Coastal Engineering Technical Note

BREAKING WAVE FORCES ON WALLS

PURPOSE: To introduce the Goda method as an alternative to the Minikin method for the determination of breaking wave forces on semirigid wall structures.

INTRODUCTION: Prediction of breaking wave forces on vertical walls is required for the design of wall structures in coastal waters. The Standard procedure followed by most harbor and coastal engineers in the US is the Minikin method documented in detail in the Shore Protection Manual (SPM, 1984). As the Minikin method is based on the shock pressure caused by breaking waves, the resulting forces and structure designs analyzed by using this procedure are generally considered to be conservative. The SPM cautions its users about the extremely high wave forces associated with the Minikin method.

A less conservative method recommended by Goda (1974) is an alternative procedure for breaking wave force determination. The Technical Standards for Port and Harbour Facilities in Japan (1980) has adopted the Goda method but cautions that this method may underestimate the wave force. A factor of safety of 1.2 is recommended for structure design against sliding and overturning. The rationale of using the Goda method for design analysis is that the duration of the impulsive breaking force is relatively brief, on the order of tenth or hundredth of a second, and the effect of this force on the stability of massive concrete wall structures, particularly those with rubble mound bases, may be rather insignificant. In design practice, conditions that cause the occurrence of impulsive wave loading on structures should be avoided (Goda, 1985). For sensitive coastal structures, physical modeling may be required to ascertain the avoidance of impulsive breaking wave conditions.

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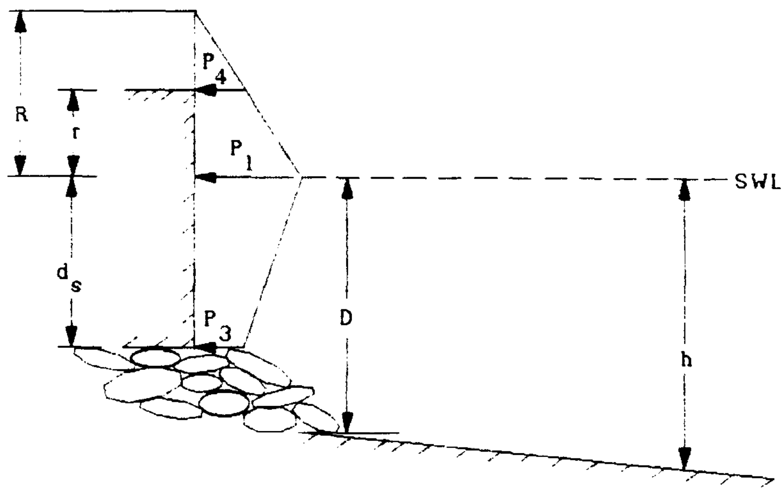

Breaking Wave Pressures on a Vertical Wall

GODA'S FORMULAS: The above figure shows the structure configuration for which the Goda method is applied and illustrates the linear pressure distribution on the wall face due to wave impact. The key components of the pressure diagram are:

$$P_1 = (\alpha_1 + \alpha_2) \cdot \omega \cdot H_b$$

$$P_3 = \alpha_3 \cdot P_1$$

$$P_4 = (1 - r/R) \cdot P_1$$

where $R = 1.5 \cdot H_b$

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

$$\alpha_2 = \min\left(\left(\frac{h - d_s}{3h}\right)\left(\frac{H_b}{d_s}\right)^2, \frac{2d_s}{H_b}\right)$$

$$\alpha_3 = 1 - d_s/D(1 - 1/\cosh(2\pi D/L))$$

ω = specific weight of water
H_b = highest of the random waves breaking at a distance of $5H_s$ seaward of the wall; H_s is the significant wave height of the design sea state
h = water depth at where H_b is determined
$\min(a, b)$ = smaller of a and b
L = wavelength calculated by linear wave theory at the wall

According to Goda (1985), the above equations are applicable to either breaking or nonbreaking wave conditions.

WAVE FORCE AND MOMENT: The integration of pressure distribution on the wall yields the force per unit length of the structure, F,

$$F = 0.5 \cdot (P_1 + P_3) \cdot d_s + 0.5 \cdot (P_1 + P_4) \cdot (d_s + hc)$$

where hc is the centroid of the pressure prism defined by P_1 and P_4 above the mean water level. The overturning moment, M due to waves is

$$M = F \cdot hc$$

where hc' is the centroid of pressure prism above the wall base.

APPLICATION PROCEDURE: The Goda method is developed for the design of caisson type breakwaters with rubble foundations. The following procedures are recommended for the design analysis.

a. Select a design sea state and identify the significant wave height, H_s, and significant wave period, T_s.

b. Determine h by $h = D + 5 \cdot m \cdot H_s$, where m is the bottom slope.

c. Calculate the breaking wave height, H_b, at h. Note that if H_b is greater than the maximum wave height of the design sea state, there will be no breaking wave force exerted on the wall. In that case, use the maximum wave height for the wave force analysis or use methods described in the SPM (1984). The maximum wave height may be estimated as 1.8 times H_s according to Goda(1985).

d. Calculate wavelength L for depth D using the significant wave period of the design sea state and the linear wave theory or Tables C-1 and C-2 of Appendix C of the SPM.

e. Calculate the wave force and moment using Goda equations provided in this note.

EXAMPLE: Given a vertical wall, 4.3 m (14 ft.) high sited in sea water with d_s = 2.5 m (8.2 ft.). The wall is built on a bottom slope of 1:20 (m = 0.05). Reasonable wave periods range from 6 to 10 seconds. Find the maximum pressure, horizontal force, and overturning moment about the toe of the wall.

Since there is no rubble mound base, the water depth D = d_s = 2.5 m. For T = 10 seconds, find by using Figure 7-4 of the SPM, the design breaking wave height, H_b = 3.2 m. Without knowledge of significant wave height, H_s, the breaking depth, h, is determined directly by using Figure 7-2, which yields h = 3.07 m. The wave breaks at a distance of 11.4 m (=(3.07 - 2.5)/.05) from the wall. Using Table C-1 of Appendix C, SPM or computer program SINWAVES, wave length, L at D = 2.5 m is determined to be 48.7 m. Then, α_1, α_2, and α_3 are calculated to be 1.036, 0.101, and 0.950, respectively. Furthermore,

$$R = 1.5\, H_b = 4.8 \text{ m} > 1.8 \text{ m} \qquad \text{(overtopping)}$$

The pressure components are calculated as

$$P_1 = (a_1 + a_2) \cdot w \cdot H_b$$

$$= 36.4 kN/m^2$$

$$P_3 = a_3 . P_1$$

$$= 34.6 kN/m^2$$

$$P_4 = P_1 \cdot 3.0/4.8$$

$$= 22.8 kN/m^2$$

The total horizontal force due to breaking wave is

$$F = .5 \cdot (P_1 + P_4) \cdot 1.8 + .5 \cdot (P_1 + P_3) \cdot 2.5$$

$$= 142 \text{ kN/m}$$

The overturning moment about the toe excluding moments due to uplift and hydrostatic forces is

$$M = 289 \text{ kN-m/m}$$

Similar procedures are used to calculate the peak pressure, force and moment on the wall due to the 6 second wave. This example is the same as EXAMPLE PROBLEM 34 of Page 7-182 of SPM. The comparison with results based on the Minikin method are summarized in the following table.

	Goda Method		Minikin Method	
Wave Period (sec)	6	10	6	10
P_1 (kN/m^2)	26.6	36.4	336	176
F (kN/m)	99.6	142	309	194
M (kN-m/m)	204	289	772	485

ADDITIONAL INFORMATION: For additional information contact the CERC Coastal Design Branch, (601) 634-2067.

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