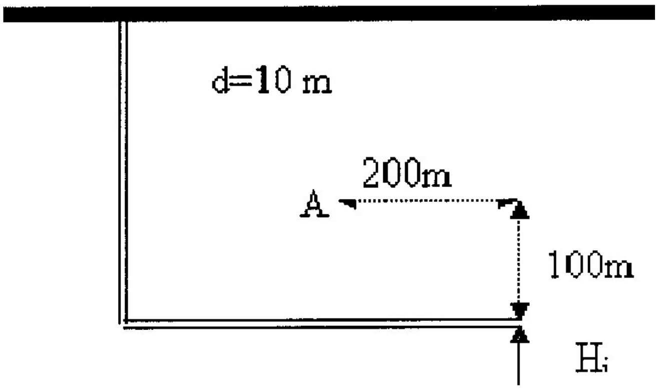
■In deep water a wave has a height of 2 m and a period of 8 sec. Diffraction coefficient is 0.15 at point A inside the harbor. Calculate the wave height at point A.



K_{DA}=0.15 H_0=2 m   T=8 s

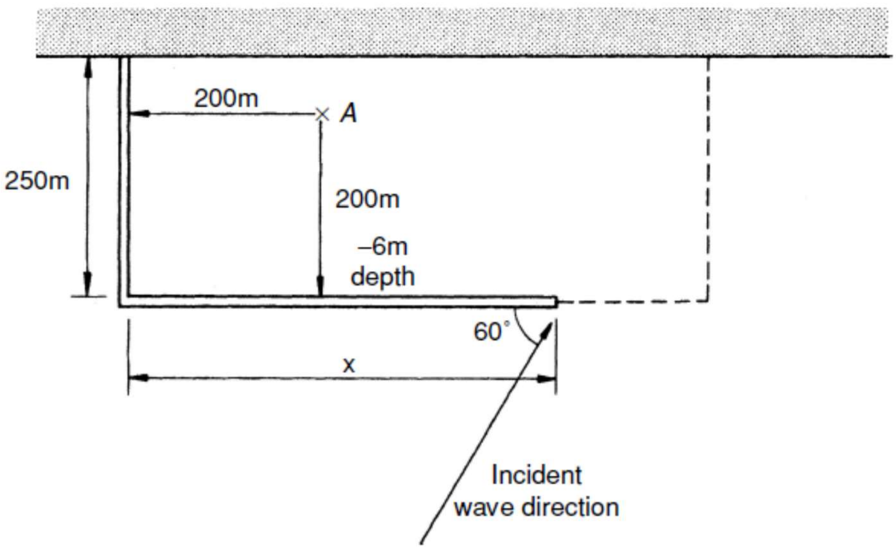
$$H_i = H_0 \times K_{si}.$$

$$\frac{d}{L_0} = \frac{10}{100} = 0.1 \xrightarrow{GWT} K_{s10} = 0.9327$$

$$H_{10} = 2 \times 0.9327 = 1.865\ m$$

$$H_A = H_i \times K_{DA}. = 1.865 \times 0.15 = 0.28\,m$$

■ Consider the L-shaped breakwater that protects a small harbor dredged to a uniform depth of 6 m. For a 2 m high, 6 s period incident wave at the head of the breakwater having the direction shown, what length (B) must the seaward arm of the breakwater have to diminish the wave height to 0.5 m at point A?"



d=6m H_i=2 m   T=6s   β=120° H_A=0.5 m

$$L_0 = 1.56T^2 = 1.56 \times 6^2 = 56.16\,m$$

$$\frac{d}{L_0} = \frac{6}{56.16} = 0.1068 \xrightarrow{GWT} \frac{d}{L_i} = 0.1471 \rightarrow L_i = 40.78m$$

$$H_A = H_i \times K_{DA} \rightarrow 0.5 = 2 \times K_D \rightarrow K_D = 0.25$$

$$\left.\begin{aligned} \frac{x}{L_i} &= \frac{x}{40.78} = ? \\ \frac{y}{L_i} &= \frac{200}{40.78} = 5 \end{aligned}\right\} \rightarrow \frac{x}{40.78} = 0.25 \rightarrow x = 10.2\,\text{m}$$

B=200+10.2=210.2 m

■ H_0=4 m, T=9 sec, α_0=20°, m=s=0.02. Calculate the breaking parameters (H_b, d_b, α_b=?).

Kr=1 (assume)

$$H_0' = H_0 K_r \rightarrow H_0' = H_0 = 4\text{m}$$

$$\frac{H_0'}{gT^2} = \frac{4}{9.81 \times 9^2} = 0.005 \xrightarrow{\text{Fig. 2.43}} \frac{H_b}{H_0'} = 1.08 \rightarrow H_b = 1.08 \times 4 = 4.32\,\text{m.}$$

$$\frac{H_b}{gT^2} = \frac{4.32}{9.81 \times 9^2} = 0.0054 \xrightarrow{\text{Fig.2.44}} \frac{d_b}{H_b} = 1.17 \rightarrow d_b = 1.17 \times 4.32 = 5.05\ \text{m.}$$

$$d_b / L_0 = 5.05/126.36 = 0.04 \xrightarrow{\text{GWT}} \tanh kd_b = 0.4802$$

$$\frac{\sin \alpha_b}{\sin \alpha_0} = \tanh kd_b \rightarrow \frac{\sin \alpha_b}{\sin 20} = 0.4802 \rightarrow \alpha_b = 9.2^\circ$$

$$K_{rb} = \sqrt{\frac{\cos \alpha_0}{\cos \alpha_b}} = \sqrt{\frac{\cos 20}{\cos 9.2}} = 0.98 \neq 1$$

Second trial :Kr=0.98 (assume)

$$H_0' = H_0 K_r = 4 \times 0.98 = 3.92\,\text{m}$$

$$\frac{H_0'}{gT^2} = \frac{3.92}{9.81 \times 9^2} = 0.0049 \xrightarrow{\text{Fig. 2.43}} \frac{H_b}{H_0'} = 1.08 \rightarrow H_b = 1.08 \times 3.92 = 4.23\,\text{m.}$$

$$\frac{H_b}{gT^2} = \frac{4.23}{9.81 \times 9^2} = 0.0053 \xrightarrow{\text{Fig.2.44}} \frac{d_b}{H_b} = 1.165 \rightarrow d_b = 1.165 \times 4.23 = 4.93\ \text{m.}$$

$$d_b / L_0 = 4.93/126.36 = 0.04 \xrightarrow{\text{GWT}} \tanh kd_b = 0.4802$$

$$\frac{\sin \alpha_b}{\sin \alpha_0} = \tanh kd_b \rightarrow \frac{\sin \alpha_b}{\sin 20} = 0.4802 \rightarrow \alpha_b = 9.2^\circ$$

$$K_{rb} = \sqrt{\frac{\cos \alpha_0}{\cos \alpha_b}} = \sqrt{\frac{\cos 20}{\cos 9.2}} = 0.98 \cong 0.98$$

$$H_b = 4.23\,\text{m. and } d_b = 4.93\ \text{m.}$$

■ A wave with a period of T=8 sec and a height of H_0=5m propagates toward the shore from deep water.

a) Calculate the breaking wave height, breaking depth and breaking type for the sea bottom slope of s=m=0.05.

b) If the wave crests in deep water are oriented at an angle of 45° with the shoreline calculate the breaking parameters.

a) $L_0 = 1.56T^2 = 1.56 \times 8^2 = 99.84\,\text{m}$

$\alpha_0=0 \quad Kr=1$

$H_0' = H_0 K_r \rightarrow H_0' = H_0 = 5\,\text{m}$

$$\frac{H_0'}{gT^2} = \frac{5}{9.81\times 8^2} = 8\times 10^{-3} \xrightarrow{\text{Fig. 2.43}} \frac{H_b}{H_0'} = 1.14 \rightarrow H_b = 1.14\times 5 = 5.7\,\text{m.}$$

$$\frac{H_b}{gT^2} = \frac{5.7}{9.81\times 8^2} = 0.0091 \xrightarrow{\text{Fig.2.44}} \frac{d_b}{H_b} = 1.12 \rightarrow d_b = 1.12\times 5.7 = 6.38\ \text{m.}$$

$$\xi = \frac{S}{\sqrt{\frac{H_0}{L_0}}} = \frac{0.05}{\sqrt{\frac{5}{99.84}}} = 0.22 < 0.5 \quad \textit{spilling breaker}$$

b) $\alpha_0=45°$

First trial : Kr=1 (assume)

$H_0' = H_0 K_r \rightarrow H_0' = H_0$

$$\frac{H_0'}{gT^2} = \frac{5}{9.81\times 8^2} = 8\times 10^{-3} \xrightarrow{\text{Fig. 2.43}} \frac{H_b}{H_0'} = 1.14 \rightarrow H_b = 1.14\times 5 = 5.7\,\text{m.}$$

$$\frac{H_b}{gT^2} = \frac{5.7}{9.81\times 8^2} = 0.0091 \xrightarrow{\text{Fig.2.44}} \frac{d_b}{H_b} = 1.12 \rightarrow d_b = 1.12\times 5.7 = 6.38\ \text{m.}$$

$$d_b / L_0 = 6.38/99.84 = 0.064 \xrightarrow{\text{GWT}} \tanh kd_b = 0.591$$

$$\frac{\sin\alpha_b}{\sin\alpha_0} = \tanh kd_b \rightarrow \frac{\sin\alpha_b}{\sin 45} = 0.591 \rightarrow \alpha_b = 24.7^\circ$$

$$K_{rb} = \sqrt{\frac{\cos\alpha_0}{\cos\alpha_b}} = \sqrt{\frac{\cos 45}{\cos 24.7}} = 0.88 \neq 1$$

Second trial : Kr=0.88 (assume)

$H_0' = H_0 K_r = 5\times 0.88 = 4.4\,\text{m}$

$$\frac{H_0'}{gT^2} = \frac{4.4}{9.81\times 8^2} = 0.007 \xrightarrow{\text{Fig. 2.43}} \frac{H_b}{H_0'} = 1.18 \rightarrow H_b = 1.18\times 5 = 5.2\,\text{m.}$$

$$\frac{H_b}{gT^2} = \frac{5.2}{9.81\times 8^2} = 0.0083 \xrightarrow{\text{Fig.2.44}} \frac{d_b}{H_b} = 1.08 \rightarrow d_b = 1.08\times 5.2 = 5.62\ \text{m.}$$

$$d_b / L_0 = 5.62/99.84 = 0.056 \xrightarrow{GWT} \tanh kd_b = 0.5574$$

$$\frac{\sin\alpha_b}{\sin\alpha_0} = \tanh kd_b \rightarrow \frac{\sin\alpha_b}{\sin 45} = 0.5574 \rightarrow \alpha_b = 23.2^\circ$$

$$K_{rb} = \sqrt{\frac{\cos\alpha_0}{\cos\alpha_b}} = \sqrt{\frac{\cos 45}{\cos 23.2}} = 0.877 \cong 0.88$$

$H_b = 5.2\,m.$ and $d_b = 5.62$ m.

$$\xi = \frac{S}{\sqrt{\frac{H_0}{L_0}}} = \frac{0.05}{\sqrt{\frac{5}{99.84}}} = 0.22 < 0.5 \quad \textit{spilling breaker}$$

■ Waves with a period of T=8 sec break at a depth of 5 m. Calculate the breaking wave height and the deep water wave height if the bottom slope is 1/30 (s=m=1/30).

$\alpha_0=0$ Kr=1 (waves are approaching parallel to the shoreline)

$$H_0' = H_0 K_r \rightarrow H_0' = H_0$$

$$L_0 = 1.56T^2 = 1.56 \times 8^2 = 99.84 \text{ m.}$$

$$\frac{d_b}{H_b}\ \frac{H_b}{gT^2} = \frac{5}{9.81\times 8^2} = 0.008$$

$$\downarrow \quad \downarrow$$

$$1.14 \times 0.007 = 0.00798 \cong 0.008$$

$$H_b = 5/1.14 = 4.39\,m$$

$$\frac{H_b}{H_0'}\ \frac{H_0'}{gT^2} = \frac{4.39}{9.81\times 8^2} = 0.007$$

$$\downarrow \quad \downarrow$$

$$1.065 \times 0.0065 = 0.00692$$

$$\frac{H_0'}{gT^2} = 0.0065 \rightarrow H_0' = 4.12\,m$$

$$H_0' = H_0 K_r \rightarrow 4.12 \text{ m.}$$

■ Waves with a period of T=8 s break at an angle of 15 degrees and a height of 3 m. Calculate the breaking depth and the deep water wave height (s=m=0.033).

H_b=3 m, T=8 sec, α_b=15°, (H_0, d_b=?)

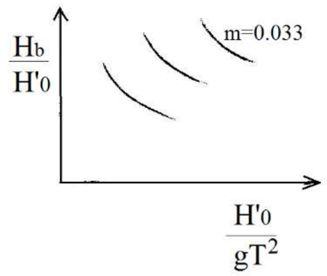
$$L_0 = 1.56T^2 = 1.56 \times 8^2 = 99.84 \text{ m.}$$

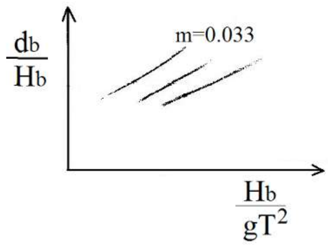
$$\frac{H_b}{gT^2} = \frac{3}{9.81 \times 8^2} = 0.0048 \xrightarrow{\text{Fig.2.44}} \frac{d_b}{H_b} = 1.1 \rightarrow d_b = 1.1 \times 3 = 3.3 \text{ m.}$$

$$d_b / L_0 = 3.3/99.84 = 0.033 \xrightarrow{\text{GWT}} \tanh kd_b = 0.4392$$

$$\frac{\sin \alpha_b}{\sin \alpha_0} = \tanh kd_b \rightarrow \frac{\sin 15}{\sin \alpha_0} = 0.4392 \rightarrow \alpha_0 = 36^\circ$$

$$K_{rb} = \sqrt{\frac{\cos \alpha_0}{\cos \alpha_b}} = \sqrt{\frac{\cos 36}{\cos 15}} = 0.92$$





$$\frac{H_b}{H_0'} \frac{H_0'}{gT^2} = \frac{3}{9.81 \times 8^2} = 0.048$$

$$\downarrow \quad \downarrow$$

$$1.14 \times 0.0042 \cong 0.0048$$

$$H_b / H_0' = 1.14 \rightarrow H_0' = 3/1.14 = 2.63$$

$$H_0' = H_0 K_r \rightarrow 2.63 = H_0 \times 0.92 = 2.86 \text{ m.}$$

■ A wave record for 10 minutes taken during a storm is analyzed by the zero-upcrossing method and contains 100 waves. Calculate the significant wave height ($H_{1/3}$=H_s), the mean wave height (H_{mean}), the maximum wave height (H_{max}) and $H_{1/100}$ using the table below.

H	Wave Number	H	Wave Number
0.6	15	1.8-1.99	2
0.6-0.79	15	2.0-2.19	2
0.8-0.99	7	2.2-2.39	2
1.0-1.19	17	2.4-2.59	3
1.2-1.39	5	2.6-2.79	1
1.4-1.59	9	2.8-2.99	1
1.6-1.79	20	3.0-3.19	1

H	Wave Number	Mean wave height at each interval	Total wave height
0.6	15	**0.6**	**9**
0.6-0.79	15	**0.695**	**10.425**
0.8-0.99	7	**0.895**	**6.265**
1.0-1.19	17	**1.095**	**18.615**
1.2-1.39	5	**1.295**	**6.475**
1.4-1.59	9	**1.495**	**13.455**
1.6-1.79	20	**1.695**	**33.9**
1.8-1.99	2	**1.895**	**3.79**
2.0-2.19	2	**2.095**	**4.19**
2.2-2.39	2	**2.295**	**4.59**
2.4-2.59	3	**2.495**	**7.485**
2.6-2.79	1	**2.695**	**2.695**
2.8-2.99	1	**2.895**	**2.895**
3.0-3.19	1	**3.095**	**3.095**
Total	100		**126.88**

$$H_{1/3} = \frac{1}{N}\sum_{i=1}^{N} H_i = \frac{1}{33}\sum_{i=1}^{N=33} H_i = \frac{64.14}{33} = 1.94\, m$$

$$H_{mean} = \frac{1}{N}\sum_{i=1}^{N} H_i = \frac{1}{100}\sum_{i=1}^{N=100} H_i = \frac{126.88}{100} = 1.27\, m$$

$$H_{max} = 3.095\,\mathrm{m}$$

$$H_{1/100} = \frac{1}{N}\sum_{i=1}^{N} H_i = \frac{1}{1}\sum_{i=1}^{N=1} H_i = \frac{3.095}{1} = 3.095\,\mathrm{m}$$

■ A wind with an average velocity of 9.96 m/s is blowing over for a period of 10 hours. The effective fetch in the direction of wind is 15 km. Using the CERC (1984) method, what significant wave height and period will be generated after a) 10 hours and b) 50 minutes? (H_s, T_s=?).

a) U=9.96 m/sec, F_g=15 km, t_g=10 hours

$$U_A = 0.71 \times U^{1.23} = 0.71 \times 9.96^{1.23} = 12\,\mathrm{m/sec}$$

$$F_{FAS} = \left(\frac{U_A}{0.62}\right)^{1.96} = \left(\frac{12}{0.62}\right)^{1.96} = 333\,\mathrm{km} > F_g = 15\,\mathrm{km}$$

$$t_{FAS} = 2.027 \times U_A = 2.027 \times 12 = 24\,\mathrm{h} > t_g = 10\,\mathrm{h}$$

F_{FAS}>F and t_{FAS}>t_g $\Rightarrow$ Developing sea

$$t = 8.93\times10^{-1}\times\left(\frac{F^2}{U_A}\right)^{1/3} = 8.93\times10^{-1}\times\left(\frac{15^2}{12}\right)^{1/3} = 2.37\,h < t_g = 10\,h \ \text{ fetch limited}$$

$$H_s = 1.616\times10^{-2}U_A F^{1/2} = 1.616\times10^{-2}\times12\times15^{1/2} = 0.75\,m$$

$$T_m = 6.238\times10^{-1}(U_A F)^{1/3} = 6.238\times10^{-1}\times(12\times15)^{1/3} = 3.52\,sec$$

$$T_s = 0.95T_m = 3.35\,sec$$

b) U=9.96 m/sec, F=15 km, t=50 min

$$U_A = 0.71\times U^{1.23} = 0.71\times9.96^{1.23} = 12\,m/sec$$

$$F_{FAS} = \left(\frac{U_A}{0.62}\right)^{1.96} = \left(\frac{12}{0.62}\right)^{1.96} = 333\,km > F_g = 15\,km$$

$$t_{FAS} = 2.027\times U_A = 2.027\times12 = 24\,h > t_g = 10\,h$$

F_{FAS}>F and t_{FAS}>t $\Rightarrow$ Developing sea

$$t = 8.93\times10^{-1}\times\left(\frac{F^2}{U_A}\right)^{1/3} = 8.93\times10^{-1}\times\left(\frac{15^2}{12}\right)^{1/3} = 2.37\,h > t_g = 50\,min \ \text{ Duration limited}$$

$$\frac{50}{60} = 8.93\times10^{-1}\times\left(\frac{F^2}{12}\right)^{1/3} \rightarrow F = 3.123\,km$$

$$H_s = 1.616\times10^{-2}U_A F^{1/2} = 1.616\times10^{-2}\times12\times3.123^{1/2} = 0.34\,m$$

$$T_m = 6.238\times10^{-1}(U_A F)^{1/3} = 6.238\times10^{-1}\times(12\times3.123)^{1/3} = 2.09\,sec$$

$$T_s = 0.95T_m = 1.98\,sec$$

■ Wind duration is 3 and 5 hours, respectively for directions below. Calculate the deep water significant wave heights and periods for each direction (H_s, T_s=?).

a) SSE F=1000 km (effective fetch) U=12.6 m/sec (wind speed)

b) WNW F=30 km (effective fetch) U=7.2 m/sec (wind speed)

a) U=12.6m/s, F_g=1000km, t_g=3 hours

$$u_A = 0.71\times12.6^{1.23} = 16\,m/s$$

$$F_{FAS} = \left(\frac{16}{0.62}\right)^{1.96} = 585\,km < F_g$$

$$t_{FAS} = 2.027\times16 = 32.4\,saat > t_g$$

$F_{FAS}<F_g$ and $t_{FAS}>t_g$ $\Rightarrow$ Developing sea / duration limited

Fetch?? (after 3 hours)

$$3 = 8.93\times10^{-1}\times\left(\frac{F^2}{16}\right)^{1/3} \rightarrow F = 24.6\text{km}$$

$$H_s = 1.616\times10^{-2}\times16\times24.6^{1/2} = 1.28\,\text{m}$$

$$T_m = 6.238\times10^{-1}\times\left(16\times24.6\right)^{1/3} = 4.57\text{s}$$

$$T_s = 0.95T_m = 4.34\text{s}$$

b) U=7.2m/s, F=30km, t=5 hours

$$u_A = 0.71\times7.2^{1.23} = 8.05\text{m/s}$$

$$F_{FAS} = \left(\frac{8.05}{0.62}\right)^{1.96} = 150\text{km} > F_g$$

$$t_{FAS} = 2.027\times8.05 = 16\text{saat} > t_g$$

$F_{FAS}>F$ and $t_{FAS}>t$ $\Rightarrow$ Developing sea

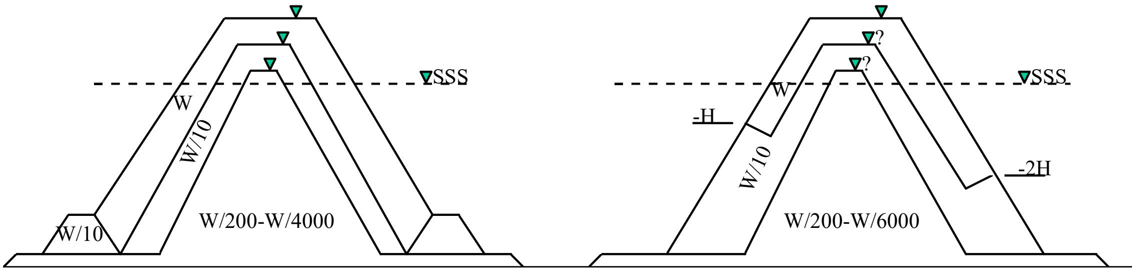
$$5 = 8.93\times10^{-1}\left(\frac{F^2}{8.05}\right)^{1/3} \Rightarrow F = 37.6\text{km} > F_g = 30\,\text{km} \text{ Fetch limited}$$

$$H_s = 1.616\times10^{-2}\times8.05\times30^{1/2} = 0.71\text{m}$$

$$T_m = 6.238\times10^{-1}\times\left(8.05\times30\right)^{1/3} = 3.88\text{s}$$

$$T_s = 0.95T_m = 3.69\text{s}$$

■ A breakwater will be constructed at a 14 m water depth. The biggest rock weight to be used in cover layer is 30 kN. Stability coefficient (K_D) is 4 at trunk and 3 at head. The bottom slope fronting the structure is m=1/50.
In this question, regular wave conditions will be taken into account for shoaling calculations and deep water condition will be accepted.
a) The deep water wave height and the period are 3.5 m and 8 sec, respectively. Accordingly, resize the breakwater trunk section without permitting overtopping (n=2). Which cross-section below is convenient for the design? Find all layer thicknesses (armor layer, filter layer and core). Write the dimensions on the breakwater section.
b) Calculate the armor face slope angle at the head section.
Use HUDSON METHOD.
(ρ_{rock}=2700 kg/m^3 ρ_{water} =1030 kg/m^3)



a) Section for breaking wave **b) Section for non-breaking wave**

$$\text{a)}\ \frac{H'_0}{gT^2} = \frac{3.5}{9.81\times 8^2} = 0.0055\times 10^{-3} \xrightarrow{\text{Fig. 2.43}} \frac{H_b}{H'_0} = 1.1 \rightarrow H_b = 1.1\times 3.5 = 3.85\,\text{m.}$$

$$\frac{H_b}{gT^2} = \frac{3.85}{9.81\times 8^2} = 0.0061 \xrightarrow{\text{Fig.2.44}} \frac{d_b}{H_b} = 1.18 \rightarrow d_b = 1.18\times 3.85 = 4.54\ \text{m.}$$

$d_b < d_s$ non-breaking wave condition $\rightarrow H_d = H_0 \times K_s \times K_r \rightarrow K_r = 1$

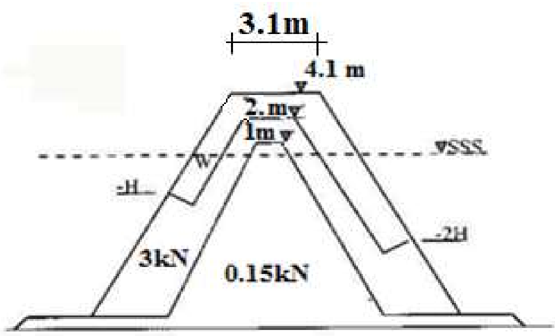
$$\frac{d}{L_0} = \frac{14}{100} = 0.14 \xrightarrow{\text{GWT}} K_{s14} = 0.9146$$

$H_{14} = H_0 \times K_{s14} = 3.5\times 0.9146 = 3.2\,\text{m.}$ (Wave height at the toe of the structure; DESIGN WAVE HEIGHT)

Trunk

$$W = \frac{\gamma_r \times {H_{1/10}}^3}{K_D \times (S_r - 1)^3 \times cot\beta} \qquad H_{1/10} = 1.27\times 3.2 = 4.06m$$

$$30000 = \frac{2700\times 9.81\times 4.06^3}{4\times(2.62-1)^3\times cot\beta} \rightarrow cot\beta = 3.47 \rightarrow \beta = 16°$$



$$R_u/H_0 = 1.016\tan\beta\left(H_0/L_0\right)^{-0.5}\gamma_r$$

$$\frac{R_u}{3.5} = 1.016\times 0.288\left(3.5/100\right)^{-0.5}\times 0.5 \rightarrow R_u = 2.7\,\mathrm{m}$$

Rock weights for the non-breaking wave condition

Filter	$W/10 = 30/10 = 3\,\mathrm{kN}$
Core	$W/200 = 30/200 = 0.15\,\mathrm{kN}$
Armor layer thickness	$t_k = nK'_D(W/\rho_r g)^{1/3} = 2\times 1\times(30000/2700\times 9.81)^{1/3} = 2.1\,\mathrm{m}$
Filter layer thickness	$t_f = nK'_D(W/\rho_r g)^{1/3} = 2\times 1\times(3000/2700\times 9.81)^{1/3} = 0.97\,\mathrm{m} \cong 1\,\mathrm{m}$
Crest width	$b = nK'_D(W/\rho_r g)^{1/3} = 3\times 1\times(30000/2700\times 9.81)^{1/3} = 3.13\,\mathrm{m} \cong 3.1\,\mathrm{m}$
Crest height	h_c=1+1+2.1=4.1 m

Ru= 2.7 m < R_c=4.1 m There will be no overtopping under these design wave conditions.

b) Head

$$30000 = \frac{2700\times 9.81\times 4.06^3}{3\left(2.62-1\right)^3\cot\beta} \rightarrow \cot\beta = 4.63 \rightarrow \beta = 12°$$

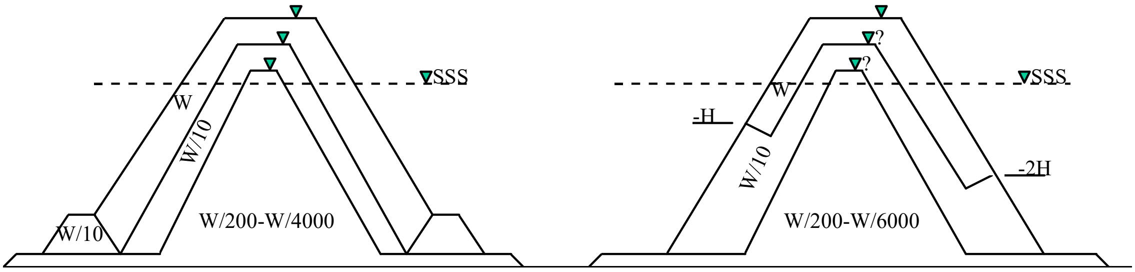
■ A breakwater will be built in a 7 m water depth. The deep water wave height and period are 2 m and 6 sec, respectively.

Calculate the rock weight. Calculate the crest height without permitting overtopping. Which cross-section below is convenient for the design? Find all layer thicknesses (armor layer, filter layer and core). Write the dimensions on the brekwater section.

(ρ_{rock}=2650 kg/m^3 ρ_{water} =1030 kg/m^3, K_D=3, sea bottom slope m=1/50)

Use the methods given below:

a) Hudson method
b) Van der Meer method (Stability calculations and Run-up height with irregular wave shoaling)



a) Section for breaking wave **b) Section for non-breaking wave**

a) Hudson

$$\frac{H_0'}{gT^2} = \frac{2}{9.81 \times 6^2} = 0.00566 \times 10^{-3} \xrightarrow{\text{Fig. 2.43}} \frac{H_b}{H_0'} = 1.19 \rightarrow H_b = 1.19 \times 2 = 2.38\,\text{m.}$$

$$\frac{H_b}{gT^2} = \frac{2.38}{9.81 \times 6^2} = 0.0067 \xrightarrow{\text{Fig.2.44}} \frac{d_b}{H_b} = 1.21 \rightarrow d_b = 1.21 \times 2.38 = 2.88 \text{ m.}$$

$d_b < d_s$ non-breaking wave $\rightarrow H_d = H_0 \times K_s \times K_r \rightarrow K_r = 1$

$$\frac{d}{L_0} = \frac{7}{56.16} = 0.125 \xrightarrow{\text{GWT}} K_{s7} = 0.9185$$

$H_{s7} = H_0 \times K_{s7} = 2 \times 0.9185 = 1.84\,\text{m.}$ (Design wave height)

Incline of slope 1/1.5

$$W = \frac{\gamma_r \times {H_{1/10}}^3}{2 \times \left(\frac{\gamma_r}{\gamma_w} - 1\right)^3 \times \cot\beta} \qquad H_{1/10} = 1.27 \times 1.84 = 2.34m$$

$$W = \frac{2.65 \times 9.81 \times 2.34^3}{3 \times (2.57 - 1)^3 \times 1.5} = 19kN$$

$$R_u / H_0 = 1.016 \tan\beta \left(H_0 / L_0\right)^{-0.5} \gamma_r$$

$$\frac{R_u}{2} = 1.016 \times (1/1.5) \left(2/56.16\right)^{-0.5} \times 0.5 \rightarrow R_u = 3.59\,\text{m}$$

Non-breaking wave Filter $W/10 = 19/10 = 1.9\,\text{kN}$

Core $W/200 = 19/200 = 0.095\,\text{kN}$

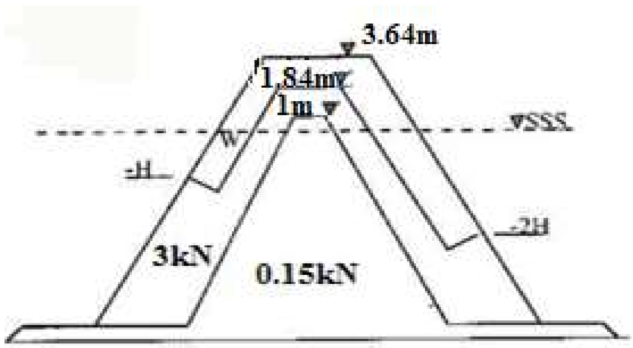
Armour layer thickness $t_k = nK'_D(W/\rho_r g)^{1/3} = 2\times1\times(19/2.65\times9.81)^{1/3} = 1.8\,\text{m}$

Filter layer thickness $t_f = nK'_D(W/\rho_r g)^{1/3} = 2\times1\times(1.9/2.65\times9.81)^{1/3} = 0.84\,\text{m}$

Crest width $b = nK'_D(W/\rho_r g)^{1/3} = 3\times1\times(19/2.65\times9.81)^{1/3} = 2.7\,\text{m}$

Crest height R_c=1+0.84+1.8=3.64 m

Ru= 3.59 m < R_c=3.64 m No overtopping



b) Van der Meer

$$\frac{d}{Hs,toe} = \frac{7}{1.84} = 3.8 > 3\ deep\ water$$

Van der Meer (1988) deep water solution: (tanβ=1/1.5, P=0.4, S=2 and N=3000)

$$T_s = 1.16T_m \rightarrow 6 = 1.16T_m \rightarrow T_m = 5.17\,\text{s}$$
$$T_{m-1,0} = 1.13T_m = 1.13\times5.17 = 5.84\,\text{s}$$

$$\xi_m = \frac{tan\alpha}{\sqrt{\frac{H_{s,toe}}{L_{m0}}}} = \frac{1/1.5}{\sqrt{\frac{1.84}{41.69}}} = 3.17 \qquad L_{m0} = 1.56\times5.17^2 = 41.69m$$

$$\xi_{mc} = \left[6.2P^{0.31}\sqrt{\tan\alpha}\right]^{\frac{1}{P+0.5}} = \left[\frac{6.2}{1}\times0.4^{0.31}\sqrt{(1/1.5)}\right]^{\frac{1}{0.4+0.5}} = 4.42$$

$\xi_m < \xi_{mc}$ for plunging waves

$$\frac{H_s}{\Delta D_{n50}} = 6.2P^{0.18}\left(\frac{S}{\sqrt{N}}\right)^{0.2}\xi_m^{-0.5}$$

$$\frac{H_s}{\Delta D_{n50}} = 6.2\times0.4^{0.18}\left(\frac{2}{\sqrt{3000}}\right)^{0.2}3.17^{-0.5} = 1.52$$

$$\Delta = \frac{\rho_r - \rho_w}{\rho_w} = \frac{2650-1030}{1030} = 1.57$$

$$\frac{H_s}{\Delta D_{n50}} = 1.52 \rightarrow \frac{1.84}{1.57 D_{n50}} = 1.52 \rightarrow D_{n50} = 0.77\,\text{m}$$

$$W = \gamma_r (D_{n50})^3 = \rho_r g (D_{n50})^3 = 2.65 \times 9.81 \times 0.77^3 = 11.91kN$$

$$\xi_{m-1,0} = \frac{tan\alpha}{\sqrt{\frac{H_{s,toe}}{L_{m-1,0}}}} = \frac{1/1.5}{\sqrt{\frac{1.84}{53.29}}} = 3.58 \qquad L_{m-1,0} = 1.56 \times 5.84^2 = 53.2m$$

$$\frac{R_{u\%2}}{H_{s,toe}} = 1.75\gamma_b \gamma_f \gamma_\beta \xi_{m-1,0}$$

$\gamma_b = 1 \qquad \gamma_\beta = 1 \qquad \gamma_f = 0.4(rock)$

$$\frac{R_{u\%2}}{1.84} = 1.75 \times 1 \times 0.4 \times 1 \times 3.58 \rightarrow R_{u\%2} = 4.61m$$

Non-breaking wave Filter $W/10 = 11.91/10 = 1.2\text{kN}$

Core $W/200 = 11.91/200 = 0.06\,\text{kN}$

Armor layer thickness $t_k = nK'_D(W/\rho_r g)^{1/3} = 2 \times 1 \times (11.91/2.65 \times 9.81)^{1/3} = 1.55\,\text{m}$

Filter layer thickness $t_f = nK'_D(W/\rho_r g)^{1/3} = 2 \times 1 \times (1.2/2.65 \times 9.81)^{1/3} = 0.73\,\text{m}$

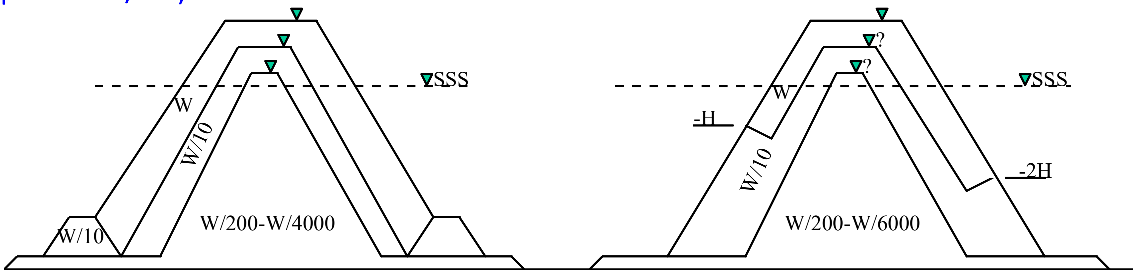
Crest width $b = nK'_D(W/\rho_r g)^{1/3} = 3 \times 1 \times (11.91/2.65 \times 9.81)^{1/3} = 2.75\,\text{m}$

Crest height R_c=1+0.73+1.55=3.28 m

$R_{u\%2}$= 4.61 m > R_c=3.28 m

Overtopping can be reduced by using crown wall or increasing the width of crest width or height.

■ A breakwater for a small marina is constructed at a depth of 6 m. The armor face slope of the breakwater is 1/3. The incident deep water wave height is 7 m with a period of 10 s.
By using HUDSON METHOD;
a) Calculate the rock weight for the trunk.
b) Calculate the crest height without permitting overtopping.
c) Which cross-section below is convenient for the design? Find all layer thicknesses (armor layer, filter layer and core). Write the dimensions on the appropriate breakwater section.
(Wave orthogonal is perpendicular with the bathymetry. ρ_{rock}=2.6 t/m^3 ρ_{water} =1 t/m^3, K_D=2, n_{filter}=n_{cover}=2, breakwater crest will be build up by placing 5 stones side by side, sea bottom slope is m=1/ 33)



a) Section for breaking wave **b) Section for non-breaking wave**

a) α_0=0 Kr=1

$$H_0' = H_0 = 7\,m$$

$$L_0 = 1.56 \times T^2 = 1.56 \times 10^2 = 156m$$

$$\frac{H_0'}{gT^2} = \frac{7}{9.81 \times 10^2} = 0.0071 \xrightarrow{\text{Fig. 2.43}} \frac{H_b}{H_0'} = 1.1 \rightarrow H_b = 7.7\,m$$

$$\frac{H_b}{gT^2} = \frac{7.7}{9.81 \times 10^2} = 0.0078 \xrightarrow{\text{Fig.2.44}} \frac{d_b}{H_b} = 1.18 \rightarrow d_b = 9.08\ m$$

$d_b > d_s$ breaking wave condition

d_b= 6 m $\rightarrow H_b$=?

$$\frac{d_b}{H_b}\frac{H_b}{gT^2} = \frac{6}{9.81 \times 10^2} = 0.0061 \rightarrow H_b = 5.37\,m$$

$$W = \frac{\rho_r \times H_{1/10}{}^3}{K_D \times \left(\frac{\rho_r}{\rho_w} - 1\right)^3 \times cot\beta} \qquad H_{1/10} = 1.27 \times 5.37 = 6.82m$$

$$W = \frac{2.6 \times 6.82^3}{2 \times (2.6 - 1)^3 \times 3} = 33t$$

Rock weights for the breaking wave condition

Since it is not possible to obtain the stone of the specified weight from the quarry, armour layer will be formed with the concrete block.

The slope slope with tetrapod will be taken as 1 / 1.5.

Tetrapod $\gamma_{beton} = 2.4\,t/m^3$ $K_{D,tetrapod} = 7$ $W = \dfrac{2.4 \times 5.37^3}{7(2.4-1)^3 1.5} = 12.9\,t$

Breaking wave Filter $W/10 = 12.9/10 = 1.3\,t$

Core $W/(200-4000) = 12.9/(200-4000) = (0.065-0.003)\,t$

Armour layer thickness $t_k = nK'_D(W/\rho_r)^{1/3} = 2 \times 1.1 \times (12.9/2.4)^{1/3} = 3.5m$

For Tetrapod $K'_D = 1.1$

Filter layer thickness $t_k = nK'_D(W/\rho_r)^{1/3} = 2 \times 1.1 \times (1.3/2.4)^{1/3} = 1.58m$

Crest width $b = nK'_D(W/\rho_r)^{1/3} = 5 \times 1.1 \times (12.9/2.4)^{1/3} = 8.8m$

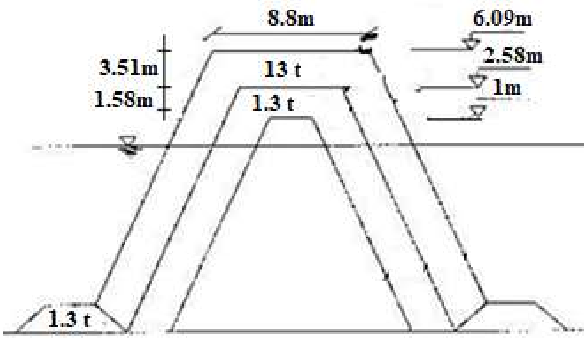
$$\frac{R_u}{H_0} = 1.016 tan\beta (H_0/L_0)^{-0.5}\gamma_r$$

$$\frac{R_u}{7} = 1.016(1/1.5)(7/156)^{-0.5} \times 0.5 \rightarrow R_u = 11.2$$

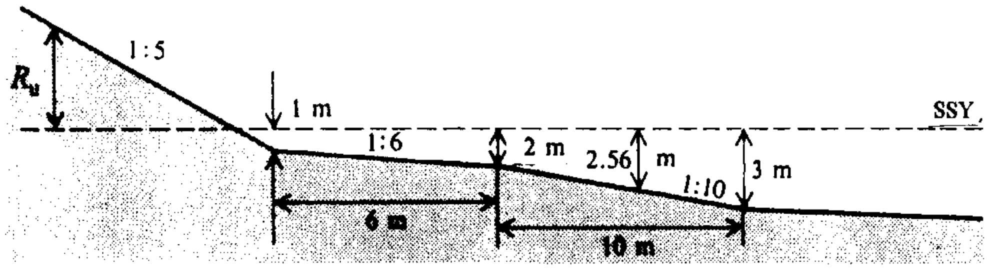
Crest height:

R_c=1+1.58+3.5=6.08 m

Ru= 11.2 m >R_c=6.08 m There will be overtopping under these circumtances



■ At a depth of 20 m, waves of height 1.9 m and period 7 s are observed to travel inshore. Estimate the run-up of the waves on the composite slope as shown in Figure.



L_0=1.56T^2=76.5m

d/L_0=20/76.5=0.26 K_{s20}=0.9356 H_{20}=H_0 Ks H_0=2 m

Breaking depth is determined using the breaking charts, d_b=3.30 m

First trial;

Assume a run-up of 2m above SWL.

from the wave breaking section to the run-up

The horizontal distance is x=10+5+6+10+3=34 m

The vertical distance is y=2+3.3=5.3 m

The average slope is $\tan\beta$=5.30/34= 0.1564.

$Ru/H_0=1.016\tan\beta(H_0/L_0)^{-0.5}$

$Ru/2=1.016x0.156x(2/76.5)^{-0.5}$

Ru=2x0.98=1.96 m $\neq$ 2 m

Second trial; Assume that Ru_1.96 m.

The horizontal distance is x=9.8+5+6+10+3=33.8 m

The vertical distance is y= 1.96+3.30=5.26 m

The average slope is $\tan\beta$=5.26/33.8=0.156

$Ru/2=1.016x0.156x(1.96/76.5)^{-0.5}$

Ru=2x0.98=1.96 m = 1.96 m

Wave run-up is 1.96 m.

- A wave with a significant period of Ts=9.4 s and a height of Hs_0=4m propagates toward the shore from deep water on parallel bottom contours where refraction coefficient is Kr=1. Sea bottom slope is s=m=1/30. Assume that T1/3=9.4 s is representative for all the individual waves in the sea state, find the percent of waves breaking with Hb≥4.7 m (i.e. breaker height is equal or bigger than 4.7 m.

$$L_0 = 1.56T^2 = 1.56 \times 9.4^2 = 137.84\,\text{m}$$

$$\frac{H_b}{gT^2} = \frac{}{9.81 \times 9.4^2} = 0.0048 \xrightarrow{\text{Fig.2.44}} \frac{H_b}{H_0'} = 1.24 \rightarrow H_0' = \frac{4.7}{1.24} = 3.79\ \text{m.} = H_0\,(K_r = 1)$$

$$Q = (H_0 \geq 3.79\,\text{m}) = \exp(-2(3.79/4)^2) = 0.166\,\text{m}$$

Statistical Design Wave Parameters

- For Rayleigh distribution

$H_{\%33} = H_{1/3} = H_s$ = the average height of the highest %33 of the waves
$H_{\%10} = 1.27H_{1/3}$ the average height of the highest %10 of the waves
$H_{\%5} = 1.37H_{1/3}$ the average height of the highest %5 of the waves
$H_{\%1} = 1.76H_{1/3}$ the average height of the highest %1 of the waves

- For Jonswap Spectrum $\gamma = 3.3$
- Peak wave period and mean wave period $T_P = 1.25T_m$
- Peak wave period and spectral wave period $T_p \cong 1.107T_{m-1,0}$
- Spectral wave period and mean wave period $T_{m-1,0} \cong 1.13T_m$
- Significant wave period and mean wave period $T_s = T_{1/3} = 1.16T_m$
- Wave steepness for swell waves $H/L \cong 0.01$
- Wave steepness for wind waves $H/L \cong 0.04$ ile 0.06
- Surf parameter

$$\xi = \frac{\tan\alpha}{[H_{1/3}/L_o]^{0.5}} = \frac{1.25\, T_{m-1,o} \tan\alpha}{(H_{1/3})^{0.5}}$$

Type of armour	No. of layers	γ_f mean
Smooth	–	1.00
Rock (two layers; permeable core)	2	0.40
Rock (two layers; impermeable core)	*2*	*0.55*
Rock (one layer; permeable core)	*1*	*0.45*
Rock (one layer; impermeable core)	*1*	*0.60*
Cube	2	0.47
Cube (single layer)	1	0.49
Antifer	2	0.50
Haro	2	0.47
Tetrapod	2	0.38
Accropode	1	0.46
Core-Loc™	1	0.44
Xbloc™	1	0.44
Dolosse	*2*	*0.43*
Berm breakwater	*2*	*0.40*
Icelandic berm breakwater	*2*	*0.35*

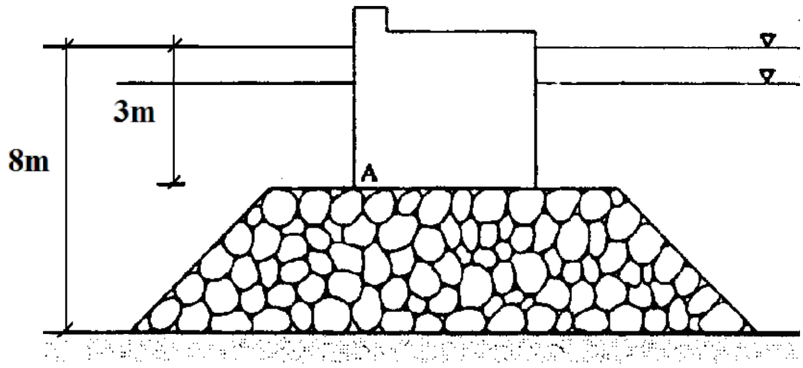
γ_r for various armour units

Armour unit	γ_r
Smooth, impervious	1.0
Concrete slabs	0.9
Concrete block	0.85–0.9
Grass on clay	0.85–0.9
One layer of quarrystone (impervious)	0.8
Rubble stone placed at random	0.5–0.8
Two or more layers of rockfill	0.5
Tetrapods	0.5

Those values may be considerably exceeded if $\tan\beta(H_0/L_0)^{-0.5} > 2$ (β = slope of cover layer).

■ A storm in deep water generates waves which travel towards the shore, impinging on a breakwater. The breakwater is a vertical wall erected on a rubble mound as shown in the figure. Design wave height and period are 1.87m and 4.7s, respectively.

The base of the vertical wall and the sea bed are respectively 3m and 8m below HWL. Find the maximum force on the vertical wall and the bending moment about A using Sainflou's method.



Deep water wave length;

$L_0=1.56T^2=1.56x4.7^2=34.5$ m

$d/L_0=8/34.5=0.23 \rightarrow L=32m$

H/d=1.87/8=0.23 NO BREAKING, there is clapotis, therefore;

Pmax on the bed is given by;

$$p_{maks} = \rho g\left[\frac{H}{\cosh(kd)} + d\right]$$

$k=2\pi/L$ $\quad\quad$ $kd=2\pi d/L=2\pi x8/32=1.57$

$$p_{maks} = 1030x9.81\left[\frac{1.87}{2.51} + 8\right] = 88.4x10^3$$ N/m²

$$h_0 = \frac{\pi H^2}{L}\cot anh(\frac{2\pi d}{L}) = \frac{\pi 1.87^2}{32}\cot anh(1.57) = 0.37m$$

Assume linear distribution;

$d+H+h_0=8+1.87+0.37=10.24$ m.

Take y positive downwards from SWL. The pressure on the base of the vertical wall, with the crest of clapotis at the wall, is;

$$p_{\max} = \rho g\frac{(z+H+h_0)}{(d+H+h_0)}\left[\frac{H}{\cosh(kd)} + d\right] = \frac{88.4x10^3}{10.24}(z+h_0+H)$$

$= 8.63x10^3(3+0.37+1.87)=8.63x10^3x5.24$ N/m²

The force on the vertical face is;

$$F_{maks} = \frac{1}{2}\rho g(d+H+h_0)\left[\frac{H}{\cosh(kd)}+d\right] = (d+H+h_0)p_{maks}/2$$

$F_{max}=8.63x10^3x5.24^2/2=118.5x10^3$ N/m^2 (per unit length of the wall)

MOMENT ABOUT A because of the linear pressure distribution,

$M_A=118.5x103x5.24/3=206.9x10^3$ Nm/m

■ A vertical breakwater with a water depth of 10 m will be constructed. The incident angle of a wave with a deep water significant wave height of 4 m and a period of 9 s is 30°. The permitted wave height at the harbour side of the breakwater is 0.75m. Calculate the safety factors of this structure, which will be constructed 15 m high and 6 m wide, against overturning and sliding. Consider the friction factor of concrete as μ = 0.8 and the specific gravity of the concrete as γ_c=24 kN/m^3.

$L_0=1.56T^2=1.56x9^2=126$ m

$d/L_0=10/126=0.0794$

$d/L=0.122$ $L=82.97$ m

$K_s=0.956$ $\sin\alpha_0/\sin\alpha=L_0/L$ $\sin 30/\sin\alpha=126/82.97$

$\sin\alpha=0.329$ $\alpha=19°$

$$K_r = \sqrt{\frac{\cos\alpha_0}{\cos\alpha}} = \sqrt{\frac{\cos 30}{\cos 19}} = 0.957$$

$H=H_0.K_r.K_s =4x0.956x0.957=3.66$ m

$d/H=10/3.66=2.73>1.2$ non-breaking wave.

Offshore side;

$$h_0 = \frac{\pi H^2}{L}\coth\left(\frac{2\pi d}{L}\right) = \frac{\pi x 3.66^2}{82.97}\coth\left(\frac{2\pi x10}{82.97}\right) = 0.79m$$

Harbor side;

$$h_0 = \frac{\pi x 0.75^2}{82.97}\coth\left(\frac{2\pi x10}{82.97}\right) = 0.03m$$

Max. pressure at the offshore side;

$$P_{max2} = \rho g\frac{H}{\cosh(kd)} = 10\frac{3.66}{1.31} = 27.9\,\text{kN/m}^2$$

Pressure at SWL For z=0 ;

$$P_{\max 1} = \rho g \frac{z + H + h_0}{d + H + h_0}\left[\frac{H}{\cosh(kd)} + d\right]$$

$$P_{maks1} = \rho g \frac{H + h_0}{d + H + h_0}\left[\frac{H}{\cosh(kd)} + d\right] = P_{maks1} = \frac{H + h_0}{d + H + h_0}\left[\rho g\left(\frac{H}{\cosh(kd)} + d\right)\right]$$

$$P_{maks1} = \frac{H + h_0}{d + H + h_0}\left[P_{mak2} + \rho g d\right]$$

$$P_{maks1} = \frac{3.66 + 0.79}{10 + 3.66 + 0.79}\left[27.9 + 10x10\right] = 39.4 \text{ kN/m}^2$$

Harbour side;;

$$P'_{maks2} = \rho g \frac{H}{\cosh(kd)} = 10x\frac{0.75}{1.31} = 5.7 \text{ kN / m}^2$$

$$P'_{maks1} = \rho g(H - h_0) = 10x(0.75 - 0.03) = 7.2 \text{ kN/m}^2$$

Forces (kN)		Moment arm (m)	Moment (kNm)	Overturning moment (kNm)
W=6x(5x24+10x14)	=1560.0	3.0	4680	
U_1=1/2x6x5.7	=17.1	2.0	34.2	
U_2=1/2x6x27.9	=83.7	4.0		334.8
$\Sigma V=W+U_1-U_2$	=1493.4			
$F_1=1/2P_{mak1}x(H+h_0)$=1/2x39.4x4.45	=87.7	11.48		1006.8
F_2=10x27.9	=279.0	5.0		1385.0
F_3=1/2x(39.4-27.9)x10	=57.5	6.67		383.5
F_4=1/2x(0.75x7.2)	=2.6	9.52		24.8
$F_5=P'_{mak2}(10-(H-h_0))$=5.7x9.28	=52.9	4.64		245.5
F_6=1/2x(7.2-5.7)x9.28	=7.5	6.16		46.2
ΣH	=487.2		4714.2	3426.6

$$Fs_{deviren} = \frac{\Sigma M_{direnç}}{\Sigma M_{deviren}} = \frac{4714.2}{3426.6} = 1.37 \qquad Fs_{kayma} = \frac{\mu \Sigma V}{\Sigma H} = \frac{0.8x(1493.4)}{487.2} = 2.45$$

Resultant force; R,

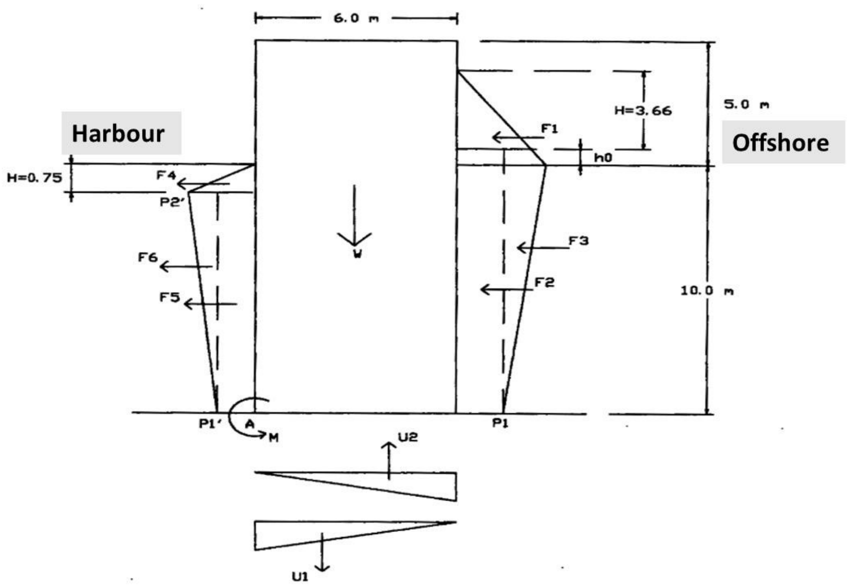
R=$(1493.4^2+487.2^2)$=1571 kN

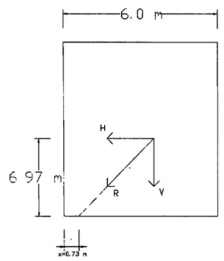
$\Sigma M_{overturning} = \Sigma H.y$

3426.6=487.2y y=7.03m

1493.4(6/2-x)-487.2(7.03)=0

x=0.73 m



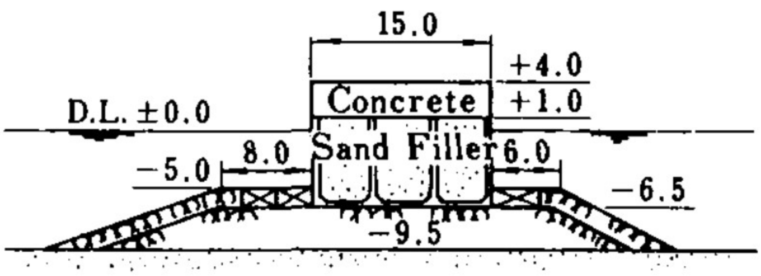


■ Calculate the wave pressure, uplift pressure, and their moments produced by waves of the following characteristics incident on the upright section of the vertical breakwater shown in the figure (Goda, 2000)

Waves : $H'_0 = 6.3\text{m}$, $T_{1/3}$=11.4 s, β=15°

Tide level : 0.6 m

Sea bottom slope : $\tan\theta$ = 1/100



Cross-section of a vertical breakwater (units in meters)

1) Water depth and crest elevation

h=10.1 m

$h' = 7.1\text{m}$

d=5.6 m

h_c=3.4 m

2) Wave length and wave height

$L_0=1.56T^2=1.56\times 11.42=202.7$ m

$$\frac{H'_0}{L_0}=0.031 \quad \frac{h}{L_0}=0.05$$

Significant wave height infront of the structure

$H_{1/3}$=5.8 m (water depth: h=10.1 m)

The design wave height :

$h_b=10.1+5\times 5.8\times(1/100)=10.4$ m

H_{maks}=8.0 m

3) Coefficients for the wave pressure

$$\alpha_1=0.6+\frac{1}{2}\left[\frac{4\pi h/L}{\sinh(4\pi h/L)}\right]^2=0.92$$

$$\alpha_2=\min\left\{\frac{h_b-d}{3h_b}\left(\frac{H_{mak}}{d}\right)^2,\frac{2d}{H_{mak}}\right\}=\min\left\{\frac{10.4-5.6}{3\times 10.4}\left(\frac{8.0}{5.6}\right)^2,\frac{2\times 5.6}{8.0}\right\}=\min\{0.314,1.40\}=0.314$$

$$\alpha_3=1-\frac{h'}{h}\left[1-\frac{1}{\cosh(2\pi h/L)}\right]=1-\frac{7.1}{10.1}(1-0.847)=0.892$$

4) Maximum elevation of the wave pressure

$$\cos\beta=0.966$$

$$\eta^*=0.75(1+\cos\beta)H_{maks}$$

$$\eta^*=0.75(1+0.966)\times 8.0=11.8\text{m}$$

5) Pressure components

$$p_1=\frac{1}{2}(1+\cos\beta)(\alpha_1+\alpha_2\cos^2\beta)\rho g H_{mak}=\frac{1}{2}(1+0.966)(0.920+0.314\times 0.966^2)\times 1030\times 9.8\times 8.0$$

p_1=96.3 kPa

$p_3=\alpha_3 p_1=0.892\text{x}96.3=85.9$kPa

$$\eta^*>h_c\Rightarrow p_1(1-h_c/\eta^*)$$
$$\eta^*\le h_c\Rightarrow 0$$

$$p_4=96.3\left(1-\frac{3.4}{11.8}\right)=68.6\text{kPa}$$

6) Total pressure and uplift

$$p_u = \frac{1}{2}(1+\cos\beta)\alpha_1\alpha_3\rho g H_{maks} = 0.983\times 0.920\times 0.892\times 1030\times 9.8\times 8.0 = 65.1\text{kPa}$$

$$h_c^* = \min(\eta^*, h_c) = \min(11.8, 3.4) = 3.4$$

$$P = \frac{1}{2}(p_1+p_3)h' + \frac{1}{2}(p_1+p_4)h_c^* = \frac{1}{2}(96.3+85.9)\times 7.1 + \frac{1}{2}(96.3+68.6)\times 3.4 = 927\text{kN}/\text{m}$$

$$U = \frac{1}{2}p_u B = \frac{1}{2}\times 65.1\times 15.0 = 488\text{kN}/\text{m}$$

7) Moment of wave pressure

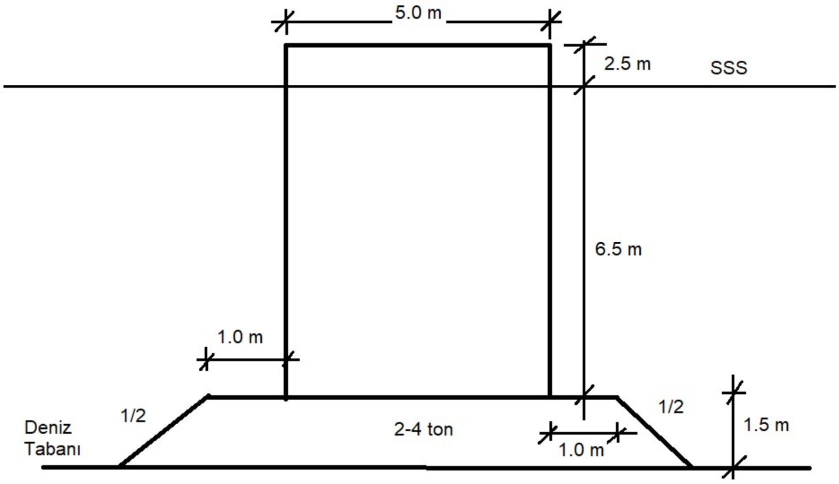
$$M_p = \frac{1}{6}(2p_1+p_3)h'^2 + \frac{1}{2}(p_1+p_4)h'h_c^* + \frac{1}{6}(p_1+2p_u)h_c^{*2}$$

$$M_p = \frac{1}{6}(2\times 96.3+85.9)\times 7.1^2 + \frac{1}{2}(96.3+68.6)\times 71\times 3.4 + \frac{1}{6}(96.3+2\times 68.6)\times 3.4^2$$

M_p = 4780 kNm/m

8) Moment of uplift pressure $$M_u = \frac{2}{3}UB = \frac{2}{3}\times 488\times 15.0 = 4880\text{kNm}/\text{m}$$

- Calculate the stability of the caisson structure to be built in the project area where the specific gravity of the sea water is 10.20 kN/m^3. The deep water significant wave height and significant wave period are H_{s0}=4.0m and T_s=8.0s., respectively. Bottom slope will be considered as 1/30. Friction factor between caisson concrete structure and rubble mound foundation is $\mu = 0.5$. Safety factor against sliding will be considered as 1.1 whereas safety factor against overturning as 1.2.



Water depth at the toe of the structure d=8m

$$L_0 = 1.56T^2 = 1.56\times 8^2 = 100\ \text{m.}$$

$$\frac{h}{L_0} = \frac{8}{100} = 0.08 < 0.2$$

$$H_s = \min\left\{(\beta_0 H_0' + \beta_1 h), \beta_{maks} H_0',\ K_s H_0'\right\}$$

$$H'_0 = H_0 K_r K_d = H_0 H_{s0} = 4\text{m}$$

K_s=0.9548 (GWT)

$$\beta_0 = 0.028\left(\frac{H'_0}{L_0}\right)^{-0.38} \exp\left[20\tan^{1.5}(\theta)\right] = 0.028(0.04)^{-0.38}\exp\left[20\left(1/30\right)^{1.5}\right] = 0.1705$$

$$\beta_1 = 0.52\exp\left[4.2\tan(\theta)\right] = 0.5981$$

$$\beta_{\text{maks}} = \text{maks}\left\{0.92, 0.32\left(\frac{H'_0}{L_0}\right)^{-0.29} \exp\left[2.4\tan(\theta)\right]\right\}$$

$$\beta_{\text{maks}} = \text{maks}\left\{0.92, 0.32\left(0.04\right)^{-0.29} \exp\left[\frac{2.4}{30}\right]\right\} = \text{maks}\left\{0.92, 0.8816\right\} = 0.92$$

$$H_s = \min\left\{\left(\beta_0 H'_0 + \beta_1 h\right), \beta_{\text{maks}} H'_0,\ K_s H'_0\right\} = \min\left\{\left(0.1075\times 4 + 0.5981\times 8\right), (0.92\times 4),\ 0.9548\times 4\right\}$$
$$H_s = \min\left\{\left(5.2148\right), (3.68),\ (3.82)\right\} = 3.68\,\text{m}$$

h_b=Water depth at a distance of $5H_s$ seaward of the toe of the structure

$$h_b = h + 5H_s m = 8 + 5\times 3.68\times(1/30) = 8.61\text{m}$$

H_{max} = Design wave height ($\approx 1.8H_s$)

$$\frac{h_b}{L_0} = \frac{8.61}{100} = 0.0861 < 0.2$$

$$H_{\text{maks}} = \min\left\{\left(\beta_0^* H'_0 + \beta_1^* h_b\right), \beta_{\text{maks}}^* H'_0,\ 1.8K_s H'_0\right\}$$

$$H'_0 = H_0 K_r K_d = H_0 H_{s0} = 4\text{m}$$

$$\beta_0^* = 0.052\left(\frac{H'_0}{L_0}\right)^{-0.38} \exp\left[20\tan^{1.5}(\theta)\right] = 0.1994$$

$$\beta_1^* = 0.63\exp\left[3.8\tan(\theta)\right] = 0.7151$$

$$\beta_{\text{maks}}^* = \text{maks}\left\{1.65,\ 0.53\left(\frac{H'_0}{L_0}\right)^{-0.29} \exp\left[2.4\tan(\theta)\right]\right\} = 1.65$$

$$H_{\text{maks}} = \min\left\{\left(\beta_0^* H'_0 + \beta_1^* h_b\right), \beta_{\text{maks}}^* H'_0,\ 1.8K_s H'_0\right\} = 6.6\text{m}$$

$$\eta^* = 0.75\left[1 + \lambda_1\cos\beta\right]H_{\text{maks}}$$

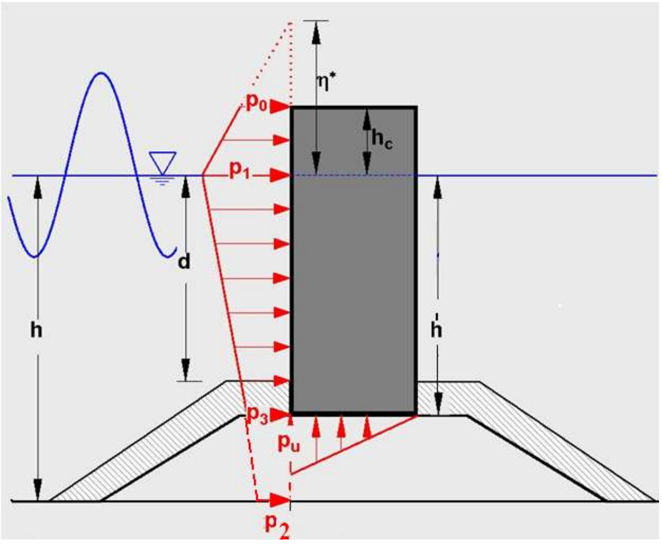
λ_1=Configuration factor (=1)

β=Wave approaching angle (usually taken as 15°, but to be on the safe side it is considered as 0)

$$\eta^* = 0.75\left[1+(1)\cos(0)\right]6.6 = 9.9\text{m}$$

Wave pressure on the front of the structure

$$\frac{h}{L_0} = \frac{8}{100} = 0.08 \rightarrow \text{ADKT}\ \frac{h}{L} = 0.1232 \rightarrow L = 64.9\text{m}$$



$$\alpha_1 = 0.6 + \frac{1}{2}\left[\frac{4\pi\frac{h}{L}}{\sinh\left(4\pi\frac{h}{L}\right)}\right]^2 = 0.6 + \frac{1}{2}\left[\frac{4\pi\frac{8}{64.9}}{\sinh\left(4\pi\frac{8}{64.9}\right)}\right]^2 = 0.8374$$

$$\alpha_2 = \min\left\{\frac{h_b - d}{3h_b}\left(\frac{H_{maks}}{d}\right)^2, \frac{2d}{H_{maks}}\right\}$$

$$\alpha_2 = \min\left\{\frac{8.61-6.5}{3\times 8.61}\left(\frac{6.6}{6.5}\right)^2, \frac{2\times 6.5}{6.6}\right\} = \{0.0843,\ \ 1.9697\} = 0.0843$$

$$\alpha_3 = 1 - \frac{h'}{h}\left[1 - \frac{1}{\cosh\left(2\pi\frac{h}{L}\right)}\right]^2 = 1 - \frac{6.5}{8}\left[1 - \frac{1}{\cosh\left(2\pi\frac{8}{64.9}\right)}\right]^2 = 0.8051$$

$$p_1 = \frac{1}{2}(1+\cos\beta)\left(\alpha_1\lambda_1 + \alpha_2\lambda_2\cos^2\beta\right)\rho g H_{maks}$$

λ_2 =Correction factor depends on the structure type (=1)

$$p_1 = \frac{1}{2}(1+\cos 0)\left(0.8374\times 1 + 0.0843\times 1\times\cos^2 0\right)10\times 6.6 = 60.8\,\text{kN/m}^2$$

$$p_2 = \frac{p_1}{\cosh\left(2\pi\frac{h}{L}\right)} = \frac{60.8}{\cosh\left(2\pi\frac{8}{64.9}\right)} = 46.2\,kN/m^2$$

$$p_3 = \alpha_3 p_1 = 0.8051 \times 60.8 = 49\,kN/m^2$$

Uplift pressure

$$p_u = \frac{1}{2}(1+\cos\beta)\alpha_1\alpha_3\lambda_3\rho g H_{maks}$$

λ_3 =Yapı tipine bağlı düzeltme faktörü (=1)

$$p_u = \frac{1}{2}(1+1)(0.8374 \times 0.8051 \times 1)10 \times 6.6 = 44.5\,kN/m^2$$

Check factors of safety

Total wave pressure force

$$p = \frac{1}{2}(p_1 + p_3)h' + \frac{1}{2}(p_1 + p_4)h_c^*$$

$$h_c^* = \min\left(h_c,\ \eta^*\right) = 2.5\,m$$

$$p_4 = \left\{\begin{matrix} p_1\left(1-\frac{h_c}{\eta^*}\right); & \eta^* > h_c \\ 0 \quad ; & \eta^* \le h_c \end{matrix}\right\} \rightarrow p_4 = 60.8\left(1-\frac{2.5}{9.9}\right) = 45.5\,kN/m^2$$

$$p = \frac{1}{2}(60.8+49)6.5 + \frac{1}{2}(60.8+45.5)2.5 = 489.8\ kN/m$$

Total moment due to wave pressure force

$$M_p = \frac{1}{6}(2p_1 + p_3)(h')^2 + \frac{1}{2}(p_1 + p_4)h'h_c^* + \frac{1}{6}(p_1 + 2p_4)(h_c^*)^2$$

$$M_p = \frac{1}{6}(2\times 60.8 + 49)(6.5)^2 + \frac{1}{2}(60.8 + 45.5)6.5 \times 2.5 + \frac{1}{6}(60.8 + 2\times 45.5)(2.5)^2$$

$$M_p = 2223.5\,kN/m$$

Total uplift pressure force

$$U = \frac{1}{2}p_u B = 0.5 \times 44.5 \times 5 = 111.3\ kN/m$$

Total moment due to uplift force

$$M_u = \frac{2}{3} UB = \frac{2}{3} \times 111.3 \times 5 = 370.8\,kN/m$$

Factor of safety against sliding

$$F.S. = \frac{\left(M_g - U\right)\mu}{p}$$

$$M_g = \gamma_c B\left(h' + h_c\right) - \gamma_w Bh' = 755\,kN/m$$

$\gamma_w Bh'$ is buoyancy force

$$F.S. = \frac{\left(755 - 111.3\right)0.5}{489.8} = 0.657 < 1.1$$ Not safe

Factor of safety against overturning

$$F.S. = \frac{\left(M_g t - M_u\right)}{M_p}, \qquad t = B/2$$

$$F.S. = \frac{\left(755 \times (5/2) - 370.8\right)}{2223.5} = 0.682 < 1.2$$ Not safe