Coastal Engineering Technical Note

AN EMPIRICAL METHOD FOR DESIGN OF BREAKWATERS AS SHORE PROTECTION STRUCTURES

PURPOSE: To present an empirical method that can be used for preliminary design of detached breakwater systems for shore protection. This CETN supplements general information about functional application and design considerations for segmented offshore breakwaters presented in CETN-III-22.

BACKGROUND: The empirical design method was developed by the River Bureau of the Japanese Ministry of Construction (hereafter, JMC 1986) based on a survey of over 1500 shore protection projects conducted from 1983 through 1985. This CETN summarizes and presents the JMC approach and discusses results of its application with an example problem.

The structures surveyed by JMC included permeable, impermeable, continuous (length greater than 200 m), and segmented systems. However, the majority (1,458 or 94 percent) were permeable segmented structures, constructed of concrete armor units without internal zonation. Most are positioned inside the surf zone, where they function to dissipate wave energy, thereby allowing suspended sediment moving onshore to deposit.

Tombolo formation occurred in about 60 percent of the cases reported in the JMC experience, with most shorelines advancing from 10 to 20 m. Contrary to U.S. design practice, the use of beach fill placed to the lee of the structure(s) to mitigate potential adverse effects of the project is not a part of the JMC design.

The JMC breakwater data were collected from five types of coasts, distinguished by the beach profile, sediment size, relative intensity of sediment transport, and availability of a sediment source. Enough data were available from two of these types of coasts (Beach Types B and C, Table 1) to develop relationships between shoreline response and structural parameters. The wave parameters required for the JMC design are average height and period from the "five highest non-storm waves" occurring in a year as specified by JMC (1986). It is advisable that the WIS data be used for design wave selection. The JMC design method follows a series of steps, where variables used in the design procedure are illustrated in Figure 1. The JMC design method is illustrated herein by way of an example problem.

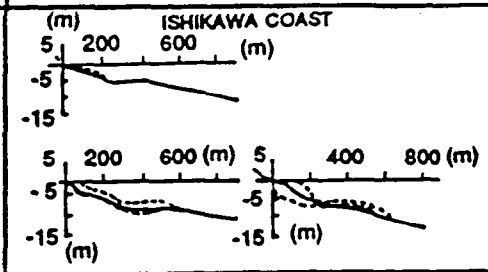
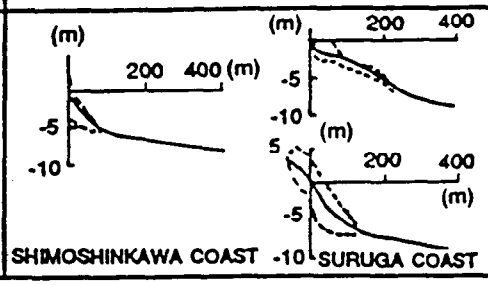
**********EXAMPLE**********

Given: Average of five highest deepwater wave heights occurring in a year H_{o5} = 2.5 m, corresponding wave period T_5 = 12.0 sec, desired salient length X_s = 15 m, length of project shoreline L_p = 380 m, beach slope I = 1/30. Beach has well-developed offshore bar, with sand-sized material.

Because beach is mildly sloped with well-developed bar and sand-sized beach material, use Type B Beach for breakwater design.

Table 1

Definition of Beach Type for use in JMC Design Method

TYPE OF BEACH	PROFILE	CHARACTERISTICS
B		• BAR IS WELL DEVELOPED. • BEACH SLOPE IS GENTLE AT DEPTH FOR THRESHOLD OF SEDIMENT MOTION. • COASTLINE IS PERPENDICULAR TO AVERAGE WAVE DIRECTION. $H_o \geq 0.5$ m I = 1/30 SAND
C		• BOTTOM SLOPE IS RELATIVE STEEP AND THERE IS NO BAR. $H_o \geq 0.5$ m I = 1/15 SAND AND PEBBLES

Step 1: Calculate breaking water depth at the site (d_{b5}) using deep water wave steepness (H_{o5}/L_{o5}) and (Figure 2).

$$L_{o5} = \frac{g\ T_5^2}{2\pi} = \frac{(9.81)(12)^2}{2(3.14)} = 224.8 \text{ m}$$

$$\frac{H_{o5}}{L_{o5}} = \frac{2.5}{224.8} = 0.011$$

With $I = 1/30$ and $H_{o5}/L_{o5} = 0.011$, estimate $\frac{d_{b5}}{H_{o5}} = 1.8$, (Figure 2)

Therefore, $d_{b5} = 1.8(2.5) = 4.5$ m

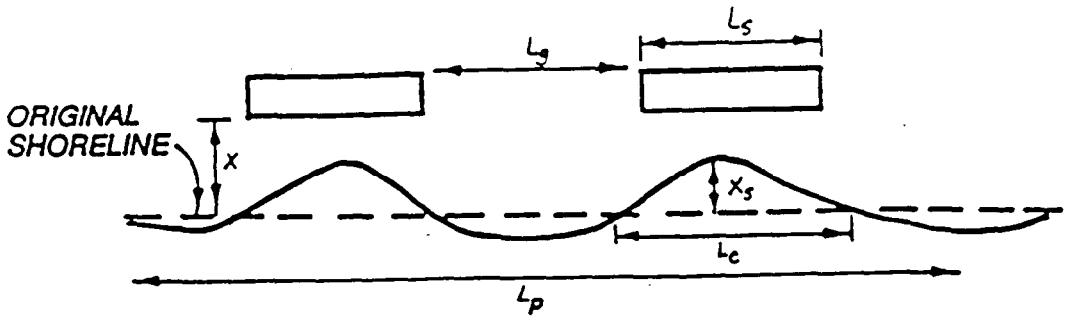
Step 2: Choose a design water depth at the structure, d′ , such that

$$d_{b5} > d' > X_s\ I \qquad (1)$$

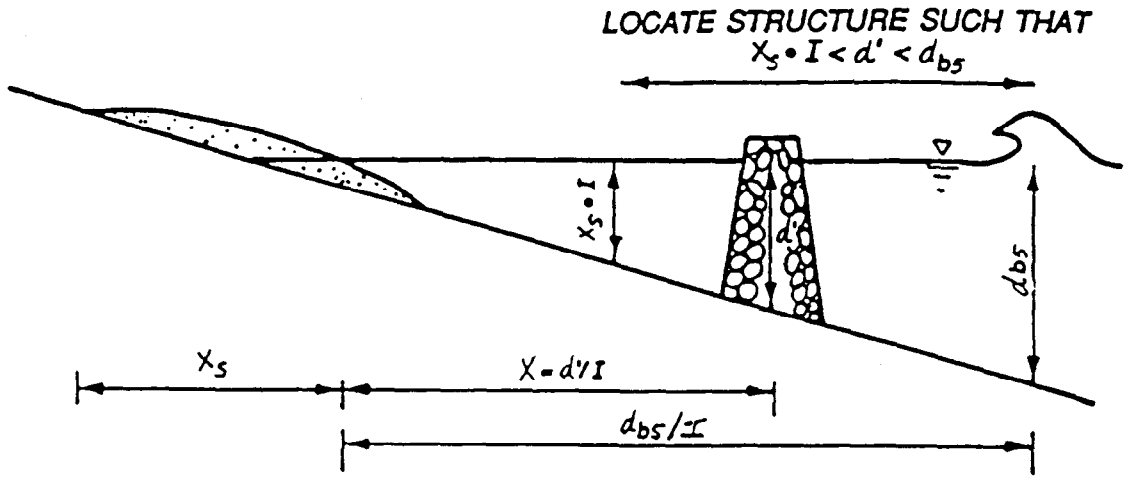
(Usual initial guess is $d' = (d_{b5} + X_s\ I)/2$).

Equation (1) will result in the structure being located at least one salient length offshore from the original shoreline, but shoreward of the breaker zone.

$$d' = \frac{d_{b5} + X_s\ I}{2} = \frac{4.5 + 15(1/30)}{2} = 2.5 \text{ m}$$



a. Plan view



b. Cross-sectional view

Figure 1. Variables used in JMC design method

Step 3: Read salient area ratio (SAR) from Figure 3a or 4a (Beach Type B or C) using ratio of d'/d_{bs}. SAR approximates the planform area of the salient as a triangle, and divides by the protected area as follows:

$$SAR = \frac{0.5 \quad L_c \quad X_s}{X \quad L_s} \tag{2}$$

where X_s is as defined previously, and
L_c = salient length in longshore direction;
X = structure distance offshore; and
L_s = structure length.

with $\frac{d'}{d_{bs}} = \frac{2.5}{4.5} = 0.56$, obtain SAR = 0.6 from Figure 3a.

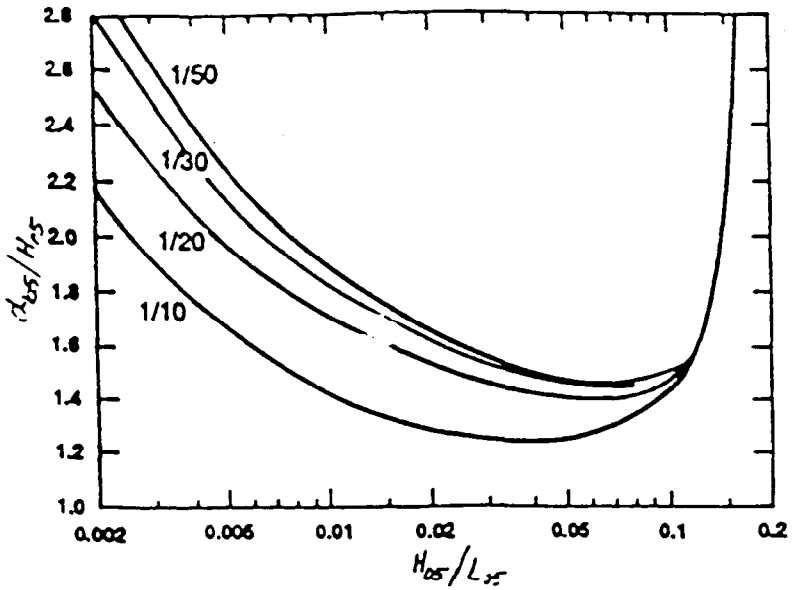


Figure 2. Deepwater wave steepness versus nearshore steepness (Goda 1970)

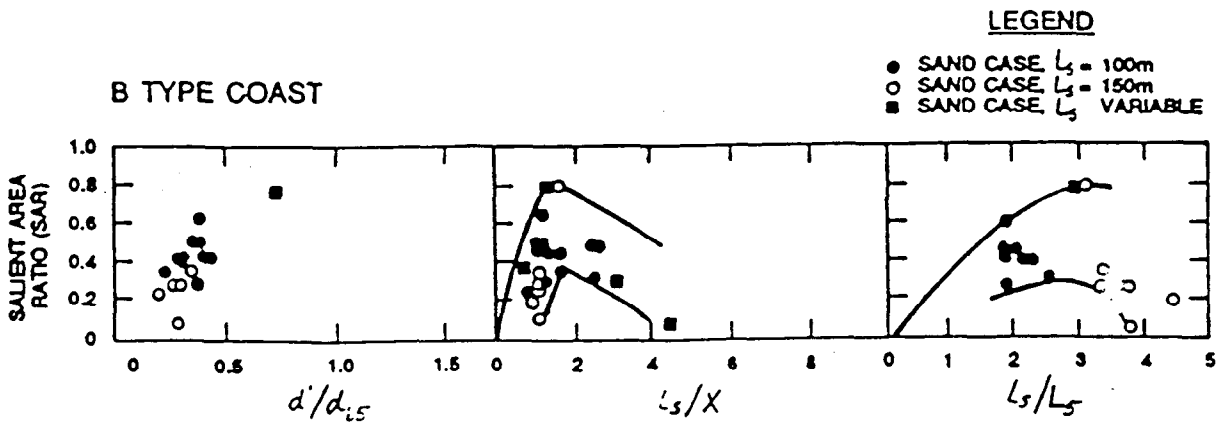
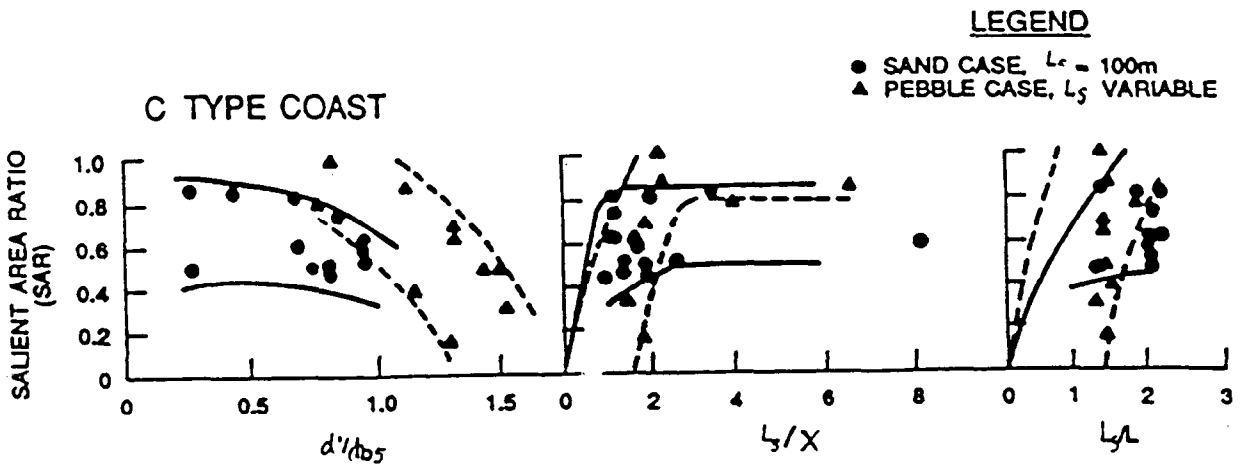


Figure 3a-3c. Salient area ratio versus site parameters for Beach Type B (modified from JMC 1986)



Figures 4a-4c. Salient area ratio versus site parameters for Beach Type C (modified from JMC 1986)

Step 4: Calculate first approximation to structure distance offshore, X':

$$X' = \frac{d'}{I} = \frac{2.5}{(1/30)} = 75 \text{ m}$$

Step 5: Calculate X_s'. First approximate X_s' by

$$X_s' = SAR \ X' \tag{3}$$

If X_s' is approximately equal to the given desired shoreline advancement X_s, then proceed to step 6, and let $X_s = X_s'$ and $X = X'$. Otherwise, repeat steps 2 through 5 until X_s' is approximately equal to the desired value, X_s. By comparing Equations (2) and (3), it is apparent that L_c, the length of the salient in the longshore direction, is assumed for the initial calculation to be twice the structure length (L_s).

$$X_s' = SAR \ X' = 0.6(75) = 45 \text{ m}$$

Since the desired salient length, X_s, is not 15 m, repeat steps 2 through 5 with a second estimate of structure depth, d'. Let water depth at structure $d' = 1.5$ m; then, using $d'/d_{b5} = 0.33$, estimate $SAR = 0.35$. The structure distance offshore is then $X' = 1.5/(1/30) = 45$ m. Estimated salient length $X_s' = 0.35\ (45) = 15.8$ m, approximately equal to desired salient length (15 m). Therefore, $X_s = X_s' = 15.8$ m, and $X = X' = 45$ m.

Step 6: Calculate ranges of structure segment length, L_s, based on ratios of structure length over local wave length at the structure ($L_5 = T_5(g\ d')^{1/2}$) using Figures 3c and 4c. Inspection of Figures 3c and 4c results in the following recommended ranges of L_s/L_5 for a sand-type beach:

Beach Type B: $$1.8 < \frac{L_s}{L_5} < 3.0 \tag{4}$$

Beach Type C: $$1.4 < \frac{L_s}{L_5} < 2.3 \tag{5}$$

$$L_5 = T_5\ (g\ d')^{1/2} = 12.0\ (9.81(1.5))^{1/2} = 46.0 \text{ m}$$

Using Equation (5) obtains $82.8 \text{ m} < L_s < 138.0$ m

Step 7: Calculate ranges of structure length, L_s, based on ratios of structure length to distance offshore from original shoreline, X, using Figures 3b and 4b. Inspection of Figures 3b and 4b results in the following recommended ranges of L_s/X for a sand-type beach:

Beach Type B: $$0.8 < \frac{L_s}{X} < 2.5 \tag{6}$$

Beach Type C: $$1.0 < \frac{L_s}{X} < 3.5 \tag{7}$$

Using Equation (6) obtains $36.0 \text{ m} < L_s < 112.5$ m

Step 8: Using Equations (4) and (6) for a Beach Type B, or Equations (5) and (7) for a Beach Type C, obtain ranges for structure length using the maximum lower value and minimum upper value, i.e. the intersection of the two equations. Structure length is then calculated as the average of the minimum and maximum values.

$$82.8 \text{ m} < L_s < 112.5 \text{ m}$$

Structure length is calculated as the average of the extremes:

$$L_s = \frac{82.8 + 112.5}{2} = 98 \text{ m}$$

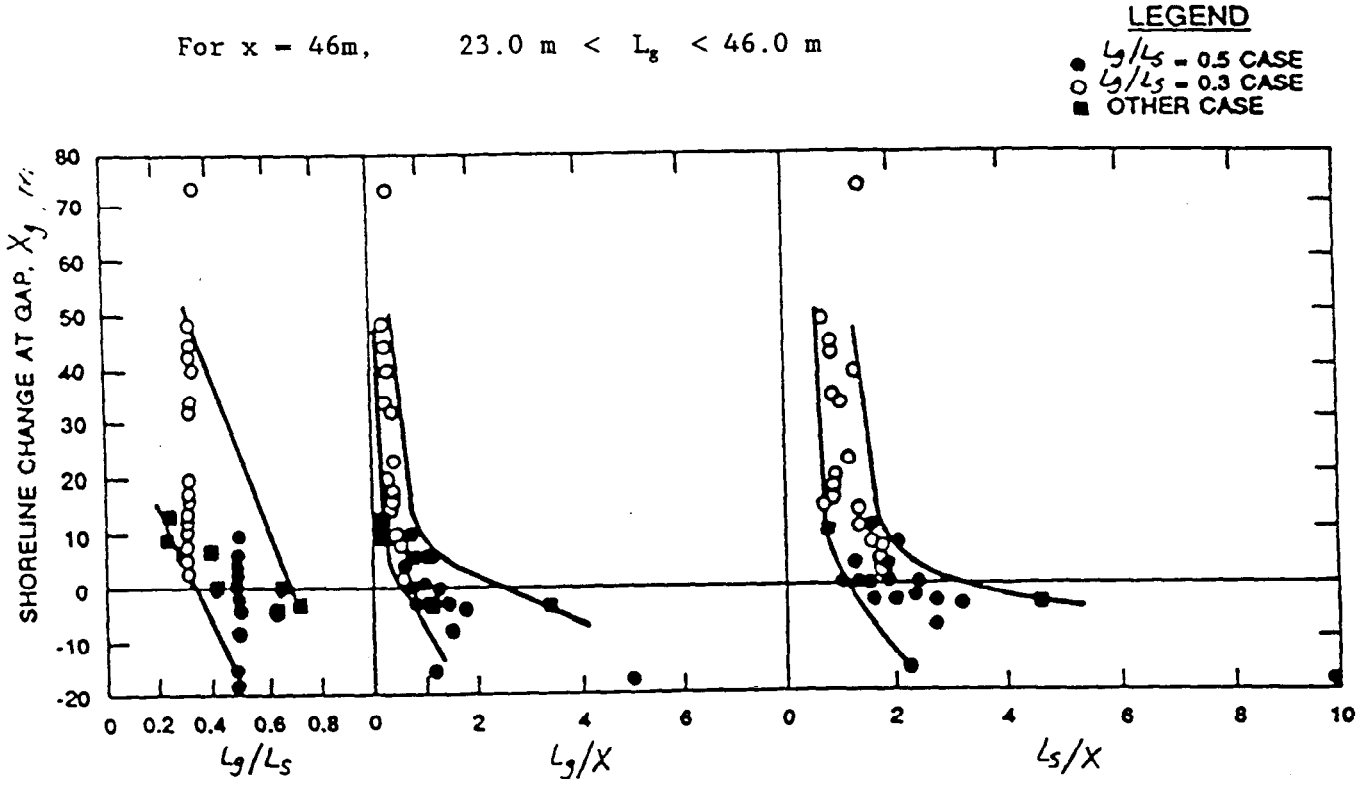
Step 9: If two times the structure length ($2L_s = L_c$) is less than the length of shoreline to be protected L_p, calculate a gap width, L_g, from Figures 5b and 5c. Inspection of Figures 5b and 5c results in the following recommended ranges of gap width for sand-type beaches:

$$0.7 < \frac{L_g}{X} < 1.8 \qquad (8)$$

$$0.5 < \frac{L_g}{L_s} < 1.0 \qquad (9)$$

For x = 45m, $31.5 \text{ m} < L_g < 81.0 \text{ m}$

For x = 46m, $23.0 \text{ m} < L_g < 46.0 \text{ m}$



Figures 5a-c. Relationship between nondimensional parameters and shoreline change at gap (JMC 1986)

Step 10: Obtain a range of values for L_g using the intersection of Equations (8) and (9) similar to step 8. The gap width, L_g, can then be calculated as the average of the maximum and minimum values.

For $31.5 \text{ m} < L_g < 46.0 \text{ m}$ the average of the two values yields

$$L_g = \frac{31.5 + 46.0}{2} = 39 \text{ m}$$

Step 11: Develop a functional design using the structure segment length, L_s, gap width, L_g, and distance offshore of the original shoreline, X, such that the length of project shoreline, L_p, will be protected.

To protect the length of project shoreline, $L_p = 380$ m, three breakwater segments with length $L_s = 98$ m are required, with a corresponding gap width of 39 m (Figure 6).

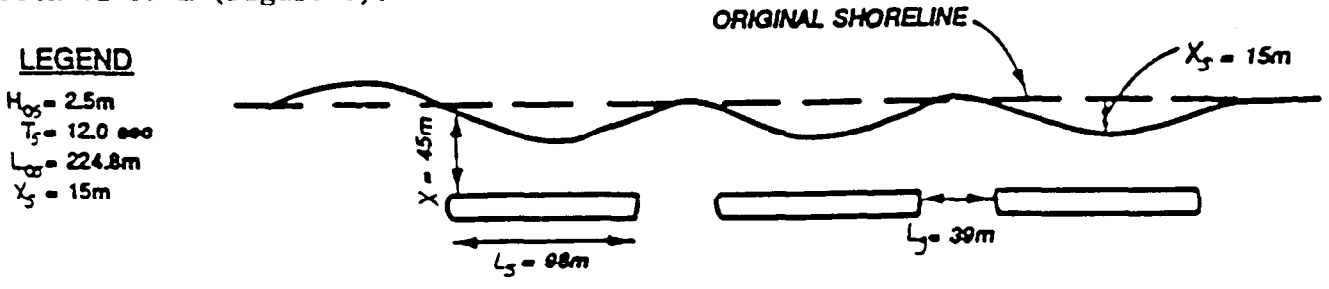


Figure 6. Design example

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DISCUSSION: Several other example problems are presented by Rosati and Truitt (in preparation), including the re-design of an existing three-segment detached breakwater project at Lakeview Park, Lorain, Ohio. Comparison of existing projects to those designed using the JMC method indicates that the JMC method tends to result in more numerous, shorter length segments with a decreased gap width. The structures are typically designed closer to the original shoreline than observed in U.S. projects. Empirical relationships developed from U.S. project data presented in the SPM (1984) and Dally and Pope (1986) predict that the shoreline may connect to the structure (true tombolo formation) at the design example presented above.

The JMC design procedure has been illustrated to give reasonable project parameters for a design example, and provides an alternative design process for field use. As with any design procedure, the limitations of this empirical method must be realized throughout the design process. In addition, the JMC procedure is developed based on prototype data obtained from the Japanese coast whose wave and longshore transport characteristics differ in may ways from that of the US coastline. In particular, care must be exercised when this procedure is applied to the shorelines of the Great Lakes and Gulf Coasts. Nevertheless, the JMC procedure serves to identify the specific steps and knowledge required in the preliminary design, suggesting directions for future research and better monitoring. The procedure may be directly applicable to the Pacific coast or the coasts of Hawaii.

ADDITIONAL INFORMATION: For further information about the JMC empirical design method, contact Dr. Yen-hsi Chu, CEWES-CD-SE (601) 634-2067, or Ms. Julie Rosati, CEWES-CR-P (601) 634-3005.

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