Woods Hole Group 81 Technology Park Drive E. Falmouth, MA 02536 USA TELEPHONE: 508.540.8080 FAX: 508.540.1001 www.woodsholegroup.com

July 28, 2015

John Grace, CFM
Mitigation Risk Analysis Branch
FEMA Region I
99 High Street, Sixth Floor
Boston, MA 02110

Re: Re: Re: Re: Summary of Additional Data Required to Support an Appeal of the Preliminary Flood Insurance Rate Map (FIRM) number 33015CO432F in the Town of Rye, NH.

Dear Mr. Grace:

The Woods Hole Group is providing this Response to Comment Letter to address the July 14, 2015 letter from FEMA requesting the as-built drawings of the seawall and revised modeling and flood mapping related to the March 5, 2015 Preliminary FIRM Appeal for the Town of Rye in Rockingham Country, New Hampshire.

Included with this submittal are the following items:

- The July 20, 2015 as-built drawings of the seawall for the properties at 2220 and 2238 (TR-39) Ocean Blvd.
- The prior 2004 and 2013 existing site survey plans for 2220 Ocean Blvd
- Revised CHAMP database including WHAFIS and Runup 2.0 results for Transect TR-39
- Revised Runup calculations using the TAW method for TR-39 and the adjacent property at 2220 Ocean Blvd
- GIS Shapefiles showing the revised Flood Zone Mapping

All calculations for wave envelope, runup, and overtopping were revised based on the recent July 20, 2015 as-built survey drawings for Transect 2238 (TR-39) and 2220 Ocean Blvd. First, WHAFIS and Runup2.0 were used to evaluate for the intact seawall case for TR-39 (TR-42 in Champ database) and a depiction of the results can be seen below in Figure 1. The total water level (TWL) of 10.35 feet NAVD88 that includes both the 1%SWEL (8.36 ft NAVD88 from Preliminary FIS) and wave setup (1.99 ft computed by WHG using SWAN1D in the March 5, 2015 appeal). The resulting 2% runup value of 3.54 ft was calculated using Runup2.0 for a runup elevation, $Z_{2\%}$, of 13.9 ft NAVD88 that is below the crest of the structure at 14.1 ft NAVD88. As can be seen from Figure 1, the 2% runup (red line) is the controlling process since the line is well above and landward of limit of wave activity from WHAFIS (green dashed line). Since the elevation of the grade of the beach at the seawall (11.4 ft NAVD88) is above the TWL (10.35 ft NAVD88), no other method can be applied since there is no water depth at the of the base of the structure.

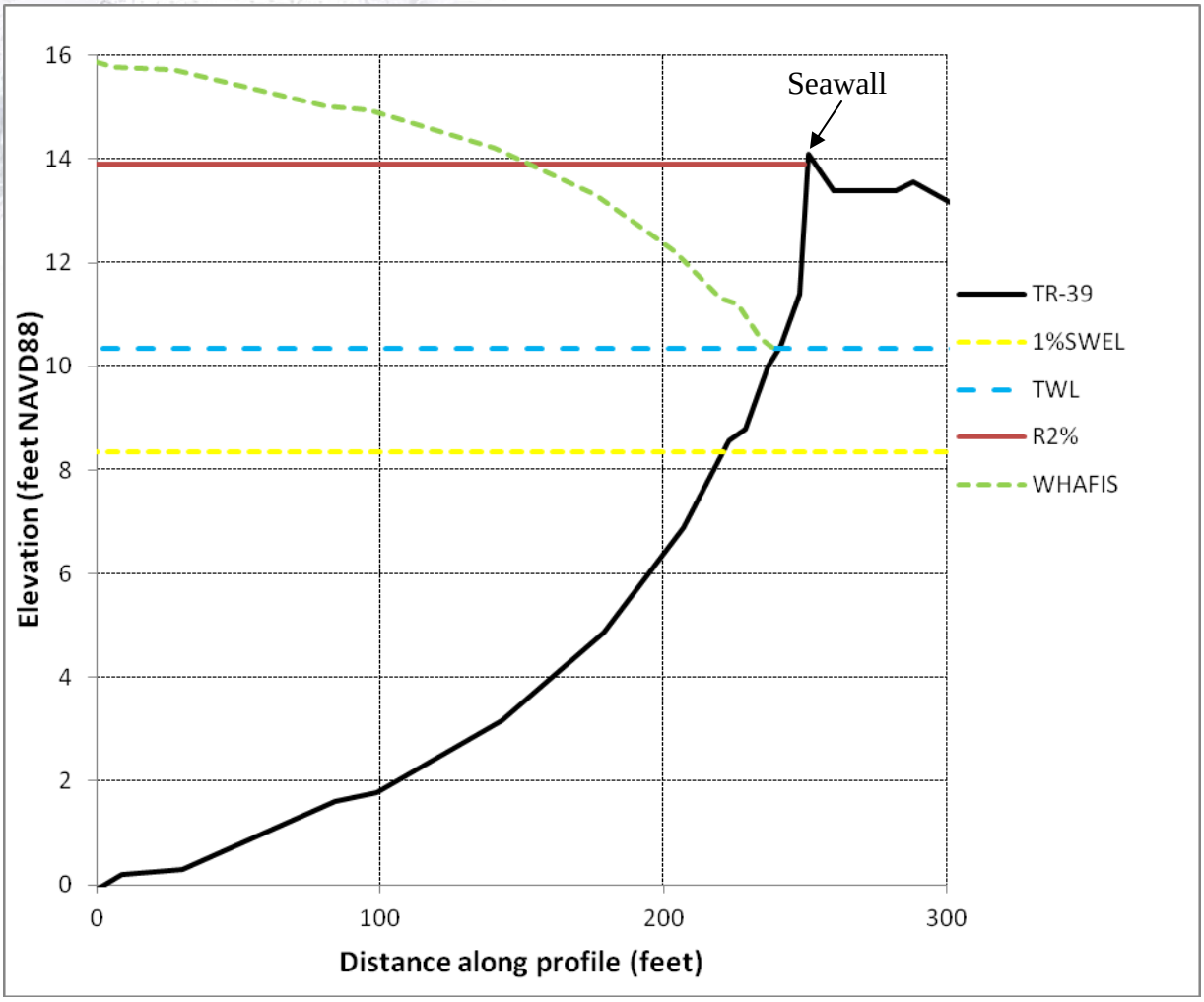


Figure 1. Revised CHAMP Results for TR-39 (TR-42 in CHAMP).

Next, the runup and overtopping was analyzed for the case of an intact vertical seawall at 2220 Ocean Blvd. For this case, the elevation of the grade of the beach (8.5 ft NAVD88) is below the TWL (10.35) meaning that there is a water depth of 1.85 ft at the base of the vertical seawall. Figure D.2.8-3 from the 2007 FEMA guidelines was used to estimate the mean runup on a vertical wall. The incident breaking wave height at the toe of the vertical was estimated by calculating the depth limited wave at the base of the vertical wall: 0.78 * 1.9 = 1.44 ft. Since the resulting ratio of d_s/H'_0 of 1.28 is between the 0.6 and 3 curves (lines), a value of approximately $R/H'_0 = 3.0$ was interpolated between the curves using an $H'_0/gT^2 = 0.0003$. The resulting mean runup, R_{mean}, is then calculated to be 4.3 ft. Since $R_{2\%}$ is equal to $2.2*R_{mean}$ based on the FEMA 2007 Guidelines, the resulting $R_{2\%}$ elevation is 19.9 ft NAVD88 as shown in Table 1 below.

Table 1. Calculation of runup on vertical wall using Figure D.2.8-3 of FEMA 2007 Guidelines.

	Input		Intermediate Output			Output		
Parameter	d_s	H_0	d_s/H'_0	H'_0/gT^2	R/H'_0	R_{mean}	$R_{2\%}$	$Z_{2\%}$
Units	feet	feet	--	--	--	feet	feet	ft NAVD88
Value	1.85	1.44	1.28	0.0003	3.0	4.3	9.5	19.9

Last, the TAW method was used to calculate runup for the case of a failed seawall at both TR-39 and 2220 Ocean Blvd using the updated survey data from the July 20, 2015 as-built

Woods Hole Group 81 Technology Park Drive E. Falmouth, MA 02536 USA TELEPHONE: 508.540.8080 FAX: 508.540.1001 www.woodsholegroup.com

survey for each property. See the attached calculation sheets for details on the calculation of runup for each location. Table 2 presents a complete summary of the runup and overtopping results for all methods including the TAW method, Runup2.0, and vertical wall runup. Also shown is the depth of water overtopping the structure crest as well as the associated mean overtopping rates, Q_{mean}, calculated using the van deer Meer Equation VI-5-25 of the Coastal Engineering Manual (also shown in attached calculations). The last column indicates the resulting flood mapping results based upon the TAW method results using Table D.2.8-6 of FEMA 2007 Guidelines.

Table 2. Runup and Overtopping Results for Transect Reach TR-39.

Case	Method	$R_{2\%}$	$Z_{2\%}$	Depth	Q_{mean}	Zone
Unit		**ft**	**ft NAVD88**	**ft**	**cfs/ft**	
TR-39 Intact	Runup2.0	3.54	13.9	0	0	AE
TR-39 Failed	TAW	5.0	15.4	2.0	0.001	AO (2ft)
2220 Ocean Intact	FEMA 2007	9.5	19.9	6.1	> 1	30ft VE Splash zone/ AO (3ft)
2220 Ocean Blvd Failed	TAW	9.2	19.5	5.7	0.1	30ft VE Splash zone/ AO (3ft)

The results indicate that the flood hazard zone mapping varied from an AE Zone to an AO 3-ft depth Zone fronted by a 30-ft VE splash zone (from the crest of the seawall). Considering the proximity and similarities between the properties at 2220 and 2238 (TR-39) Ocean Blvd, only one zone can be mapped. Typically, the more conservative case is mapped meaning that a 30-ft VE Splash Zone (El. 13 ft) is mapped from the crest of the seawall followed by an AO Depth 3-ft Zone based on Table D.2.8-6 of FEMA 2007 Guidelines. Since the AO (3-ft depth) zone matches the mapping from the original FEMA April 9, 2014 PFIRM, the original extent and landward boundary of the AO is retained. The LiMWA has been moved to the landward edge of the VE Splash Zone at the boundary with the AO 3-ft depth Zone. Note that this maps assumes that the PFD has been removed as explained in the original Appeal (please see original Appeal for documentation related to the PFD). Please see Figure 2 for revised FIRM mapping and associated GIS files enclosed in the attached CD.

Woods Hole Group 81 Technology Park Drive E. Falmouth, MA 02536 USA TELEPHONE: 508.540.8080 FAX: 508.540.1001 www.woodsholegroup.com

If there are any questions in regards to the responses to the comments or there is need for additional data, please feel free to contact myself, Mitchell Buck, via phone (508-495-6210) or email (mbuck@whgrp.com).

Sincerely,

Mitchell Buck, P.E.
Coastal Engineer
Woods Hole Group
81 Technology Park Drive
East Falmouth, MA 02536

Enclosures: as stated

cc: Fay Rubin, UNH
Craig Musselman, Town of Rye
Marilyn Hilliard, FEMA Region 1
Jennifer Gilbert, CFM, New Hampshire Office of Energy and Planning
Edward O'Meara, Homeowner
Peter Rowell, Town of Rye
Michael Magnant, Town of Rye
Kim Reed, Town of Rye
Mike Labrie, Town of Rye

Woods Hole Group 81 Technology Park Drive E. Falmouth, MA 02536 USA TELEPHONE: 508.540.8080 FAX: 508.540.1001 www.woodsholegroup.com

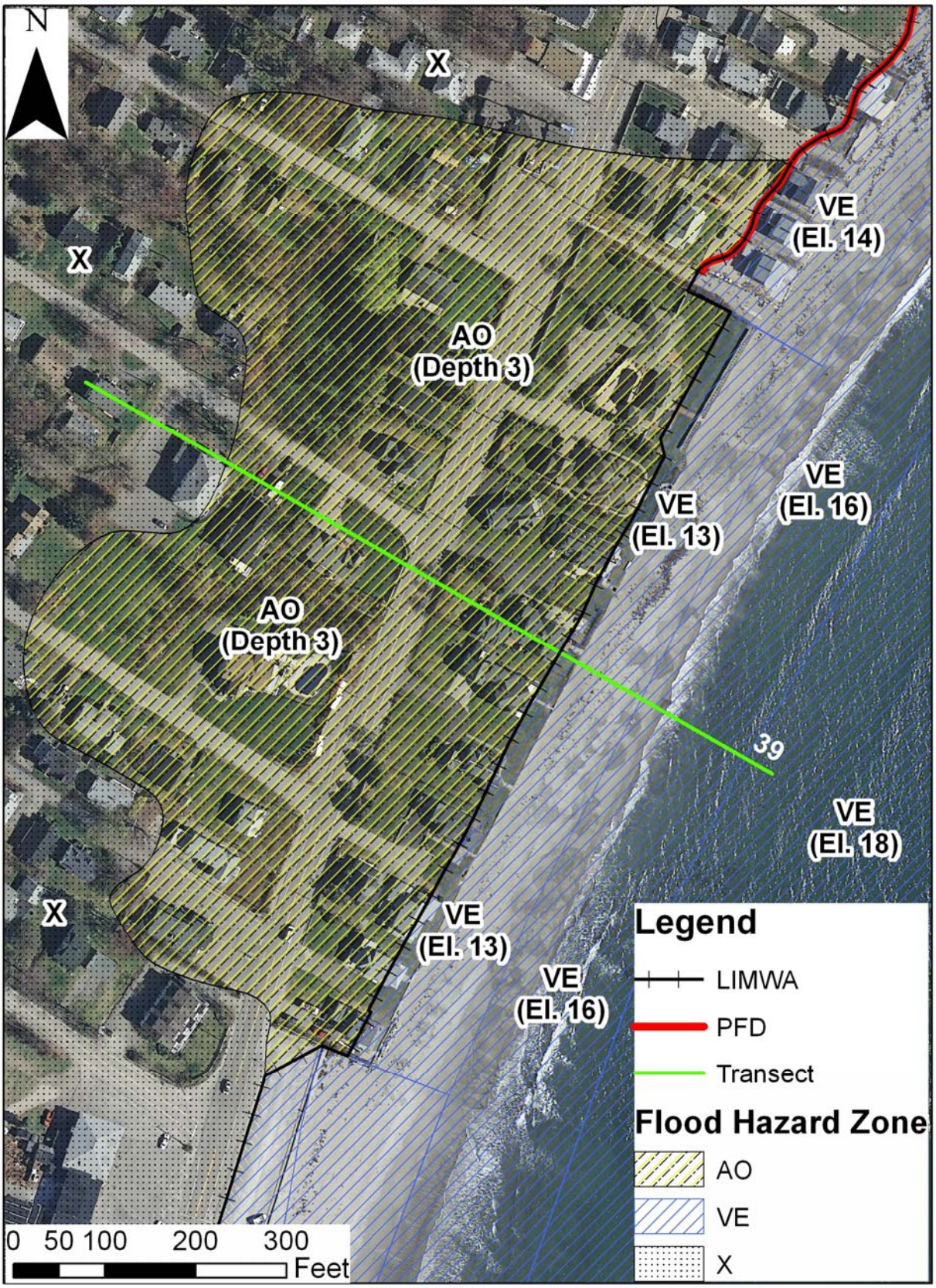


Figure 2. Revised Flood Mapping for Transect TR-39 on FEMA FIRM 33015C0432F.

Woods Hole Group 81 Technology Park Drive E. Falmouth, MA 02536 USA TELEPHONE: 508.540.8080 FAX: 508.540.1001 www.woodsholegroup.com

CALCULATIONS IN SUPPORT OF RUNUP

1) Analysis of Wave Runup on a Failed Seawall by TAW Method for Transect TR-39 (TR-42 in CHAMP) in Town of Rye, NH

This worksheet uses the TAW Method to evaluate runup on the failed seawall for Transect TR-39 in the Town of Rye, NH. The intact case for TR-39 was analyzed using Runup2.0 Module of CHAMP, and the results can be found in the attached Data folder on CD. The TAW method was originally formulated for manmade dikes, but has since successfully been applied by FEMA to natural shorelines that mimic a dike in function. The TAW method in this case was analyzed for the failed structure (seawall) case with scour. Note that initially this case was analyzed for a failed slope of 1V:1.5H as specified in the FEMA document "New_Hampshire_Failed_Structures_070313.docx"; however, it was found that Iribarren was not acceptable for the TAW Method and the failed slope was set to 1V:3H. It appears that FEMA had similar issues as a slope of 1V:3H was in fact used for TR-39/TR-42 for the TAW Method & Overtopping in the Overtopping Data Based in the Coastal Backup Data Disk.

Input Data and Assumptions

The following assumptions from are utilized:

- The Preliminary April 9, 2014 Preliminary FIRM Backup Data apply except where noted.
- Wave height, H_{mo}, is the deepwater wave height and is not in water of transitional depth.
- Wave period, T_p, remains constant and independent of depth for oscillatory waves
- Wave setup dynamically calculated by SWAN1D includes both the effects of static and dynamic wave setup.
- Acceleration due to gravity: **g = 32.17 ft/s^2**

The offshore wave parameters utilized by FEMA in the April 9, 2014 Preliminary FIRM Coastal Backup Data and WHG Modeling Results from the March 5, 2015 Appeal for Transect TR-39 apply to this location including:

- Peak Wave Period: **T_p = 11.66 seconds** (FEMA OFFSHORE STWAVE Results)
- Deepwater significant wave height: **H_0 = 25.1 feet** (FEMA OFFSHORE STWAVE Results)
- 1% Stillwater Elevation: **SWEL1% = 8.36 feet NAVD88** (FEMA Preliminary FIS)
- Wave Setup **η = 1.99** feet (WHG computed by SWAN1D)

The specifications for the seawall were taken from the July 20, 2015 As-built survey drawings including:

- Structure Crest Elevation = **14.1 – 14.2 feet NAVD88** (July 2015 Survey)
- Topo Crest Elevation = **13.4 feet NAVD88** (July 2015 Survey)
- Structure toe elevation = **8.6 – 9.3 ft NAVD88** (July 2015 Survey)
- Elevation of grade at base of wall = **11.4 ft NAVD88** (July 2015 Survey)

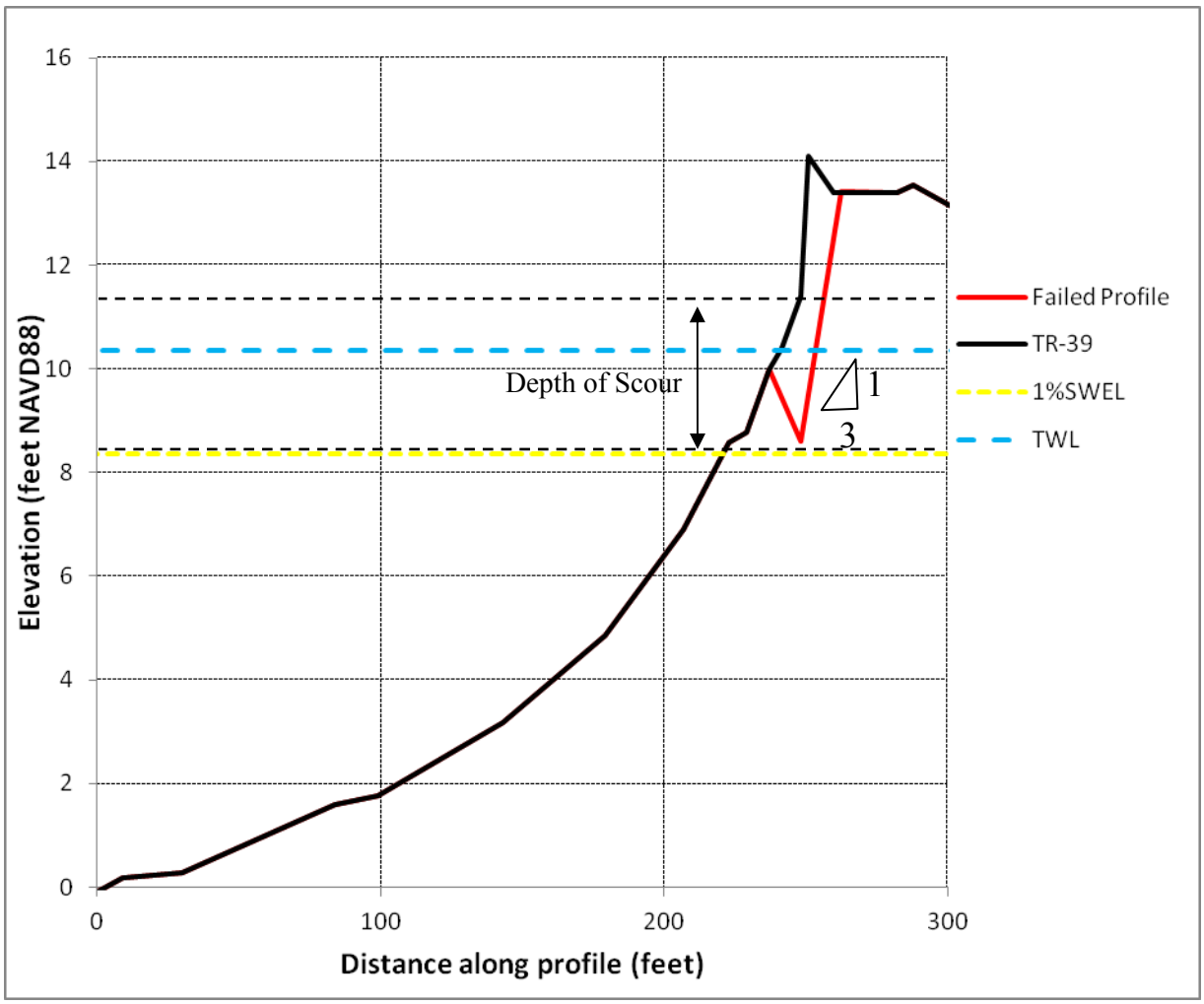
STEP ONE – Determine Water Levels and Structure Configuration

The TAW method assumes that the wave that impacts the structure is the depth-limited wave at the toe of the structure (where the beach slope intersects the wall). The depth-limited wave is calculated by

finding the water depth at the base of the structure (11.4 ft NAVD88) relative to the total water level, the sum of the SWEL% and Wave setup, for the 100-year storm:

→ TWL = SWEL1% + Wave Setup = 8.36 + 1.99 = 10.35 ft NAVD88

The TWL (10.35 ft NAVD88) is below the grade at the base of the wall (11.4 ft NAVD88) meaning that there is no depth-limit wave impacting at the base of the structure for the intact structure case, which is why the intact case was only analyzed using Runup 2.0 on the attached CD. The failed structure case is evaluated here and includes scour at the base of the wall; however, all scour methodologies from both the FEMA 2007 Guidelines and Coastal Engineering Manual rely on having a water depth at the structure toe meaning that scour cannot be directly computed. Therefore, scour has to be estimated based on engineering judgment. The most conservative estimate for scour would be equivalent to the toe of the structure (the very bottom), which would be to the minimum toe elevation of 8.6 ft NAVD88. For this failed seawall case, it is assumed that the structure would first scour to 8.6 feet NAVD88 and then fail on a 1V:3H slope from the scour hole. The failed structure slope of 1V:3H would start at this new scoured toe depth and continue landward until it merged into the existing profile creating a new topo crest at 13.4 feet NAVD88 as seen in Figure 1.



The depth at the toe is then calculated by subtracting the elevation of the scoured toe (8.6 ft NAVD88) from the total water level (10.35 feet NAVD88). Therefore, the depth, d_s, is calculated by:

→ d_s = TWL – depth at toe = 10.35 – 8.60 = **1.75 feet**

STEP TWO – Determine Wave Parameters

Now we need to determine the wave parameters at the failed seawall based on the offshore wave characteristics and transect data.

Check if Wave is depth limited at the structure:

- "Broken" if: $H_0 \geq 0.78*d_s$
  "Not Broken" if: $H_0 < 0.78*d_s$
  "Undetermined" if: otherwise

  → $H_0 = 0.78*d_s$ = **1.37 feet** < 25.1 feet
  Therefore, the wave that impacts the seawall is **"Broken"** and H_b will be used in place of the deepwater H_{mo}.

- Need to determine the deepwater wave length, L_0, from existing wave parameters:
  $L_0 = \frac{g * Tp^2}{2\pi}$ → Therefore, $\mathbf{L_0}$ **= 696.7 feet**

The wave type at the seawall is determined by the following criteria:

- Wave Type = "Shallow" if $d_s/L_0 < 0.2$
  "Transitional" if $0.2 \leq d_s/L_0 < 0.5$
  "Deep" if $d_s/L_0 \geq 0.5$

  → $d_s/L_0 = 0.002 < 0.2$ Therefore, the wave is a **"Shallow water wave"**

Now determine the local wave parameters at the seawall (H_{mo}, T_{m10}, and L_{mo}):

- H_{mo} = "d_s * 0.78" if wave "Broken"
  "H_{mo}" if wave "Not Broken"
  "0" otherwise

  → Wave Type is "Broken" from the first bullet therefore calculate the depth-limited wave:
  $H_{mo} = d_s * 0.78$ = **1.37 feet**.

The corresponding T_{m10} and L_{mo} are calculated as follows:

- $T_{m10} = T_p/1.1$ = **10.6 seconds**
- $L_{mo} = \frac{g * T_{m10}^2}{2\pi}$ = **575.8 feet**

STEP THREE – Check TAW validity

The TAW method is valid is the following criteria are met:

- TAW Method is valid if:
  a. $0.5 < \zeta_{om} < 8\text{-}10$ where ζ_{om} is the Iribarren Number

b. 1:1 < m < 1:8 where m is the slope

→ Determine Iribarren number: $\zeta_{om} = \frac{m}{\sqrt{Hmo/Lmo}}$

Now calculate the Iribarren Number ζ_{om} based on the slope *m* of the failed seawall set to 1V:3H:

→ $\zeta_{om} = \frac{m}{\sqrt{Hmo/Lmo}} = \mathbf{6.6}$

Therefore, the **TAW Method is Valid** since 0.5 < ζ_{om} = **6.6** < 8-10 & 1:1 < m = **1:3** < 1:8-10

STEP FOUR – Calculate Runup

Runup is calculated based on the TAW by the following method:

- Runup $R_{2\%}$ =

H_{mo} (1.77 * $\gamma_r * \gamma_b * \gamma_\beta * \gamma_p * \zeta_{om}$)	if $0.5 \leq \gamma_b * \zeta_{om} < 1.8$
H_{mo} [$\gamma_r * \gamma_b * \gamma_\beta * \gamma_p * (4.3 - 1.6/\sqrt{\zeta om})$]	if $1.8 \leq \gamma_b * \zeta_{om}$
0	Otherwise

Where γ_r, γ_b, γ_β, and γ_p are influence or reduction factors that are determined below:

- Roughness reduction factor: $\boldsymbol{\gamma_r = 1}$
→ Default 1.

- Wave Direction Factor: $\boldsymbol{\gamma_\beta = 1}$
→ The waves are normally incident, therefore this value is set to the default of 1.

- Berm Section Factor: $\boldsymbol{\gamma_b = 1}$
→ There is no berm so this value is set to the default is 1.

- Porosity Factor: $\boldsymbol{\gamma_p = 1}$
→ For an assumed default porosity of 0.5, the default is 1.

- Now determine which runup equation to use by calculating $\gamma_b * \zeta_{om}$

→ $\gamma_b * \zeta_{om}$ = 1*6.6 = 6.6 > 1.8, therefore use second equation:

$R_{2\%} = H_{mo}$ [$\gamma_r * \gamma_b * \gamma_\beta * \gamma_p * (4.3 - 1.6/\sqrt{\xi_{om}})$] = **5.0 feet**

- Now calculate the runup elevation by summing the runup and SWEL1%:

→ $Z_{2\%} = R_{2\%}$ + SWEL1% = **15.4 feet NAVD88**

STEP FIVE – Check for Overtopping

Last, determine whether overtopping is occurring and, if so, the severity of the overtopping.

- Is the 2% runup elevation exceeding the barrier crest?

  → $Z_{2\%}$ = 15.4 ft > failed structure crest =13.4 ft

→ Yes, overtopping of the structure is occurring. The runup Depth is 15.4 – 13.4 = 2.0 feet over the structure crest which falls in the range 1.5 to 2.9 feet that indicates that it is an AO Zone with a Depth of 2 foot based upon the 2007 FEMA Guidelines Section D.2.8.1.7.

- The mean overtopping rate is then calculated by the Coastal Engineering Manual (CEM) using the following formula (Eqn. VI-5-25) for overtopping by Van der Meer and Jansen (1995) for $\zeta_{om} > 2$:

  $$Q_{mean} = 0.2\sqrt{gH_s^3}\ exp\left[-2.6\ \frac{Re}{H_s}\ \frac{1}{\gamma_r\ \gamma_\beta\ \gamma_b\ \gamma_p}\right]$$

  where R_e is the crest elevation above the TWL = 13.4 ft – 10.35 ft = 3.05 ft
  H_s = water depth at toe of structure = 1.75 feet
  $\gamma_r = \gamma_b = \gamma_B = \gamma_p = 1$

  → Q_{mean}= **0.03 cfs/ft**

→ Based on Table D.2.8-6 of FEMA Guidelines, a Q_{mean} of 0.03 cfs/ft equates to an AO Zone with a 2 foot depth, which matches the first bullet; this table is reproduced below:

Table 1. Table D.2.8-6 Reproduced from the FEMA 2007 Guidelines.

Q_{mean} (cfs/ft)	Zone
<0.0001	X
0.0001 - 0.01	AO (1-ft)
0.01 - 0.1	AO (2-ft)
0.1 - 1	AO (3-ft)
>1.0	30ft VE Splashzone /AO (3ft)

2) Analysis of Wave Runup on a Failed Seawall by TAW Method for 2220 Ocean Blvd near Transect TR-39 (TR-42 in CHAMP) in Town of Rye, NH

This worksheet uses the TAW Method to evaluate runup for the failed seawall case for 2220 Ocean Blvd in the Town of Rye, NH. The intact case for TR-39 was analyzed separately using Figure D.2.8-3 of the FEMA 2007 Guidelines.

Input Data and Assumptions

The following assumptions from are utilized:

- The Preliminary April 9, 2014 Preliminary FIRM Backup Data apply except where noted.
- Wave height, H_{mo}, is the deepwater wave height and is not in water of transitional depth.
- Wave period, T_p, remains constant and independent of depth for oscillatory waves
- Wave setup dynamically calculated by SWAN1D includes both the effects of static and dynamic wave setup.
- Acceleration due to gravity: **g = 32.17 ft/s^2**

The offshore wave parameters utilized by FEMA in the April 9, 2014 Preliminary FIRM Coastal Backup Data and WHG Modeling Results from the March 5, 2015 Appeal for Transect TR-39 apply to this location including:

- Peak Wave Period: **T_p = 11.66 seconds** (FEMA OFFSHORE STWAVE Results)
- Deepwater significant wave height: **H_0 = 25.1 feet** (FEMA OFFSHORE STWAVE Results)
- 1% Stillwater Elevation: **SWEL1% = 8.36 feet NAVD88** (FEMA Preliminary FIS)
- Wave Setup **η** = **1.99** feet (WHG computed by SWAN1D)

The specifications for the seawall were taken from the July 20, 2015 As-built survey drawings including:

- Structure Crest Elevation = **13.8 – 13.9 feet NAVD88** (July 2015 Survey)
- Topo Crest Elevation = **13.4 feet NAVD88** (July 2015 Survey)
- Structure toe elevation **6.4 – 7.1 ft NAVD88** (July 2015 Survey)
- Elevation of grade at base of wall = **8.5 – 8.6 NAVD88** (July 2015 Survey)

STEP ONE – Determine Water Levels and Structure Configuration

The TAW method assumes that the wave that impacts the structure is the depth-limited wave at the toe of the structure (where the beach slope intersects the wall). The depth-limited wave is calculated by finding the water depth at the base of the structure (11.4 ft NAVD88) relative to the total water level, the sum of the SWEL% and Wave setup, for the 100-year storm:

→ TWL = SWEL1% + Wave Setup = 8.36 + 1.99 = 10.35 ft NAVD88

The failed structure case must also include scour at the base of the structure. The maximum scour for this case can be calculated by scouring an equivalent amount equal to the depth limited wave at the structure toe. The depth limited wave at the toe is calculated by subtracting the elevation of the grade pf the beach at the seawall (8.5 ft NAVD88) from the total water level (10.35 feet NAVD88). Therefore, the depth, d_s, is calculated by:

→ d_s = TWL – depth at toe = 10.35 – 8.50 = **1.85 feet**

The depth limited wave is then calculated as H_{mo} = 0.78 * d_s = 0.78 * 1.85 = **1.44 feet**

The scour depth associated with this storm event would therefore be equal to 1.44 ft, and the resulting elevation of the grade at the toe of the wall would be 8.5 ft NAVD88 – 1.44 ft = 7.06 ft NAVD88. For this failed seawall case, it is assumed that the structure would first scour to 7.06feet NAVD88 and then fail on a 1V:3H slope from the scour hole. The failed structure slope of 1V:3H would start at this new scoured toe depth and continue landward until it merged into the existing profile with a new topo crest of 13.4 feet. The new scoured depth at the toe of the structure would be:

→ d_s = TWL – depth at toe = 10.35 – 7.06 = **3.29 feet**

STEP TWO – Determine Wave Parameters

Now we need to determine the wave parameters at the failed seawall based on the offshore wave characteristics and transect data.

Check if Wave is depth limited at the structure:

- "Broken" if: $H_0 \geq 0.78*d_s$
  "Not Broken" if: $H_0 < 0.78*d_s$
  "Undetermined" if: otherwise

  Depth of Scour

  → $H_0 = 0.78*d_s$ = **2.57 feet** < 25.1 feet
  Therefore, the wave that impacts the seawall is **"Broken"** and H_b will be used in place of the deepwater H_{mo}.

- Need to determine the deepwater wave length, L_0, from existing wave parameters:
  $L_0 = \frac{g * Tp^2}{2\pi}$ → Therefore, $\mathbf{L_0}$ **= 696.7 feet**

The wave type at the seawall is determined by the following criteria:

- Wave Type = "Shallow" if $d_s/L_0 < 0.2$
  "Transitional" if $0.2 \leq d_s/L_0 < 0.5$
  "Deep" if $d_s/L_0 \geq 0.5$

  → $d_s/L_0 = 0.002 < 0.2$ Therefore, the wave is a **"Shallow water wave"**

Now determine the local wave parameters at the seawall (H_{mo}, T_{m10}, and L_{mo}):

- H_{mo} = "d_s * 0.78" if wave "Broken"
  "H_{mo}" if wave "Not Broken"
  "0" otherwise

  → Wave Type is "Broken" from the first bullet therefore calculate the depth-limited wave:
  $H_{mo} = d_s$ * 0.78 = **2.57 feet**.

The corresponding T_{m10} and L_{mo} are calculated as follows:

- $T_{m10} = T_p/1.1 =$ **10.6 seconds**
- $L_{mo} = \frac{g * T_{m10}^2}{2\pi}$ = **575.8 feet**

STEP THREE – Check TAW validity

The TAW method is valid is the following criteria are met:

- TAW Method is valid if:
  a. $0.5 < \zeta_{om} < 8\text{-}10$ where ζ_{om} is the Iribarren Number
  b. $1{:}1 < m < 1{:}8$ where m is the slope

→ Determine Iribarren number: $\zeta_{om} = \frac{m}{\sqrt{Hmo/Lmo}}$

Now calculate the Iribarren Number ζ_{om} based on the slope *m* of the failed seawall set to 1V:3H:

→ $\zeta_{om} = \frac{m}{\sqrt{Hmo/Lmo}} =$ **4.8**

Therefore, the **TAW Method is Valid** since $0.5 < \zeta_{om} =$ **4.8** $<$ 8-10 & $1{:}1 < m =$ **1:3** $<$ 1:8-10

STEP FOUR – Calculate Runup

Runup is calculated based on the TAW by the following method:

- Runup $R_{2\%}$ =

$H_{mo}\,(1.77 * \gamma_r * \gamma_b * \gamma_\beta * \gamma_p * \zeta_{om})$	if $0.5 \le \gamma_b * \zeta_{om} < 1.8$
$H_{mo}\,[\,\gamma_r * \gamma_b * \gamma_\beta * \gamma_p * (4.3 - 1.6/\sqrt{\zeta om})]$	if $1.8 \le \gamma_b * \zeta_{om}$
0	Otherwise

Where γ_r, γ_b, γ_β, and γ_p are influence or reduction factors that are determined below:

- Roughness reduction factor: $\boldsymbol{\gamma_r = 1}$
  → Default 1.

- Wave Direction Factor: $\boldsymbol{\gamma_\beta = 1}$
  → The waves are normally incident, therefore this value is set to the default of 1.

- Berm Section Factor: $\boldsymbol{\gamma_b = 1}$
  → There is no berm so this value is set to the default is 1.

- Porosity Factor: $\boldsymbol{\gamma_p = 1}$
  → For an assumed default porosity of 0.5, the default is 1.

- Now determine which runup equation to use by calculating $\gamma_b * \zeta_{om}$

→ $\gamma_b * \zeta_{om} = 1*6.6 = 6.6 > 1.8$, therefore use second equation:

$R_{2\%} = H_{mo}\ [\ \gamma_r * \gamma_b * \gamma_\beta * \gamma_p * (4.3 - 1.6/\sqrt{\xi_{om}})]$ **= 9.17 feet**

- Now calculate the runup elevation by summing the runup and SWEL1%:

  → $Z_{2\%} = R_{2\%}$ + SWEL1% = **19.5 feet NAVD88**

STEP FIVE – Check for Overtopping

Last, determine whether overtopping is occurring and, if so, the severity of the overtopping.

- Is the 2% runup elevation exceeding the barrier crest?

  → $Z_{2\%}$ = 19.5 ft > failed structure crest =13.4 ft

Yes, overtopping of the structure is occurring. The runup Depth is more than 3 feet over the structure crest that would indicate a 30-foot VE Splash Zone from the crest of the wall followed by an AO Zone with a Depth of 3 foot based upon the 2007 FEMA Guidelines Section D.2.8.1.7.

- The mean overtopping rate is then calculated by the Coastal Engineering Manual (CEM) using the following formula (Eqn. VI-5-25) for overtopping by Van der Meer and Jansen (1995) for $\zeta_{om} > 2$:

  $$Q_{mean} = 0.2\sqrt{gH_s^3}\ exp\left[-2.6\ \frac{Re}{H_s}\ \frac{1}{\gamma_r\ \gamma_\beta\ \gamma_b\ \gamma_p}\right]$$

  where R_e is the crest elevation above the TWL = 13.4 ft – 10.35 ft = 3.05 ft
  H_s = water depth at toe of structure = 3.29 feet
  $\boldsymbol{\gamma_r = \gamma_b = \gamma_B = \gamma_p} = 1$

  → Q_{mean}= **0.6 cfs/ft**

→ Based on Table D.2.8-6 of FEMA Guidelines this Q_{mean} of 0.6 cfs/ft equates to an AO Zone with a 3 foot depth, which matches the previous calculation.