basis for this appeal comes from page 7 of the Guidance Document: "Technically Incorrect BFEs, Base Flood Depths, SFHA Zone Designations, or Regulatory Floodways." Ransom[2] applied a new hydrologic analysis in which the original methodology was applied differently ("the methodology was not applied correctly") More specifically, the appeal is based on:

1) Use of a different incident wave height and period than used by FEMA on each of the two transects based on the examination of the significant wave height (Hs=Hmo) contours given to us by STARR as an x,y,z file as output from STARR's STWAVE model for Plymouth County. The incident wave height and period were selected near the

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[1] The modeling, calculations, reporting, and website from which Ransom downloaded data were created by STARR, the consultant for FEMA. However, since the maps are being promulgated by FEMA, the report commonly refers to FEMA as if it were the creator of the studies being challenged.

[2] Ransom Consulting, Inc., is a civil and environmental engineering firm with offices in Hamilton, New Jersey; Providence, Rhode Island; Byfield, Massachusetts; Portsmouth, New Hampshire; and Portland, Maine

shore where the density of wave contours increased (suggesting breaking) and was approximately equal to one wave length out from the shore. As explained below, this methodology has been used and accepted in coastal studies in Maine that have been prepared by Ransom and accepted by FEMA.

III. Technical Basis of the Appeal

Ransom Consulting, Inc. (Ransom), prepared the technical aspects of this appeal. Elevations are all referenced to NAVD88 in feet, unless otherwise noted.

The Wave Transects that this appeal focuses on that were used in the FEMA setup, CHAMP, and runup models for the detailed studies in this area are shown on **Attachment 1**. Coastal flood analyses require a number of modeling calculations in a certain sequence and can become quite complicated. STARR has developed a lengthy and complex MATHCAD sheet to compute many of the intermediate modeling steps that may be required. Ransom has used STARR's MATHCAD sheet, where appropriate, and their assumptions and inputs, where appropriate. This report points out where the Ransom inputs and methodology differ from STARR's.

The first and most important step in the process is defining the incident significant wave height and peak period that is used to calculate wave setup and drive the CHAMP and runup models. With the exception of inside Duxbury Bay, all of the incident wave heights used by FEMA are deep offshore ocean waves calculated as the 1% annual chance offshore wave calculated from WIS station statistics. For Duxbury Bay, as an example, STARR uses a significant incident wave height for Wave Transect PL-113 of 30.67' and for the adjacent Wave Transect PL-112 the incident wave height is 4.76'. The latter was derived from a nested grid STWAVE model carved out of a coarser grid STWAVE model that covers all of Plymouth County. For unknown reasons, then, STARR uses its STWAVE model to pick off incident wave heights for the purpose of calculating wave setup, critical wave height (WHAFIS), and wave runup inside Duxbury Harbor, but nowhere else in Plymouth County. We note that Ransom has performed a lot of STWAVE modeling on the coast of Maine as part of FEMA appeals and LOMRs to develop incident wave heights for the purpose of calculating wave setups, CHAMP inputs and runup. This approach has been discussed with Region 1 and adopted as an acceptable way to calculate incident wave heights.

Ransom has taken the x,y,z nested STWAVE significant wave height and Tp "results" files and gridded them in SURFER™ at a grid cell size of Δ10m x Δ10m and then contoured it to develop maps of wave height and of wave period and from those maps, chose incident wave heights and periods for PL-64 and PL-66 (**Attachments 2** and **3**). Using these data, Ransom calculated wave setup, then ran WHAFIS and then ran the appropriate runup models.

Attachment 5 is the Excel spreadsheet used to do an independent check on the open ocean wave setup for PL-64. **Attachment 6** is STARR's MATHCAD sheet for PL-64 modified by Ransom to take into account a different choice of incident wave properties. **Attachment 7** is the WHAFIS intact revetment model text output. **Attachment 8** is the Wave Profile from WHAFIS with the Runup added by hand to the intact revetment condition. **Attachment 9** is the WHAFIS failed revetment model text output. **Attachment 10** is the Wave Profile from WHAFIS with the Runup added by hand to the failed revetment condition.

Attachment 11 is the Excel spreadsheet used to do an independent check on the open ocean wave setup for PL-66. **Attachment 12** is STARR's MATHCAD sheet for PL-66, modified by Ransom for a different choice of incident wave properties. **Attachment 13** is the worksheet to develop the input for the ACES runup model for PL-66 intact revetment condition. **Attachment 14** text output for the WHAFIS model of the intact revetment condition. **Attachment 15** is the Wave Profile from WHAFIS with the Runup added by hand to the intact revetment condition for PL-66. **Attachment 16** is the WHAFIS failed revetment model text output. **Attachment 17** is the Wave Profile from WHAFIS with the Runup added by hand to the failed revetment condition for PL-66.

Attachment 18 is Ransom's remapping of the flood zones around PL-64 and PL-66.

The summary of results and comparison with the FEMA results are summarized in the Table in **Attachment 19**.

Other Comments:

Besides the major comment that STWAVE should have been used to define the incident wave height and period for setup, WHAFIS, and runup modeling, Ransom has two other comments on the new MATHCAD sheet developed by STARR. First, the decision tree for the choice of porosity reduction factor in the TAW Runup portion of the sheet does not function properly. For the porosity = 0.1 and porosity = 0.4 the reduction factors are supposed to be proportioned between the calculated value for porosity = 0.5 and no reduction (reduction factor = 1.0); however that is not the case in the sheet.

Second, the "berm" reduction factor in the TAW Runup portion of the sheet is toggled to either 1.0 or 0.6 regardless of the elevation of the berm relative to SWEL or to the width of the berm. Ransom suggests that STARR add a note asking the user to use the TAW recommended formula for calculating the berm reduction factor.

We noted late in our work that the GIS files given to us by STARR contained two separate S_FLD_HAZ_AR shape files. We worked with and modified the one we found in the "Spatial" subdirectory of the Plymouth County detailed study files. In producing **Attachment 18** we noticed that there appeared to be an AO zone missing in STARR's shape file along Wave Transect PL-061. After searching around in the complex directory tree in the download we obtained from STARR, we found another shape file of the same name that contained AO and X zones which were missing in the file we used from the "Spatial" subdirectory. We are not proposing to modify the AO or X zones, particularly the AO zone in the vicinity of PL-061. In **Attachment 18** we have only labeled the zones that Ransom modified. Zones where Ransom did not modify the Zone type or BFE are not labeled.

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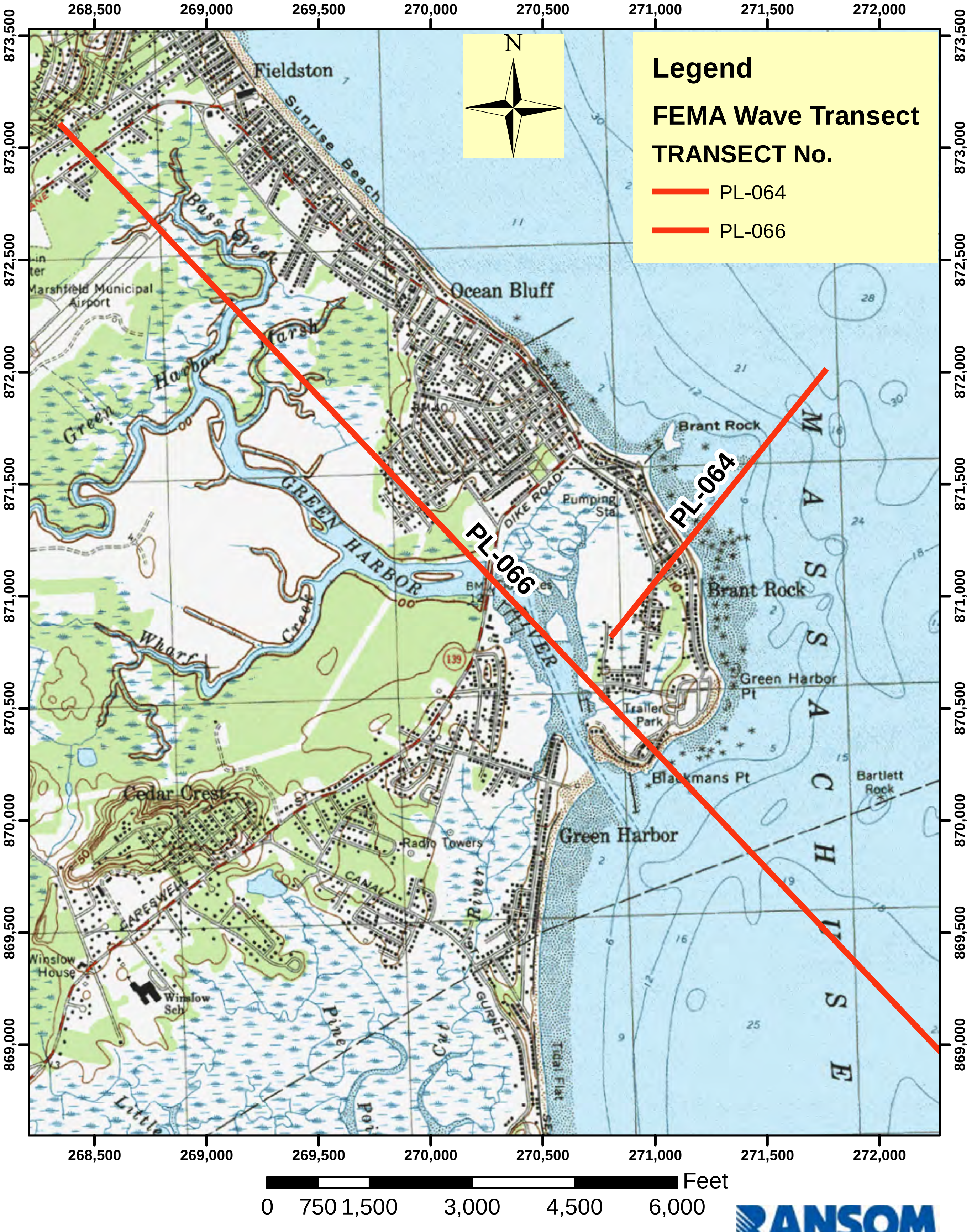
Kenneth W. Milender, PE, Senior Project Manager, Ransom Consulting, Inc., Portsmouth, NH

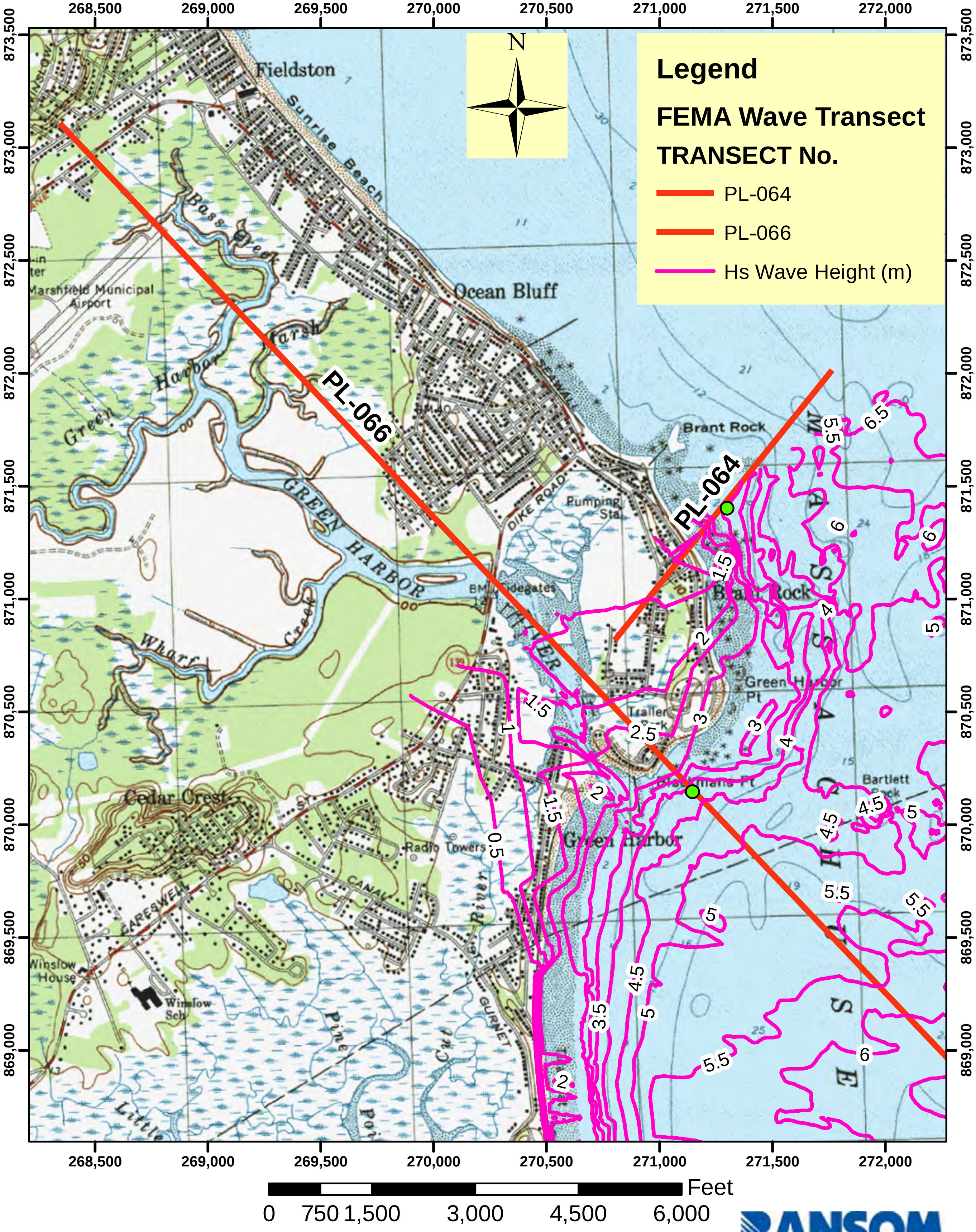
Attachments 1-19, and CD with model data sets and associated files



Transect Locations upon which appeal is Based
Marshfield, MA
Base Maps are USGS Marshfield 7.5' quads
Grid is Mass. State Plane, Mainland, NAD83 (m)
RGG 9/30/13 131.06145

RANSOM
Consulting, Inc.

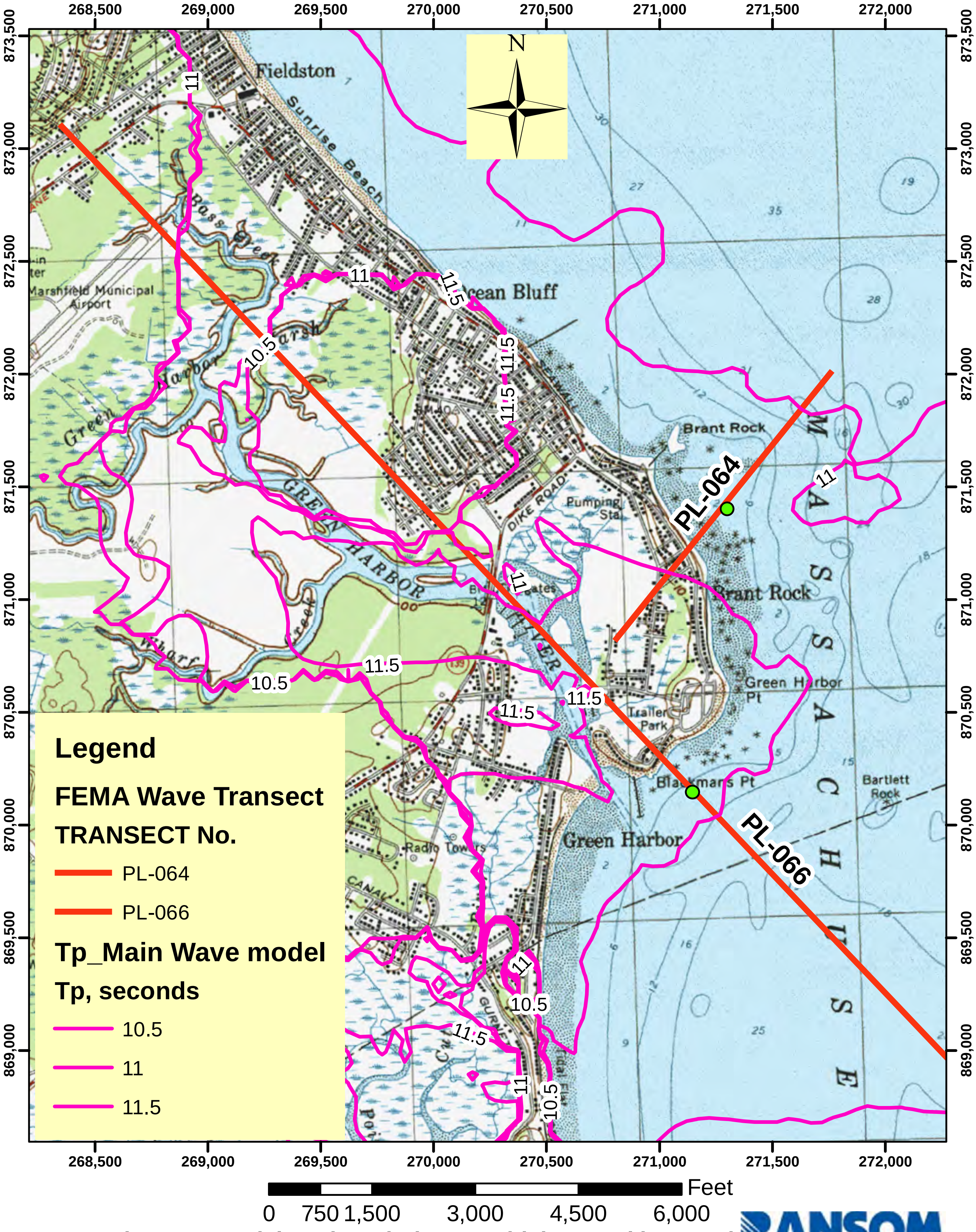
Attachment 1



STARR Nested Grid Wave Heights upon which appeal is Based
Marshfield, MA
Base Maps are USGS Marshfield 7.5' quads
Grid is Mass. State Plane, Mainland, NAD83 (m)
RGG 9/30/13 131.06145

RANSOM Consulting, Inc.

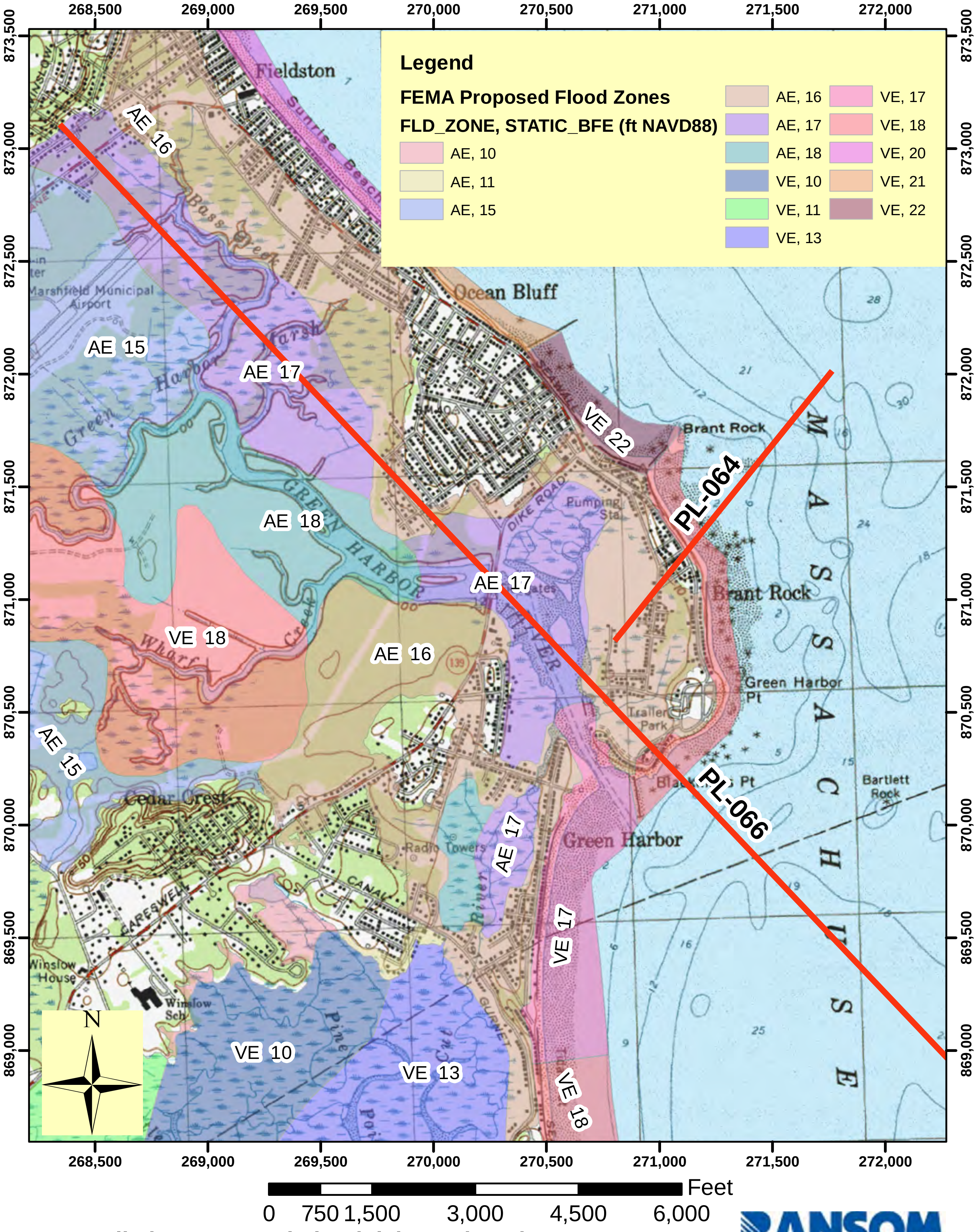
Attachment 2



STARR Main Wave Model Peak Period upon which appeal is Based
Marshfield, MA
Base Maps are USGS Marshfield 7.5' quads
Grid is Mass. State Plane, Mainland, NAD83 (m)
RGG 9/30/13 131.06145

RANSOM Consulting, Inc.

Attachment 3



FEMA Preliminary Coastal Floodplain Designations
Marshfield, MA
Base Maps are USGS Marshfield 7.5' quads
Grid is Mass. State Plane, Mainland, NAD83 (m)
RGG 9/30/13 131.06145

RANSOM Consulting, Inc.

Attachment 4

Wave Setup for Marshfield, MA, Transect PL-64 Intact

LO	642.9	ft		INCIDENT WAVE LENGTH
HO	11.5	ft		INCIDENT WAVE HEIGHT FROM STWAVE Model
Ho/Lo	0.0179		$H_b = \frac{H_0}{3.3\left(\frac{H_0}{L_0}\right)^{1/3}}$	
Hb	13.3246344	ft		CALCULATE Hb USING MUNK 1949

Instructions:	**Insert Values into Highlighted Cells**

Db	17.0828647	ft	FIND DEPTH OF WAVE BREAKING USING 0.78Db=Hb

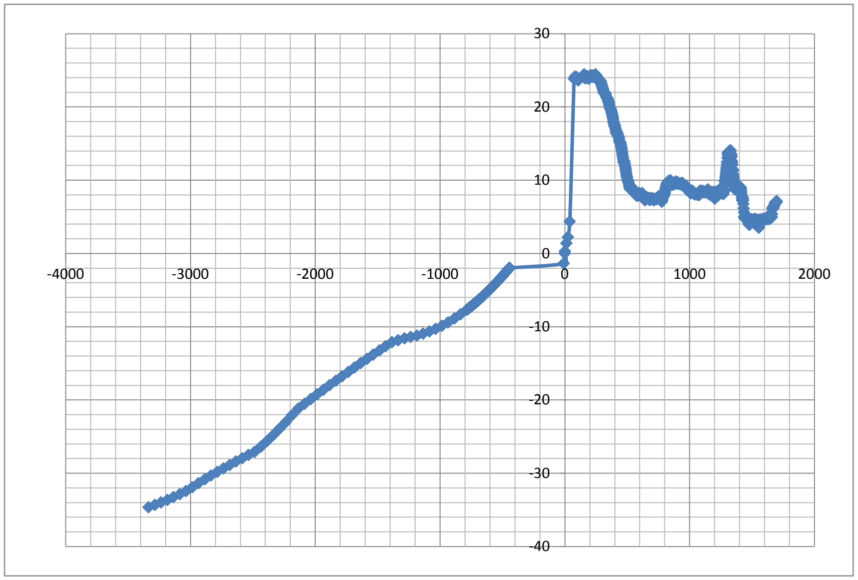
1% SWEL		10.46	NAVD88	TOP OF SLOPE
		17.08286		of water supports the breaking wave height
	therefore,	-6.62286	NAVD88	BOTTOM OF SLOPE

RISE	17.08286 *ft*	
RUN	757.6355 *ft*	taken off Profiles
SLOPE	0.022548	
1:ON	44.35061	

Wave Setup				
H'o =	11.5	feet	Deepwater Significant Wave Height	
T =	11.2	sec	Peak Wave Period	
m =	0.0225	ft/ft	Average Slope of Transect	
Lo =	642.9	feet	Deepwater Wavelength	Lo = (g*T^2)/2π
H'o/Lo =	0.0179	ft/ft	Deepwater Wave Steepness	
Irabarren Number	0.1686	ft/ft		I.N. = m/sqrt(Ho/L0)
Sigma(2)	0.5816	ft		Sigma(2) = 0.3*I.N.*Ho
Setup	1.92717316			nopen = Hmo*0.16*(m/(H'o/Lo))^0.2
n	**1.92717316**	**ft**	**Total Static Setup**	n = 4.0*G(H)*G(T)*G(Gamma)*G(Slope)

Marshfield SWEL	10.46	NAVD88	FEET

FEMA extracted profile		Interpolation		
x	y	delta y	delta x	
39.77	4.364	-19.483	-34	interpolate to get X position of SWEL
73.77	23.847			
0	0	50.4082		xcoord of sought for y value of SWEL
-708.23	-6.63762			
-706.23	-6.60819	delta y	delta x	
		-0.029	-2	interpolate to get X position of Db
		-707.227		xcoord of sought for y value of elevation at Db
		757.6355		calculated run



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

VERSION
12

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: Robert G. Gerber
Date: Sept. 18, 2013
County: Plymouth, MA
Transect Number: PL-66
Airport:
Years of Data set: ST WAVE MODEL

Associated Files: \\chifednas2\fema\R01\Mass\Plymouth\ENGINEERING

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

Client:_Town of Marshfield__
County:___Plymouth, MA
Transect Number:_PL-64

Wave Height and Wave Period Calculation Worksheet
PL-64

Calc By:___RGG__________
Date:____9-30-13_________

unrestricted radio button is selected above

$U_{10} := 35.76 \frac{m}{s}$

Wind speed based on CHAMP model default offshore wind = 80 mph
Taken from file:

$U_{10} = 117.32 \cdot \frac{ft}{s}$

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:

$C_D := 0.001 \cdot \left[1.1 + \left(0.035 \cdot U_{10} \cdot \frac{s}{m}\right)\right]$ $C_D = 0.0024$

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

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

Given

$C_D = \frac{u_s^{\,2}}{U_{10}^{\,2}}$ $u_s := \mathrm{Find}(u_s)$ $u_s = 1.73 \cdot \frac{m}{s}$

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

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

$X = 20663.98 \cdot m$ $u_s = 1.73 \cdot \frac{m}{s}$ $g = 9.81 \frac{1}{s} \cdot \frac{m}{s}$

Given

$$\frac{g \cdot H_{m0}}{u_s^{\,2}} = 0.0413 \cdot \left(\frac{g \cdot X}{u_s^{\,2}}\right)^{0.5} \qquad H_{m0} := \text{Find}(H_{m0}) \qquad H_{m0} = 3.29 \cdot m \qquad H_{m0} = 10.79 \, ft$$

Calculate Wave Period, T_P (sec):

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

$X = 20663.98 \cdot m$ $u_s = 1.73 \cdot \frac{m}{s}$ $g = 9.81 \frac{1}{s} \cdot \frac{m}{s}$

Given

$$\frac{g \cdot T_P}{u_s} = 0.751 \cdot \left(\frac{g \cdot X}{u_s^{\,2}}\right)^{\frac{1}{3}} \qquad T_P := \text{Find}(T_P) \qquad T_P = 5.4 \cdot s$$

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 File:

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

$H_{m0STWAVE} := 3.5 \cdot m$

$T_{PSTWAVE} := 11.2 \cdot sec$

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: \\chifednas2\fema\Mass\Plymouth\ENGINEERING\COASTAL\GENERAL

$$H_{m0} := \begin{cases} H_{m0STWAVE} & \text{if } FetchStatus = \text{"STWAVE Input (Hmo, Tp)"} \\ H_{m0ACES} & \text{if } FetchStatus = \text{"Restricted Fetch Input from ACES (Hmo, Tp)"} \\ H_{m0} & \text{otherwise} \end{cases}$$

RESULT:

$H_{m0} := 11.5 \cdot ft$

$T_P := 11.2 \cdot sec$

$FetchStatus = \text{"STWAVE Input (Hmo, Tp)"}$

Based on STWAVE model Results

5.2 Wave Setup, η, Calculation

5.2.1 Open Coast Wave Setup Analysis

Definition of Variables:

$m := 0.022548$

Insert value of average transect slope based on GIS data
(see Ransom spreadsheet

Calculate Deep Water Wave Length, L_0:

$L_0 := \frac{g \cdot T_P^{\,2}}{2 \cdot \pi}$ $L_0 = 642.34 \, ft$

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

Calculate Wave Slope, S:

$S := \frac{H_{m0}}{L_0}$ $S = 0.0179$ $S = 1.79 \cdot \%$

Calculate Static Open Coast Wave Setup:

$\eta_{open} := H_{m0} \cdot 0.160 \cdot \frac{m^{0.2}}{S^{0.2}}$ $\eta_{open} = 1.93 \, ft$

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

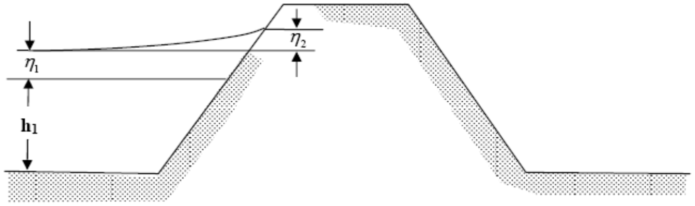


Figure D.2.6-6. Definition Sketch for Nonovertopped Levee

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("PL64_Sta_El.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	-3334.7	-34.65
1	-3284.7	-34.34
2	-3234.7	-34
3	-3184.7	-33.65
4	-3134.7	-33.27
5	-3084.7	-32.87
6	-3034.7	-32.44
7	-2984.7	...

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

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

Array of horizontal distance from the shoreline

Station =

	0
0	-3334.7
1	-3284.7
2	-3234.7
3	...

ft

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

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

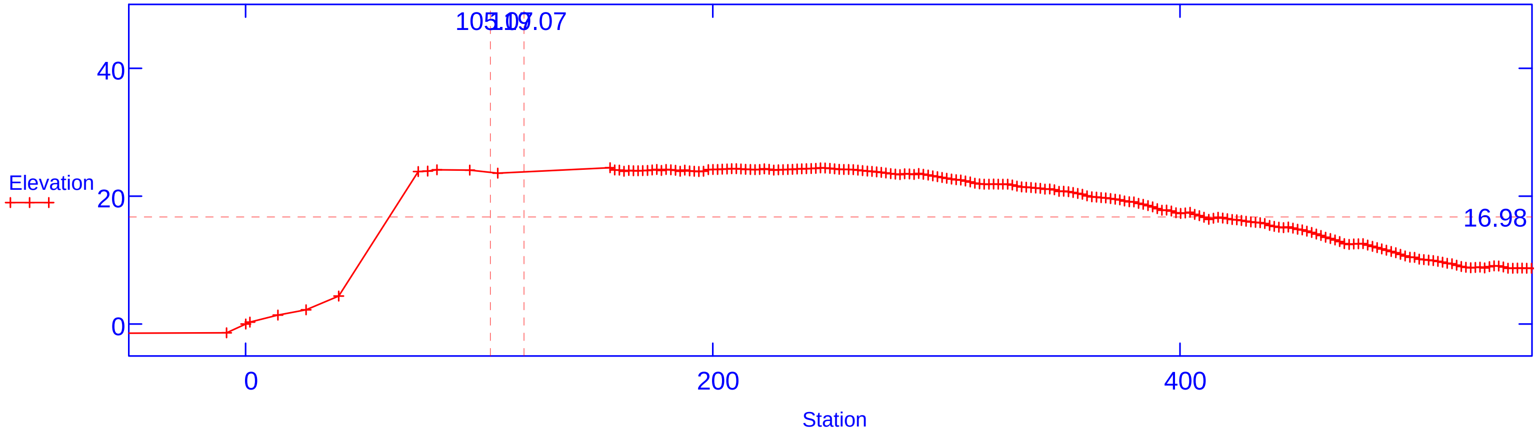
Array of Elevations associated with each horizontal distance from the shoreline:

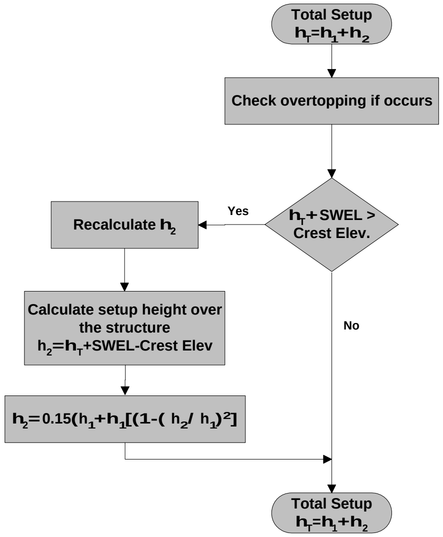
Elevation =

	0
0	-34.65
1	-34.34
2	-34
3	...

ft

The following displays the profile of the


105.09
117.07
40
20
0
Elevation
16.98
0
200
400
Station


Total Setup
$h_T=h_1+h_2$
Check overtopping if occurs
h_T+SWEL > Crest Elev.
Yes
Recalculate h_2
No
Calculate setup height over the structure
$h_2=h_T$+SWEL-Crest Elev
$h_2=0.15(h_1+h_1[(1-(h_2/h_1)^2]$
Total Setup
$h_T=h_1+h_2$

Identify station and elevation of the toe of the structure:

$Toe_{sta} := 39.77ft$

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

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

$Toe_{ele} = 4.36\,ft$

Identify station and elevation of the top of the structure:

$Top_{sta} := 73.77 \cdot ft$

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

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

$Top_{ele} = 23.85\,ft$

Enter 1% annual chance stillwater elevation (ft):

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

$SWEL := 10.46 \cdot ft$

Calculate Water Depth at Structure, h

$h := SWEL - Toe_{ele}$ $h = 6.1\ ft$

Calculate the Breaking Wave Height, H_b:

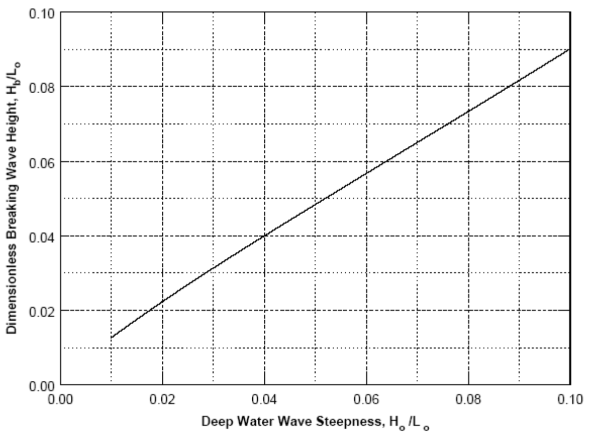


Figure D.2.6-7. Dimensionless Breaking Wave Height vs. Deepwater Wave Steepness

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

$b_h := 0.8481 \cdot s + 0.0057$ $b_h = 0.02$ Estimated curve equation in Figure D.2.6-7

$H_b := b_h \cdot L_0$ $H_b = 13.41\ \text{ft}$

Calculate the Breaking Wave Depth, H_d:

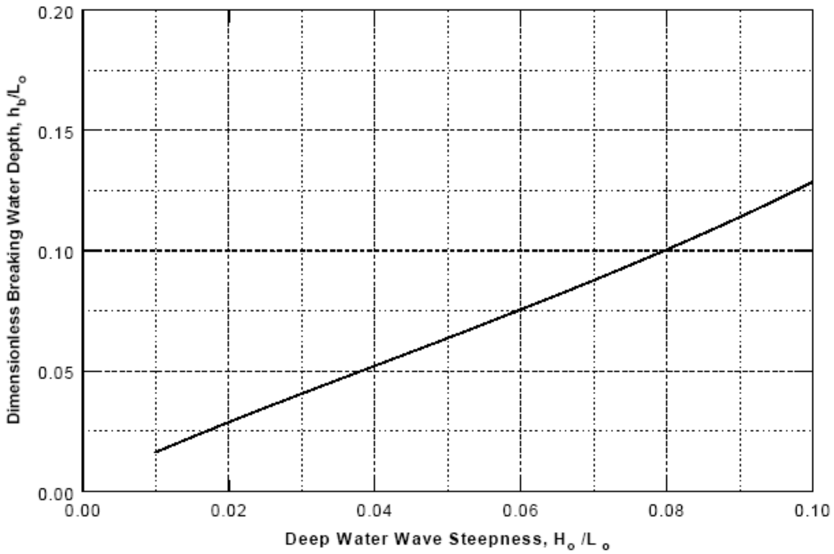


Figure D.2.6-8. Dimensionless Breaking Water Depth vs. Deepwater Wave Steepness.

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

$H_d := b_d \cdot L_0$ $H_d = 16.16\,\text{ft}$

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

Figure from: Atlantic Ocean and

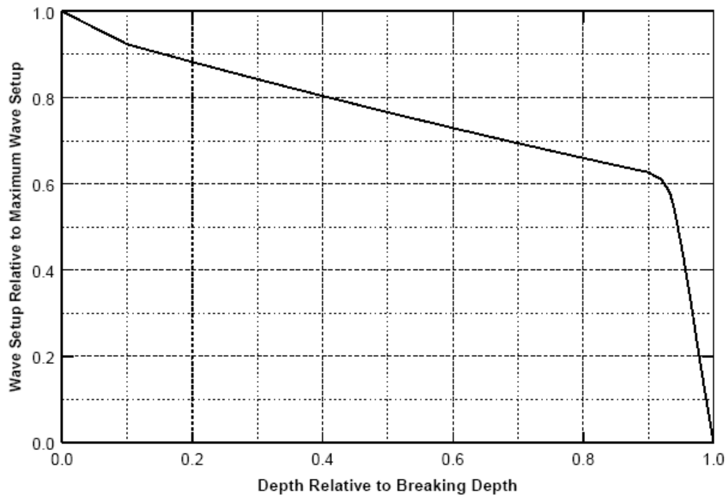


Figure D.2.6-9. Proportion of Maximum Wave Setup that Has Occurred vs. a Proportion of the Breaking Depth.

Gulf of Mexico Coastal
Guidelines Update Feb 2007

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

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

$R = 0.81$ $\quad\quad \frac{h}{H_d} = 0.38$

$\eta_1 := R \cdot \eta_{open}$ $\quad\quad \eta_1 = 1.56\,ft$ $\quad\quad \eta_2 := 0.15 \cdot (h + \eta_1)$ $\quad\quad \eta_2 = 1.15\,ft$

$\eta_{Structure} := \eta_1 + \eta_2$ $\quad\quad \eta_{Structure} = 2.71\,ft$

Total Setup against a coastal structure without considering overtopping

Check Overtopping if Coastal Structure Exists:

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

$Overtopped = \text{"No"}$

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

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

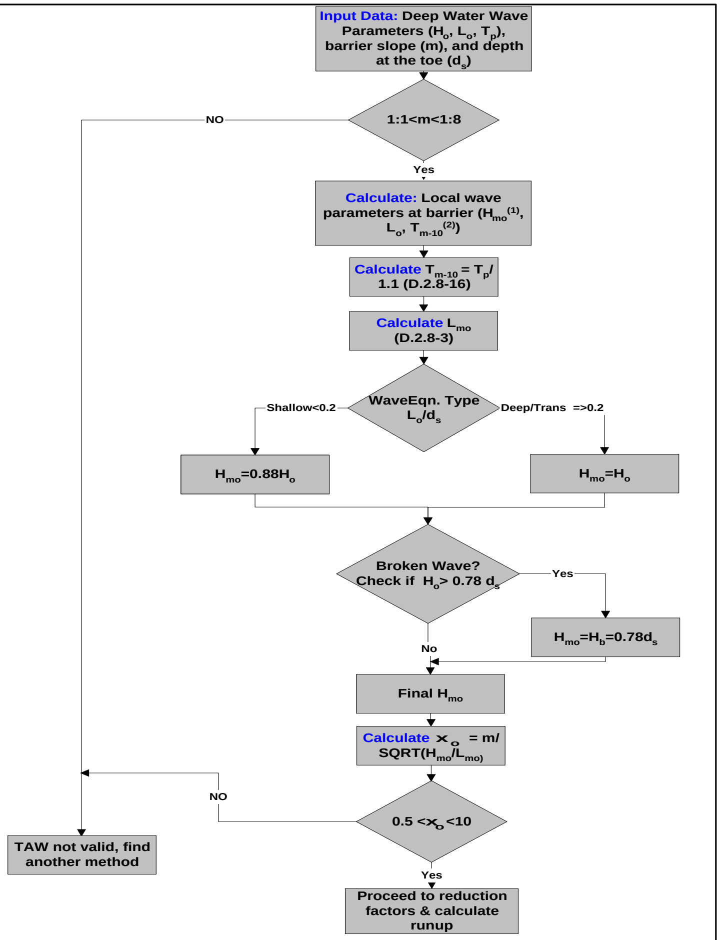
$$\eta_2 := \begin{cases} 0.15 \cdot (h + \eta_1) \cdot \left[1 - \left(\frac{h_2}{h}\right)^2\right] & \text{if } Overtopped = \text{"Yes"} \\ \eta_2 & \text{otherwise} \end{cases}$$

$\eta_{Structure} := \eta_1 + \eta_2$ $\quad\quad \eta_{Structure} = 2.71\,ft$

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:

$$Slope_{Revet} := \frac{\left(Top_{ele} - Toe_{ele}\right)}{\left(Top_{sta} - Toe_{sta}\right)} \qquad Slope_{Revet} = 57.3\cdot\%$$

$$Slope_{RevetOneOn} := \frac{1}{Slope_{Revet}} \qquad Slope_{RevetOneOn} = 1.75$$

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

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

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

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

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

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

Determine Wave Type:

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

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

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

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

$H_{m0runup1} = 10.12\,\mathrm{ft}$

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

$H_{m0runup} = 4.75\,\mathrm{ft}$

Calculate the Spectral Wave Period, T_{m10}

$T_{m10} := \frac{T_P}{1.1}$ Equation D.2.8-16 $T_{m10} = 10.18\,s$

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 $L_{m0} = 530.86\,ft$

Calculate the Iribarren Number, ξ_{0m}:

$\xi_{om} := \frac{Slope_{Revet}}{\sqrt{\frac{H_{m0runup}}{L_{m0}}}}$ $\xi_{om} = 6.05$

Check TAW Method for Validity based on Iribarren Number:

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

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

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

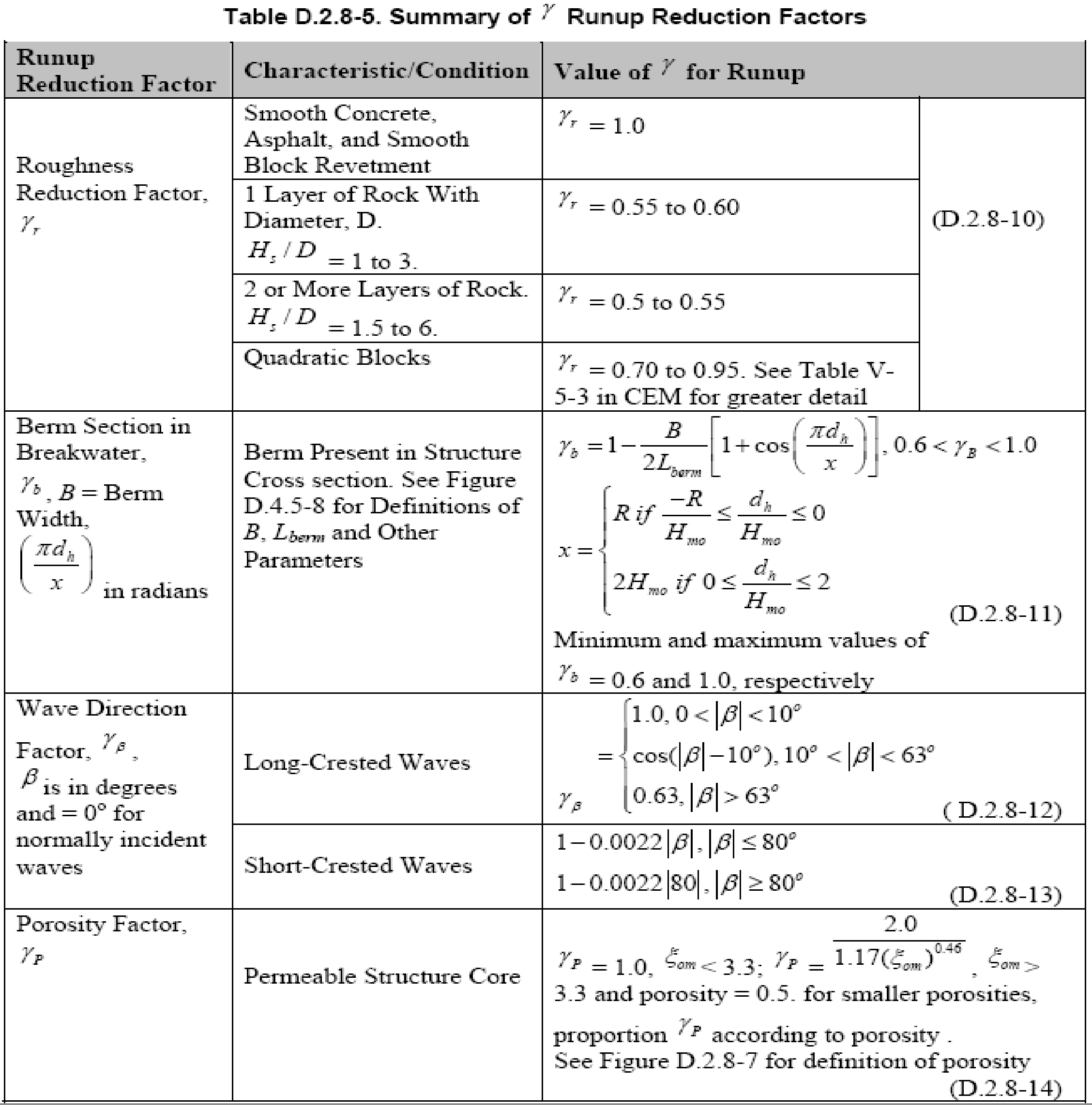


Table D.2.8-5. Summary of γ Runup Reduction Factors

Runup Reduction Factor	Characteristic/Condition	Value of γ for Runup	
Roughness Reduction Factor, γ_r	Smooth Concrete, Asphalt, and Smooth Block Revetment	$\gamma_r = 1.0$	(D.2.8-10)
	1 Layer of Rock With Diameter, D. $H_s / D = 1$ to 3.	$\gamma_r = 0.55$ to 0.60	
	2 or More Layers of Rock. $H_s / D = 1.5$ to 6.	$\gamma_r = 0.5$ to 0.55	
	Quadratic Blocks	$\gamma_r = 0.70$ to 0.95. See Table V-5-3 in CEM for greater detail	
Berm Section in Breakwater, γ_b, $B =$ Berm Width, $\left(\frac{\pi d_h}{x}\right)$ in radians	Berm Present in Structure Cross section. See Figure D.4.5-8 for Definitions of B, L_{berm} and Other Parameters	$\gamma_b = 1 - \frac{B}{2L_{berm}}\left[1+\cos\left(\frac{\pi d_h}{x}\right)\right], 0.6 < \gamma_B < 1.0$ $x = \begin{cases} R\ if\ \frac{-R}{H_{mo}} \le \frac{d_h}{H_{mo}} \le 0 \\ 2H_{mo}\ if\ 0 \le \frac{d_h}{H_{mo}} \le 2 \end{cases}$ (D.2.8-11) Minimum and maximum values of $\gamma_b = 0.6$ and 1.0, respectively	
Wave Direction Factor, γ_β, β is in degrees and = 0° for normally incident waves	Long-Crested Waves	$\gamma_\beta = \begin{cases} 1.0, 0 < \lvert\beta\rvert < 10^o \\ \cos(\lvert\beta\rvert - 10^o), 10^o < \lvert\beta\rvert < 63^o \\ 0.63, \lvert\beta\rvert > 63^o \end{cases}$ (D.2.8-12)	
	Short-Crested Waves	$1-0.0022\lvert\beta\rvert, \lvert\beta\rvert \le 80^o$ $1-0.0022\lvert 80\rvert, \lvert\beta\rvert \ge 80^o$ (D.2.8-13)	
Porosity Factor, γ_P	Permeable Structure Core	$\gamma_P = 1.0$, $\xi_{om} < 3.3$; $\gamma_P = \frac{2.0}{1.17(\xi_{om})^{0.46}}$, $\xi_{om} >$ 3.3 and porosity = 0.5. for smaller porosities, proportion γ_P according to porosity . See Figure D.2.8-7 for definition of porosity (D.2.8-14)	

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

Default Value - 1 layer of rock with diameter Hs/D = 1 to 3

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

$\gamma_r = 0.58$

Select Berm Section in Breakwater, γ_b:

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

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

Default Value - No Berm

$\gamma_b = 1$

Select Wave Direction Factor, γ_β:

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

Default Value - Short Crested Wave with normally incident wave

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

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

$\gamma_\beta = 1$

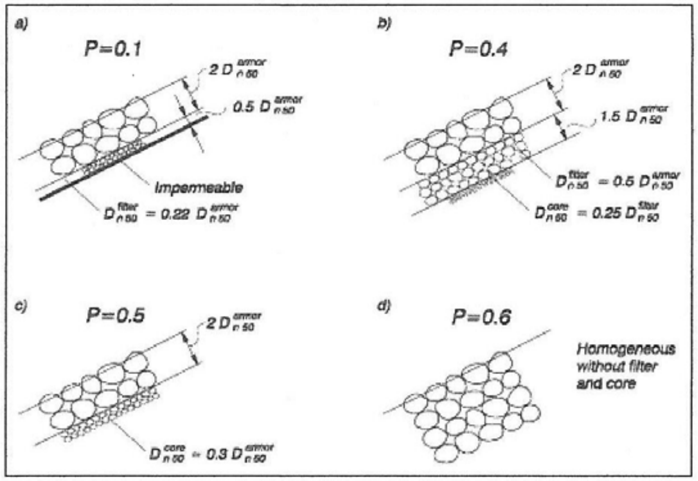


Figure VI-5-11. Notational permeability coefficients (van der Meer 1988)

Select Porosity Factor, γ_P:

Porosity :=
○ 0.1
○ 0.4
● 0.5
○ 0.6

Default Porosity = 0.5

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

Default Value -
P=0.5

$\gamma_p = 0.75$

Summary of Reduction Factors:

$\gamma_p = 0.75$

$\gamma_\beta = 1$

$\gamma_b = 1$

$\gamma_r = 0.58$

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

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

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

$R_{2\%} = 7.51\,ft$

Check for Overtopping:

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

$OVERTOPPED_{Runup} = \text{"NO Overtopping"}$

5.4 Failed Revetment Structure Analysis

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

Calculate Slope of the Revetment:

$\text{Slope} := \frac{(\text{Top}_{ele} - \text{Toe}_{ele})}{(\text{Top}_{sta} - \text{Toe}_{sta})}$ $\text{Slope} = 0.57$

Calculate the Midpoint of the Revetment:

$\text{Length} := \sqrt{(\text{Top}_{sta} - \text{Toe}_{sta})^2 + (\text{Top}_{ele} - \text{Toe}_{ele})^2}$ $\text{Length} = 39.19\,\text{ft}$

$\text{Midpoint} := \frac{\text{Length}}{2}$ $\text{Midpoint} = 19.59\,\text{ft}$

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

$\text{Mid}_{sta} := \left[\left(\frac{\text{Midpoint}}{\text{Length}}\right)\cdot(\text{Top}_{sta} - \text{Toe}_{sta})\right] + \text{Toe}_{sta}$ $\text{Mid}_{sta} = 56.77\,\text{ft}$

Determine the Elevation of the Midpoint of the Revetment:

$\text{Mid}_{ele} := \text{linterp}(\text{Station}, \text{Elevation}, \text{Mid}_{sta})$ $\text{Mid}_{ele} = 14.11\,\text{ft}$

Calculate the Upper Quarter of the Revetment:

$\text{Quarter} := \frac{\text{Length}\cdot 3}{4}$ $\text{Quarter} = 29.39\,\text{ft}$

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

$\text{Quarter}_{sta} := \left[\left(\frac{\text{Quarter}}{\text{Length}}\right)\cdot(\text{Top}_{sta} - \text{Toe}_{sta})\right] + \text{Toe}_{sta}$ $\text{Quarter}_{sta} = 65.27\,\text{ft}$

Determine the Elevation of the Upper Quadrant of the Revetment:

$\text{Quarter}_{ele} := \text{linterp}(\text{Station}, \text{Elevation}, \text{Quarter}_{sta})$ $\text{Quarter}_{ele} = 18.98\,\text{ft}$

Calculate Scour at the Toe of the Revetment:

$ToeR_{scour} := Toe_{ele} - Armor_D$ $ToeR_{scour} = 0.36\ ft$

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 $Toe_{location}$, $Mid_{location}$, $Quarter_{location}$, or $Top_{location}$ 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, $Mid_{location}$, $Quarter_{location}$, and $Top_{location}$.

$Offset_{toe}$, $Offset_{mid}$, $Offset_{qua}$, and $Offset_{top}$ 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.

Station = (ft)

	0
0	-3334.7
1	-3284.7
2	-3234.7
3	-3184.7
4	-3134.7
5	-3084.7
6	-3034.7
7	-2984.7
8	-2934.7
9	-2884.7
10	-2834.7
11	-2784.7
12	-2734.7
13	-2684.7
14	-2634.7
15	...

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

$\text{Toe}_{\text{location}} := \text{match}(\text{Toe}_{\text{sta}}, \text{Station})$ $\text{Toe}_{\text{location}} = (225)$ $\text{Toe}_{\text{location}_0} = 225$ $\text{Toe}_{\text{sta}} = 39.77\,\text{ft}$

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

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

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

$\text{Toe}_{\text{Staloc}} = 225$

Determine if station of the midpoint of the revetment is within the Station array and if not, add a data point2

$\text{Mid}_{\text{location}} := \text{match}(\text{Mid}_{\text{sta}}, \text{Station})$ $\text{Mid}_{\text{location}} := \begin{pmatrix} 225 \\ 226 \end{pmatrix}$ $\text{Mid}_{\text{location}_0} = 225$ $\text{Mid}_{\text{sta}} = 56.77\,\text{ft}$

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

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

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

$\text{Mid}_{\text{Staloc}} = 226$ $\text{FailRevetSta}_{\text{Mid}_{\text{Staloc}}} := \text{Mid}_{\text{sta}}$

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

$\text{Quarter}_{\text{location}} := \text{match}(\text{Quarter}_{\text{sta}}, \text{Station})$ $\text{Quarter}_{\text{location}} := \begin{pmatrix} 225 \\ 226 \end{pmatrix}$ $\text{Quarter}_{\text{location}_0} = 225$ $\text{Quarter}_{\text{sta}} = 65.27\,\text{ft}$

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

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

$$\mathrm{Quarter}_{Staloc} := \begin{cases} \mathrm{Quarter}_{location_0} + \mathrm{Offset}_{toe} + \mathrm{Offset}_{mid} + \mathrm{Offset}_{qua} & \text{if } \mathrm{Quarter}_{sta} \geq \mathrm{Station}_{\left(\mathrm{Quarter}_{location_0}\right)} \\ \left(\mathrm{Quarter}_{location_0} + \mathrm{Offset}_{toe} + \mathrm{Offset}_{mid}\right) & \text{otherwise} \end{cases}$$

$\mathrm{Quarter}_{Staloc} = 227$ $\mathrm{FailRevetSta}_{\mathrm{Quarter}_{Staloc}} := \mathrm{Quarter}_{sta}$

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

$\mathrm{Top}_{location} := \mathrm{match}\left(\mathrm{Top}_{sta}, \mathrm{Station}\right)$ $\mathrm{Top}_{location} = (226)$ $\mathrm{Top}_{location_0} = 226$ $\mathrm{Top}_{sta} = 73.77\,\mathrm{ft}$

$$\mathrm{Offset}_{top} := \begin{cases} 0 & \text{if } \mathrm{Station}_{\left(\mathrm{Top}_{location_0}\right)} = \mathrm{Top}_{sta} \\ 1 & \text{otherwise} \end{cases}$$

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

$$\mathrm{Top}_{Staloc} := \begin{cases} \mathrm{Top}_{location_0} + \mathrm{Offset}_{toe} + \mathrm{Offset}_{mid} + \mathrm{Offset}_{qua} + \mathrm{Offset}_{top} & \text{if } \mathrm{Top}_{sta} \geq \mathrm{Station}_{\left(\mathrm{Top}_{location_0}\right)} \\ \left(\mathrm{Top}_{location_0} + \mathrm{Offset}_{toe} + \mathrm{Offset}_{mid} + \mathrm{Offset}_{qua}\right) & \text{otherwise} \end{cases}$$

$\mathrm{Top}_{Staloc} = 228$ $\mathrm{FailRevetSta}_{\mathrm{Top}_{Staloc}} := \mathrm{Top}_{sta}$

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

$i := \mathrm{Toe}_{location_0} .. 0$ $\mathrm{FailRevetSta}_i := \mathrm{Station}_i$ $\mathrm{FailRevetSta}_{\mathrm{Toe}_{Staloc}} := \mathrm{Toe}_{sta}$

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

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

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

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

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

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

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

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

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

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

$$FailRevet_{Sta_z} := \left| \begin{array}{ll} Station_{z-Offset_{toe}-Offset_{mid}-Offset_{qua}} & \text{if } z \neq Quarter_{Staloc} \\ Quarter_{sta} & \text{otherwise} \end{array} \right.$$

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

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

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

$$end = 1005$$

$$w := \left(Top_{Staloc} + 1\right) .. end$$

$$FailRevet_{Sta_w} := Station_{w-Offset_{toe}-Offset_{mid}-Offset_{qua}-Offset_{top}}$$

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

$$FailRevet_{Ele_i} := Elevation_i$$

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

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

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

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

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

Sets the elevation of the middle of the revetment

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

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

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

Sets the elevation of the upper quadrant of the revetment

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

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.

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

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

$failed := last\left(FailRevet_{Ele}\right)$ $\quad failed = 230$

$b_{land} := 0$

Finds the intersection point of failed profile and intact profile:

$b_{failed} := 0$

$Station_{failed-Offset_{toe}-Offset_{mid}-Offset_{qua}+1} = 95.77\ ft$ $\quad Station_{failed-Offset_{toe}-Offset_{mid}-Offset_{qua}} = 81.77\ ft$

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

$Land_{slope} = -0$

Given

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

$b_{land} := Find(b_{land}) = 24.41\ ft$

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

Given

$FailRevetEle_{failed} = FailRevetSta_{failed} \cdot Failed_{slope} + b_{failed}$

$b_{failed} := Find(b_{failed}) = -38.28\ ft$

Given

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

$X := Find(X) = 93.56\ ft$

$Y := X \cdot Failed_{slope} + b_{failed} = 24.09\ ft$

$FailTop_{Sta} := X$ $FailTop_{Sta} = 93.56\ ft$

$FailTop_{Ele} := Y$ $FailTop_{Ele} = 24.09\ ft$

$$\text{Offset}_{\text{intersect}} := \left|\begin{array}{l} 0 \ \ \text{if} \ \ \text{FailTop}_{\text{Sta}} = \text{Station}_{\text{failed}-\text{Offset}_{\text{toe}}-\text{Offset}_{\text{mid}}-\text{Offset}_{\text{qua}}} \\ 1 \end{array}\right.$$

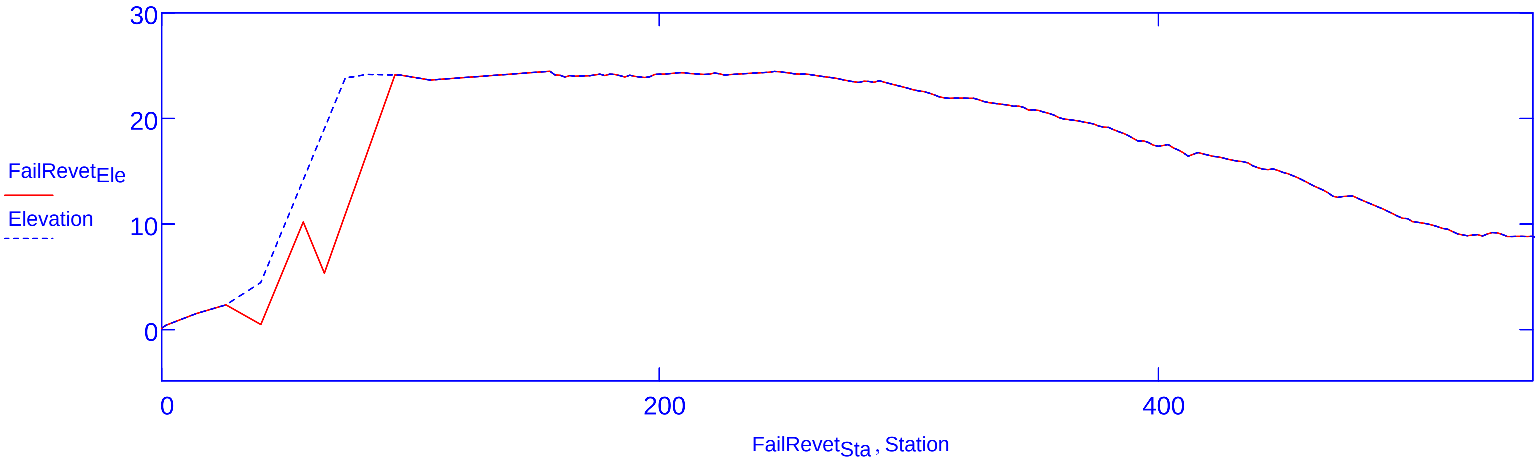
$$\text{Offset}_{\text{intersect}} = 1$$

$$\text{FailRevetSta}_{\text{failed}+\text{Offset}_{\text{intersect}}} := X \qquad \text{FailRevetEle}_{\text{failed}+\text{Offset}_{\text{intersect}}} := Y$$

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

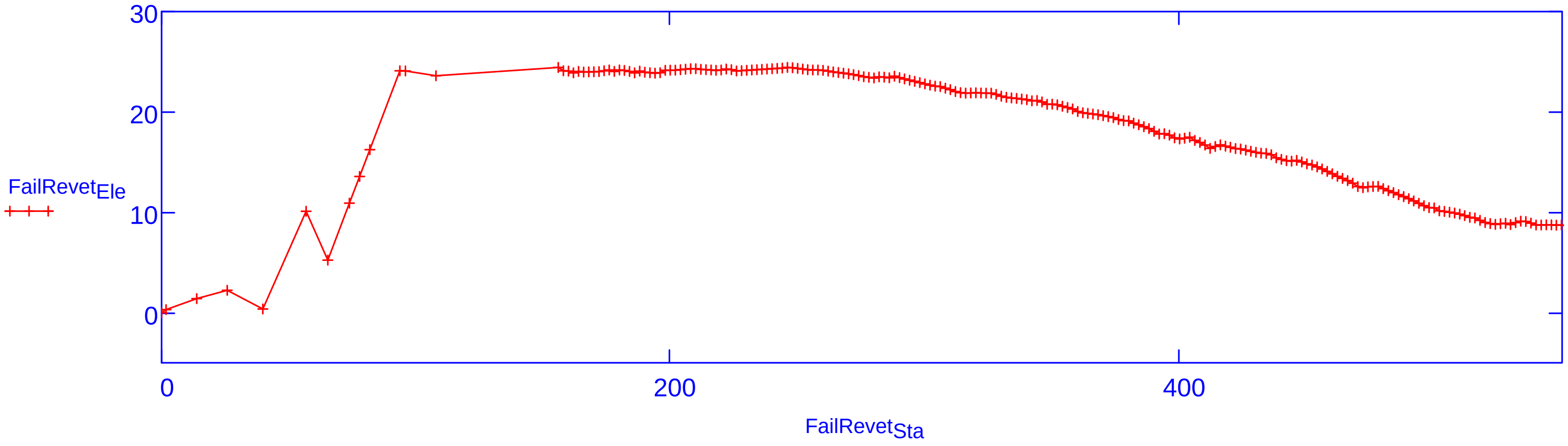
$$\text{FailRevetSta}_a := \text{Station}_{a-\text{Offset}_{\text{toe}}-\text{Offset}_{\text{mid}}-\text{Offset}_{\text{qua}}-\text{Offset}_{\text{intersect}}}$$

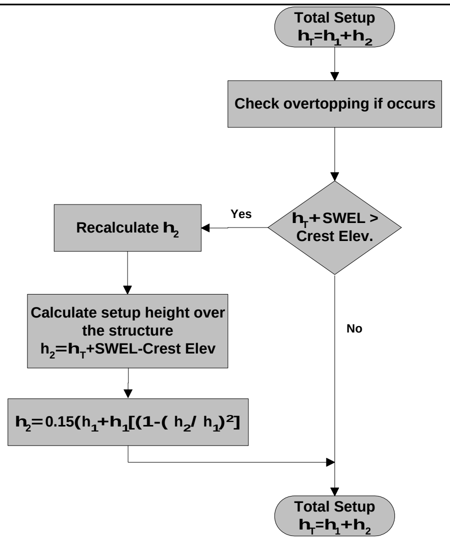
$$\text{FailRevetEle}_a := \text{Elevation}_{a-\text{Offset}_{\text{toe}}-\text{Offset}_{\text{mid}}-\text{Offset}_{\text{qua}}-\text{Offset}_{\text{intersect}}}$$



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

$h := SWEL - ToeR_{scour}$ $\qquad h = 10.1\,ft$

$H_b := b_h \cdot L_0$ $\qquad H_b = 13.41\,ft$ $\qquad H_d := b_d \cdot L_0$ $\qquad H_d = 16.16\,ft$

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

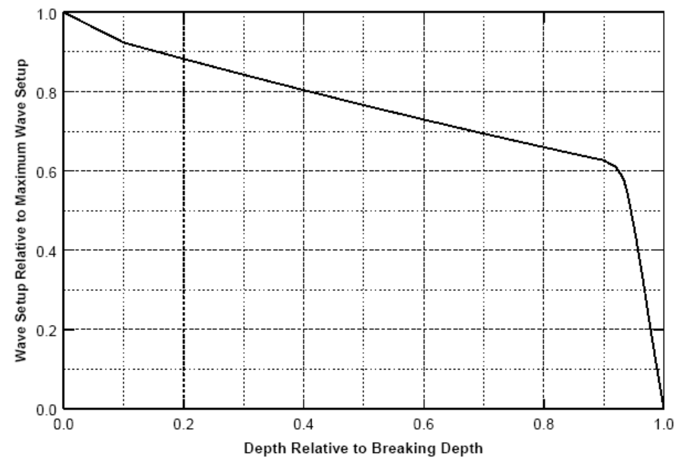


Figure D.2.6-9. Proportion of Maximum Wave Setup that Has Occurred vs. a Proportion of the Breaking Depth.

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

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

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

$R = 0.72$

$\frac{h}{H_d} = 0.62$

$\eta_1 := R\cdot\eta_{open}$ $\eta_1 = 1.39\,\text{ft}$ $\eta_2 := 0.15\cdot(h+\eta_1)$ $\eta_2 = 1.72\,\text{ft}$

$\eta_{FailedStructure} := \eta_1 + \eta_2$ $\eta_{FailedStructure} = 3.11\,\text{ft}$

Total Setup against a coastal structure without considering overtopping

Check Overtopping if Coastal Structure Exists:

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

$Overtopped = \text{"No"}$

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

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

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

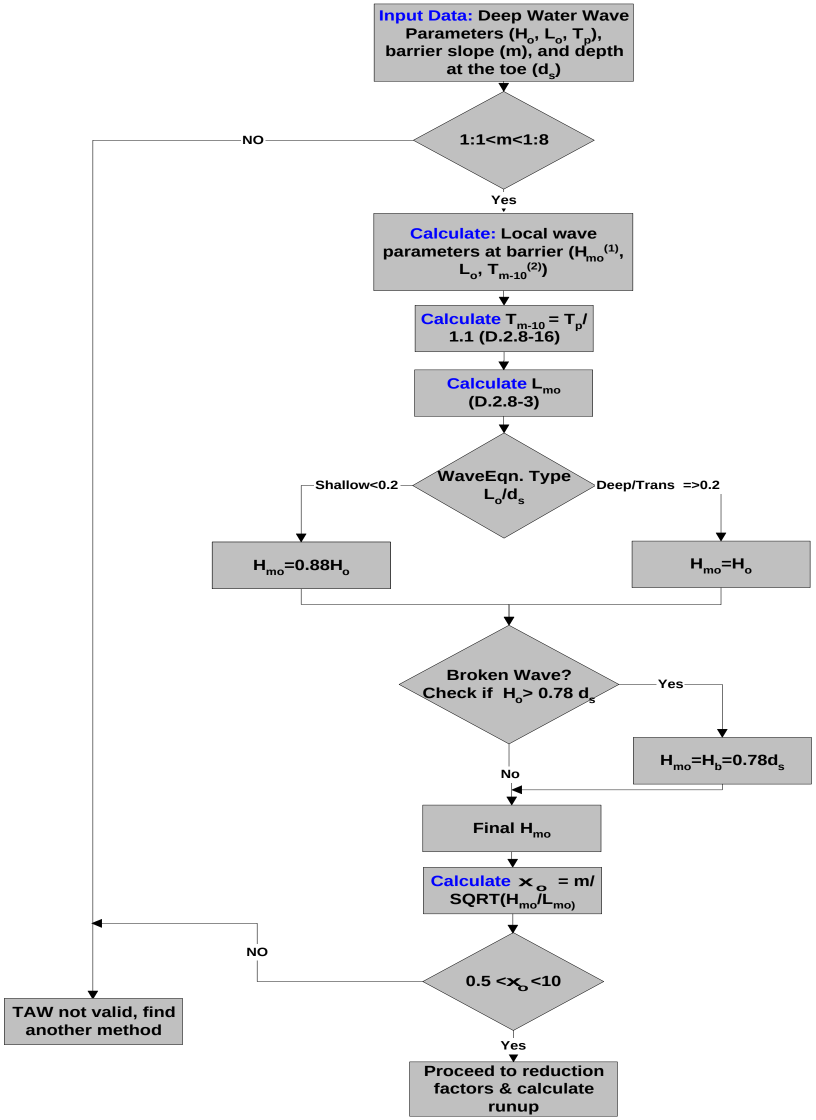
$\eta_{FailedStructure} := \eta_1 + \eta_2$

$\eta_{FailedStructure} = 3.11\,\text{ft}$

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:

$$\text{Slope}_{\text{FAILRevet}} := \frac{\left(\text{FailTop}_{\text{Ele}} - \text{ToeR}_{\text{scour}}\right)}{\left(\text{FailTop}_{\text{Sta}} - \text{Toe}_{\text{sta}}\right)} \qquad \text{Slope}_{\text{FAILRevet}} = 44.12 \cdot \%$$

$$\text{Slope}_{\text{FAILRevetOneOn}} := \frac{1}{\text{Slope}_{\text{FAILRevet}}} \qquad \text{Slope}_{\text{FAILRevetOneOn}} = 2.27$$

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

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

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

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

If wave is depth limited, H_b will be used rather than

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

Determine Wave Type:

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

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

Determine Significant Wave Height Depending on WaveType and DepthLimited Condition:

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

$$H_{m0runupFAIL1} = 10.12\,\text{ft}$$

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

$$H_{m0runupFAIL} = 7.87\,\text{ft}$$

Calculate the Iribarren Number, ξ_{0m}:

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

$$\xi_{om} = 3.62$$

Check TAW Method for Validity based on Iribarren Number:

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

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

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

Select Roughness Reduction Factor, γ_r:

Default - 1 layer of rock with diameter, d, where Hs/d = 1 to 3

$\gamma_r :=$
○ 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

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

$\gamma_b = 0.6$

Default = No Berm

Select Wave Direction Factor, γ_β:

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

Default - Short crested with beta = 0

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

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

$\gamma_\beta = 1$

Select Porosity Factor, γ_P:

Porosity :=
○ 0.1
○ 0.4
● 0.5
○ 0.6

Default Porosity = 0.5

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

$\gamma_p = 0.95$

Summary of Reduction Factors:

$\gamma_p = 0.95$

$\gamma_\beta = 1$

$\gamma_b = 0.6$

$\gamma_r = 0.58$

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

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

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

$R_{FAIL2\%} = 5.41\ \text{ft}$

Check for Overtopping:

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

$OVERTOPPEDFAIL_{Runup} = \text{"NO Overtopping"}$

Wave Height and Wave Period Calculation Worksheet
PL-64

Calc By:___RGG___________
Date:____9-30-13_________

6.0 Conclusions/Results

Wave Height, H_{m0} $H_{m0} = 11.5$ ft FetchStatus = "STWAVE Input (Hmo, Tp)"

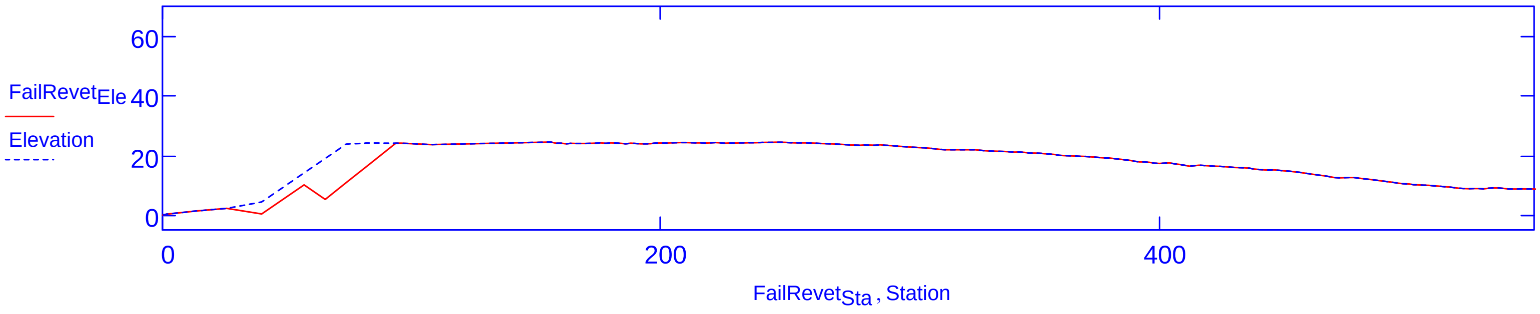
Wave Period, T_P $T_P = 11.2$ s FetchStatus = "STWAVE Input (Hmo, Tp)"

Wave Setup on an open coast, η_{open} $\eta_{open} = 1.93$ ft

Wave Setup on a revetment, $\eta_{Structure}$ $\eta_{Structure} = 2.71$ ft

Wave Runup on a revetment, $R_{2\%}$ $R_{2\%} = 7.51$ ft

Failed Structure Profile:



Wave Setup on a Failed Structure, η $\eta_{FailedStructure} = 3.11$ ft

Wave Runup on a Failed Structure, $R_{FAIL2\%}$ $R_{FAIL2\%} = 5.41$ ft

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

Top of Failed Revetment Station and Elevation:

$\text{FailTop}_{\text{Sta}} = 93.56\,\text{ft}$

$\text{FailTop}_{\text{Ele}} = 24.09\,\text{ft}$

$\text{Fail}_{\text{Sta}} := \text{FailRevet}_{\text{Sta}} \cdot 1 \cdot \frac{1}{\text{ft}}$

$\text{Fail}_{\text{Ele}} := \text{FailRevet}_{\text{Ele}} \cdot 1 \cdot \frac{1}{\text{ft}}$

NOTES:

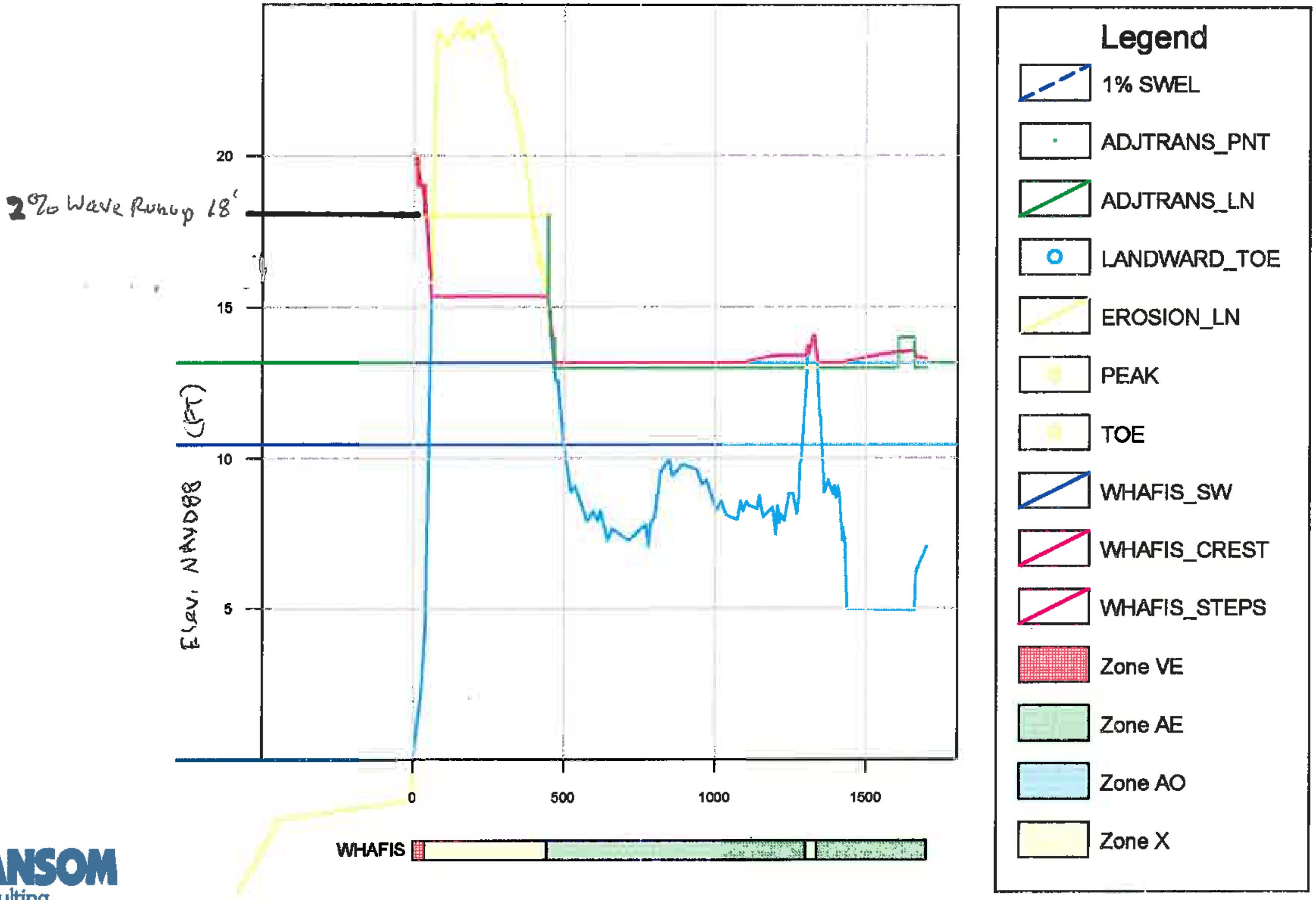
PL-064
Intact

PART6 NUMBERED A ZONES AND V ZONES

STATION OF GUTTER	ELEVATION	ZONE DESIGNATION	FHF
0.00	20.14		
		V30 EL=20	200
13.68	19.50		
		V30 EL=19	200
38.37	18.50		
		V30 EL=18	200
40.00	18.44		
59.00	15.34		
78.00	15.34		
82.00	15.34		
108.00	15.34		
156.00	15.34		
162.00	15.34		
180.00	15.34		
194.00	15.34		
208.00	15.34		
226.00	15.34		
246.00	15.34		
280.00	15.34		
288.00	15.34		
314.00	15.34		
326.00	15.34		
344.00	15.34		
380.00	15.34		

Transect PL-064
Marshfield, Massachusetts

WHAFIS Analysis on Intact Profile
September 30, 2013



RANSOM
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Engineers
and Scientists

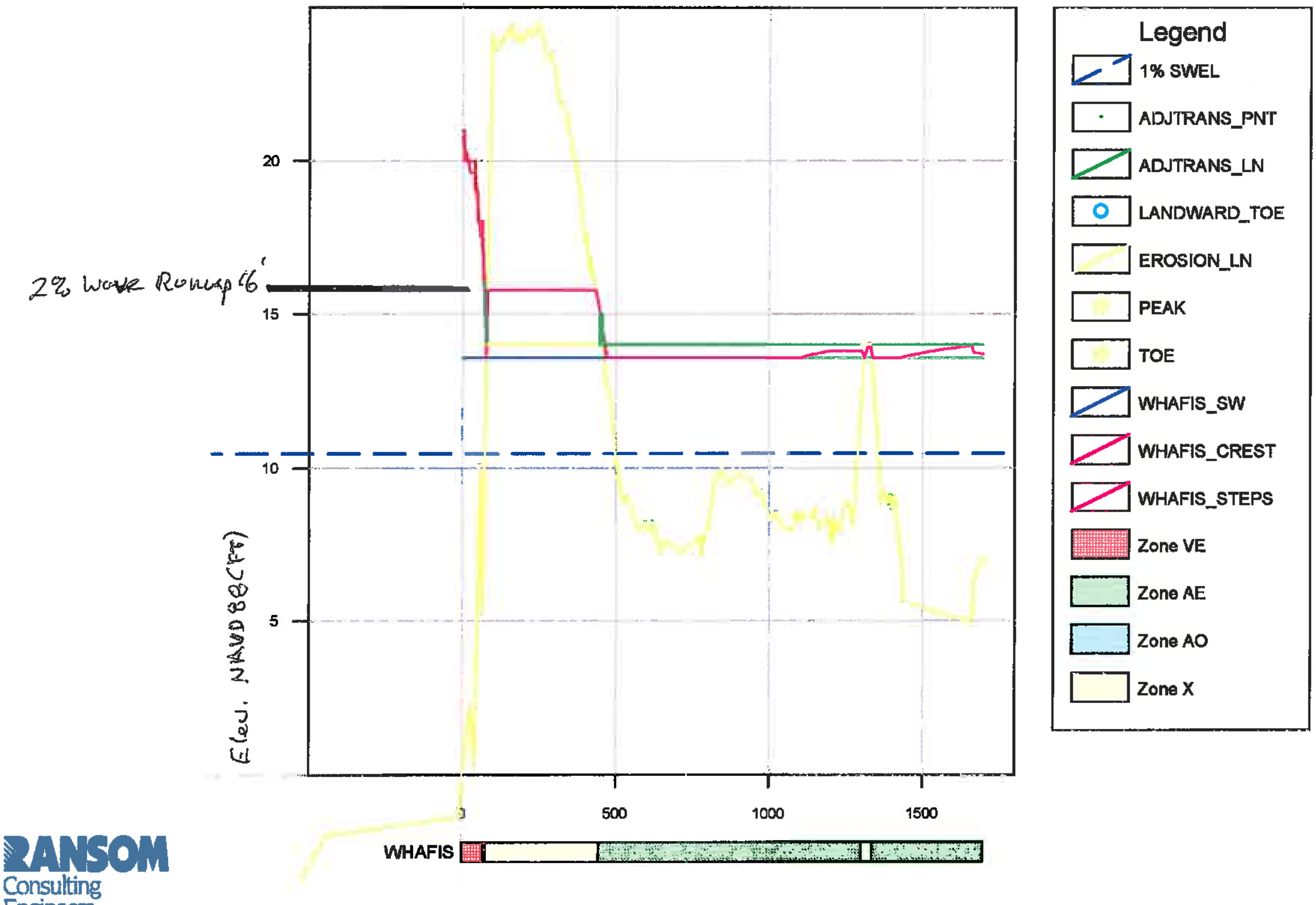
PART6 NUMBERED A ZONES AND V ZONES

PL-064
Failed Profile

STATION OF GUTTER	ELEVATION	ZONE DESIGNATION	FHF
0.00	20.74		
		V30 EL=21	200
4.10	20.50		
		V30 EL=20	200
40.81	19.50		
		V30 EL=19	200
48.99	18.50		
		V30 EL=18	200
65.07	17.50		
		V30 EL=17	200
68.36	16.50		
		V30 EL=16	200
71.10	15.67		
		A24 EL=16	140
71.66	15.50		
		A24 EL=15	140
74.95	14.50		
		A24 EL=14	140
78.00	13.58		
81.00	15.77		
108.00	15.77		
156.00	15.77		
162.00	15.77		
180.00	15.77		
194.00	15.77		
208.00	15.77		
226.00	15.77		
246.00	15.77		

Transect PL-064
Marshfield, Massachusetts

WHAFIS Analysis on Failed Profile
September 30, 2013



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and Scientists

Wave Setup for Scituate, MA, Transect PL-66 Intact

LO	677.8	ft	INCIDENT WAVE LENGTH
H0	13.3	ft	INCIDENT WAVE HEIGHT FROM STWAVE Model
Ho/Lo	0.0196		
Hb	14.9420797	ft	CALCULATE Hb USING MUNK 1949

$$H_b = \frac{H_0}{3.3\left(\frac{H_0}{L_0}\right)^{1/3}}$$

Instructions:	**Insert Values into Highlighted Cells**

Db 19.1565124 ft FIND DEPTH OF WAVE BREAKING USING 0.78Db=Hb

1% SWEL 10.46 NAVD88 TOP OF SLOPE

19.15651 of water supports the breaking wave height

therefore, -8.69651 NAVD88 BOTTOM OF SLOPE

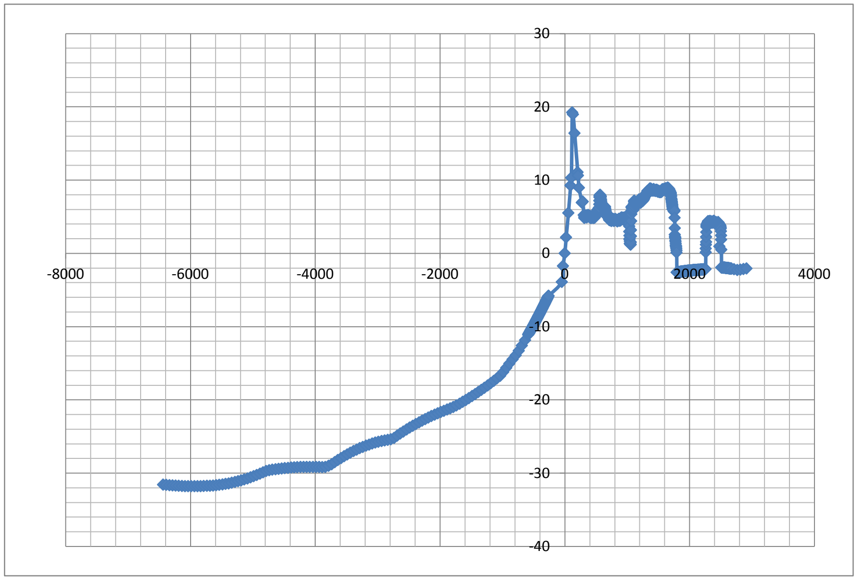
RISE	19.15651	*ft*
RUN	535.6297	*ft*
SLOPE	0.035764	
1:ON	27.96071	

taken off Profiles

Wave Setup				
H'o =	13.3	feet	Deepwater Significant Wave Height	
T =	11.5	sec	Peak Wave Period	
m =	0.0358	ft/ft	Average Slope of Transect	
Lo =	677.8	feet	Deepwater Wavelength	Lo = (g*T^2)/2π
H'o/Lo =	0.0196	ft/ft	Deepwater Wave Steepness	
Irabarren Number	0.2553	ft/ft		I.N. = m/sqrt(Ho/L0)
Sigma(2)	1.0187	ft		Sigma(2) = 0.3*I.N.*Ho
Setup	2.3994184			nopen = Hmo*0.16*(m/(H'o/Lo))^0.2
n	**2.3994184**	**ft**	**Total Static Setup**	n = 4.0*G(H)*G(T)*G(Gamma)*G(Slope)

Marshfield SWEL	10.46	NAVD88	FEET

FEMA extracted profile		Interpolation		
x	y	delta y	delta x	
105.07	10.3	-8.936	-14	interpolate to get X position of SWEL
119.07	19.236			
0	0	105.3207		xcoord of sought for y value of SWEL
-430.93	-8.70659			
-428.93	-8.67412	delta y	delta x	
		-0.032	-2	interpolate to get X position of Db
		-430.309		xcoord of sought for y value of elevation at Db
		535.6297	calculated run	



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

VERSION 12

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: Robert G. Gerber
Date: Sept. 18, 2013
County: Plymouth, MA
Transect Number: PL-66
Airport:
Years of Data set: ST WAVE MODEL

Associated Files: \\chifednas2\fema\R01\Mass\Plymouth\ENGINEERING

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)

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

$U_{10} := 35.76 \frac{m}{s}$

unrestricted radio button is selected above

Wind speed based on CHAMP model default offshore wind = 80 mph
Taken from file:

$U_{10} = 117.32 \cdot \frac{ft}{s}$

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:

$C_D := 0.001 \cdot \left[1.1 + \left(0.035 \cdot U_{10} \cdot \frac{s}{m}\right)\right]$ $\quad C_D = 0.0024$

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

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

Given

$C_D = \frac{u_s^2}{U_{10}^2}$ $\quad u_s := \text{Find}(u_s)$ $\quad u_s = 1.73 \cdot \frac{m}{s}$

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

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

$X = 20663.98 \cdot m$ $\quad u_s = 1.73 \cdot \frac{m}{s}$ $\quad g = 9.81 \frac{1}{s} \cdot \frac{m}{s}$

Given

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

$H_{m0} := \text{Find}(H_{m0})$ $H_{m0} = 3.29 \cdot m$ $H_{m0} = 10.79\,ft$

Calculate Wave Period, T_P (sec):

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

$X = 20663.98 \cdot m$ $u_S = 1.73 \cdot \frac{m}{s}$ $g = 9.81 \frac{1}{s} \cdot \frac{m}{s}$

Given

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

$T_P := \text{Find}(T_P)$ $T_P = 5.4 \cdot s$

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 File:

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

$H_{m0STWAVE} := 9.327 \cdot m$ $T_{PSTWAVE} := 13.58 \cdot sec$

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: \\chifednas2\fema\Mass\Plymouth\ENGINEERING\COASTAL\GENERAL

$$H_{m0} := \begin{cases} H_{m0STWAVE} & \text{if } FetchStatus = \text{"STWAVE Input (Hmo, Tp)"} \\ H_{m0ACES} & \text{if } FetchStatus = \text{"Restricted Fetch Input from ACES (Hmo, Tp)"} \\ H_{m0} & \text{otherwise} \end{cases}$$

RESULT:

$H_{m0} := 13.3 \cdot ft$ $T_P := 11.5 \cdot sec$ FetchStatus = "STWAVE Input (Hmo, Tp)"

Based on STWAVE model Results

5.2 Wave Setup, η, Calculation

5.2.1 Open Coast Wave Setup Analysis

Definition of Variables:

$m := 0.03576$ Insert value of average transect slope based on GIS data

Calculate Deep Water Wave Length, L_0:

$L_0 := \frac{g \cdot T_P^{\ 2}}{2 \cdot \pi}$ $L_0 = 677.21 \, ft$

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

Calculate Wave Slope, S:

$S := \frac{H_{m0}}{L_0}$ $S = 0.0196$ $S = 1.96 \cdot \%$

Calculate Static Open Coast Wave Setup:

$\eta_{open} := H_{m0} \cdot 0.160 \cdot \frac{m^{0.2}}{S^{0.2}}$ $\eta_{open} = 2.4 \, ft$

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

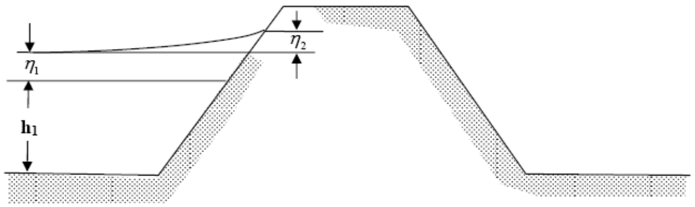


Figure D.2.6-6. Definition Sketch for Nonovertopped Levee

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("PL66_Sta_El.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:

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

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

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

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

Profile =

	0	1
0	-6436.06	-31.57
1	-6386.06	-31.62
2	-6336.06	-31.66
3	-6286.06	-31.69
4	-6236.06	-31.72
5	-6186.06	-31.75
6	-6136.06	-31.77
7	-6086.06	...

Array of horizontal distance from the shoreline

Station = ft

	0
0	-6436.06
1	-6386.06
2	-6336.06
3	...

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

Elevation = ft

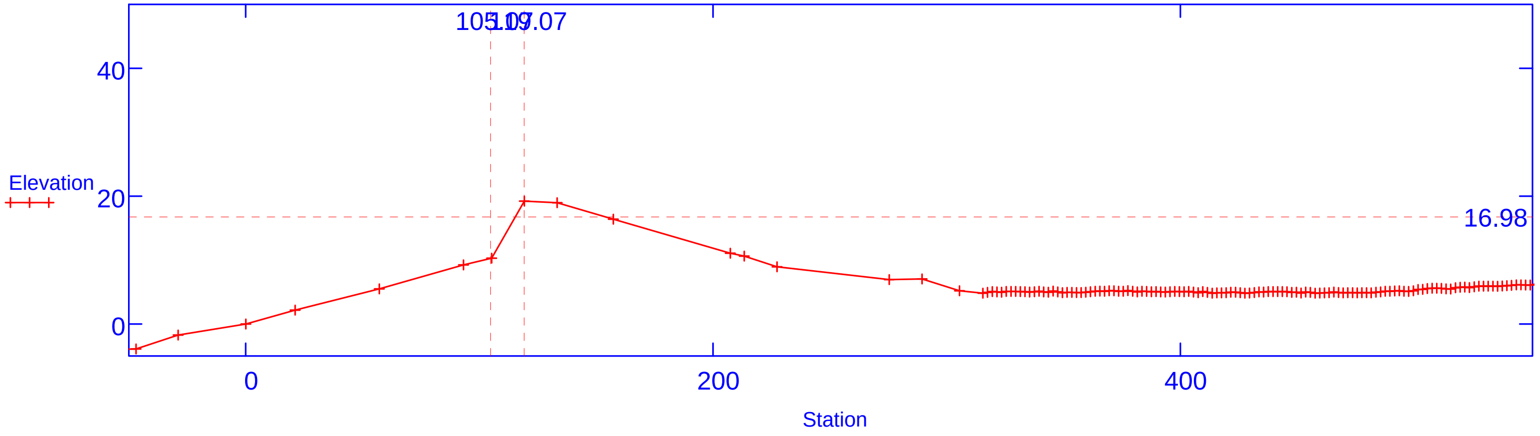
	0
0	-31.57
1	-31.62
2	-31.66
3	...

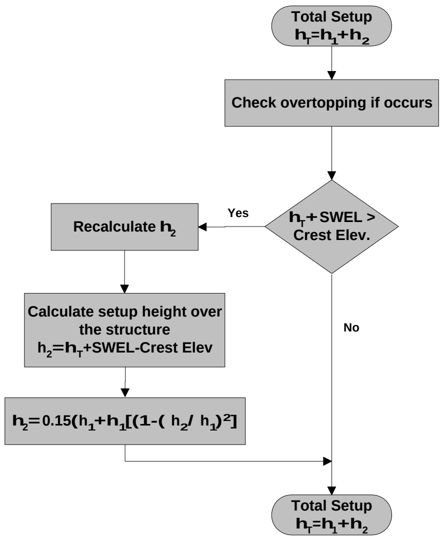
The following displays the profile of the

Client:_Town of Marshfield__________
County:___Plymouth, MA
Transect Number:_PL-66

Wave Height and Wave Period Calculation Worksheet

Calc By:___RGG___________
Date:____9-23-13_________





Wave Height and Wave Period Calculation Worksheet

Identify station and elevation of the toe of the structure:

$Toe_{sta} := 105.07ft$

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

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

$Toe_{ele} = 10.3\,ft$

Identify station and elevation of the top of the structure:

$Top_{sta} := 119.07 \cdot ft$

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

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

$Top_{ele} = 19.24\,ft$

Enter 1% annual chance stillwater elevation (ft):

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

$SWEL := 10.46 \cdot ft$

Calculate Water Depth at Structure, h

$h := SWEL - Toe_{ele}$ $h = 0.16\,ft$

Calculate the Breaking Wave Height, H_b:

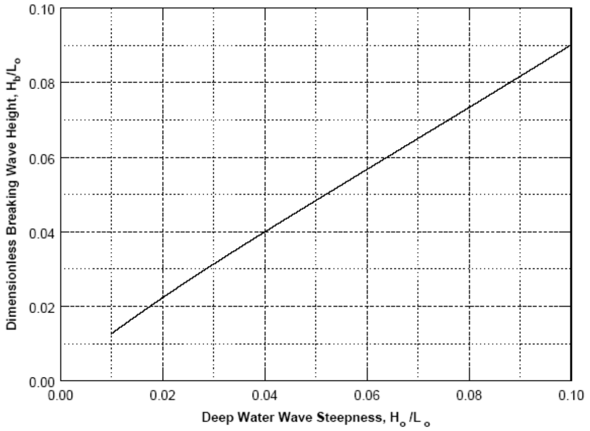


Figure D.2.6-7. Dimensionless Breaking Wave Height vs. Deepwater Wave Steepness

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

$b_h := 0.8481 \cdot s + 0.0057$ $b_h = 0.02$

Estimated curve equation in Figure D.2.6-7

$H_b := b_h \cdot L_0$ $H_b = 15.14\,\text{ft}$

Calculate the Breaking Wave Depth, H_d:

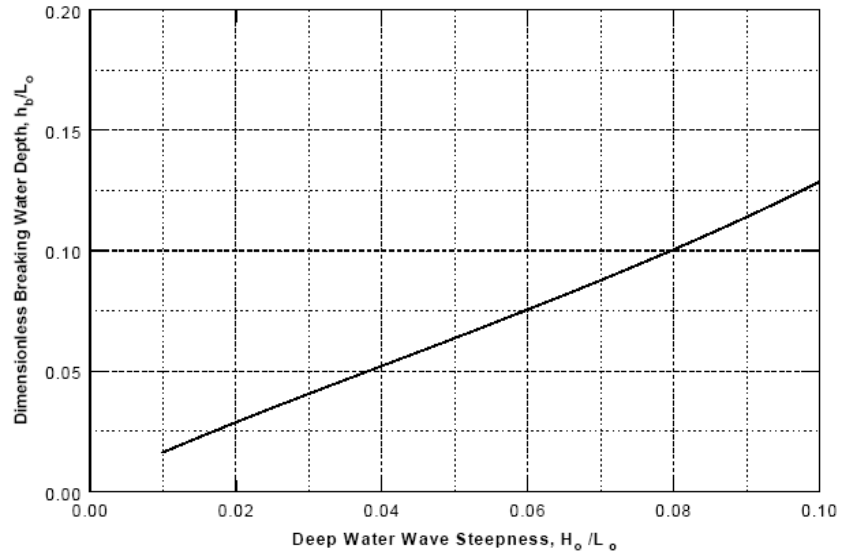


Figure D.2.6-8. Dimensionless Breaking Water Depth vs. Deepwater Wave Steepness.

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

$H_d := b_d \cdot L_0$ $H_d = 18.47\,\text{ft}$

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

Figure from: Atlantic Ocean and

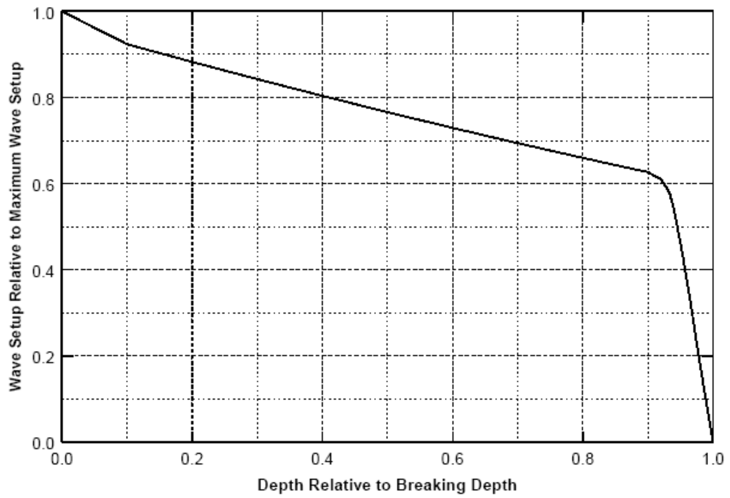


Figure D.2.6-9. Proportion of Maximum Wave Setup that Has Occurred vs. a Proportion of the Breaking Depth.

Gulf of Mexico Coastal
Guidelines Update Feb 2007

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

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

$R = 0.99$ $\frac{h}{H_d} = 0.01$

$\eta_1 := R \cdot \eta_{open}$ $\eta_1 = 2.38\,\text{ft}$ $\eta_2 := 0.15 \cdot (h + \eta_1)$ $\eta_2 = 0.38\,\text{ft}$

$\eta_{Structure} := \eta_1 + \eta_2$ $\eta_{Structure} = 2.76\,\text{ft}$

Total Setup against a coastal structure without considering overtopping

Check Overtopping if Coastal Structure Exists:

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

$Overtopped = \text{"No"}$

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

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

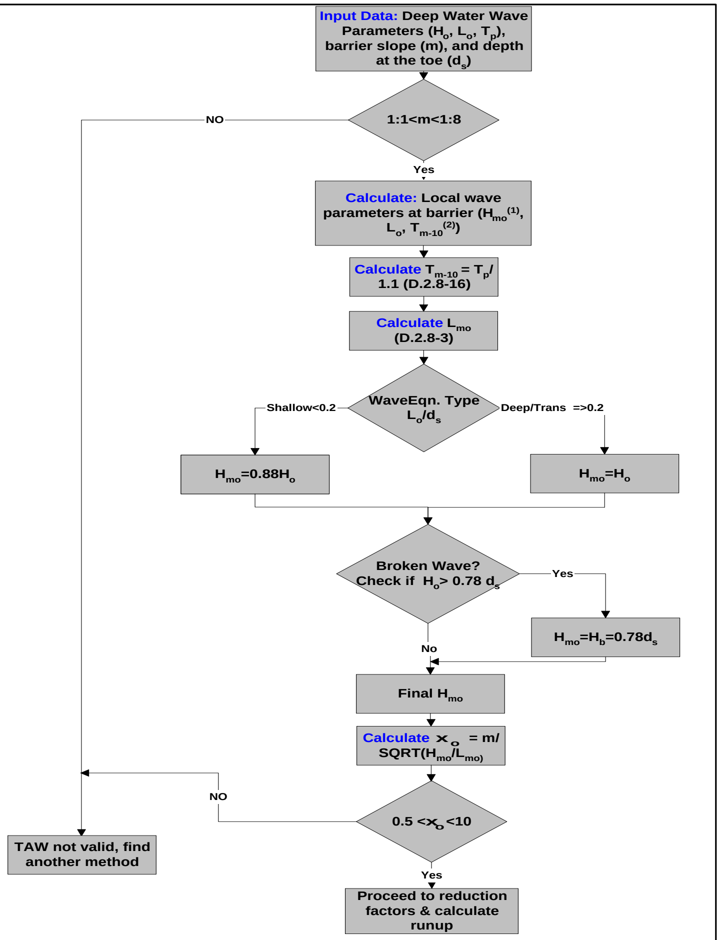
$$\eta_2 := \begin{cases} 0.15 \cdot (h + \eta_1) \cdot \left[1 - \left(\frac{h_2}{h}\right)^2\right] & \text{if } Overtopped = \text{"Yes"} \\ \eta_2 & \text{otherwise} \end{cases}$$

$\eta_{Structure} := \eta_1 + \eta_2$ $\eta_{Structure} = 2.76\,\text{ft}$

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:

$$Slope_{Revet} := \frac{\left(Top_{ele} - Toe_{ele}\right)}{\left(Top_{sta} - Toe_{sta}\right)} \qquad Slope_{Revet} = 63.83 \cdot \%$$

$$Slope_{RevetOneOn} := \frac{1}{Slope_{Revet}} \qquad Slope_{RevetOneOn} = 1.57$$

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

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

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

$Depth_{Limited} :=$ | "Limited" if $H_{m0} \ge 0.78 \cdot h$
| "Not Limited" otherwise

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

$Depth_{Limited} =$ "Limited"

Determine Wave Type:

$WaveType :=$ | "Shallow" if $\frac{h}{L_0} < 2$
| "Transitional" if $0.2 \le \frac{h}{L_0} < 0.5$
| "Deep" otherwise

$WaveType =$ "Shallow"

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

$H_{m0runup1} :=$ | $0.88 \cdot H_{m0}$ if WaveType = "Shallow"
| H_{m0} otherwise

$H_{m0runup1} = 11.7\,ft$

$H_{m0runup} :=$ | $0.78 \cdot h$ if $Depth_{Limited}$ = "Limited"
| $H_{m0runup1}$ otherwise

$H_{m0runup} = 0.12\,ft$

Calculate the Spectral Wave Period, T_{m10}

$T_{m10} := \frac{T_P}{1.1}$ Equation D.2.8-16 $T_{m10} = 10.45\,s$

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 $L_{m0} = 559.68\,ft$

Calculate the Iribarren Number, ξ_{0m}:

$\xi_{om} := \frac{Slope_{Revet}}{\sqrt{\frac{H_{m0runup}}{L_{m0}}}}$ $\xi_{om} = 42.74$

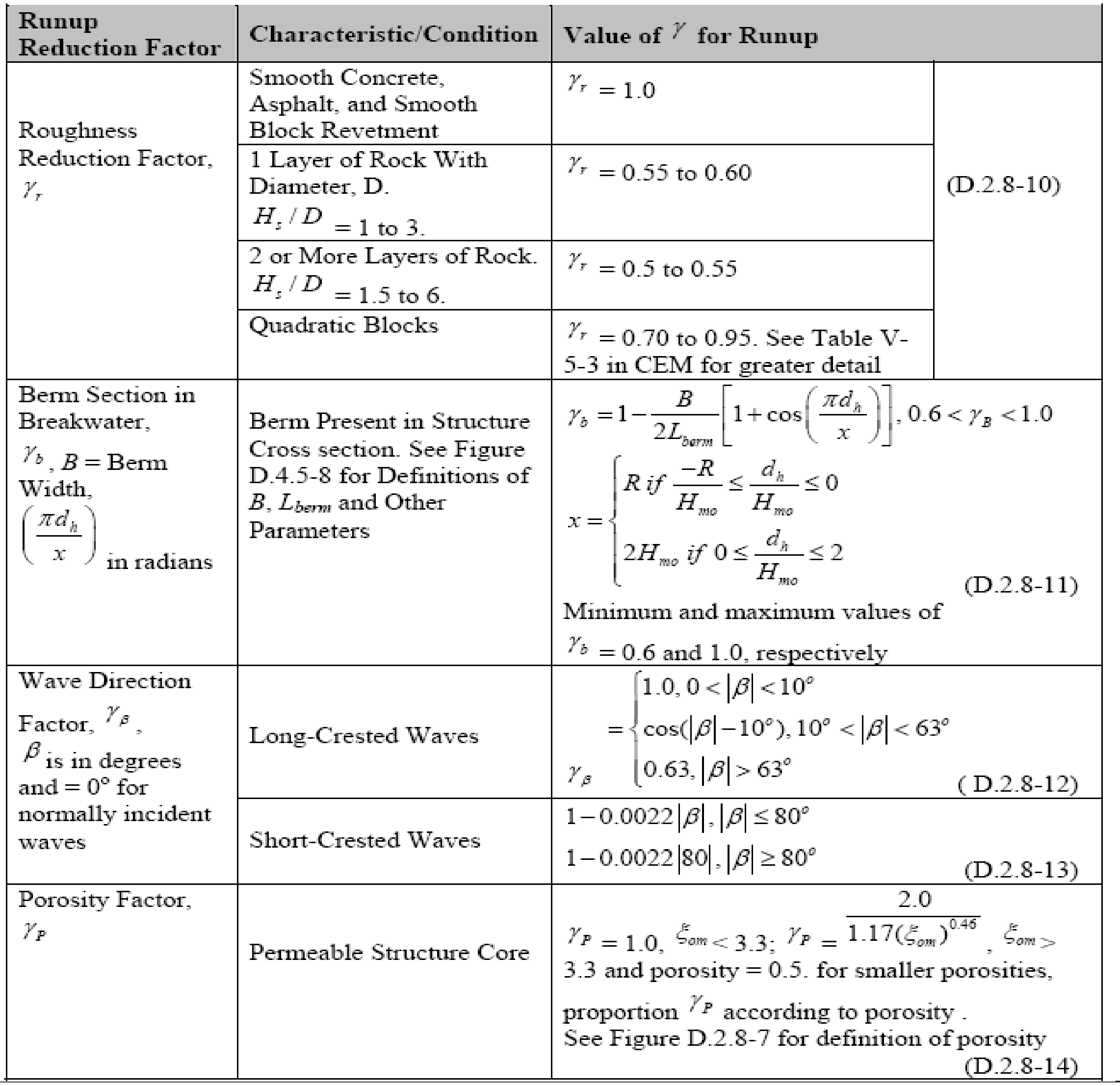
Check TAW Method for Validity based on Iribarren Number:

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

$Iribarren_{Check} =$ "TAW method is NOT vaild for this Irbarren value. Please seek alternative method."

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

Table D.2.8-5. Summary of γ Runup Reduction Factors



Runup Reduction Factor	Characteristic/Condition	Value of γ for Runup	
Roughness Reduction Factor, γ_r	Smooth Concrete, Asphalt, and Smooth Block Revetment	$\gamma_r = 1.0$	(D.2.8-10)
	1 Layer of Rock With Diameter, D. H_s / D = 1 to 3.	γ_r = 0.55 to 0.60	
	2 or More Layers of Rock. H_s / D = 1.5 to 6.	γ_r = 0.5 to 0.55	
	Quadratic Blocks	γ_r = 0.70 to 0.95. See Table V-5-3 in CEM for greater detail	
Berm Section in Breakwater, γ_b , B = Berm Width, $\left(\frac{\pi d_h}{x}\right)$ in radians	Berm Present in Structure Cross section. See Figure D.4.5-8 for Definitions of B, L_{berm} and Other Parameters	$\gamma_b = 1-\frac{B}{2L_{berm}}\left[1+\cos\left(\frac{\pi d_h}{x}\right)\right], 0.6<\gamma_B<1.0$ $x=\begin{cases} R\ if\ \frac{-R}{H_{mo}} \le \frac{d_h}{H_{mo}} \le 0 \\ 2H_{mo}\ if\ 0 \le \frac{d_h}{H_{mo}} \le 2 \end{cases}$ Minimum and maximum values of γ_b = 0.6 and 1.0, respectively	(D.2.8-11)
Wave Direction Factor, γ_β , β is in degrees and = 0° for normally incident waves	Long-Crested Waves	$\gamma_\beta = \begin{cases} 1.0, 0<\lvert\beta\rvert<10^o \\ \cos(\lvert\beta\rvert-10^o), 10^o<\lvert\beta\rvert<63^o \\ 0.63, \lvert\beta\rvert>63^o \end{cases}$	(D.2.8-12)
	Short-Crested Waves	$1-0.0022\lvert\beta\rvert, \lvert\beta\rvert \le 80^o$ $1-0.0022\lvert 80\rvert, \lvert\beta\rvert \ge 80^o$	(D.2.8-13)
Porosity Factor, γ_P	Permeable Structure Core	$\gamma_P = 1.0,\ \xi_{om} < 3.3;\ \gamma_P = \frac{2.0}{1.17(\xi_{om})^{0.46}},\ \xi_{om} >$ 3.3 and porosity = 0.5. for smaller porosities, proportion γ_P according to porosity . See Figure D.2.8-7 for definition of porosity	(D.2.8-14)

Select Roughness Reduction Factor, γ_r:

$\gamma_r :=$

Default Value - 1 layer of rock with diameter Hs/D = 1 to 3

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

$\gamma_r = 0.58$

Select Berm Section in Breakwater, γ_b:

$\gamma_b :=$

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

Default Value - No Berm

$\gamma_b = 1$

Select Wave Direction Factor, γ_β:

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

Default Value - Short Crested Wave with normally incident wave

$\gamma_\beta :=$

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

$\gamma_\beta = 1$

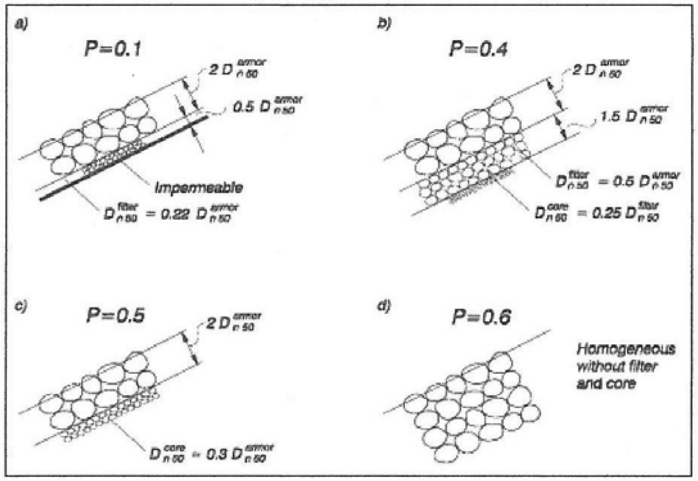


Figure VI-5-11. Notational permeability coefficients (van der Meer 1988)

Select Porosity Factor, γ_P:

Porosity :=

Default Porosity = 0.5

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

Default Value -
P=0.5

$\gamma_p = 0.3$

Summary of Reduction Factors:

$\gamma_p = 0.3$

$\gamma_\beta = 1$

$\gamma_b = 1$

$\gamma_r = 0.58$

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

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

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

$R_{2\%} = \text{"TAW Not Valid"}$

Check for Overtopping:

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

$OVERTOPPED_{Runup} =$ ▪

5.4 Failed Revetment Structure Analysis

$Armor_D := 4\cdot ft$

Insert Depth of Armor layer in Feet

Calculate Slope of the Revetment:

$\text{Slope} := \frac{(\text{Top}_{ele} - \text{Toe}_{ele})}{(\text{Top}_{sta} - \text{Toe}_{sta})}$ $\text{Slope} = 0.64$

Calculate the Midpoint of the Revetment:

$\text{Length} := \sqrt{(\text{Top}_{sta} - \text{Toe}_{sta})^2 + (\text{Top}_{ele} - \text{Toe}_{ele})^2}$ $\text{Length} = 16.61\,\text{ft}$

$\text{Midpoint} := \frac{\text{Length}}{2}$ $\text{Midpoint} = 8.3\,\text{ft}$

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

$\text{Mid}_{sta} := \left[\left(\frac{\text{Midpoint}}{\text{Length}}\right)\cdot(\text{Top}_{sta} - \text{Toe}_{sta})\right] + \text{Toe}_{sta}$ $\text{Mid}_{sta} = 112.07\,\text{ft}$

Determine the Elevation of the Midpoint of the Revetment:

$\text{Mid}_{ele} := \text{linterp}(\text{Station}, \text{Elevation}, \text{Mid}_{sta})$ $\text{Mid}_{ele} = 14.77\,\text{ft}$

Calculate the Upper Quarter of the Revetment:

$\text{Quarter} := \frac{\text{Length}\cdot 3}{4}$ $\text{Quarter} = 12.46\,\text{ft}$

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

$\text{Quarter}_{sta} := \left[\left(\frac{\text{Quarter}}{\text{Length}}\right)\cdot(\text{Top}_{sta} - \text{Toe}_{sta})\right] + \text{Toe}_{sta}$ $\text{Quarter}_{sta} = 115.57\,\text{ft}$

Determine the Elevation of the Upper Quadrant of the Revetment:

$\text{Quarter}_{ele} := \text{linterp}(\text{Station}, \text{Elevation}, \text{Quarter}_{sta})$ $\text{Quarter}_{ele} = 17\,\text{ft}$

Calculate Scour at the Toe of the Revetment:

$ToeR_{scour} := Toe_{ele} - Armor_D$ $ToeR_{scour} = 6.3\,ft$

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 $Toe_{location}$, $Mid_{location}$, $Quarter_{location}$, or $Top_{location}$ 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, $Mid_{location}$, $Quarter_{location}$, and $Top_{location}$.

$Offset_{toe}$, $Offset_{mid}$, $Offset_{qua}$, and $Offset_{top}$ 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.

Station = ft

	0
0	-6436.06
1	-6386.06
2	-6336.06
3	-6286.06
4	-6236.06
5	-6186.06
6	-6136.06
7	-6086.06
8	-6036.06
9	-5986.06
10	-5936.06
11	-5886.06
12	-5836.06
13	-5786.06
14	-5736.06
15	...

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

$\mathrm{Toe}_{location} := \mathrm{match}(\mathrm{Toe}_{sta}, \mathrm{Station})$ $\mathrm{Toe}_{location} = (286)$ $\mathrm{Toe}_{location_0} = 286$ $\mathrm{Toe}_{sta} = 105.07\ \mathrm{ft}$

$$\mathrm{Offset}_{toe} := \begin{cases} 0 & \text{if } \mathrm{Station}_{(\mathrm{Toe}_{location_0})} = \mathrm{Toe}_{sta} \\ 1 & \text{otherwise} \end{cases}$$

$$\mathrm{Toe}_{Staloc} := \begin{cases} \mathrm{Toe}_{location_0} + \mathrm{Offset}_{toe} & \text{if } \mathrm{Toe}_{sta} \geq \mathrm{Station}_{(\mathrm{Toe}_{location_0})} \\ \mathrm{Toe}_{location_0} & \text{otherwise} \end{cases}$$

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

$\mathrm{Toe}_{Staloc} = 286$

Determine if station of the midpoint of the revetment is within the Station array and if not, add a data point2

$\mathrm{Mid}_{location} := \mathrm{match}(\mathrm{Mid}_{sta}, \mathrm{Station})$ $\mathrm{Mid}_{location} := \begin{pmatrix} 286 \\ 287 \end{pmatrix}$ $\mathrm{Mid}_{location_0} = 286$ $\mathrm{Mid}_{sta} = 112.07\ \mathrm{ft}$

$$\mathrm{Offset}_{mid} := \begin{cases} 0 & \text{if } \mathrm{Station}_{(\mathrm{Mid}_{location_0})} = \mathrm{Mid}_{sta} \\ 1 & \text{otherwise} \end{cases}$$

$$\mathrm{Mid}_{Staloc} := \begin{cases} \mathrm{Mid}_{location_0} + \mathrm{Offset}_{toe} + \mathrm{Offset}_{mid} & \text{if } \mathrm{Mid}_{sta} \geq \mathrm{Station}_{(\mathrm{Mid}_{location_0})} \\ (\mathrm{Mid}_{location_0} + \mathrm{Offset}_{toe}) & \text{otherwise} \end{cases}$$

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

$\mathrm{Mid}_{Staloc} = 287$ $\mathrm{FailRevetSta}_{\mathrm{Mid}_{Staloc}} := \mathrm{Mid}_{sta}$

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

$\mathrm{Quarter}_{location} := \mathrm{match}(\mathrm{Quarter}_{sta}, \mathrm{Station})$ $\mathrm{Quarter}_{location} := \begin{pmatrix} 286 \\ 287 \end{pmatrix}$ $\mathrm{Quarter}_{location_0} = 286$ $\mathrm{Quarter}_{sta} = 115.57\ \mathrm{ft}$

$$\mathrm{Offset}_{qua} := \begin{cases} 0 & \text{if } \mathrm{Station}_{(\mathrm{Quarter}_{location_0})} = \mathrm{Quarter}_{sta} \\ 1 & \text{otherwise} \end{cases}$$

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

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

$\text{Quarter}_{\text{Staloc}} = 288$ $\qquad$ $\text{FailRevetSta}_{\text{Quarter}_{\text{Staloc}}} := \text{Quarter}_{\text{sta}}$

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

$\text{Top}_{\text{location}} := \text{match}\left(\text{Top}_{\text{sta}}, \text{Station}\right)$ $\qquad$ $\text{Top}_{\text{location}} = \left(287\right)$ $\qquad$ $\text{Top}_{\text{location}_0} = 287$ $\qquad$ $\text{Top}_{\text{sta}} = 119.07\,\text{ft}$

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

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

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

$\text{Top}_{\text{Staloc}} = 289$ $\qquad$ $\text{FailRevetSta}_{\text{Top}_{\text{Staloc}}} := \text{Top}_{\text{sta}}$

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

$i := \text{Toe}_{\text{location}_0} .. 0$ $\qquad$ $\text{FailRevetSta}_i := \text{Station}_i$ $\qquad$ $\text{FailRevetSta}_{\text{Toe}_{\text{Staloc}}} := \text{Toe}_{\text{sta}}$

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

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

$$\text{FailRevetSta}_x := \begin{cases} \text{Station}_{x - \text{Offset}_{\text{toe}}} & \text{if } x \ne \text{Toe}_{\text{Staloc}} \\ \text{Toe}_{\text{sta}} & \text{otherwise} \end{cases}$$

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

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

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

$$\text{FailRevetSta}_y := \begin{cases} \text{Station}_{y - \text{Offset}_{\text{toe}} - \text{Offset}_{\text{mid}}} & \text{if } y \ne \text{Mid}_{\text{Staloc}} \\ \text{Mid}_{\text{sta}} & \text{otherwise} \end{cases}$$

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

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

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

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

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

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

$$\mathrm{end} := \mathrm{last}(\mathrm{Station}) + \mathrm{Offset}_{toe} + \mathrm{Offset}_{mid} + \mathrm{Offset}_{qua} + \mathrm{Offset}_{top} \qquad \mathrm{end} = 1678$$

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

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

$$\mathrm{FailRevetEle}_i := \mathrm{Elevation}_i$$

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

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

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

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

$$\mathrm{FailRevetEle}_x := \left|\begin{array}{ll} \mathrm{Elevation}_{x-\mathrm{Offset}_{toe}} - \mathrm{Armor}_D & \text{if } \; x \neq \mathrm{Toe}_{Staloc} \\ \mathrm{ToeR}_{scour} & \text{otherwise} \end{array}\right.$$

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.

$$\mathrm{FailRevet}_{\mathrm{Ele}_{y}} := \left| \begin{array}{ll} \left(\mathrm{Station}_{y-\mathrm{Offset}_{\mathrm{toe}}-\mathrm{Offset}_{\mathrm{mid}}} - \mathrm{Mid}_{\mathrm{sta}}\right)\cdot\left(\mathrm{Slope}\cdot -1\right) + \left(\mathrm{Mid}_{\mathrm{ele}} - \mathrm{Armor}_{D}\right) & \text{if } y \neq \mathrm{Mid}_{\mathrm{Staloc}} \\ \left(\left(\mathrm{Mid}_{\mathrm{ele}} - \mathrm{Armor}_{D}\right)\right) & \text{otherwise} \end{array} \right.$$

Sets the elevation of the upper quadrant of the revetment

$$\mathrm{FailRevet}_{\mathrm{Ele}_{\mathrm{Quarter}_{\mathrm{Staloc}}}} := \left(\mathrm{Quarter}_{\mathrm{sta}} - \mathrm{Mid}_{\mathrm{sta}}\right)\cdot\left(\mathrm{Slope}\cdot -1\right) + \left(\mathrm{Mid}_{\mathrm{ele}} - \mathrm{Armor}_{D}\right)$$

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.

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

$$\mathrm{FailRevet}_{\mathrm{Ele}_{j}} := \left| \begin{array}{ll} \left[\left(\mathrm{FailRevet}_{\mathrm{Sta}_{j}} - \mathrm{Quarter}_{\mathrm{sta}}\right)\cdot\left(\frac{1}{1.5}\right)\right] + \mathrm{FailRevet}_{\mathrm{Ele}_{\mathrm{Quarter}_{\mathrm{Staloc}}}} & \text{if } \left[\left(\mathrm{FailRevet}_{\mathrm{Sta}_{j}} - \mathrm{Quarter}_{\mathrm{sta}}\right)\cdot\left(\frac{1}{1.5}\right)\right] + \mathrm{FailRevet}_{\mathrm{Ele}_{\mathrm{Quarter}_{\mathrm{Staloc}}}} \leq \mathrm{Elevation}_{j-\mathrm{Offset}_{\mathrm{toe}}-\mathrm{Offset}_{\mathrm{mid}}-\mathrm{Offset}_{\mathrm{qua}}} \\ \text{break} & \text{otherwise} \end{array} \right.$$

$\mathrm{failed} := \mathrm{last}\left(\mathrm{FailRevet}_{\mathrm{Ele}}\right)$ $\mathrm{failed} = 289$

$b_{\mathrm{land}} := 0$

Finds the intersection point of failed profile and intact profile:

$b_{\mathrm{failed}} := 0$

$\mathrm{Station}_{\mathrm{failed}-\mathrm{Offset}_{\mathrm{toe}}-\mathrm{Offset}_{\mathrm{mid}}-\mathrm{Offset}_{\mathrm{qua}}+1} = 133.07\,\mathrm{ft}$ $\mathrm{Station}_{\mathrm{failed}-\mathrm{Offset}_{\mathrm{toe}}-\mathrm{Offset}_{\mathrm{mid}}-\mathrm{Offset}_{\mathrm{qua}}} = 119.07\,\mathrm{ft}$

Wave Height and Wave Period Calculation Worksheet

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

$Land_{slope} = -0.02$

Given

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

$b_{land} := Find(b_{land}) = 21.49\ ft$

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

Given

$FailRevetEle_{failed} = FailRevetSta_{failed} \cdot Failed_{slope} + b_{failed}$

$b_{failed} := Find(b_{failed}) = -68.51\ ft$

Given

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

$X := Find(X) = 131.28\ ft$

$Y := X \cdot Failed_{slope} + b_{failed} = 19\ ft$

$FailTop_{Sta} := X$ $FailTop_{Sta} = 131.28\ ft$

$FailTop_{Ele} := Y$ $FailTop_{Ele} = 19\ ft$

$$\text{Offset}_{\text{intersect}} := \left| \begin{array}{l} 0 \;\; \text{if} \;\; \text{FailTop}_{\text{Sta}} = \text{Station}_{\text{failed}-\text{Offset}_{\text{toe}}-\text{Offset}_{\text{mid}}-\text{Offset}_{\text{qua}}} \\ 1 \end{array} \right.$$

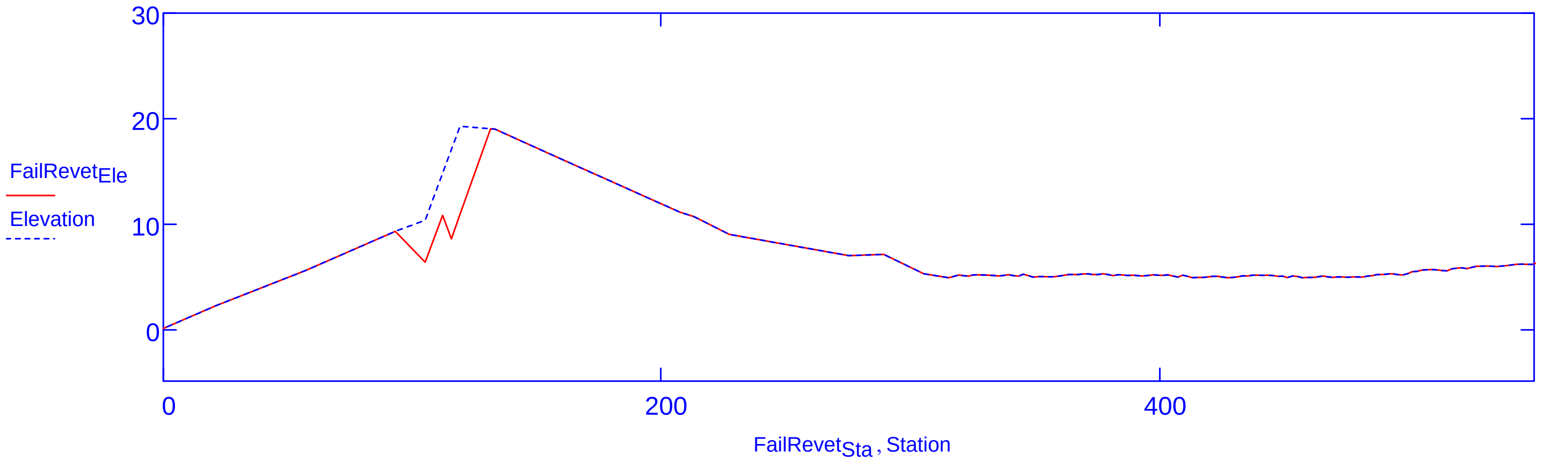
$$\text{Offset}_{\text{intersect}} = 1$$

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

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

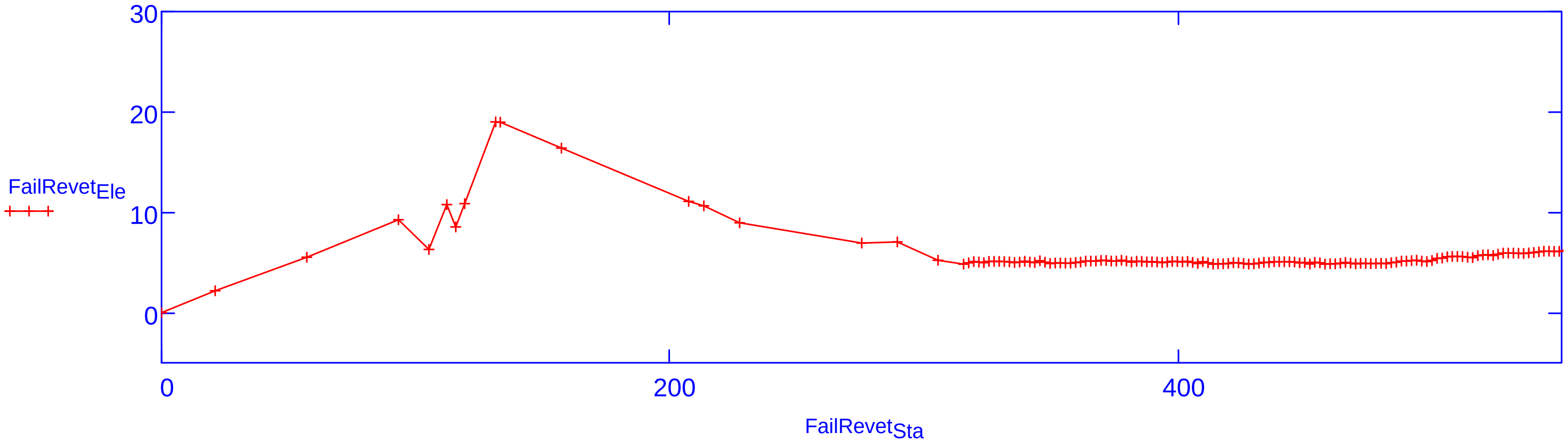
$$\text{FailRevet}_{\text{Sta}_a} := \text{Station}_{a-\text{Offset}_{\text{toe}}-\text{Offset}_{\text{mid}}-\text{Offset}_{\text{qua}}-\text{Offset}_{\text{intersect}}}$$

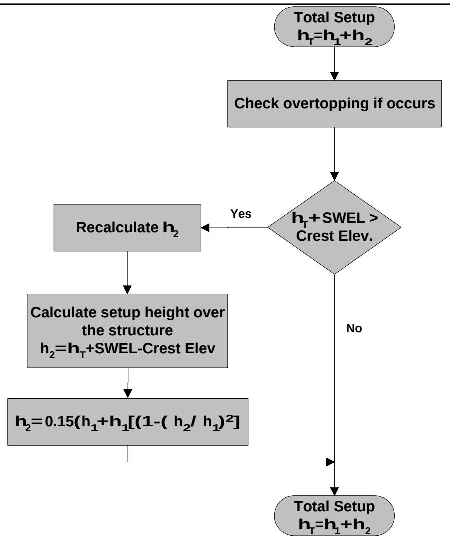
$$\text{FailRevet}_{\text{Ele}_a} := \text{Elevation}_{a-\text{Offset}_{\text{toe}}-\text{Offset}_{\text{mid}}-\text{Offset}_{\text{qua}}-\text{Offset}_{\text{intersect}}}$$



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

$h := SWEL - ToeR_{scour}$ $h = 4.16\,ft$

$H_b := b_h \cdot L_0$ $H_b = 15.14\,ft$ $H_d := b_d \cdot L_0$ $H_d = 18.47\,ft$

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

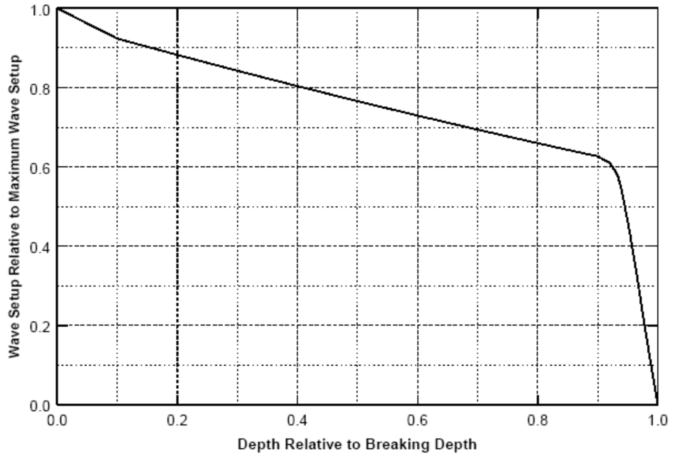


Figure D.2.6-9. Proportion of Maximum Wave Setup that Has Occurred vs. a Proportion of the Breaking Depth.

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

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

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

$R = 0.87$

$\frac{h}{H_d} = 0.23$

$\eta_1 := R\cdot\eta_{open}$ $\quad\eta_1 = 2.09\,\text{ft}$ $\quad\eta_2 := 0.15\cdot(h+\eta_1)$ $\quad\eta_2 = 0.94\,\text{ft}$

$\eta_{FailedStructure} := \eta_1 + \eta_2$ $\quad\eta_{FailedStructure} = 3.02\,\text{ft}$

Total Setup against a coastal structure without considering overtopping

Check Overtopping if Coastal Structure Exists:

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

$Overtopped = \text{"No"}$

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

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

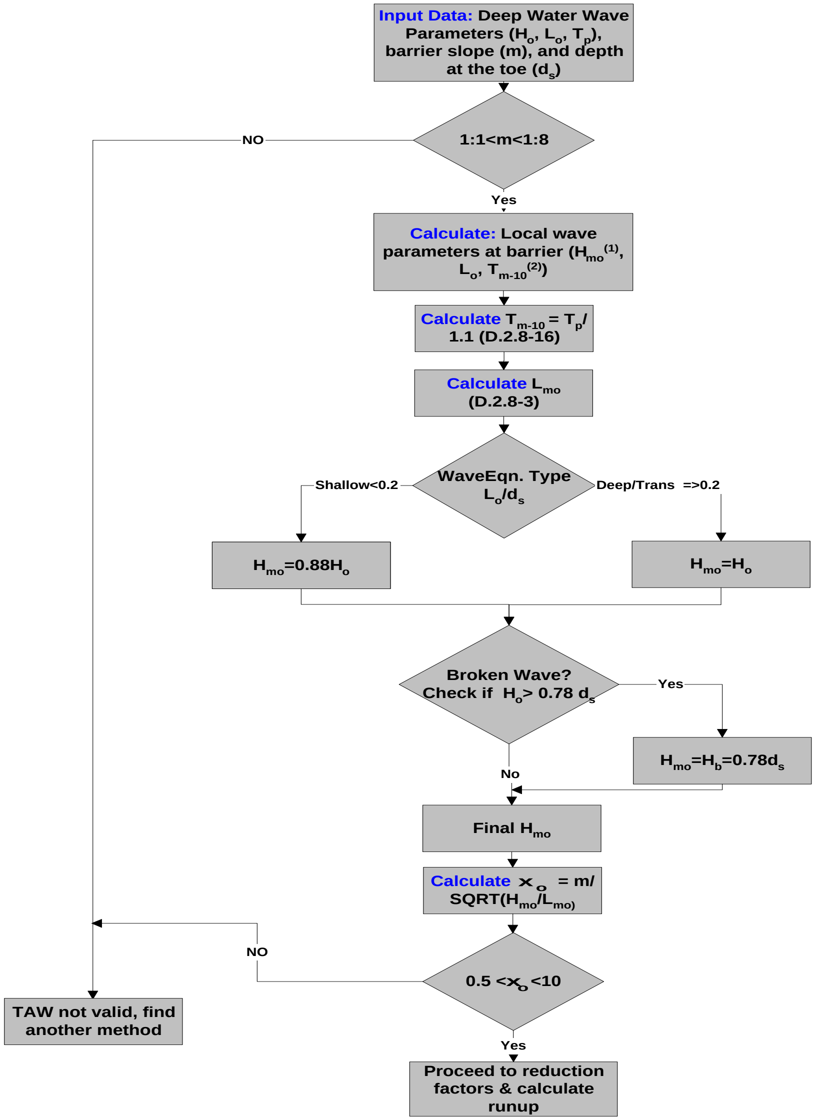
$$\eta_2 := \begin{cases} 0.15\cdot\left(h + \eta_1\right)\cdot\left[1 - \left(\frac{h_2}{h}\right)^2\right] & \text{if } Overtopped = \text{"Yes"} \\ \eta_2 & \text{otherwise} \end{cases}$$

$\eta_{FailedStructure} := \eta_1 + \eta_2$ $\eta_{FailedStructure} = 3.02\ \text{ft}$

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:

$$\mathrm{Slope}_{\mathrm{FAILRevet}} := \frac{\left(\mathrm{FailTop}_{\mathrm{Ele}} - \mathrm{ToeR}_{\mathrm{scour}}\right)}{\left(\mathrm{FailTop}_{\mathrm{Sta}} - \mathrm{Toe}_{\mathrm{sta}}\right)} \qquad \mathrm{Slope}_{\mathrm{FAILRevet}} = 48.48 \cdot \%$$

$$\mathrm{Slope}_{\mathrm{FAILRevetOneOn}} := \frac{1}{\mathrm{Slope}_{\mathrm{FAILRevet}}} \qquad \mathrm{Slope}_{\mathrm{FAILRevetOneOn}} = 2.06$$

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

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

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*

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

Determine Wave Type:

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

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

Determine Significant Wave Height Depending on WaveType and DepthLimited Condition:

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

$H_{m0runupFAIL1} = 11.7\,\text{ft}$

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

$H_{m0runupFAIL} = 3.24\,\text{ft}$

Calculate the Iribarren Number, ξ_{0m}:

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

$\xi_{om} = 6.37$

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:

Default - 1 layer of rock with diameter, d, where Hs/d = 1 to 3

$\gamma_r :=$

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

$\gamma_r = 0.58$

Select Berm Section in Breakwater, γ_b:

$\gamma_b :=$

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

$\gamma_b = 0.6$

Default = No Berm

Select Wave Direction Factor, γ_β:

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

Default - Short crested with beta = 0

$\gamma_\beta :=$

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

$\gamma_\beta = 1$

Select Porosity Factor, γ_P:

$\text{Porosity} :=$

Default Porosity = 0.5

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

$\gamma_p = 0.73$

Summary of Reduction Factors:

$\gamma_p = 0.73$

$\gamma_\beta = 1$

$\gamma_b = 0.6$

$\gamma_r = 0.58$

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

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

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

$R_{FAIL2\%} = 0.12\ \text{ft}$

Check for Overtopping:

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

$OVERTOPPEDFAIL_{Runup} = \text{"NO Overtopping"}$

6.0 Conclusions/Results

Wave Height, H_{m0} $H_{m0} = 13.3$ ft FetchStatus = "STWAVE Input (Hmo, Tp)"

Wave Period, T_P $T_P = 11.5$ s FetchStatus = "STWAVE Input (Hmo, Tp)"

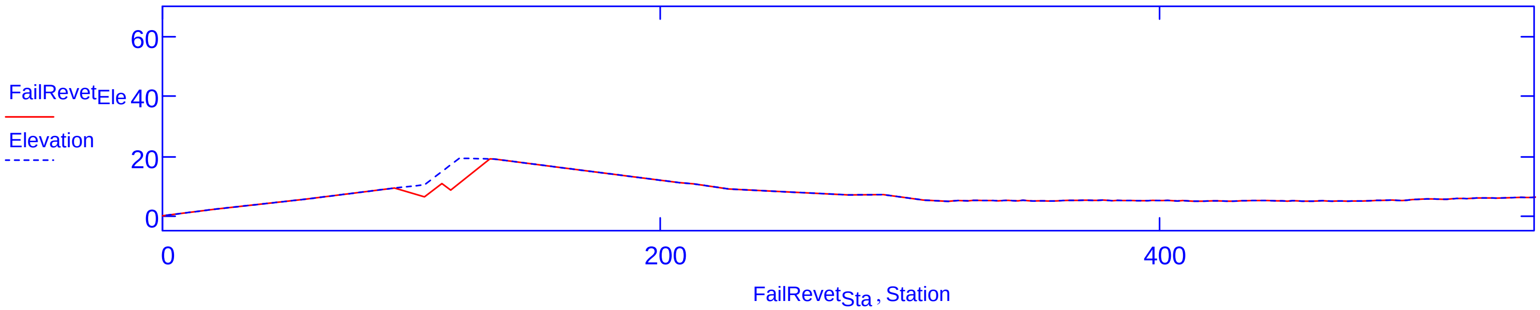
Wave Setup on an open coast, η_{open} $\eta_{open} = 2.4$ ft

Wave Setup on a revetment, $\eta_{Structure}$ $\eta_{Structure} = 2.76$ ft

Wave Runup on a revetment, $R_{2\%}$ $R_{2\%}$ = "TAW Not Valid" Runup result from ACES for intact = 0.6'

2% Runup Elevation from Runup2 intact = 3.31'

Failed Structure Profile:



Wave Setup on a Failed Structure, η $\eta_{FailedStructure} = 3.02$ ft

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

$R_{FAIL2\%} = 0.12\,ft$

$OVERTOPPEDFAIL_{Runup} =$ "NO Overtopping"

Top of Failed Revetment Station and Elevation:

$FailTop_{Sta} = 131.28\,ft$

$FailTop_{Ele} = 19\,ft$

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

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

NOTES:

RSS 9/23/13
Marshfield
FEMA Appeal

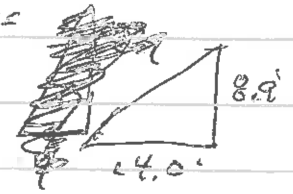
Input Parameters for ACES Runup - Intent Revetment
PL-66

Based on Runup Decision Tree

SWEL = 10.46' H_{m_0} = 13.3' TP = 11.5 sec. from STWAVE Result

transect slope = 0.03576 wave slope .0196 (Ransom) Excel

STARR : Toe_{sta} 105.1' Toe_{el} 10.3'
Top_{sta} 119.1' Top elev. 19.2' } => Wall Height = 8.9'



Total Setup on Structure = 2.76'

Iribarren # = 42.74 (Ransom MathCAD

∴ Slope > 1:8 and slope < 1:1 and Iribarren > 10

=> ACES

mean wave hgt = 0.626 × H_{m_0} = 8.33'
Mean T = 0.85 × 11.5 = 9.78 sec

Foreshore slope = 0.1 or cot 10

$$\frac{d_s}{H_0} = \frac{0.16}{8.33} = .0192 \qquad \frac{H_0}{gT^2} = \frac{8.33}{32.2(9.78)^2} = .0027$$

From ACES Mean Runup 0.27'
2% Runup 2.2 × 0.27' = 0.59'
$R_{2\%}$ elev. = 10.46 + 0.59 = 11.05'

Complete results File In

2013/131.06145/Ransom Results/

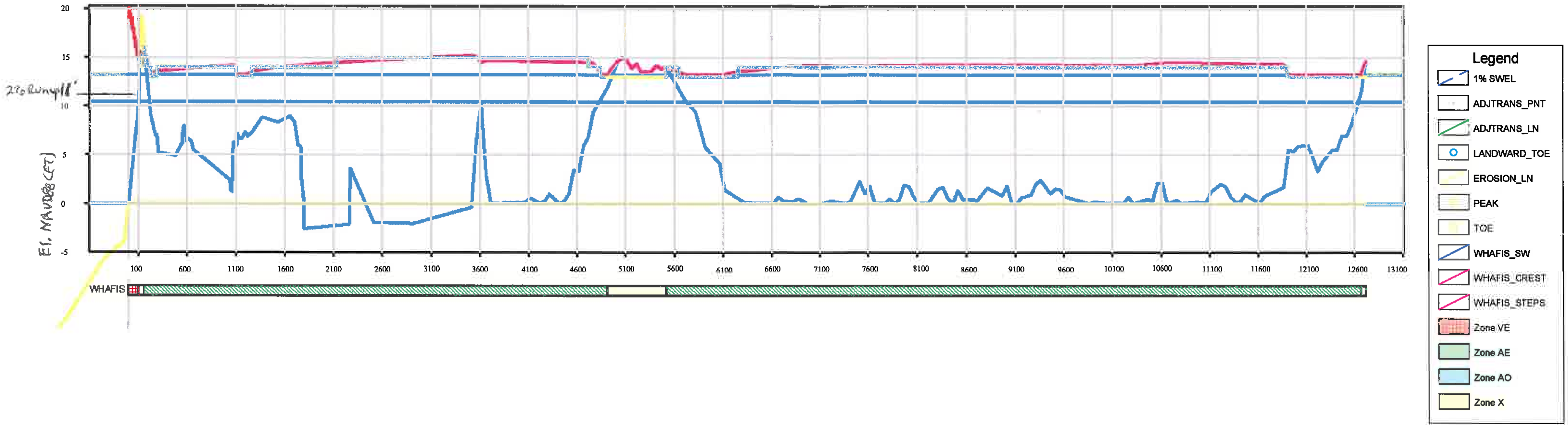
PL-066-Intact_Sep 26

```
PART6 NUMBERED A ZONES AND V ZONES

                              STATION OF GUTTER  ELEVATION  ZONE DESIGNATION   FHF

                                     0.00          20.22
                                                                V30  EL=20     200
                                    13.54          19.50
                                                                V30  EL=19     200
                                    32.61          18.50
                                                                V30  EL=18     200
                                    51.89          17.50
                                                                V30  EL=17     200
                                    71.17          16.50
                                                                V30  EL=16     200
                                    90.45          15.50
                                                                V30  EL=15     200
                                    93.63          15.32
                                                                A24  EL=15     140
                                   104.52          14.50
                                                                A24  EL=14     140
                                   105.00          14.46

                                   114.00          15.52

                                   158.00          13.22
                                                                A24  EL=16     140
                                   158.65          15.50
                                                                A24  EL=15     140
                                   191.19          14.50
                                                                A24  EL=14     140
                                   223.73          13.50
                                                                A24  EL=13     140
                                   292.80          13.50
                                                                A24  EL=14     140
                                  1103.77          13.50
                                                                A24  EL=13     140
                                  1259.43          13.50
                                                                A24  EL=14     140
```

```
    2134.81          14.50
                                    A24   EL=15      140
    4719.19          14.50
                                    A24   EL=14      140
    4841.78          13.50
                                    A24   EL=13      140
    4914.00          13.22

    5014.00          14.55

    5064.00          15.00

    5114.00          14.75

    5164.00          13.83

    5214.00          14.38

    5264.00          13.45

    5364.00          13.52

    5414.00          14.14

    5464.00          13.80

    5514.00          13.22
                                    A24   EL=14      140
    5643.11          13.50
                                    A24   EL=13      140
    6251.27          13.50
                                    A24   EL=14      140
   11901.26          13.50
                                    A24   EL=13      140
   12664.00          13.22

   12714.00          14.62


            ZONE TERMINATED AT END OF TRANSECT


            PART 7    POSTSCRIPT NOTES
```

Transect PL-066
Marshfield, Massachusetts

WHAFIS Analysis on Intact Profile
September 26, 2013



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Wave Transect PL-66 Ransom WHAFIS Output, Failed Profile

```
          PART4 LOCATION OF SURGE CHANGES

STATION          10-YEAR SURGE          100-YEAR SURGE

          NO SURGE CHANGES IN THIS TRANSECT


               PART5  LOCATION OF V ZONES

     STATION OF GUTTER          LOCATION OF ZONE

              105.82               WINDWARD


           PART6 NUMBERED A ZONES AND V ZONES

STATION OF GUTTER  ELEVATION  ZONE DESIGNATION   FHF


       0.00          20.22

                                  V30  EL=20     200

      13.54          19.50

                                  V30  EL=19     200

      32.61          18.50

                                  V30  EL=18     200

      51.89          17.50
```

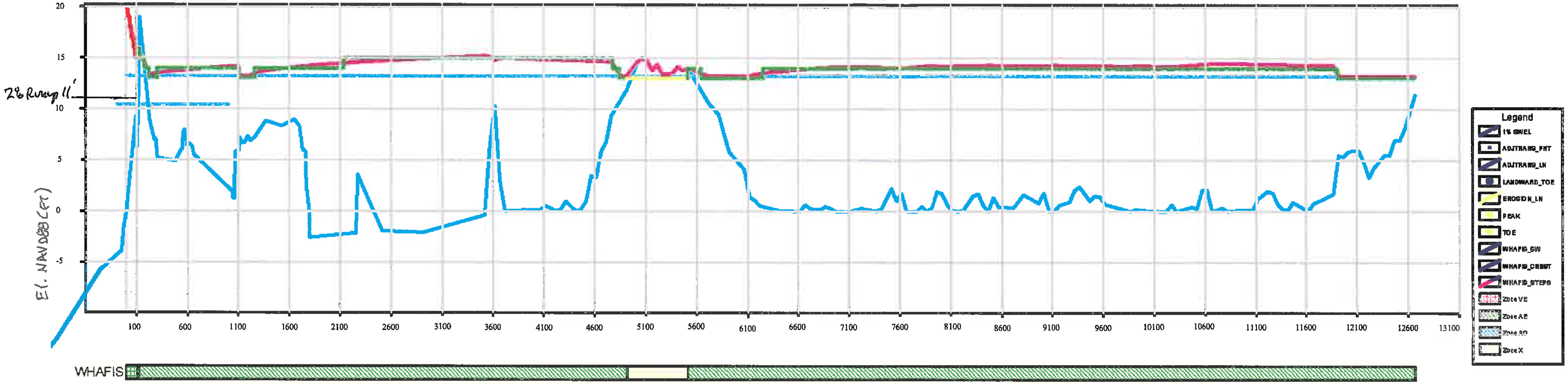
```
                              V30  EL=17     200

  71.17          16.50

                              V30  EL=16     200

  90.45          15.50

                              V30  EL=15     200

 105.82          15.32

                              A24  EL=15     140

 116.00          14.96


 126.00          13.22

                              A24  EL=16     140

 135.90          15.50

                              A24  EL=15     140

 178.97          14.50

                              A24  EL=14     140

 222.04          13.50

                              A24  EL=13     140

 301.20          13.50

                              A24  EL=14     140

1103.76          13.50
```

```
                              A24  EL=13     140
1259.43          13.50
                              A24  EL=14     140
2135.35          14.50
                              A24  EL=15     140
4774.18          14.50
                              A24  EL=14     140
4844.38          13.50
                              A24  EL=13     140
4914.00          13.22

5014.00          14.55

5064.00          15.00

5114.00          14.75

5164.00          13.83

5214.00          14.38

5264.00          13.45
```

```
 5364.00          13.52

 5414.00          14.14

 5464.00          13.80

 5514.00          13.22
                               A24  EL=14     140
 5643.11          13.50
                               A24  EL=13     140
 6252.79          13.50
                               A24  EL=14     140
11904.86          13.50
                               A24  EL=13     140
12664.00          13.22


       ZONE TERMINATED AT END OF TRANSECT


       PART 7   POSTSCRIPT NOTES
```

Transect PL-066
Marshfield, Massachusetts

WHAFIS Analysis on Failed Profile
September 24, 2013



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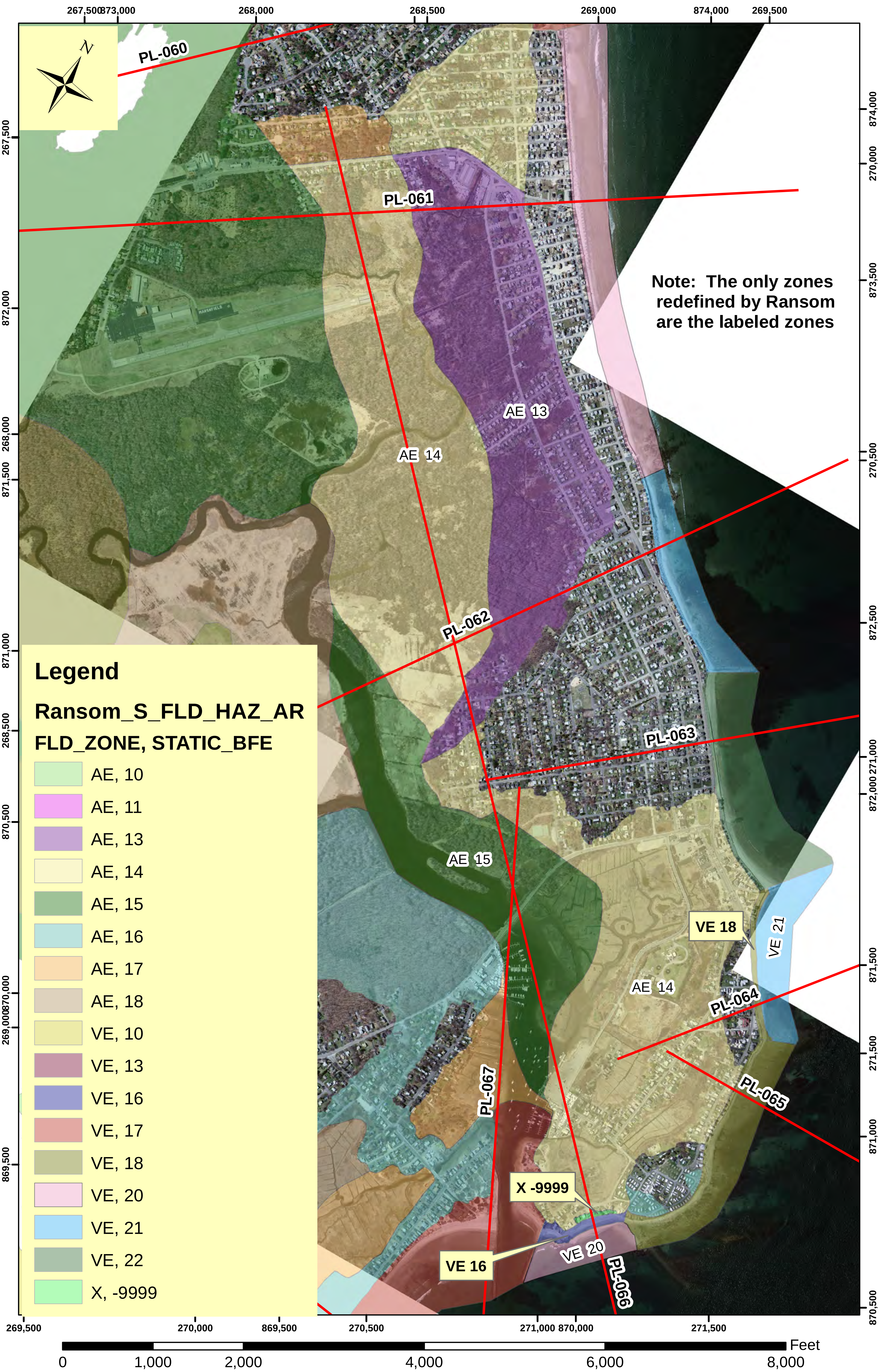

Note: The only zones redefined by Ransom are the labeled zones

Ransom Revised Flood Zones near PL64 & PL66
Marshfield, MA
Base Maps are USGS Marshfield 7.5' quads
Grid is Mass. State Plane, Mainland, NAD83 (m)
RGG 10/3/13 131.06145

RANSOM Consulting, Inc.

Attachment 18

Comparison of Ransom and STARR Engineering Calculations for Wave Transects PL-64 and PL-66

										Average Transect Slope				
TRANSECT ID	Open / Restricted	Fetch Length (mi)	Wind Speed (m/s)	SWEL	Wave Height	Wave Period	Wave Length	H_b	d_b	Toe / Breaking Wave Height Elevation	Top / SWEL Elevation	Toe Station	Top / SWEL Station	Average Transect SLOPE, m
PL-64				10.46	31.09621	10.65	581.2664	25.00822	32.06182	-21.60182266	10.46	-2158.26	50.48	0.014516
Ransom PL64	Open		35.76	10.46	11.5	11.2	642.3	13.32	17.08	-6.62	10.46	-707.2	50.41	0.022548
PL-66				10.46	30.59725	13.58	945.0952	29.0915	37.2968	-26.83679763	10.46	-1875.86	102	0.018857
Ransom PL66	Open		35.76	10.46	13.3	11.5	677.2	14.94	19.16	-8.7	10.46	-430.3	105.3	0.03576

Comparison of Ransom and STARR Engineering Calculations for Wave Transects PL-64 and PL-66

		Average Shore Slope		Wave Setup			Wave Runup			Structure Ar	
TRANSECT ID	1:ON	Average Beach Slope	1:ON	Open, h_{open} (ft)	With Structure $h_{structure}$ (ft)	Total Water Level	Runup 2% (ft)	Method	Overtopped?	Does Structure Exist?	Revetment or Vertical Structure?
PL-64	68.89003	0.207211	4.826003824	3.83	4.88	15.34	7.72	TAW	No	Yes	Revetment
Ransom PL64	44.35	0.207	4.83	1.93	2.71/3.11 failed	13.17/13.57 failed	7.51	TAW	No	Yes	Revetment
PL-66	53.03029	0.102549	9.751434034	4.39	5.06	15.52	3.41	Runup 2.0		Yes	Revetment
Ransom PL66	27.96	0.1025	9.75	2.4	2.76/3.02 failed	13.22/13.49 failed	3.31/0.6	Runup 2.0/ACES	No	Yes	Revetment

Comparison of Ransom and STARR Engineering Calculations for Wave Transects PL-64 and PL-66

	alysis			Failed Structure Analysis						Notes on Er			
TRANSECT ID	Toe Station (ft)	Top Station (ft)	Armor Depth (ft)	Failed Structure Top Station (ft)	Failed Structure Top Elevation (ft)	hFailedStructure (ft)	Runup 2% (ft)	Method	Overtopped ?	SURVEY	SWEL/TWEL	STRUCTURE	FAILURE
PL-64	39.77	73.77	4	93.56	24.09	5.31	5.55	TAW	No	Yes		Yes	Yes
Ransom PL64	39.77	73.77	4	93.56	24.09	10.1	5.41	TAW	No	Not provided		Yes	Yes
PL-66	105.07	119.07	4	131.28	19	5.27	0.14	TAW	No	Yes		Yes	No
Ransom PL66	105.07	119.07	4	131.28	19	4.2	0.12	TAW	No	Not provided		Yes	No

Comparison of Ransom and STARR Engineering Calculations for Wave Transects PL-64 and PL-66

	gineering Decisions						
TRANSECT ID	EROSION	RUNUP INTACT	RUNUP FAILED	WHAFIS INTACT	WHAFIS FAILED	General Notes	Run-Up Notes
PL-64	No	No	No	Yes	Yes		
Ransom PL64	No	Yes	No	No	Yes		
PL-66	No	No	No	Yes	No	Failed the structure using a lower toe station.	
Ransom PL66	No	No	No	Yes	No		