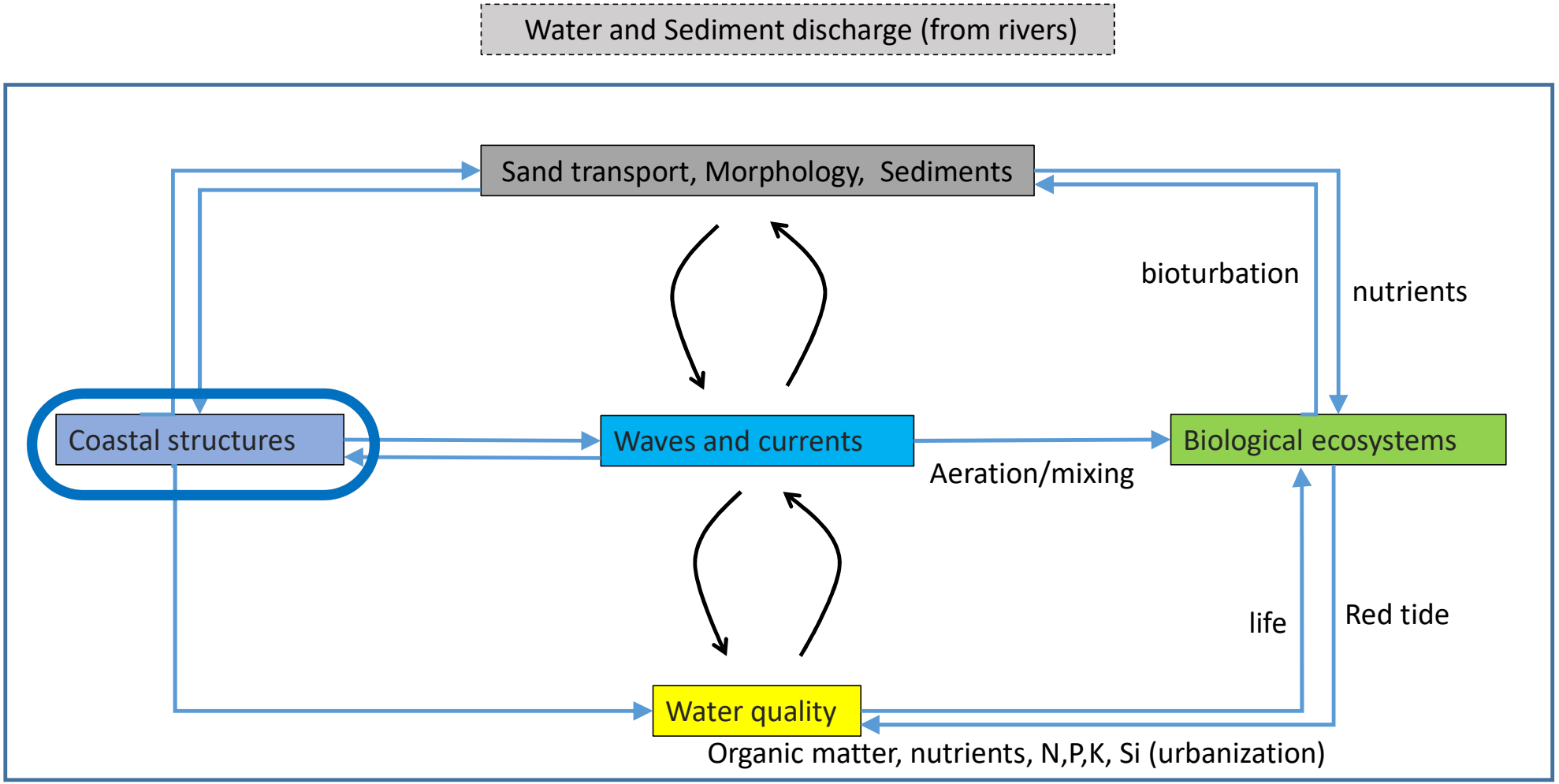
EWC 471: Basic Coastal Engineering

Lecture 13 and 14

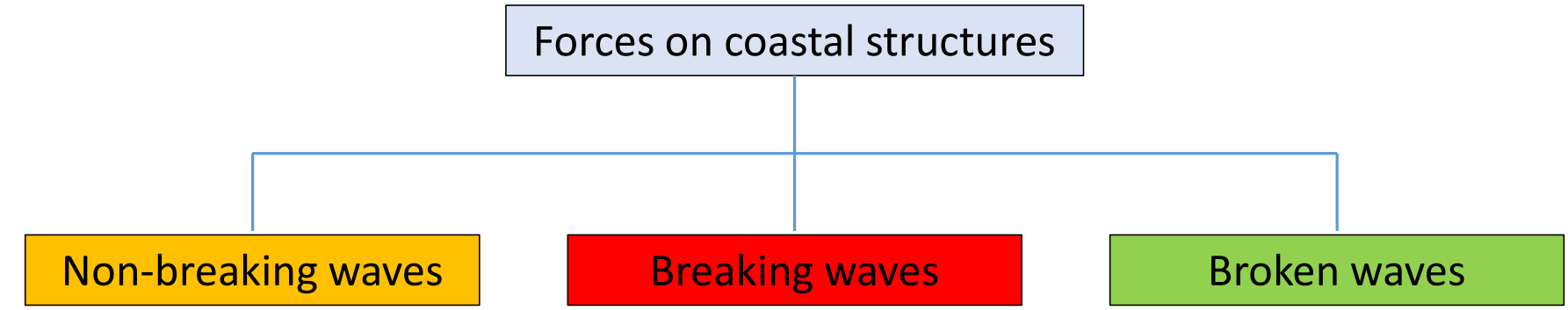
Topic: Wave Forces on Coastal Structures

Putting things in context



Wave forces on coastal structures

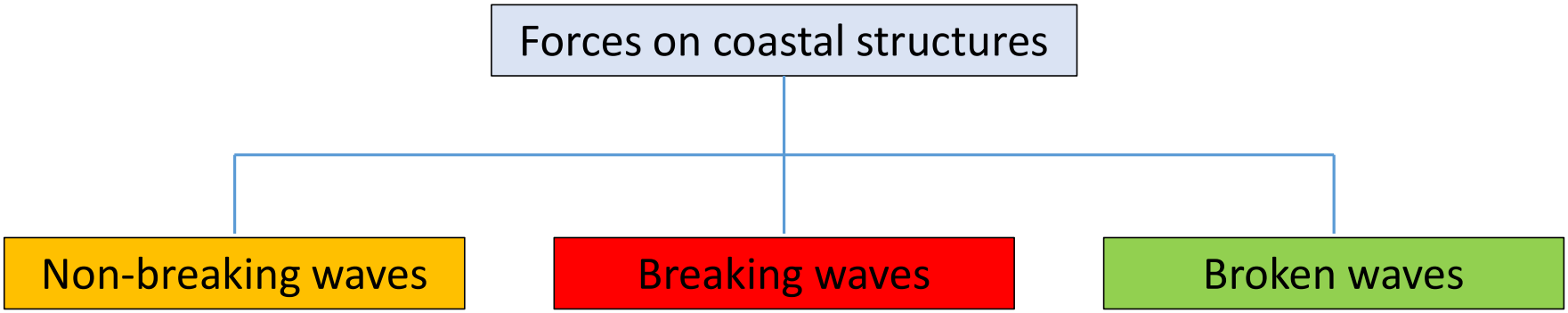
- In an analysis of wave forces on structures, a distinction is made between the action of nonbreaking, breaking, and broken waves.







Wave forces on coastal structures



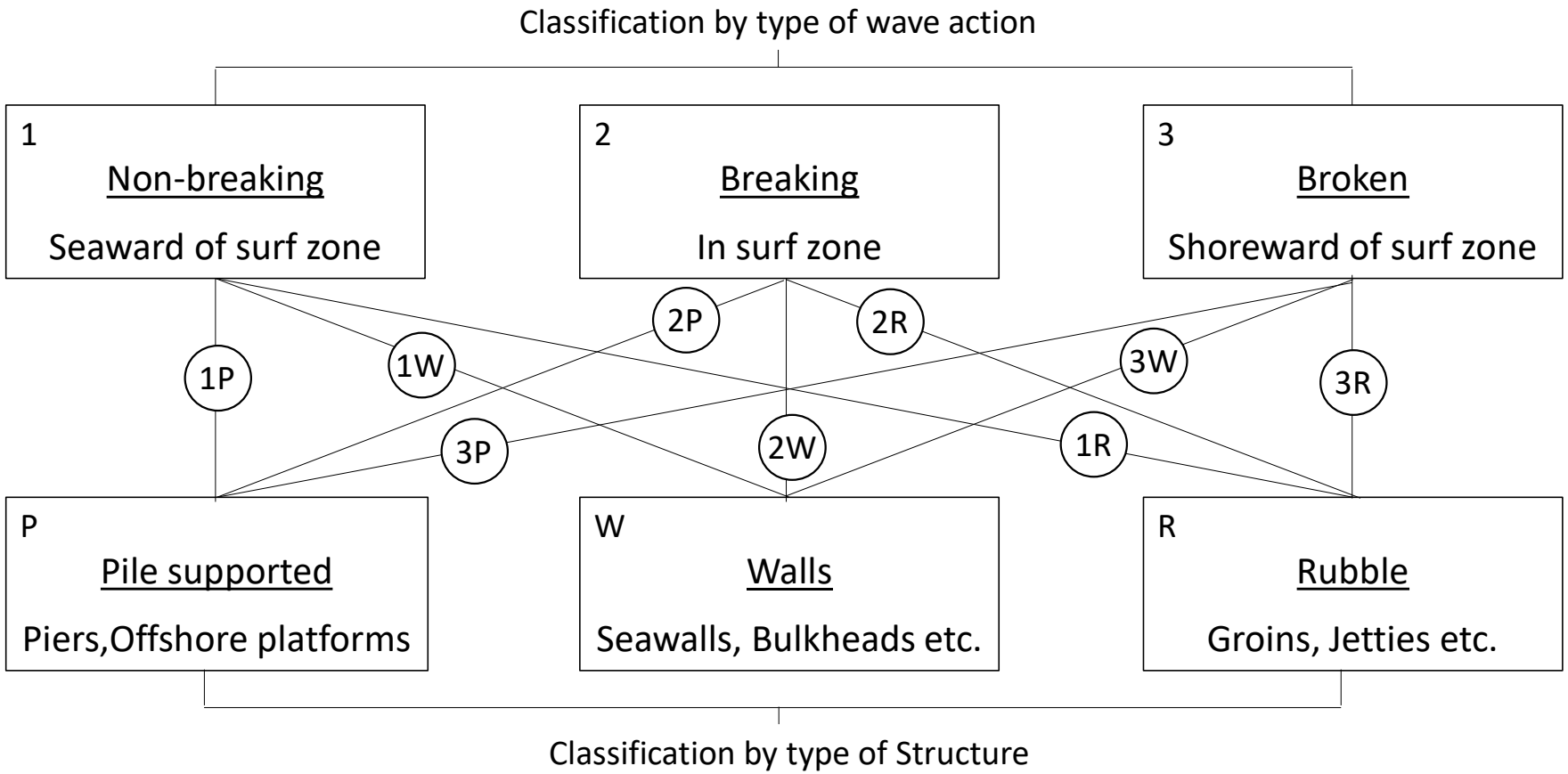
- Forces due to nonbreaking waves are primarily hydrostatic. Breaking and broken waves exert an additional force due to the dynamic effects of turbulent water and the compression of entrapped air pockets. Dynamic forces may be much greater than hydrostatic forces; therefore, structures located where waves break are designed for greater forces than those exposed only to nonbreaking waves.

Wave forces on coastal structures

Even if we stand in the location where the waves break, we feel stronger force by the waves compared to the location away from it, especially in the seaward direction.



Classification of wave force problems by type of wave action and by type of structures

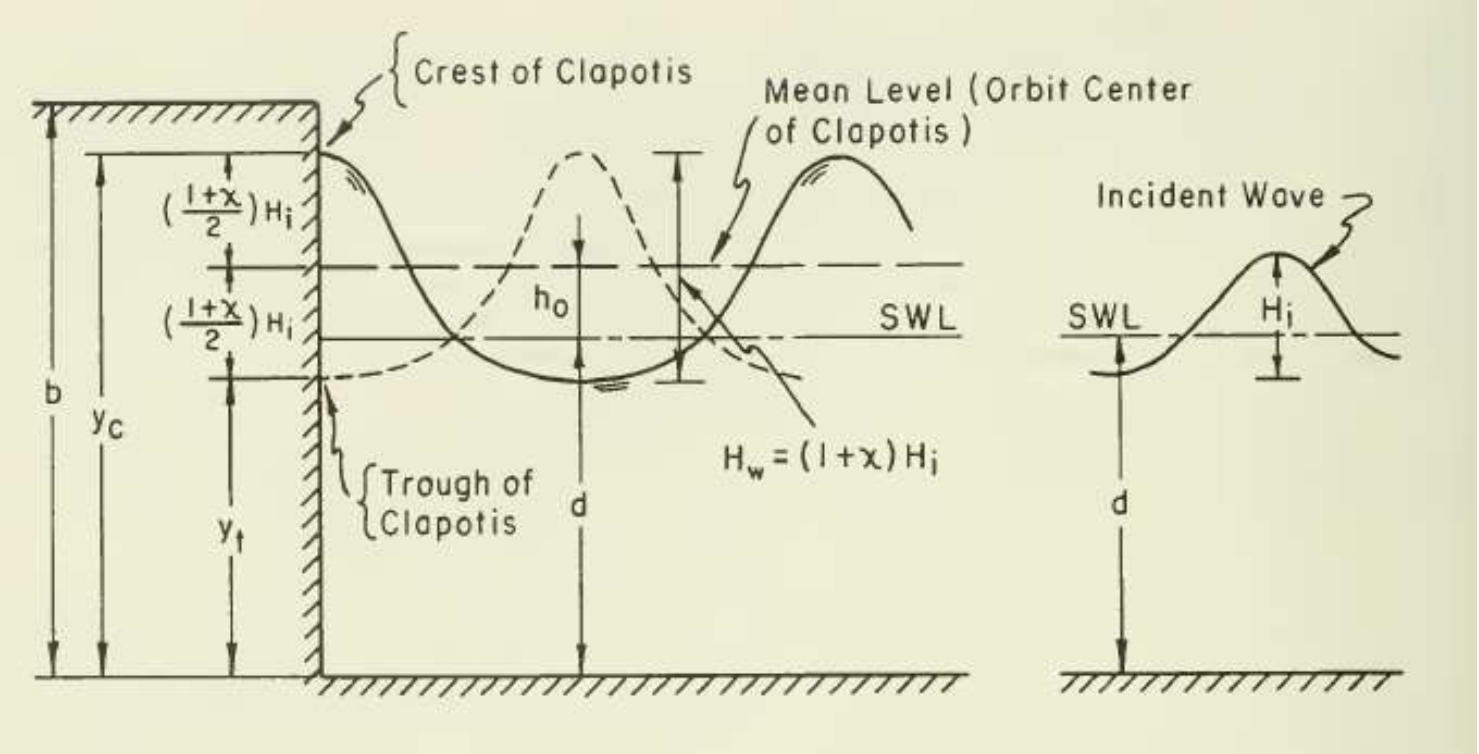


Non-breaking wave forces on coastal structures

- Typically, shore protection structures are located in depths where waves will break against them. However, in protected regions, or where the fetch is limited, and when depth at the structure is greater than about 1.5 times the maximum expected wave height, nonbreaking waves may occur.
- Scenarios for non-breaking wave forces could be:
  - ❑Non-overtopping vertical wall
  - ❑Overtopping vertical wall
  - ❑Vertical wall with rubble foundation
  - ❑Non-overtopping vertical wall with the same water depth on both sides of the structure
  - ❑Non-overtopping vertical wall with the unequal water depth between both sides of the structure

***Note: Fetch**, area of ocean or lake surface over which the wind blows in an essentially constant direction, thus generating **waves**.*

Non-breaking wave forces on coastal structures



d=depth from still water level

Hi=height of original free wave

X=wave reflection coefficient

h_0=height of clapotis orbit center (mean water level at wall) above the still water level

y_c=depth from clapotis crest = $d+h_0+\{(1+x)/2\}*hi$

y_t=depth from clapotis trough = $d+h_0-\{(1+x)/2\}*hi$

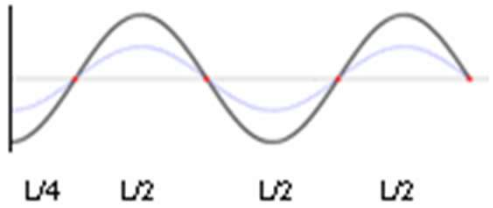
b=height of wall

* The **clapotis** is a non-breaking standing wave pattern, caused by the reflection of a traveling surface wave train from a near vertical shoreline like a breakwater, seawall or steep cliff.

Non-breaking wave forces on coastal structures

- ‘Miche-Rundgren method’ can be followed for calculating Nonbreaking Wave Forces. Wave conditions at a structure and seaward of a structure (when no reflected waves are shown) are depicted in the Figure next slide. The wave height that would exist at the location of the structure if the structure were not present is the incident wave height Hi. The wave height that actually exists at the structure is the sum of Hi and the height of the wave reflected by the structure Hr. The wave reflection coefficient X equals Hr /Hi. Wave height at the wall Hw is given as:

$$Hw = Hi + Hr = (1+x)Hi$$



Non-breaking wave forces on coastal structures

- If reflection is complete and the reflected wave has the same amplitude as the incident wave, then X = I and the height of the clapotis or standing wave at the structure will be 2Hi. The height of the clapotis crest above the bottom is given by:

$$y_c = d + h_0 + \{(1+x)/2\}*hi$$

where h_0 is the height of the clapotis orbit center above SWL. The height of the clapotis trough above the bottom is given by:

$$y_t = d + h_0 - \{(1+x)/2\}*hi$$

Non-breaking wave forces on coastal structures

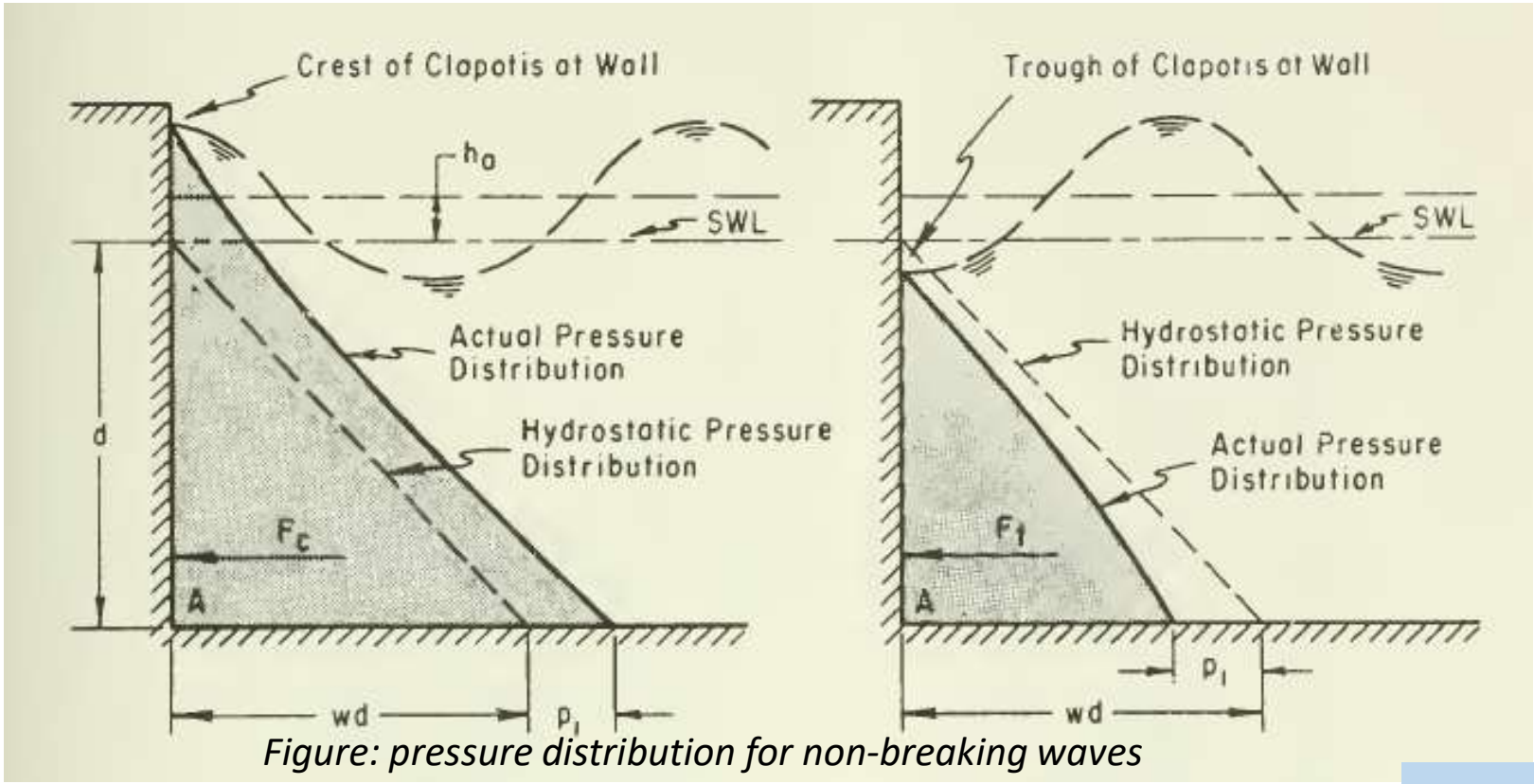


Figure: pressure distribution for non-breaking waves

$$P = \frac{1+X}{2}\frac{wH_i}{\cosh\left(\frac{2\pi d}{L}\right)}$$

Dynamic pressure P1 may be approximated as:

$$P_1 = \frac{1+X}{2}\frac{wH_i}{\cosh\left(\frac{2\pi d}{L}\right)}$$

Non-breaking wave forces on coastal structures

This nomogram is used to obtain h_0/H_i from H_i/d and H_i/gT^2

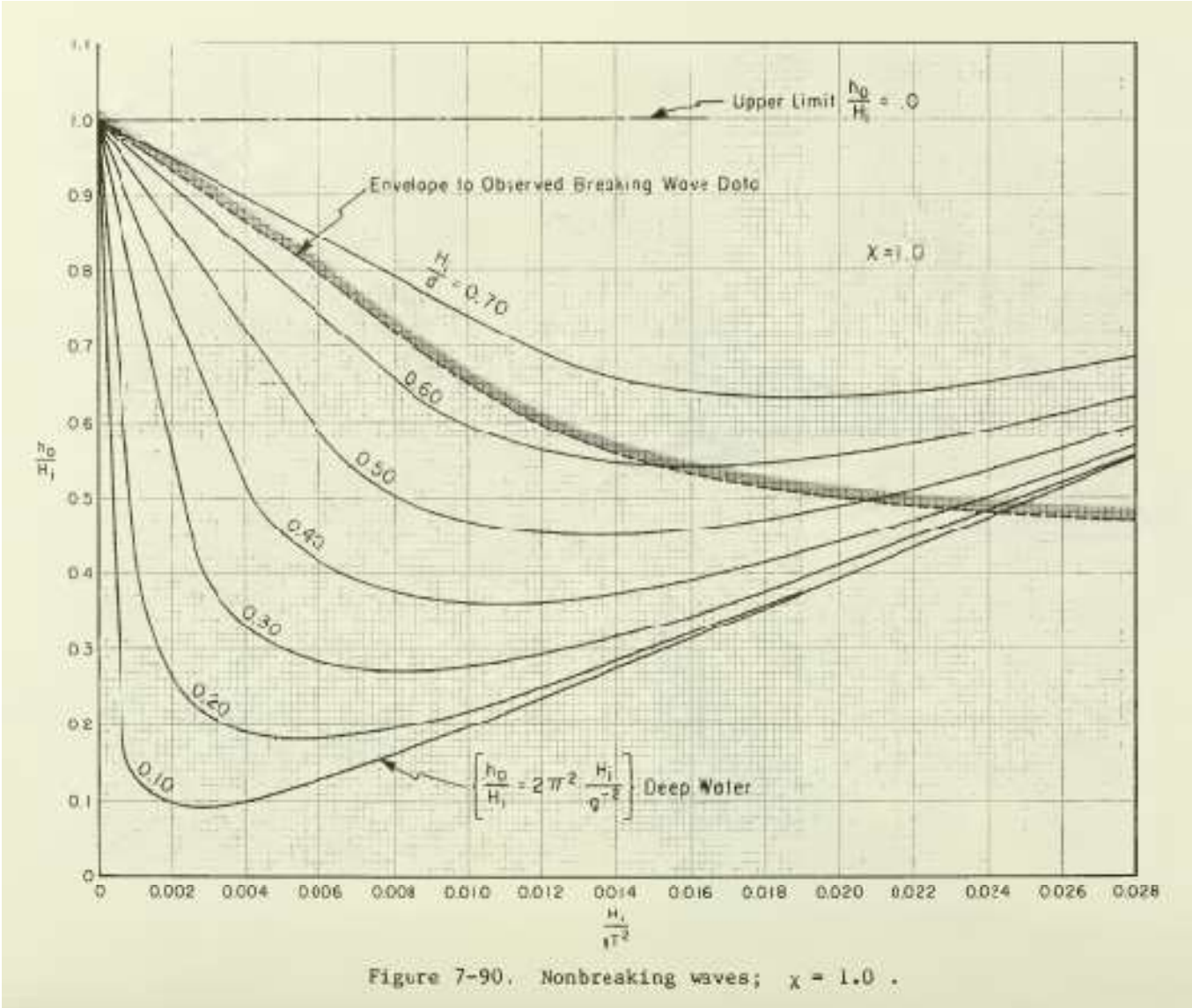


Figure 7-90. Nonbreaking waves; $\chi = 1.0$.

Non-breaking wave forces on coastal structures

When it is necessary to include the hydrostatic effects (e.g., seawalls), the total force is found by:

$F_{total} = wd^2/2 + F_{wave}$

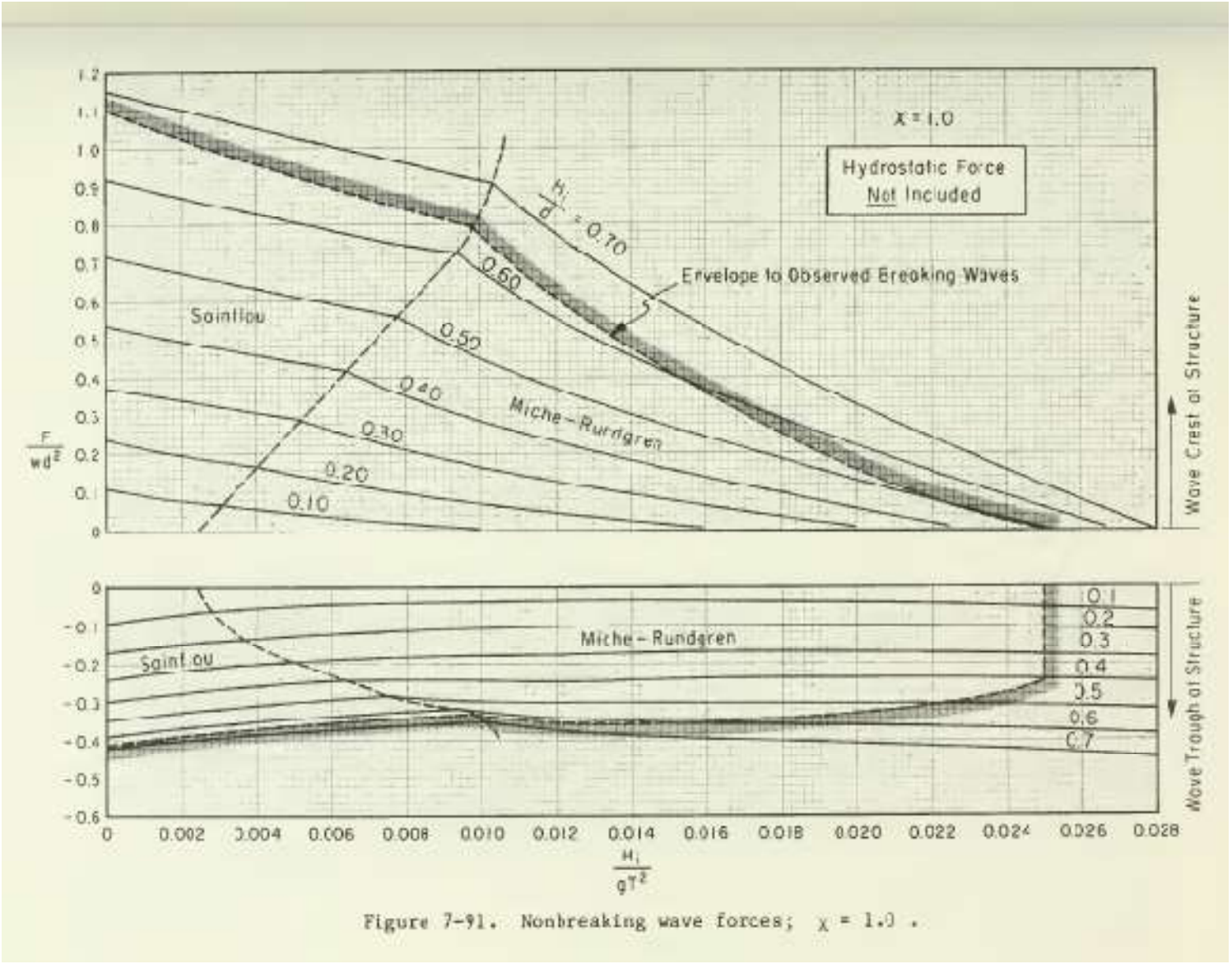


Figure 7-91. Nonbreaking wave forces; χ = 1.0 .

Non-breaking wave forces on coastal structures

When it is necessary to include the hydrostatic effects (e.g., seawalls), the total moment is found by:

$M_{total} = wd^3/6 + M_{wave}$

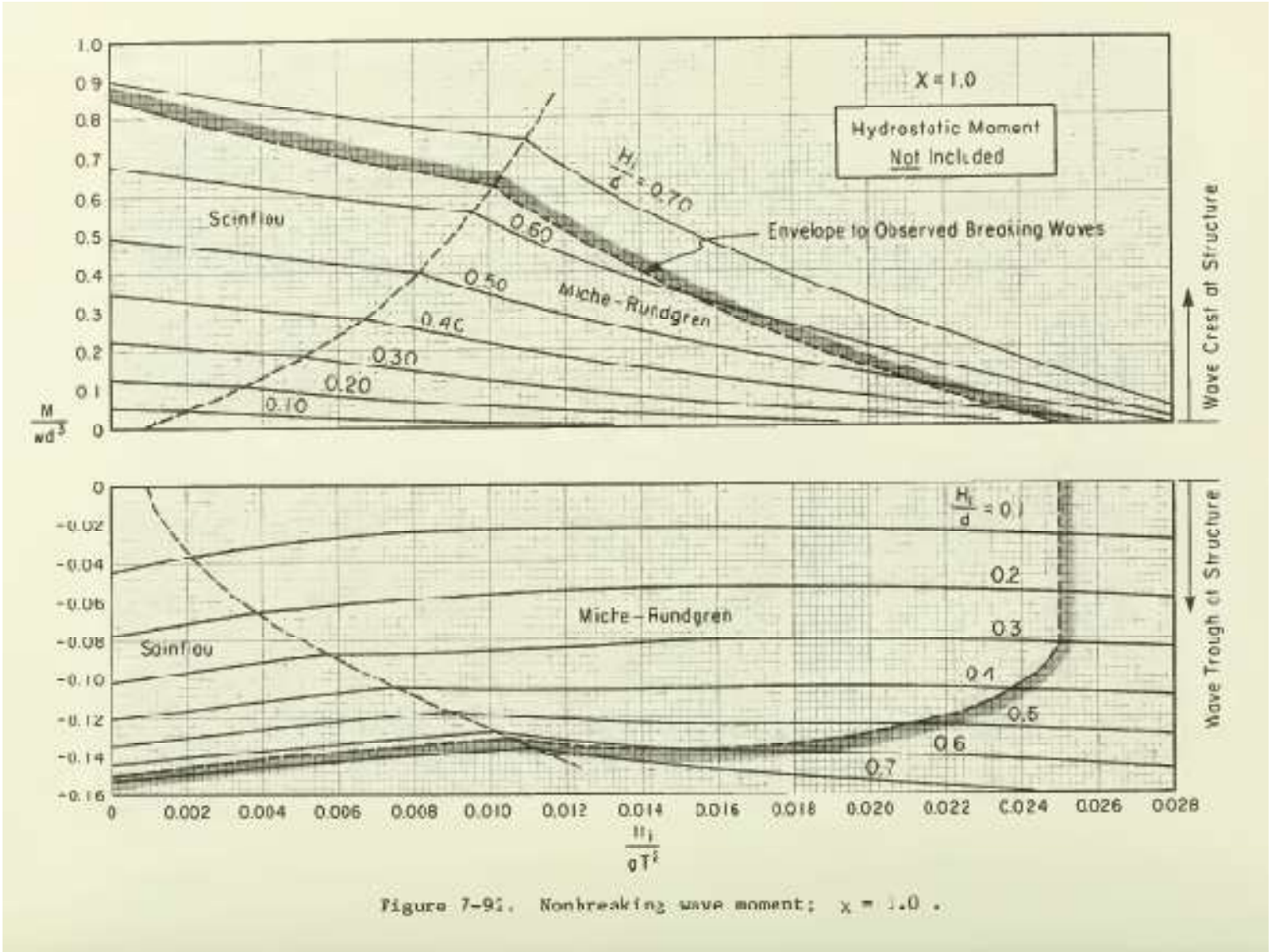


Figure 7-9. Nonbreaking wave moment; X = 1.0 .

Non-breaking wave forces on coastal structures

Example 1: Given data:

Incident wave height, Hi = 2m; d = 4m, T = 8 s (case 1) and 12 s (case 2)

Reflection coefficient, Kr = 1

Calculate Fc, Ft, Fc total, Ft total

Mc, Mt, Mc total, Mt total

for both the time periods and determine the critical condition.

Solution: $Hi/d = 0.5$

and $Hi/gT^2 = 0.0032$ (for T = 8 sec)

$= 0.0014$ (for T = 12 sec)

Non-breaking wave forces on coastal structures

This nomogram is used to obtain h_0/H_i from H_i/d and H_i/gT^2

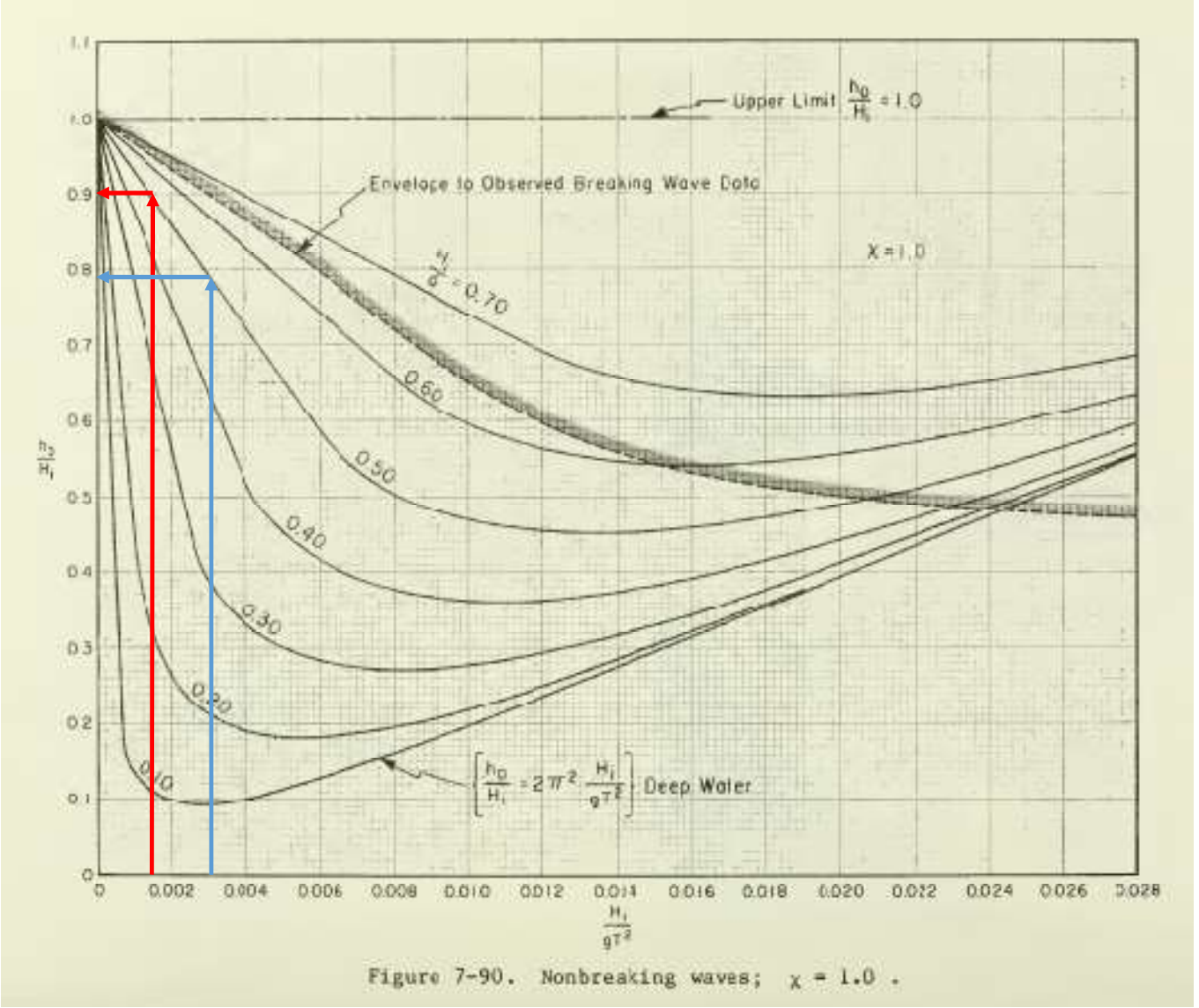


Figure 7-90. Nonbreaking waves; $\chi = 1.0$.

Non-breaking wave forces on coastal structures

From nomogram (Figure 7.90) $H_0/Hi = 0.79$ (for T = 8 sec); $H_0 = 1.58$

$= 0.90$ (for T = 12 sec); $H_0 = 1.8$

$y_c = d+H_0+(1+Kr)*Hi/2 = 4+1.58+(1+1)*2/2 = 7.58m$ (for T = 8 sec)

$= 7.8m$ (for T = 12 sec)

$y_t = d+H_0-(1+Kr)*Hi/2 = 4+1.58-(1+1)*2/2 = 3.58m$ (for T = 8 sec)

$= 3.8m$ (for T = 12 sec)

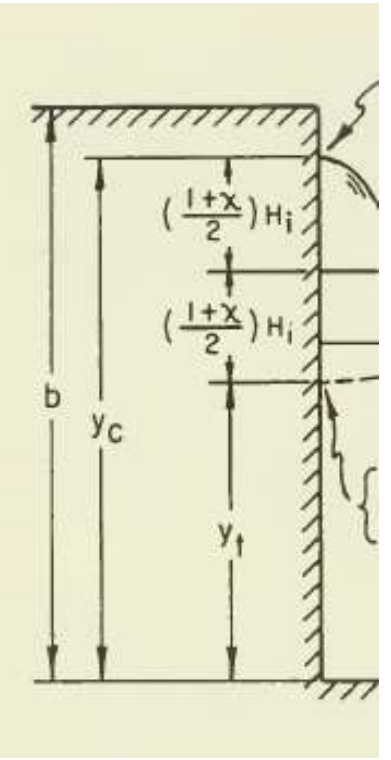
Force on structure:

From nomogram (Figure 7.91) $F_c/wd^2 = 0.65$ (for T = 8 sec);

$= 0.68$ (for T = 12 sec);

From nomogram (Figure 7.91) $F_t/wd^2 = -0.30$ (for T = 8 sec);

$=- 0.33$ (for T = 12 sec)



Non-breaking wave forces on coastal structures

When it is necessary to include the hydrostatic effects (e.g., seawalls), the total force is found by:

$F_{total} = wd^2/2 + F_{wave}$

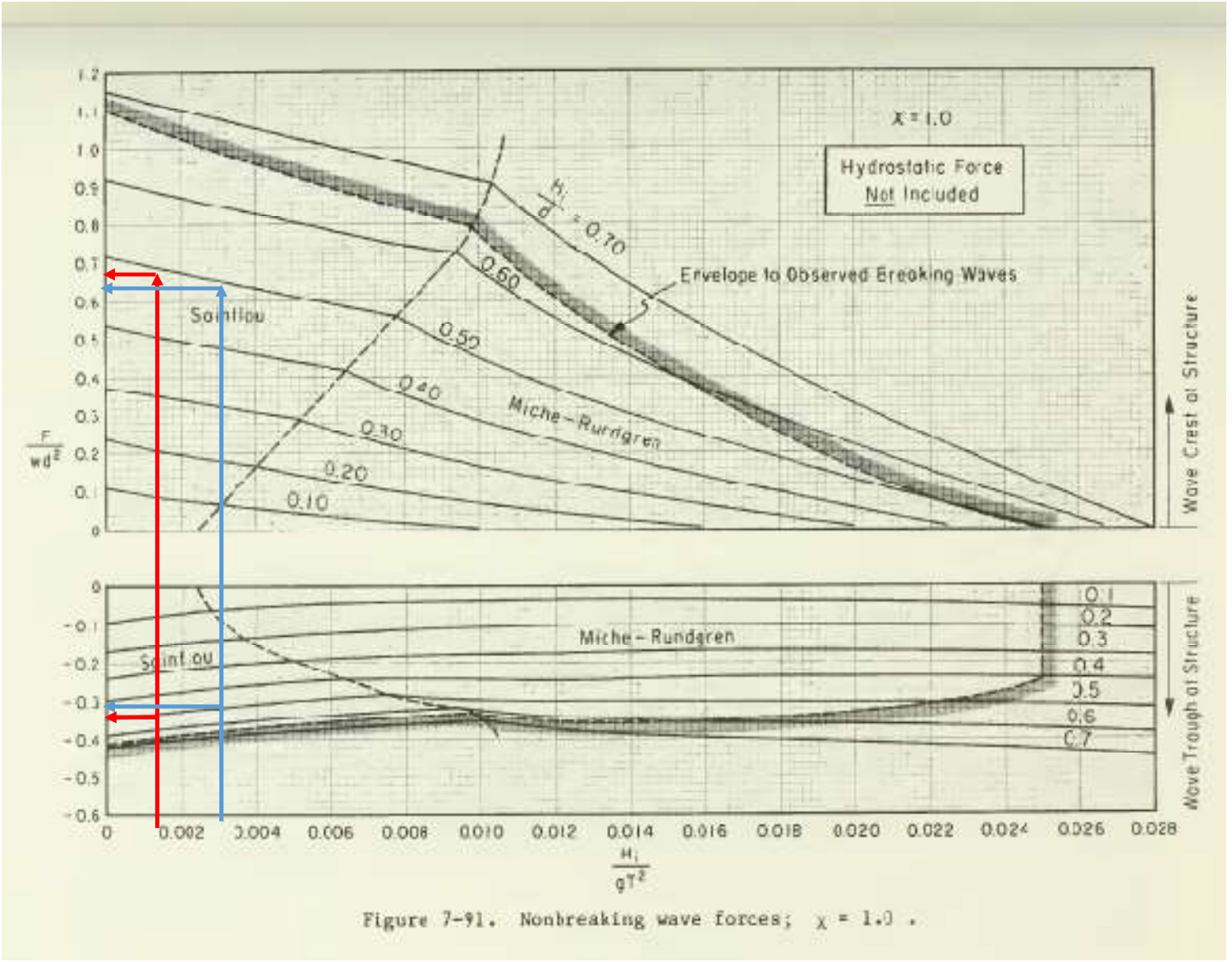


Figure 7-91. Nonbreaking wave forces; χ = 1.0 .

Non-breaking wave forces on coastal structures

When it is necessary to include the hydrostatic effects (e.g., seawalls), the total moment is found by:

$M_{total} = wd^3/6 + M_{wave}$

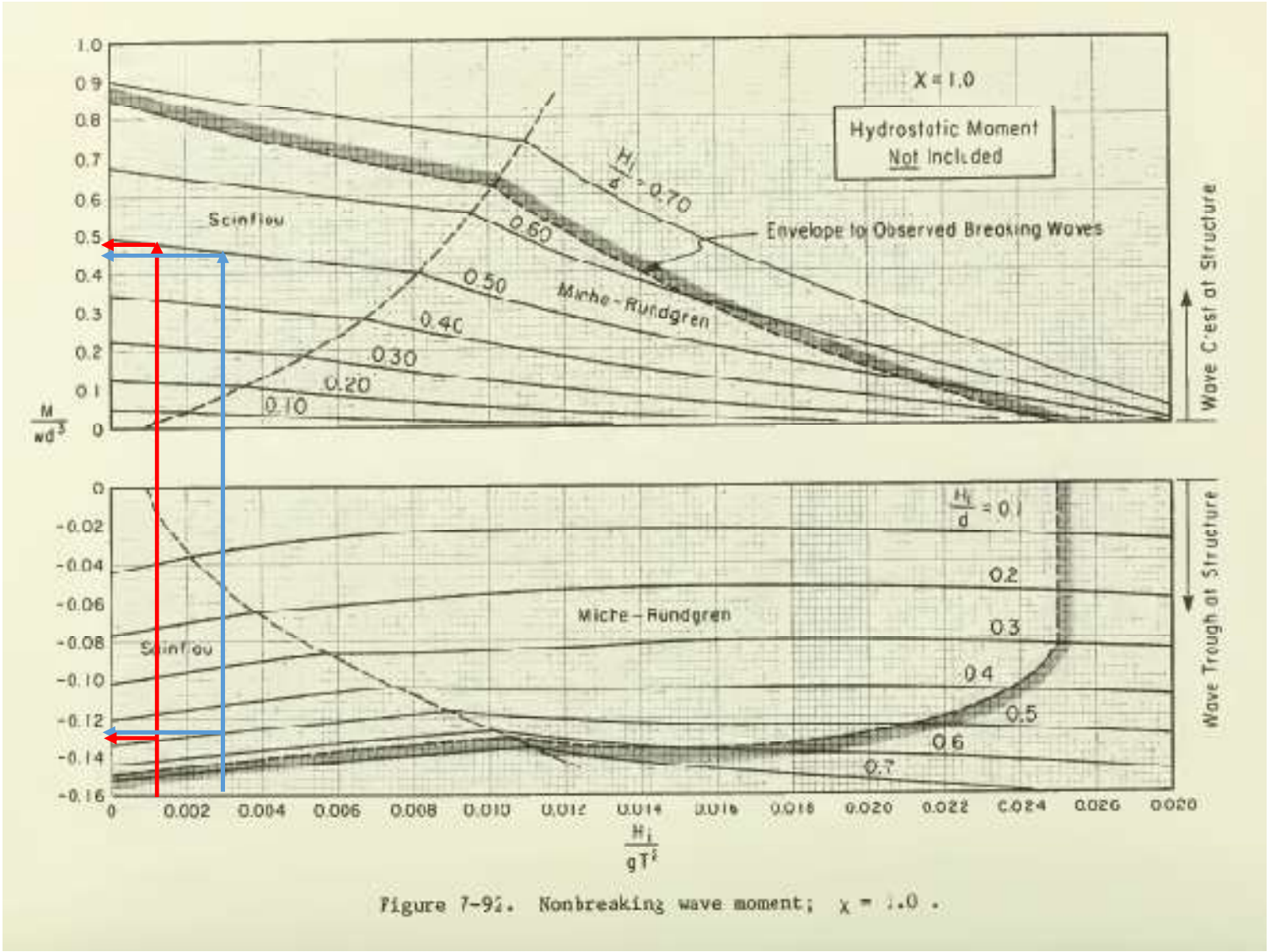


Figure 7-9. Nonbreaking wave moment; χ = 1.0 .

Non-breaking wave forces on coastal structures

$F_c = 0.65*9.8*4^2 = 101.9$ KN/m (T = 8 sec); 106.6 KN/m (T = 12 sec);

$F_t = -0.30*9.8*4^2 = -47.0$ KN/m (T = 8 sec); -51.7 KN/m (T = 12 sec);

$F_{c\ total} = F_c + wd^2/2 = 180.3$ KN/m (T = 8 sec); 185.0 KN/m (T = 12 sec);

$F_{t\ total} = F_t + wd^2/2 = 31.4$ KN/m (T = 8 sec); 26.7 KN/m (T = 12 sec);

Moment on structure:

From nomogram (Figure 7.92) $M_c/wd^3 = 0.45$ (T = 8 sec); 0.48 (T = 12 sec);

From nomogram (Figure 7.91) $M_t/wd^3 = -0.125$ (T = 8 sec); - 0.13 (T=12sec)

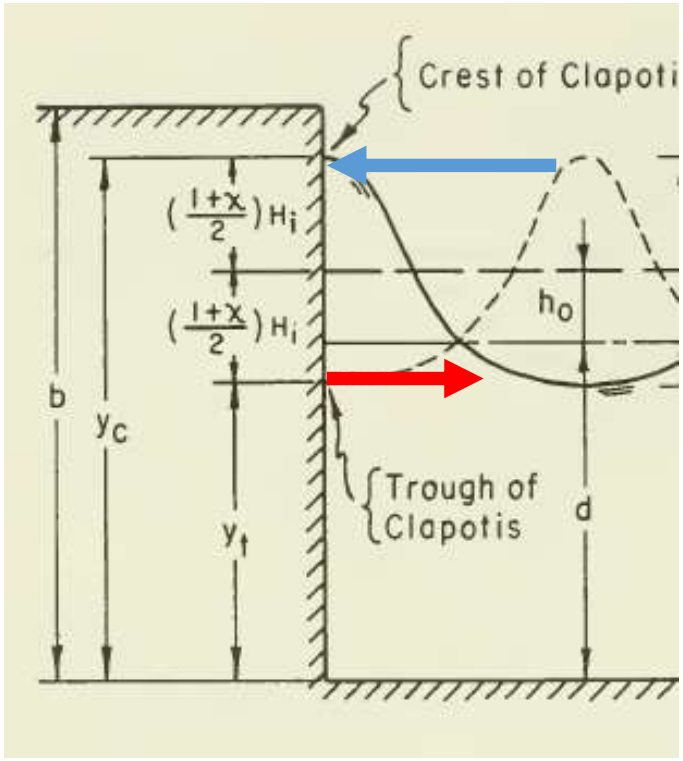
$M_c = 0.45*9.8*4^3 = 282.2$ KN-m/m (T = 8 sec); 301.06 KN-m/m (T = 12 sec);

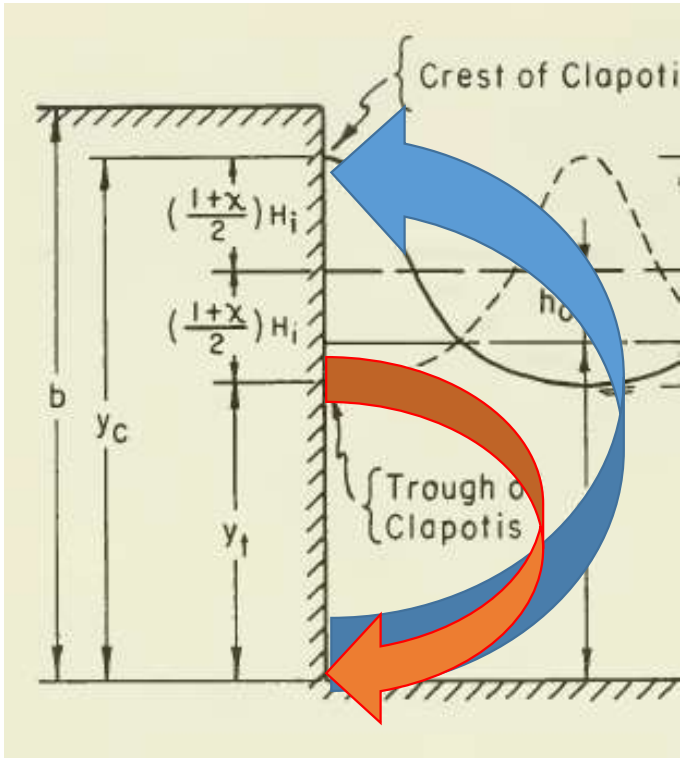
$M_t = -0.125*9.8*4^3 = -78.4$ KN-m/m (T = 8 sec); -81.5 KN-m/m (T = 12 sec);

$M_{c\ total} = M_c + wd^3/6 = 386.8$ KN-m/m (T = 8 sec); 405.6 KN-m/m (T = 12 sec);

$M_{t\ total} = M_t + wd^3/6 = 26.1$ KN-m/m (T = 8 sec); 23.0 KN-m/m (T = 12 sec);

Meaning of positive and negative forces and moments:





Non-breaking wave forces on coastal structures

Same SWL on both sides of the structure

Same wave climate

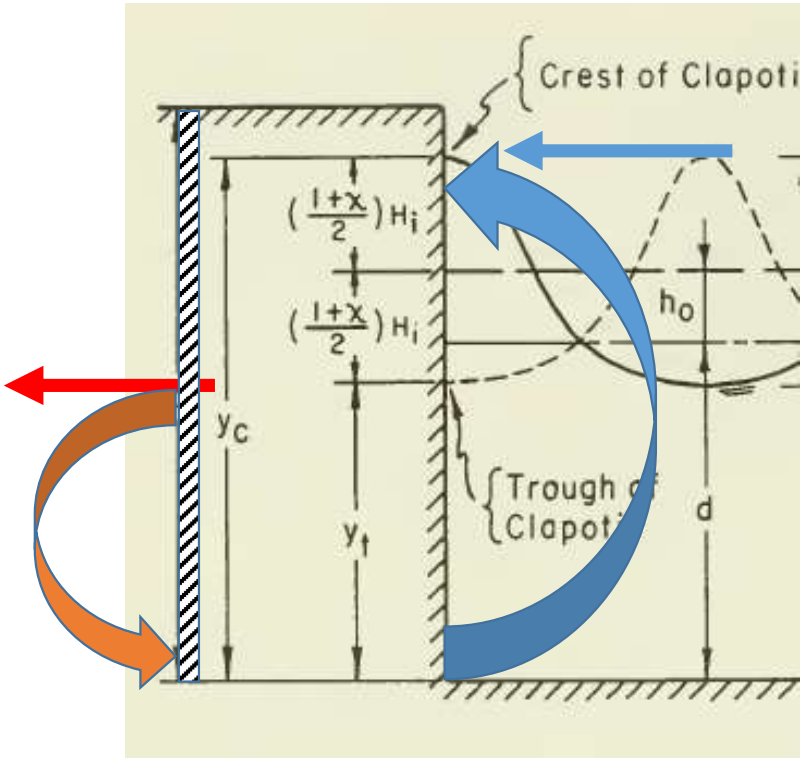
Critical condition: Wave crest on one side and wave trough on the other side:

As same water level on both sides, we can ignore force and moment due to hydrostatic pressure.

F_{net} = 101.9 – (- 47.0) = 148.9 KN/m (T = 8 sec); 158.3 KN/m (T = 12 sec)

M_{net} =282.2 – (-78.4) = 360.6 KN-m/m (T = 8 sec); 382.6 KN-m/m (T = 12 sec)

Critical condition from positive and negative forces and moments:



Non-breaking wave forces on coastal structures

Example 2: Given data:

There are non-breaking waves on both sides of a structure with unequal SWL.

At left side: Incident wave height, H_1 = 2m; d_1 = 4m, T_1 = 8 sec

At right side: Incident wave height, H_2 = 1.5m; d_2 = 3m, T_2 = 10 sec

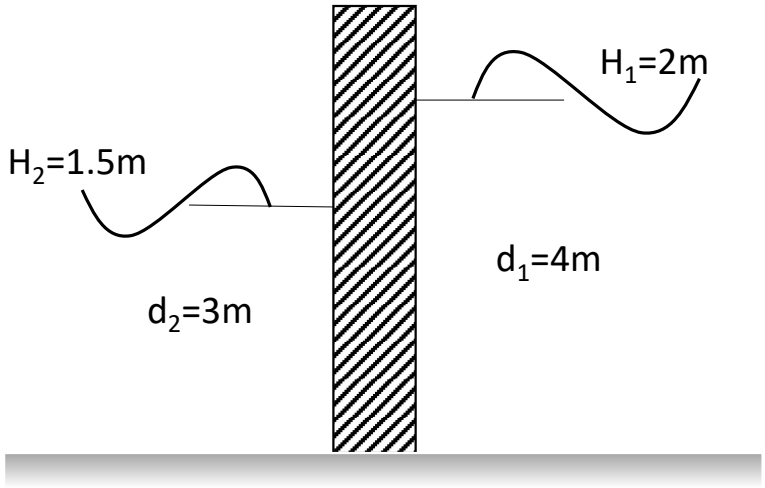
Reflection coefficient, Kr = 1

For non-over topping scenario calculate the followings:

F_c, F_t, $F_{c\ total}$, $F_{t\ total}$

M_c, M_t, $M_{c\ total}$, $M_{t\ total}$

for both sides and determine the critical conditions.



Non-breaking wave forces on coastal structures

Solution: <u>At side1:</u>

$H_1/d_1 = 0.5$ and $H_1/gT_1^2 = 0.0032$

From nomogram (Figure 7-90)

$H_0/H_1 = 0.78$

$H_{1,0} = 2*0.78 = 1.56$ m

$y_{1c} = d_1+H_{1,0}+(1+Kr)*H_1/2$

$= 4+1.56+(1+1)*2/2$

$= 7.56$m

$y_{1t} = d_1+H_{1,0}-(1+Kr)*H_1/2$

$= 4+1.56-(1+1)*2/2$

$= 3.56$m

<u>At side2:</u>

$H_2/d_2 = 0.5$ and $H_2/gT_2^2 = 0.0015$

From nomogram (Figure 7-90)

$H_0/H_2 = 0.88$

$H_{2,0} = 1.5*0.88 = 1.32$ m

$y_{2c} = d_2+H_{2,0}+(1+Kr)*H_2/2$

$= 3+1.32+(1+1)*1.5/2$

$= 5.82$m

$y_{2t} = d_2+H_{2,0}-(1+Kr)*H_2/2$

$= 3+1.32-(1+1)*1.5/2$

$= 2.82$m

Non-breaking wave forces on coastal structures

Force on structure:

From nomogram (Figure 7.91)

$F_{1c}/wd_1^2 = 0.65$

$F_{1c} = 0.65*9.8*4^2 = 101.9$ KN/m

$F_{1t}/wd_1^2 = -0.32$

$F_{1t} = -0.32*9.8*4^2 = -50.2$ KN/m

$F_{1c\ total} = F_{1c} + wd_1^2/2$

$= 180.3$ KN/m

$F_{1t\ total} = F_{1t} + wd_1^2/2$

$= 28.2$ KN/m

From nomogram (Figure 7.91)

$F_{2c}/wd_2^2 = 0.67$

$F_{2c} = 0.67*9.8*3^2 = 59.09$ KN/m

$F_{2t}/wd_2^2 = -0.33$

$F_{2t} = -0.33*9.8*3^2 = -29.1$ KN/m

$F_{2c\ total} = F_{2c} + wd_2^2/2$

$= 103.2$ KN/m

$F_{2t\ total} = F_{2t} + wd_2^2/2$

$= 14.9$ KN/m

Non-breaking wave forces on coastal structures

Moment on structure:

From nomogram (Figure 7.92)

$M_{1c}/wd^3 = 0.46$

$M_{1c} = 0.46*9.8*4^3 = 288.5$ KN/m

$M_{1t}/wd^3 = -0.125$

$M_{1t} = -0.125*9.8*4^3 = -78.4$ KN/m

$M_{1c\ total} = M_{1c} + wd_1^3/6$

$= 393.0$ KN/m

$M_{1t\ total} = M_{1t} + wd_1^3/6$

$= 26.1$ KN/m

From nomogram (Figure 7.92)

$M_{2c}/wd^3 = 0.48$

$M_{2c} = 0.48*9.8*3^3 = 127.0$ KN/m

$M_{2t}/wd^3 = -0.13$

$M_{2t} = -0.13*9.8*3^3 = -34.4$ KN/m

$M_{2c\ total} = M_{2c} + wd_2^3/6$

$= 171.1$ KN/m

$M_{2t\ total} = M_{2t} + wd_2^3/6$

$= 9.7$ KN/m

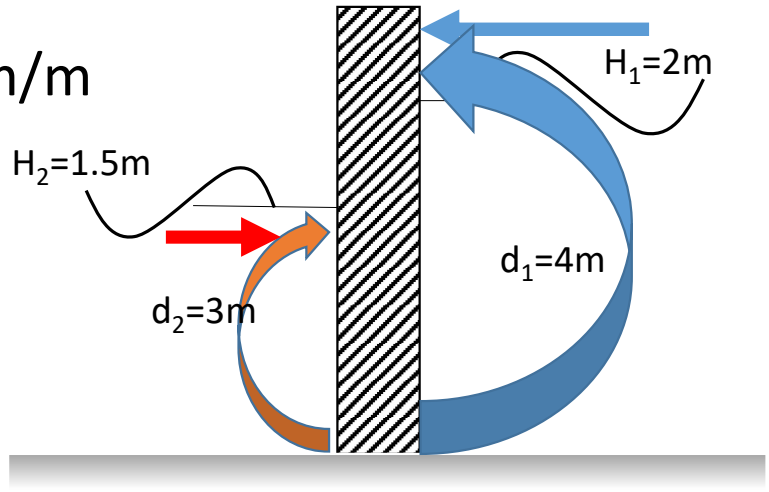
Non-breaking wave forces on coastal structures

Critical condition will arise when there is wave crest on one side and wave trough on the other side:

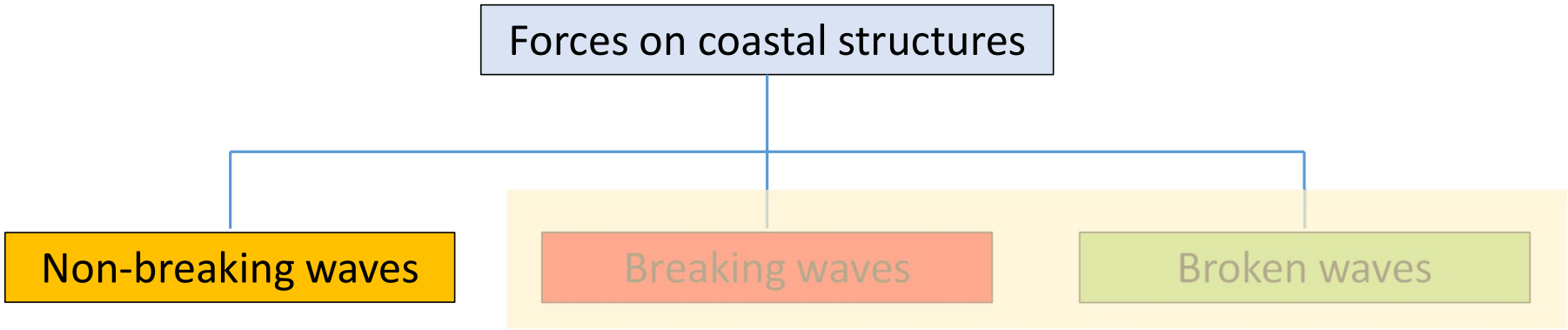
As SWL are not the same on both sides of the structure, we have to include hydrostatic force and momentum to get critical conditions.

$F_{net} = F_{1c\ total} - F_{2t\ total} = 180.3 - 14.9 = 165.4$ KN/m

$M_{net} = M_{1c\ total} - M_{2t\ total} = 393.0 - 9.7 = 383.3$ KN-m/m



Wave forces on coastal structures



- Scenarios for non-breaking wave forces could be:
  - ✓Non-overtopping vertical wall
  - ❑Overtopping vertical wall
  - ❑Vertical wall with rubble foundation
  - ✓Non-overtopping vertical wall with the same water depth on both sides of the structure
  - ✓Non-overtopping vertical wall with the unequal water depth between both sides of the structure