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July 8, 2024

TECHNICAL MEMORANDUM

To: J. R. Frey, PE, Town Engineer, Town of Hingham, Massachusetts

From: Sean W. Kelley, PE

Re: Wave Forces calculations for proposed seawall at Martins Lane.

1% (100-year) wave conditions and resulting dynamic wave forces for the Martins Lane seawall in Hingham, Massachusetts were estimated using the SWAN wave model developed previously for Hingham Harbor. This model has a 6.6-foot (2-meter) grid mesh in Hingham Harbor, but also covers the entire Boston Harbor estuary and the western area of Massachusetts Bay (see SCS technical memorandum dated November 8, 2023). Three wind conditions were run with the model, developed using the record of winds in Massachusetts Bay from the US Army Corps of Engineers Wave Information Study (WIS) hindcast. 1% winds blowing from the WSW compass sector produced the largest waves offshore of the project area. Wave model output 1% winds blowing from the WSW sector is presented in Figure 1. A listing of model input winds and output wave conditions is provided in Table 1.

Using the results of the wave model runs of 100-year storm conditions for the WSW wind case, maximum horizontal wave forces were calculated for the proposed profile of the Martins Point seawall. The method used for these force calculations was developed by Goda (1985). This method is appropriate to use for non-breaking waves. For the representative wall cross section used in this analysis, the toe of the wall is at 5.8 feet NAVD88, and the top of the wall is at 12.0 feet NAVD88. Scour at the toe of the wall is estimated to be similar in magnitude to the water depth at the wall, based on Xie (1981, 1985), as presented in the USACE Coastal Engineering Manual, Part VI (2011 version). With the lowering of the beach due to scour, the maximum wave (estimated to be 1.67 times the significant wave height, from USACE 1995) approaching the wall would begin breaking with water levels that are 7.9 feet NAVD88, which is below the 1% water level (9.7 feet NAVD88, from FEMA 2021)

A representation of the distribution of forces applied over a vertical wall section is presented in Figure 1. By Goda's method, the maximum force occurs at the water surface (P1) and is determined by

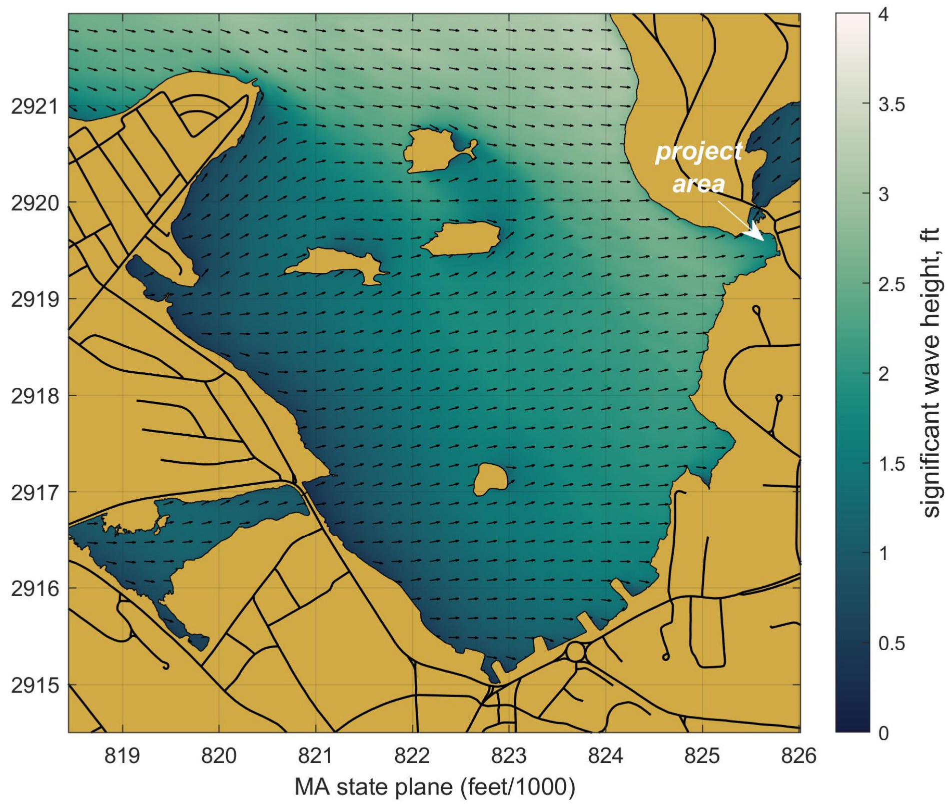

Figure 1. Contour plot of wave height (Hs) and direction (arrows) for the modeled 100-year storm conditions with winds blowing from the WSW compass sector, in Hingham Habor.

Table 1. Wind inputs and resulting wave output offshore the project shoreline.			
Wind Case	West	WSW	SW
Wind Speed, mph	50.7	51.5	47.8
Water level, feet NAVD88	9.7	9.7	9.7
Significant wave height, feet	1.9	1.9	1.6
Peak wave period, seconds	2.1	2.1	1.9

$$P_1 = 0.5(1+\cos\beta)(\alpha_1+\alpha_2\cos 2\beta)\rho_w g H_{max}$$

where ρ_w is the density of water, H_{max} is the design wave height, β is the relative wave approach angle, g is earth's gravity acceleration, and α_1 andα_2 are coefficients determined using the equations

$$\alpha_1=0.6+0.5[(4\pi h/L)/\sinh(4\pi h/L)]^2$$

$$\alpha_2=\min\{[(h_b-h)/3h_b]H_{max}/d)^2, 2h/ H_{max}\}$$

In the calculation of these two coefficients, h_b is the water depth a distance of 5 wave heights ($5H_s$) from the structure, h is the water depth at the structure, and L is the wave length of the design wave.

The force at the bottom of the wall section is determined using the relationship

$$P_3 = \alpha_3 P_1$$

where α_3 is computed as

$$\alpha_3 = 1 - h'/h[1-1/\cosh(2\pi h/L)]$$

and h′ is the depth of the wall bottom below the water surface. Finally, the force at the very top of the wall (P_4) is calculated as

$$P_4 = P_1(1 - R_c/\eta^*)$$

where R_c is the height of the wall top above the still water surface (surge elevation) and η^* is the maximum elevation above the water surface that the broken wave would reach. Goda used $\eta^* = 1.5H_{max}$. The H_{max} wave height is calculated as 1.67 times the significant wave height (H_s) per guidance from USACE and FEMA (Coastal Structures Guidance Document 42, November 2019).

By iterating wave force calculations for water levels between the point where the expected maximum wave height would begin to break and the 1% SWEL (Suffolk Co. FIS), it is determined that maximum forces occur near 7.9 NAVD88. Below that level, wave breaking would decrease the resulting force applied to the wall. Above that level, wave forces decrease as more of the wave crest overtopped the wall. The final results of the force calculations based on Goda's method with a water level of 7.9 NAVD88 are presented in Table 2 along with the input parameters.

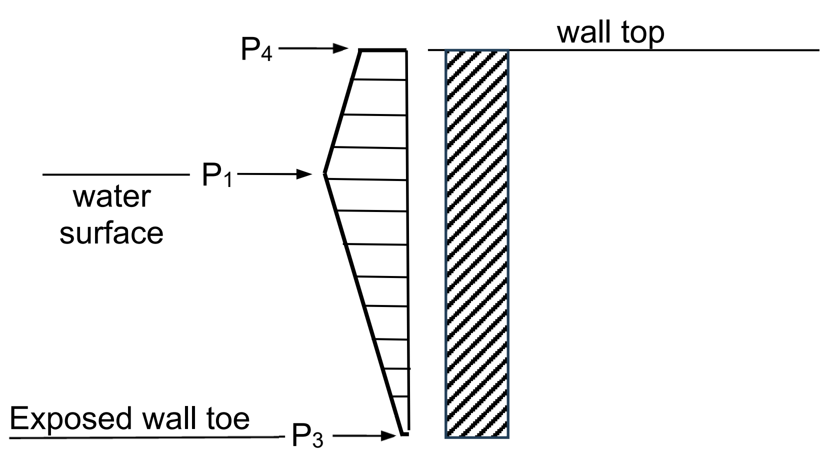

Figure 2. Force diagram showing distribution of applied wave forces on the US Army Corps wall at Black Falcon Pier, using the method of Goda (1985).

Table 2. Wave force calculation inputs and results for the proposed wall at Martins Point, Hingham, MA. Maximum average pressure occurs at 7.9 NAVD88 water level, which is below the FEMA 1% water level of 9.7 ft NAVD88

Ocean surface elevation	7.9	ft, NAVD88
wall top elevation	12.0	ft, NAVD88
Scoured wall bottom elevation	3.8	ft, NAVD88
H_s wave height	1.9	feet
H_{max} wave height	3.2	feet
T_p peak period	2.1	seconds
L wave length	19.1	feet
P1 (applied at 7.9 ft, NAVD)	132.3	psf
P3 (applied at 3.8 ft, NAVD)	64.5	psf
P4 (applied at 12.0 ft, NAVD)	18.3	psf
P average	86.8	psf
Force total for section, per linear foot	711.8	lbf

References.

Federal Emergency Management Agency (FEMA) (2021). Flood Insurance Study, Plymouth County, Massachusetts.

Goda, Y. (1985). Random Seas and Design of Maritime Structures. University of Tokyo Press, Japan.

US Army Corps of Engineers (USACE) (2011). Coastal Engineering Manual (CEM). USACE Coastal and Hydraulics Laboratory, Vicksburg, MS.

US Army Corps of Engineers (USACE) (1995). Design of Coastal Revetments, Seawalls, and Bulkheads. EM 1110-2-1614. Washington, DC.