Design charts for pontoon docks and breakwaters

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This paper introduces a series of design charts for the pontoon type breakwaters and docks with gab beneath them. The charts facilitate the design and eliminate the need to use any software. The design procedures are based on a simplified analytical method. The method predicts the forces experienced by the waves, and the flow field in the leeward of the dock. The dimensions of the pontoon are selected to minimize the environmental impact resulting from its existence while keeping its functional criteria.

يقدم هذا البحث مجموعة من المنحنيات لحساب ارتفاع الأمواج خلف الحواجز و منشآت التراكى التي تتواجد فتحـــات بأســفلها و أيضا يقدم منحنيات لحساب سرعة الجزيئات قريبا من القاع لاستخدامها فى حسابات النحر و الترسيب. تعتمد الطريقـــة المقدمـــة على تمثيل دالة الجهد في شكل متسلسلة و استخدام السرعة و الضغط عند حدود المنشأ لإيجاد ثوابت حدود المتسلسلة. أيضا تقـــدم النظرية طريقة لحساب القوى الرأسية و الأفقية و العزوم الواقعة على المنشأ نتيجة الأمواج. يمكن تقديم النتائج في شكل مجموعـــة من المنحنيات لاستخدامها فى التصميم.

Keyword: Design charts, Elevated dock, Breakwaters with gab, Environmental effect

1. Introduction

Mei and Black [1] used the variation principle to solve the problem of fixed surface or submerged obstacle. Black et al. [2] used the same approach to solve the same problem for a movable obstacle. Sharaki [3] introduced a simplified analytical approach to solve the problem of a fixed body piercing the water surface but not extending to the sea floor. The theory compares well with the previous works and has the advantage that it can be used manually without the need to any advanced programming.

This paper introduces a series of design charts based on the developed method. The charts cover a range of water depths that are normally encountered in beaches and marinas. Wide ranges of wave frequencies are considered. Finally, different ratios between the draft of the structure and the water depth are investigated, together with different ratios between the draft and the width of the structure.

Fig. 1 shows the different geometrical quantities used in the charts and in the mathematical expressions. The structure has infinite length, draft d and width 2B. The water depth is h and the gab beneath the structure is G.

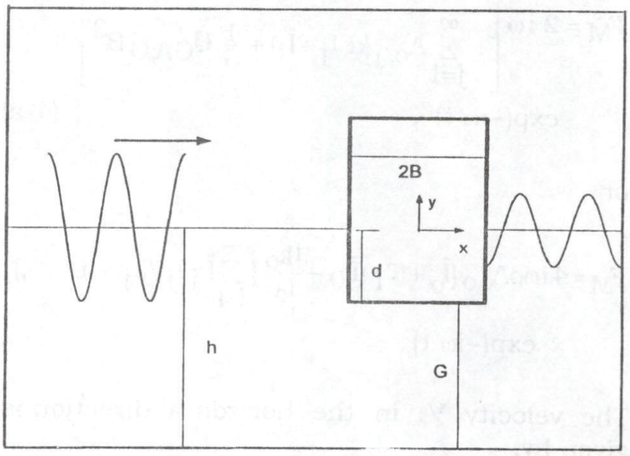

Fig. 1. Definition sketch of the pontoon.

2. The governing equations

The transmission coefficient T_f is given by Sharaki [3],

$$T_f = \frac{i I_o^2}{k_o BG + i I_o^2 + k_o \sum_{j=1}^{\infty} I_j^2 / k_j} . \quad (1)$$

The horizontal force F_h is given by, Sharaki [3],

$$F_h = 2 i \omega \rho \left[\bar{I}_o A_{oo} (1+R_a) + \sum_{j=1}^{\infty} \bar{I}_j A_{o,j} \right] \times \exp(-i\omega t), \quad (2\text{-a})$$

or

$$F_h = 4 i \omega \rho A_{oo} \left[\bar{I}_o - T_f \left(\bar{I}_o - i \frac{k_o}{I_o} \sum_{j=1}^{\infty} \bar{I}_j I_j / k_j \right) \right] \times \exp(-i\omega t) \,. \quad (2\text{-b})$$

The vertical force F_V is given by Sharaki [3],

$$F_V = 2 i \omega \rho \, B U_{GS,o} \exp(-i\omega t) \,. \quad (3)$$

The moment F_M is given by Sharaki [3],

$$F_M = 2 i \omega \left[\begin{array}{l} A_{oo}(1+R_A)(d\,\bar{I}_o + \hat{I}_o) + \\ + \sum_{j=1}^{\infty} A_{o,j}(d\,\bar{I}_j + \hat{I}_j) + \frac{1}{3} U_{GA,O} B^3 \end{array} \right] \exp(-i\omega t) \,, \quad (4\text{-a})$$

or

$$F_M = 4 i \omega \rho A_{o,o} [\hat{I}_o + T_f (\hat{I}_0 - \frac{i k_o}{I_o} \{ \sum_{j=1}^{\infty} \hat{I}_j I_j / k_j + B^3/3 \})] \times \exp(-i\omega t) \,. \quad (4\text{-b})$$

The velocity V_x in the horizontal direction is given by,

$$V_X = -2 i k_o f_o(y) S_{oo} \exp(i k_o (x+B)) \times \exp(-i\omega t) \,. \quad (5\text{-a})$$

The horizontal velocity under the dock, V_{dock}, is given by,

$$V_{dock} = U_{GA,o} \exp(-i\omega t) \,. \quad (5\text{-b})$$

The closer the ratio V_{dock} / V_x to unity, the lesser is the environmental impact resulting from the dock. In the above equations d,B,G are defined in fig. 1, and

$$I_i = \int_{-h}^{-d} f_i(y)\,dy, \quad \bar{I}_i = \int_{-d}^{0} f_i(y)\,dy \,, \quad \hat{I}_i = \int_{-d}^{0} y\, f_i(y)\,dy \,, \quad (6)$$

$$f_o(y) = \frac{\cosh[k_o(y+h)]\sqrt{2}}{\left[h + \frac{g \sinh^2 (k_o h)}{\omega^2} \right]^{0.5}} \,, \text{ and}$$

$$f_i(y) = \frac{\cos[k_i(y+h)]\sqrt{2}}{\left[h - \frac{g \sin^2 (k_i h)}{\omega^2} \right]^{0.5}} \,. \quad (7)$$

$$k_o \tanh(k_o h) = \frac{\omega^2}{g}, \qquad k_j \tan(k_j h) = -\frac{\omega^2}{g}, \quad (8)$$

$$S_{oo} = A_{oo} = -\frac{i A_m g}{2 w f_o(0)} \,,$$

$$A_{o,j} = \frac{I_j U_{Ga,o}}{K_j} \quad \text{where} \quad j = 1,2,\ldots \,, \quad (9)$$

$$U_{GA,o} = -\frac{2 A_{oo} I_o}{GB + i I_o^2 / k_o + \sum_{j=1}^{\infty} I_j^2 / k_j} \,,$$

$$U_{GS,o} = 2 S_{oo} I_o / G \,, \text{ and} \quad (10)$$

$$R_a = 1 + \frac{i U_{GAo} \,, I_o}{k_o S_{oo}} \,, \quad (11)$$

where g, ω and A_m are the gravity acceleration, the radian frequency and the amplitude of the incident wave, respectively, and $i = (-1)^{0.5}$

3. Design charts

Figs. 2 through 4 show series of design charts for three different water depths 2, 3 and 4 meters, respectively. For each depth three different values for B/h are considered 1,2 and 3. Also three different values for d/h are considered for each depth. Those ratios are 0.7, 0.8 and 0.9. For each depth, there are five charts. The first one shows the transmission coefficients as given by eq. (1).

The second one shows the relative velocity near the bed as given by eqs. (5-a, 5-b). The last three charts of each depth give the horizontal force, the vertical force and the moment experienced by the structure, as given by eqs. (2-4). The forces and moment are shown in a non-dimensional form. The horizontal and vertical forces are divided by ρ_w g A_m h, where ρ_w is the density of the water. The moment is divided by (ρ_w g A_m h^2 / 10).

It should be noted that the vertical force is insensitive to the variation in the ratio B/d, so a single curve is sufficient to represent the different values of B/d. Also, the vertical force shown is due to the dynamic pressure only. To find the total vertical force, the effect of the hydrostatic water pressure must be added.

Based on the wave height in the seaside and the required wave height in the leeward of the dock, the appropriate transmission coefficient is selected. Using the grain size analysis data, the accepted change in the water particle velocity near the bottom is determined. This information, are used to select the dimensions of the structure and the depth of erection. The charts for the forces and moment are used to design the supporting system.

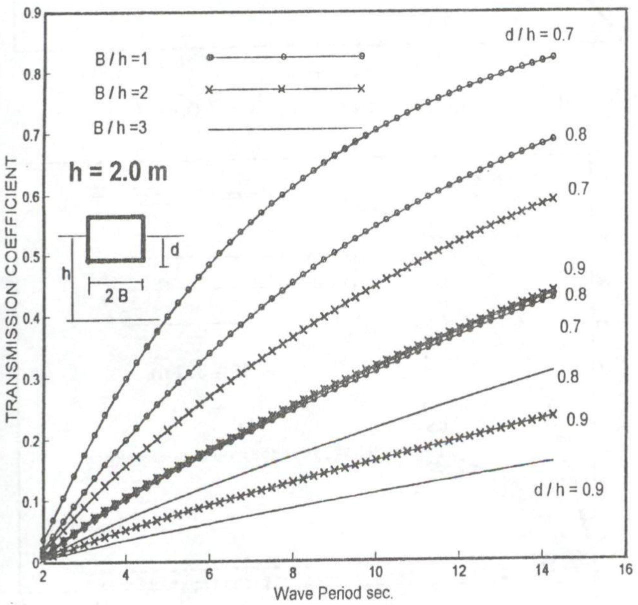

Fig. 2-a. Transmission coefficient – water depth = 2.0 m.

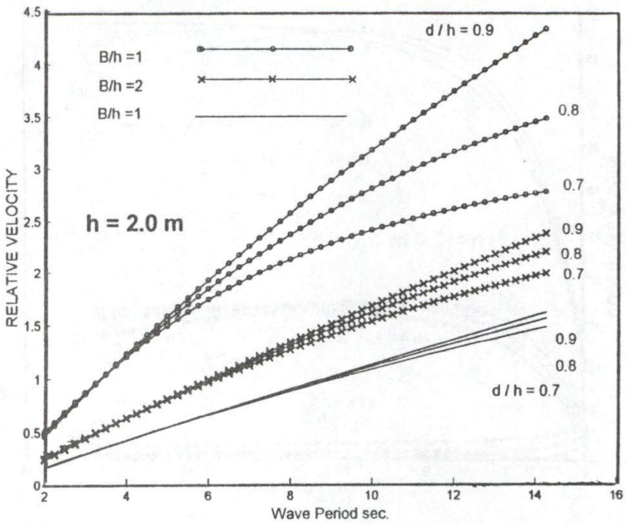

Fig. 2-b. Relative velocity – water depth = 2.0 m.

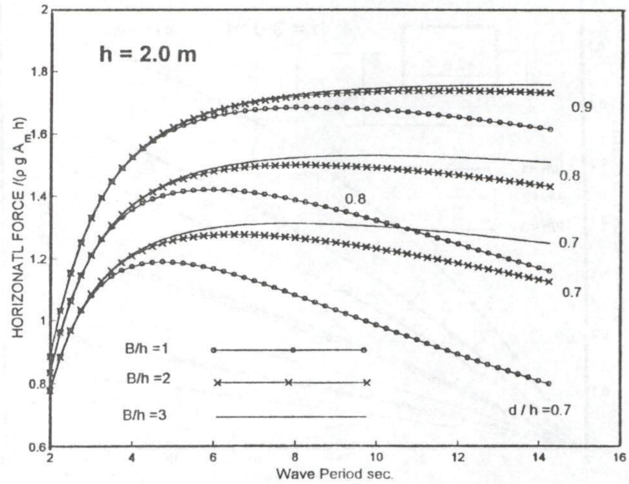

Fig. 2-c. Horizontal force – water depth = 2.0 m.

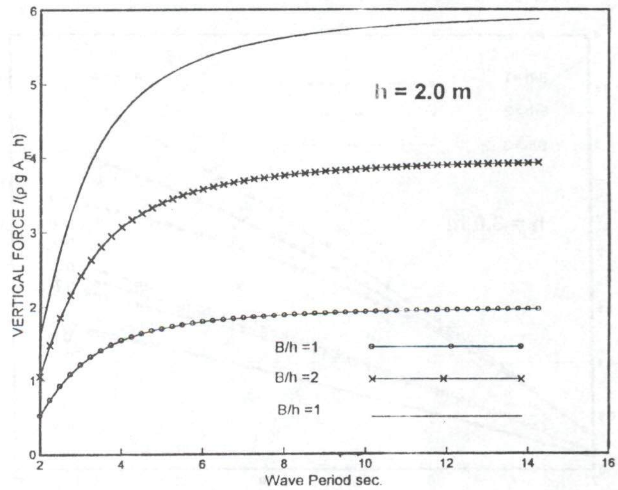

Fig. 2-d. Vertical force – water depth = 2.0 m.

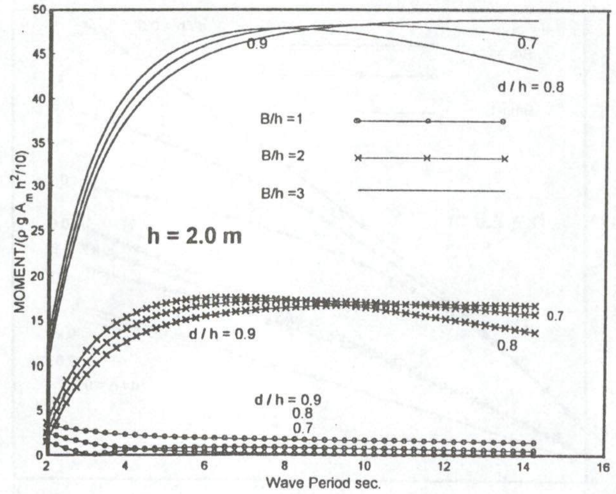

Fig. 2-e. Moment – water depth = 2.0 m.

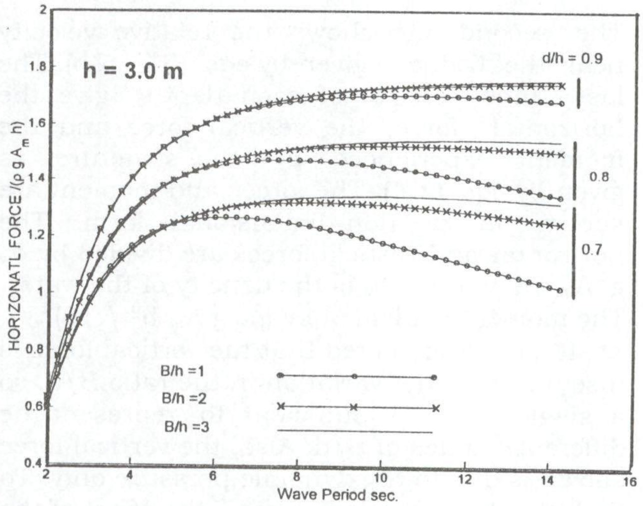

Fig. 3-c. Horizontal force – water depth = 3.0 m.

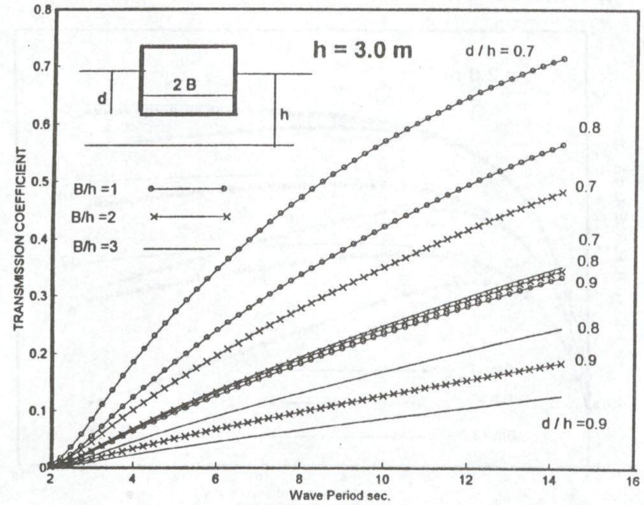

Fig. 3-a. Transmission coefficient – water depth = 3.0 m.

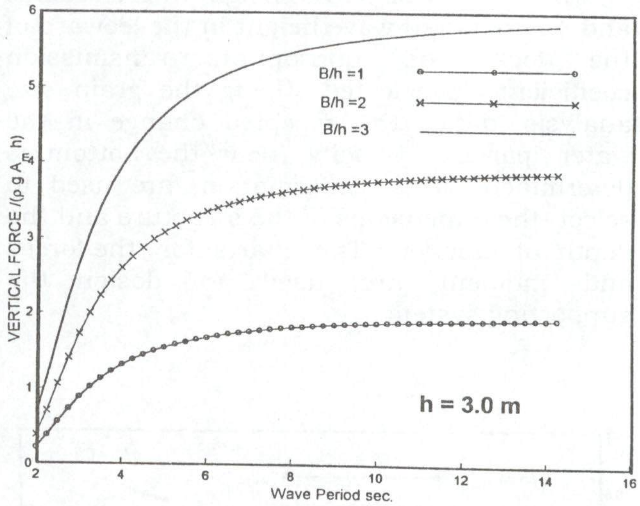

Fig. 3-d. Vertical force – water depth = 3.0 m.

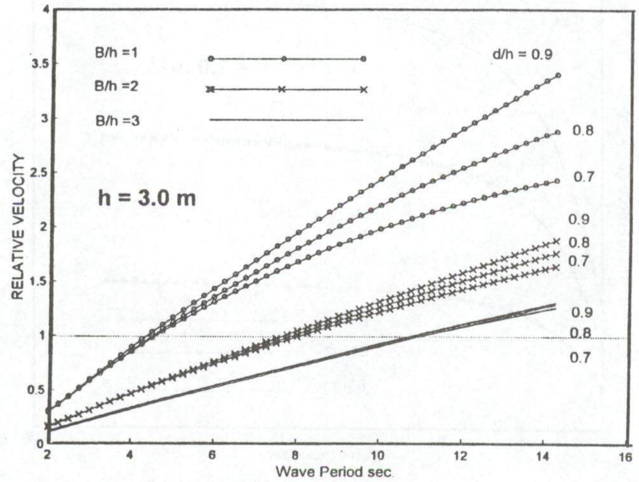

Fig. 3-b. Relative velocity – water depth = 3.0 m.

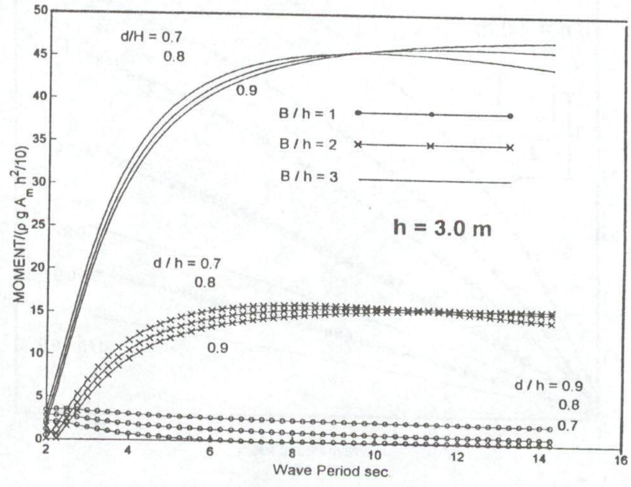

Fig. 3-e. Moment – water depth = 3.0 m.

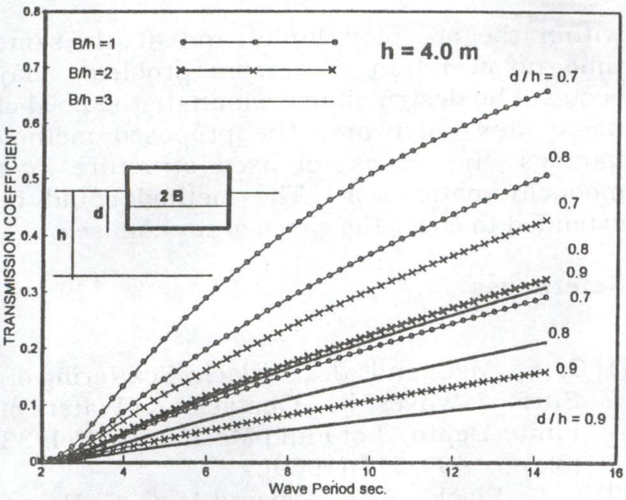

Fig. 4-a. Transmission coefficient – water depth = 4.0 m.

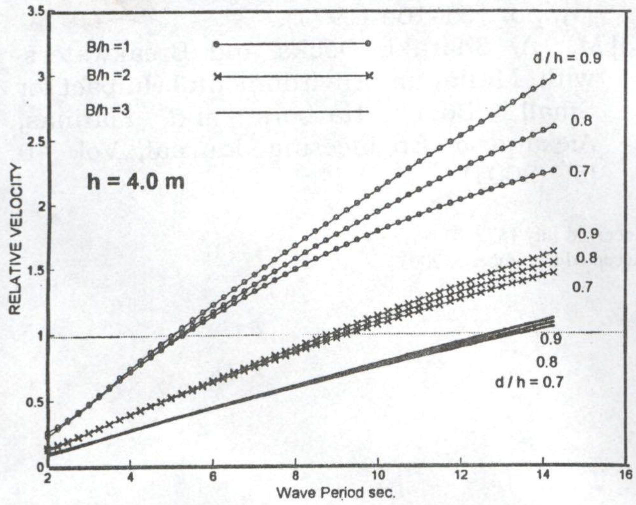

Fig. 4-b. Relative velocity – water depth = 4.0 m.

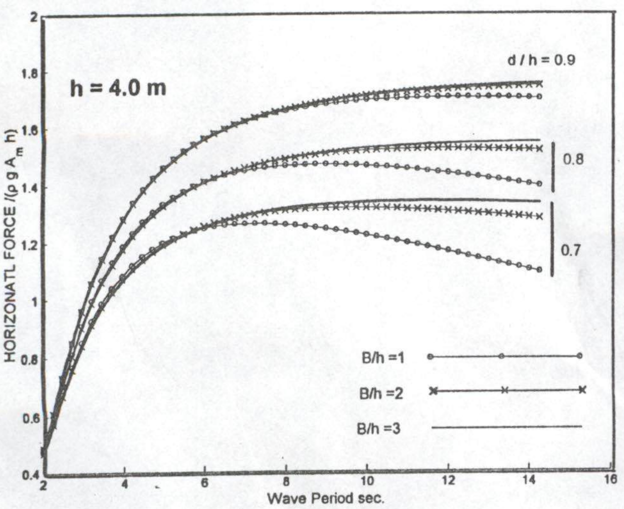

Fig. 4-c. Horizontal force – water depth = 4.0 m.

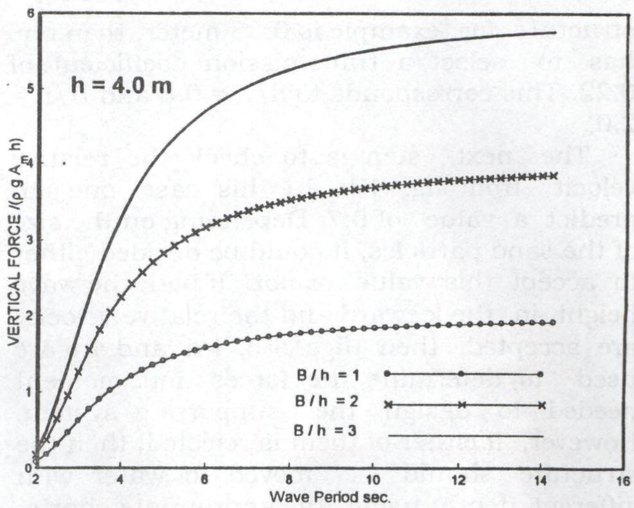

Fig. 4-d. Vertical force – water depth = 4.0 m.

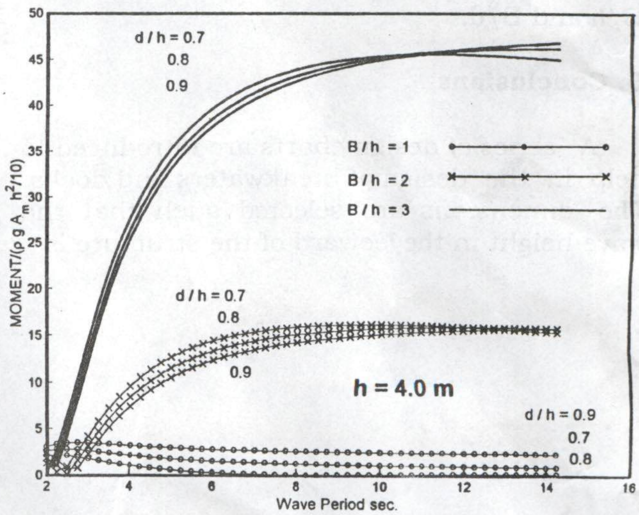

Fig. 4-e. Moment – water depth = 4.0 m.

4. Case study

As an example to see how to use the charts, assume that the incident wave period and height are 6 seconds and 1.5 meter, respectively. The deep-water wavelength L_o is found to be 56.2 meter. For water depth 4.0 meter, the wavelength is 34.75 meter and L/h = 8.687. From fig. 4-a, one finds that the transmission coefficients are 0.12, 0.22 and 0.32, for d/h = 0.9, 0.8 and 0.7, respectively, for the case with B/h = 1. For the case with B/h = 2.0, the transmission coefficients are 0.06, 0.12 and 0.17, for the cases with B/d = 0.9, 0.8 and 0.7 respectively. If the accepted height of the waves in the leeward of the structure for example is 0.35 meter, then one has to select a transmission coefficient of 0.22. This corresponds to d/h = 0.8 and B/h = 2.0.

The next step is to check the relative velocity from fig. 4-b. In this case one can predict a value of 0.7. Depending on the size of the sand particles, it could be decided either to accept this value or not. If both the wave height in the leeward and the relative velocity are accepted, then figs. 4-c, 4-d, and 4-e are used to determine the forces and moment needed to design the supporting system. However, if either of them is rejected, then the structure should be moved to water with different depth using the appropriate charts. An alternative approach is to use the charts for the same depth with different values of B/h and B/d.

5. Conclusions

A series of design charts are introduced to help in the design of breakwaters and docks. The dimensions are selected such that the wave height in the leeward of the structure is within the accepted limits and at the same time no accretion or erosion problems may occur. The design charts eliminate the need of using any software. The proposed method handles the cases of fixed structure in a monochromatic sea. The method could be extended to cover the cases of random sea.

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Received July 15, 2001
Accepted December 5, 2001