OCE421

Marine Structure Designs

Lecture #18

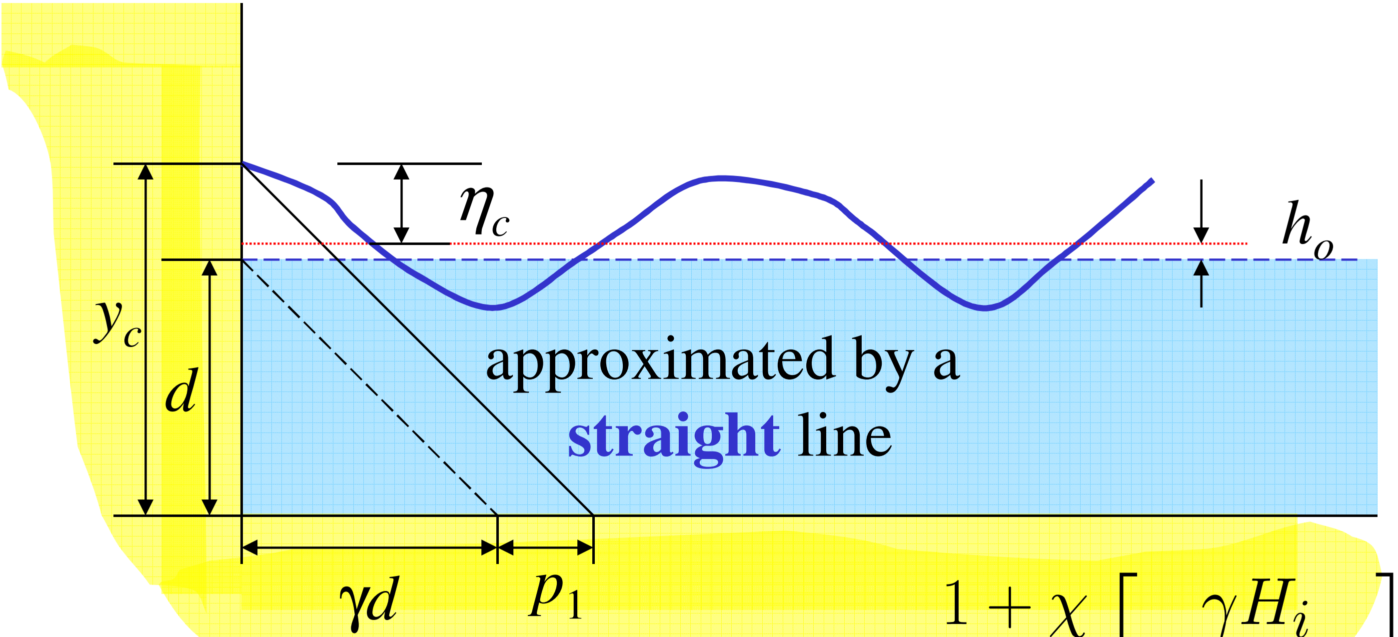
(Wave Forces on Vertical Breakwater – Goda's Method)

Pressure Distribution at Wall

$$y_c = d + h_o + \frac{1+\chi}{2} H_i$$

$$h_o = \frac{\pi H_i^2 L_o}{L^2}$$

$$y_t = d + h_o - \frac{1+\chi}{2} H_i$$



$$p_1 = \frac{1+\chi}{2}\left[\frac{\gamma H_i}{\cosh(kd)}\right]$$

Minikin's equation

For **caisson** and other vertical structures

maximum dynamic pressure:

$$p_m = 101\gamma \frac{H_b}{L_{d_1}} \frac{d_s}{d_1}(d_1 + d_s)$$

$p_m =$ maximum dynamic pressure

$H_b =$ breaker height

$d_s =$ water depth at structure toe

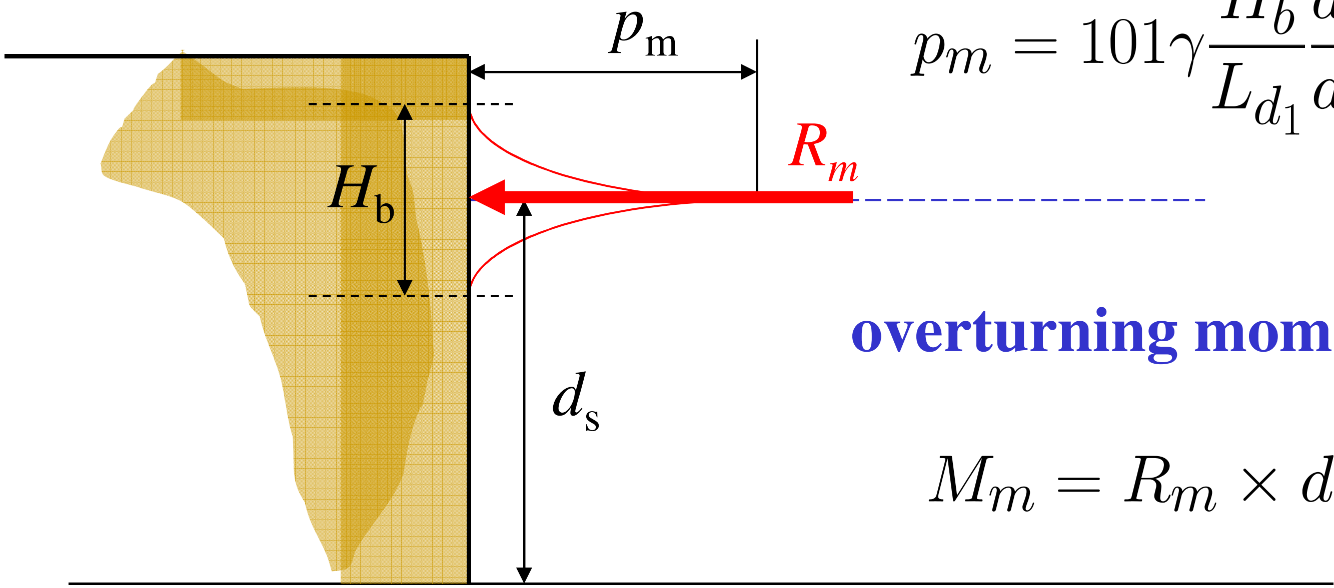
$d_1 =$ water depth at one wave length in front of the wall

$L_{d_1} =$ wave length at d_1

Resultant Force / Overturning Moment

resultant forces (due to dynamic pressure)

$$R_m = \frac{p_m H_b}{3}$$



$$p_m = 101\gamma \frac{H_b}{L_{d_1}} \frac{d_s}{d_1} (d_1 + d_s)$$

overturning moments about the toe

$$M_m = R_m \times d_s = \frac{p_m H_b d_s}{3}$$

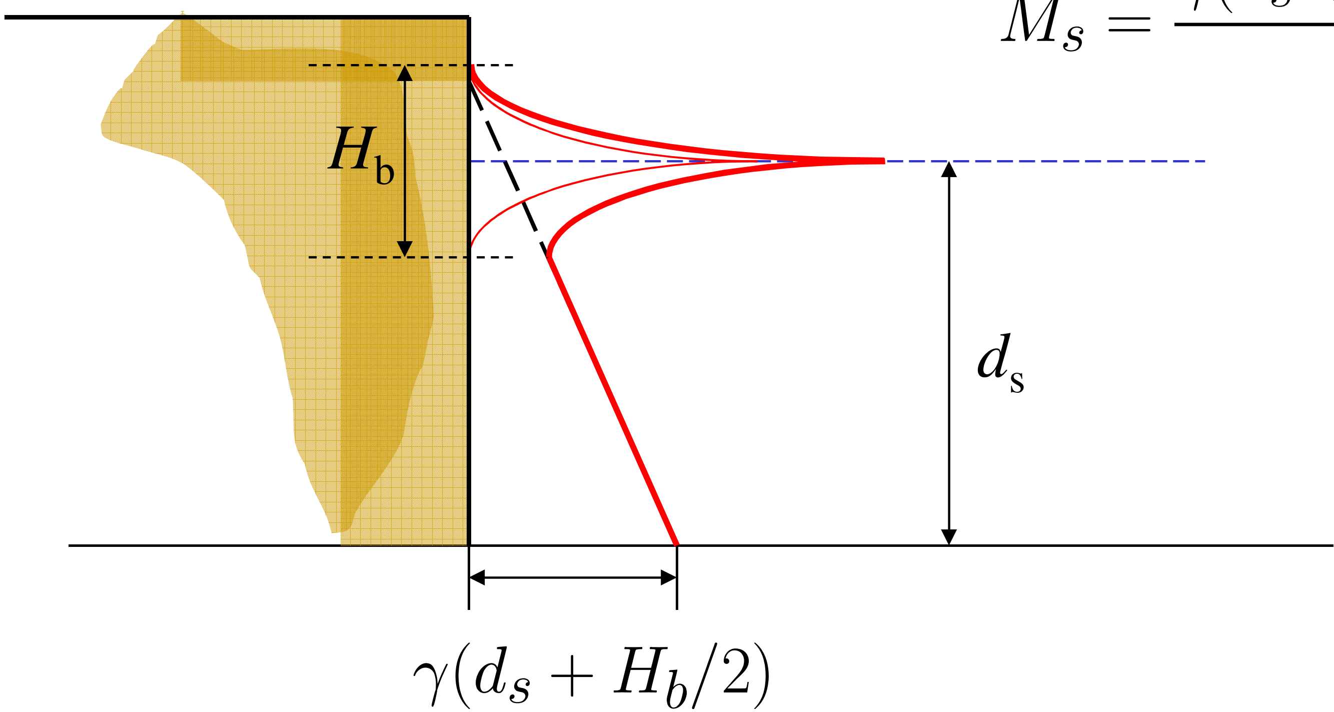
Resultant Force/Overturning Moment (II)

resultant forces (due to hydrostatic pressure)

$$R_s = \frac{\gamma(d_s + H_b/2)^2}{2}$$

overturning moments
(due to hydrostatic pressure)

$$M_s = \frac{\gamma(d_s + H_b/2)^3}{6}$$

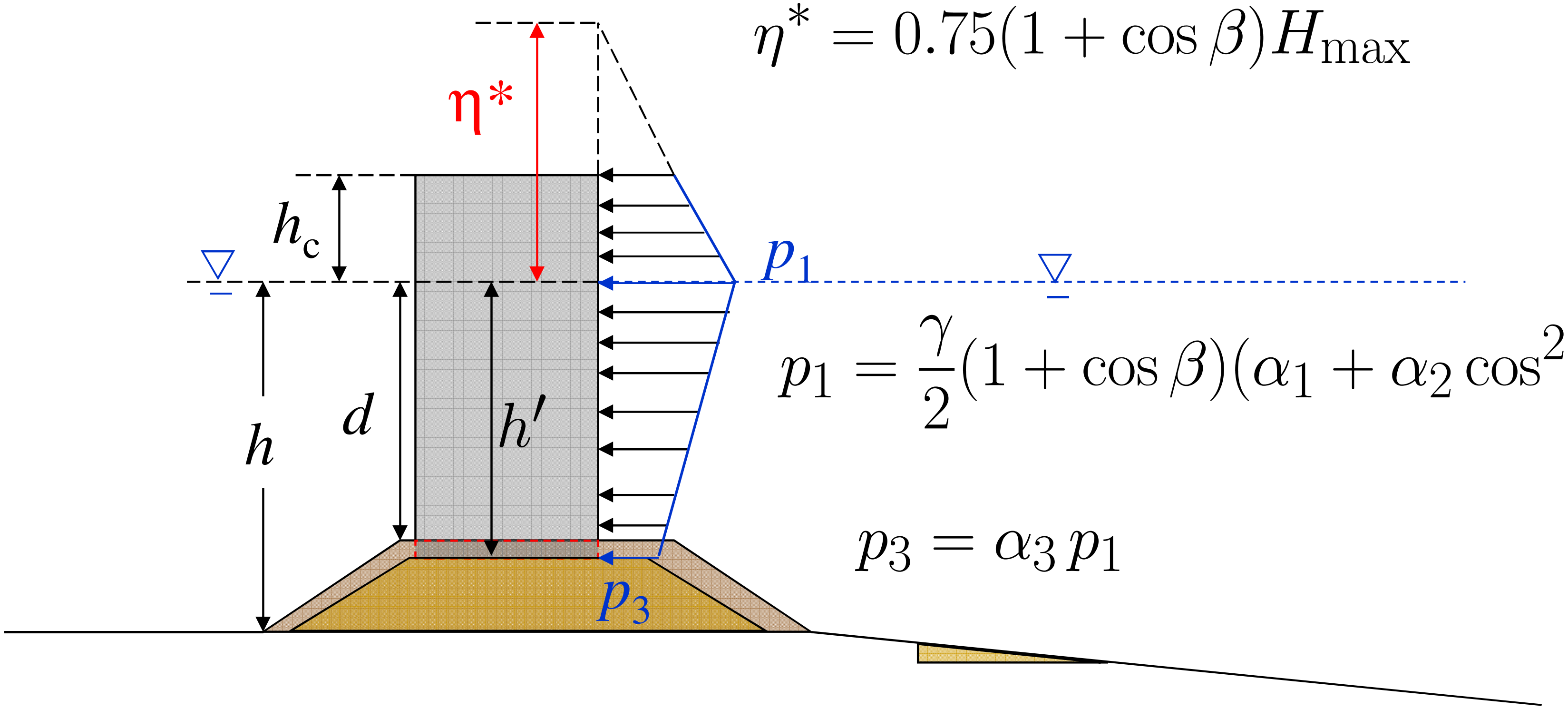


Goda's Method

- The method is applicable to both breaking and non-breaking waves

- Combined hydrostatic and dynamic pressures are assumed, maximum at the SWL and linearly decrease above and below the SWL.

Goda: Pressure Profile



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

$$p_1 = \frac{\gamma}{2}(1 + \cos\beta)(\alpha_1 + \alpha_2 \cos^2\beta)H_{\max}$$

$$p_3 = \alpha_3 p_1$$

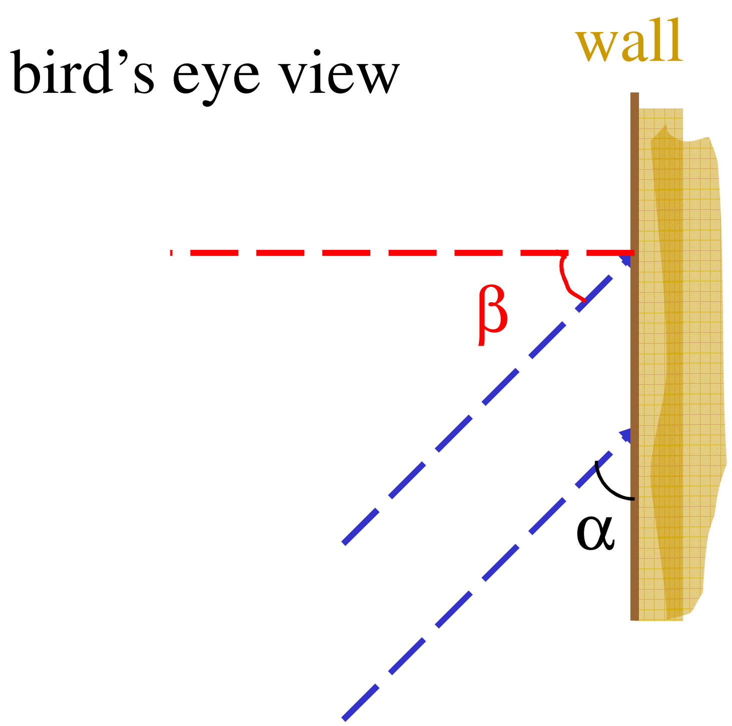
$\gamma =$ unit weight of water

$H_{\max} =$ Goda's design wave height

$\alpha_1, \alpha_2, \alpha_3 =$ coefficients to be determined

$\beta =$ angle between direction of wave approach and normal to breakwater

Definition: angle β



Goda's H_s within the surf zone

Goda's formulas for significant wave height in the surf zone:

$$H_s = \begin{cases} K_s H_o' & : h/L_o \geq 0.2 \\ \min\{(\beta_o H_o' + \beta_1 h), \beta_{\max} H_o', K_s H_o'\} & : h/L_o < 0.2 \end{cases}$$

$$\beta_o = 0.028(H_o'/L_o)^{-0.38} \exp[20 \tan^{1.5} \theta]$$
$$\beta_1 = 0.52 \exp[4.2 \tan \theta]$$
$$\beta_{\max} = \max\{0.92, 0.32(H_o'/L_o)^{-0.29} \exp[2.4 \tan \theta]\}$$

$L_o =$ deep water wave length

$K_s =$ shoaling coefficient

$\tan \theta =$ near-shore slope

Goda's $H_{\max}$ within the surf zone

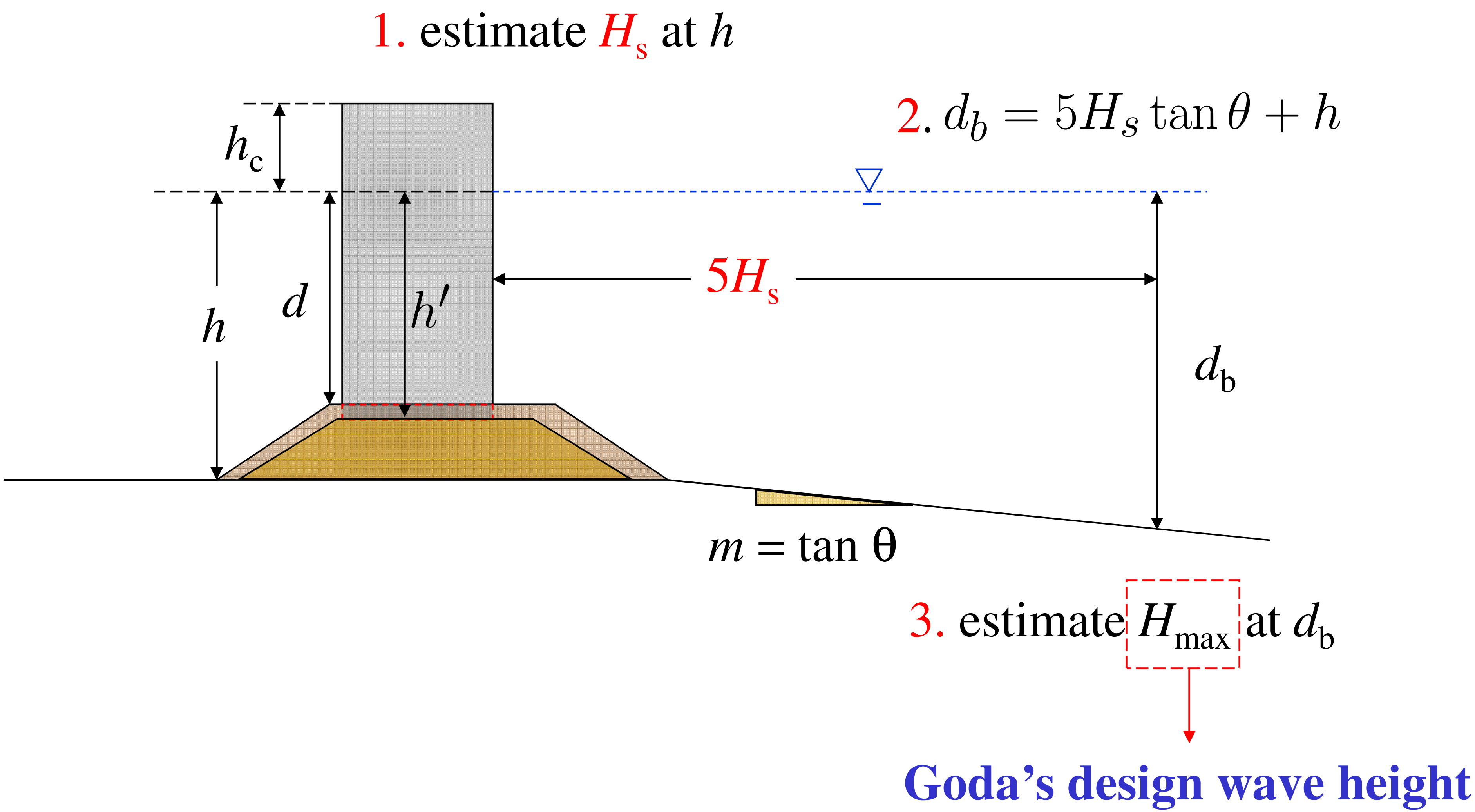
Goda's formulas for maximum wave height in the surf zone:

$$H_{\max} \equiv H_{1/250}$$

$$= \begin{cases} 1.8 K_s H_o' & : h/L_o \geq 0.2 \\ \min\{(\beta_o^* H_o' + \beta_1^* h), \beta_{\max}^* H_o', 1.8 K_s H_o'\} & : h/L_o < 0.2 \end{cases}$$

$$\beta_o^* = 0.052 (H_o'/L_o)^{-0.38} \exp[20 \tan^{1.5}\theta]$$
$$\beta_1^* = 0.63 \exp[3.8 \tan\theta]$$
$$\beta_{\max}^* = \max\{1.65, 0.53 (H_o'/L_o)^{-0.29} \exp[2.4 \tan\theta]\}$$

Goda: Design Wave Height



Determine Design Wave Height

$h/L_o \geq 0.2$?

estimate H_s at h (location of the breakwater)

↓

determine d_b: $d_b = 5H_s \tan\theta + h$

↓

$d_b/L_o \geq 0.2$?

estimate H_{max} at d_b (breaking depth)

Formulas to calculate α_i

$$p_1 = \frac{\gamma}{2}(1 + \cos\beta)(\alpha_1 + \alpha_2 \cos^2\beta) H_{\max} \qquad p_3 = \alpha_3 p_1$$

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

(L : wave length at h)

$$\alpha_2 = \min\left\{\frac{d_b - d}{3d_b}\left(\frac{H_{\max}}{d}\right)^2, \quad \frac{2d}{H_{\max}}\right\}$$

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

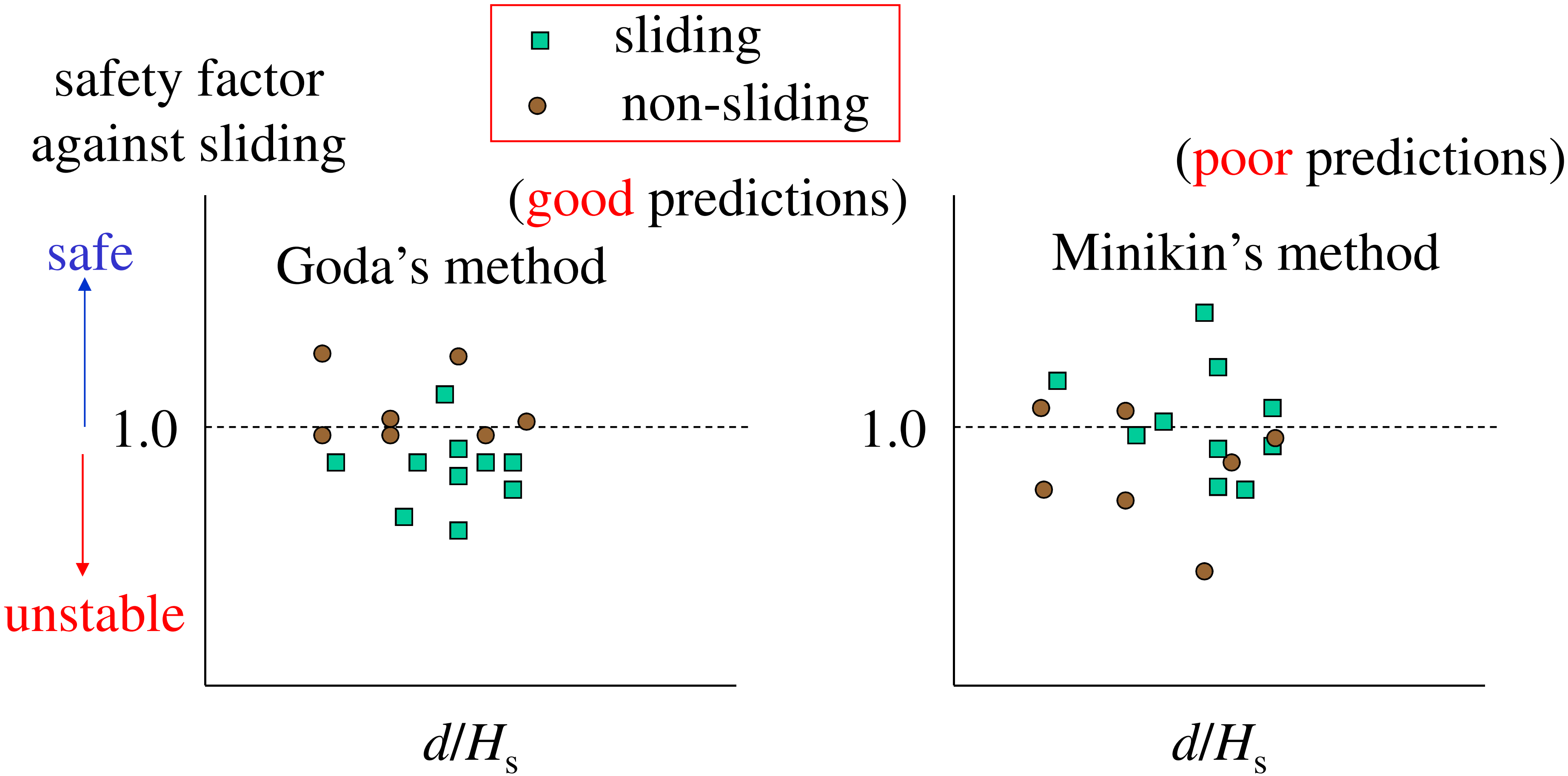
$$d_b = 5H_s \tan\theta + h$$

(H_s : significant wave height at h)

Evaluation on Minikin / Goda Formulas

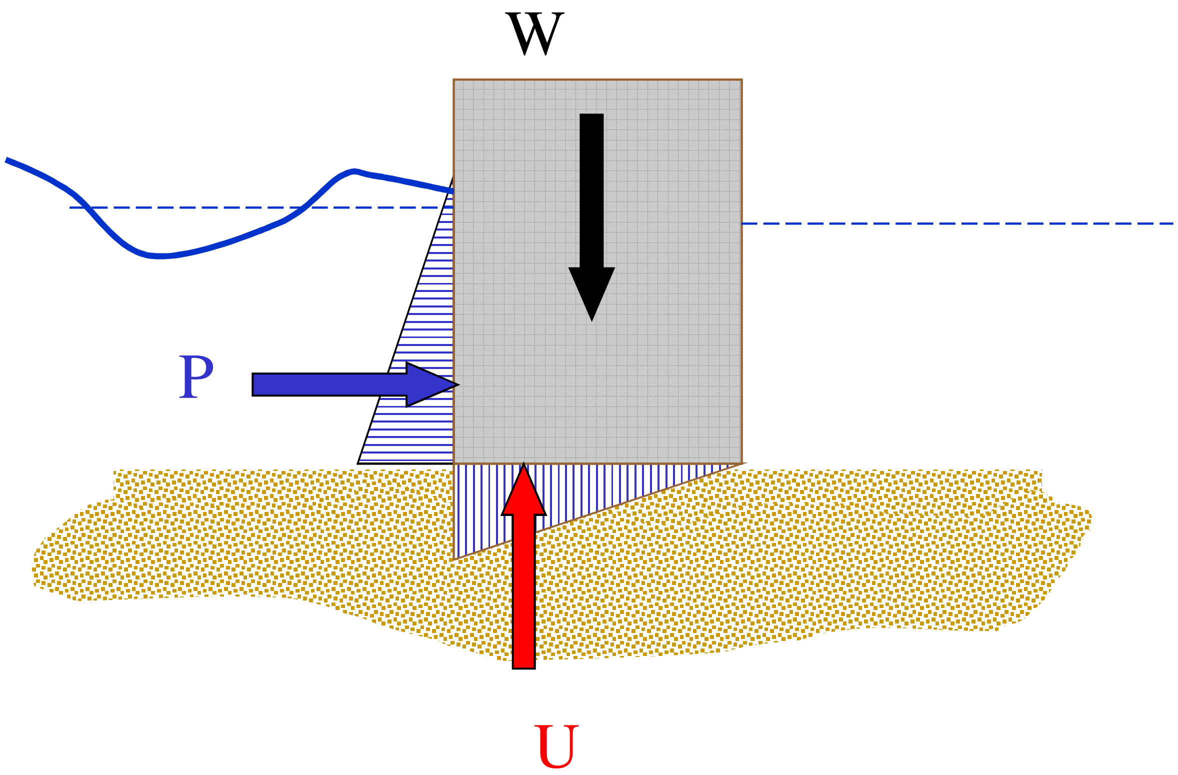
- The reliability of the calculation method for the wave pressure on a vertical breakwater is judged by the accuracy of the prediction of **breakwater stability**.

Prototype Structures against Sliding



Safety Factor against Sliding (figure)

$$\text{S.F.} = \frac{\mu(W-U)}{P}$$



Safety Factor against Sliding

$$\text{S.F.} = \frac{\mu(W - U)}{P}$$

$W =$ weight in still water (i.e. weight in air - buoyancy)

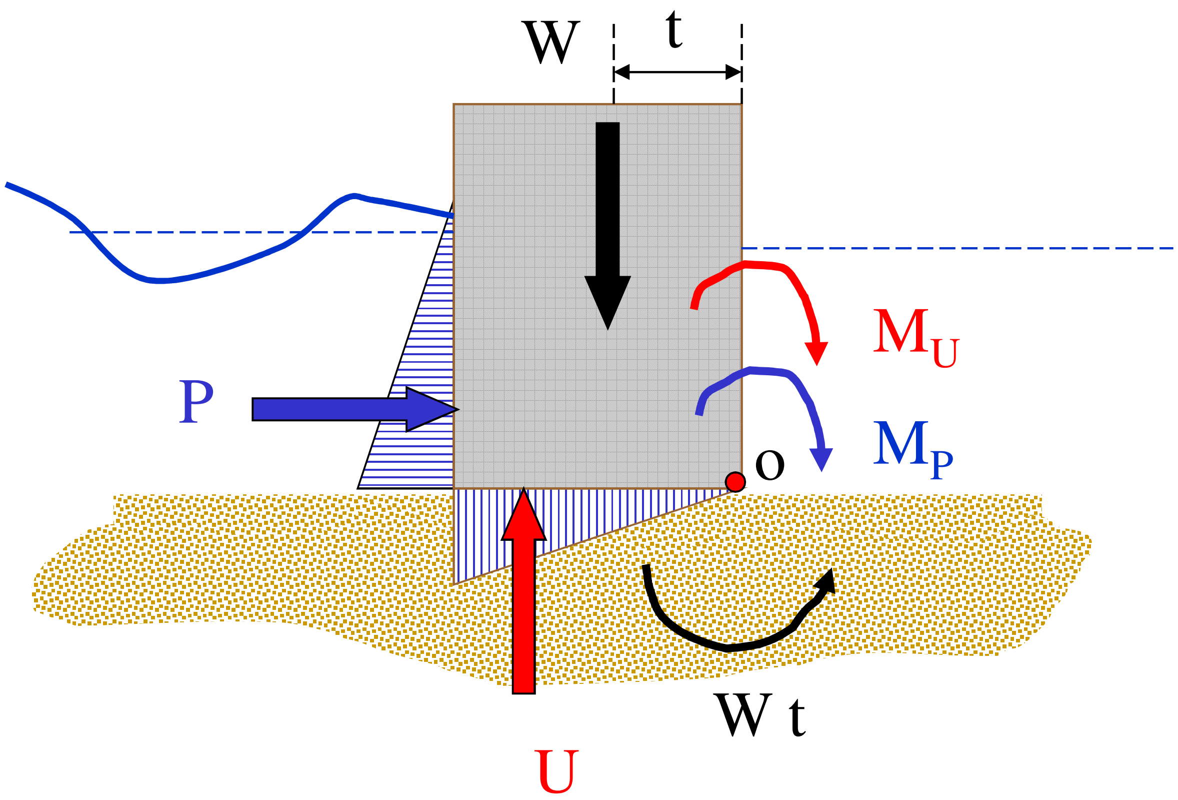
$U =$ uplift force due to the presence of the wave

$P =$ total horizontal force

$\mu =$ coefficient of friction
(between the upright section and the foundation)

Safety against Overturning (figure)

$$\text{S.F.} = \frac{W \cdot t - M_U}{M_P}$$



Safety Factor against Overturning

$$\text{S.F.} = \frac{W \cdot t - M_U}{M_P}$$

$M_U =$ moment about the heel due to U (uplift force)

$M_P =$ moment about the heel due to P (horizontal force)

$t =$ horizontal distance between c.o.g. and the heel of the upright section