Coastal Engineering Technical Note

EMPIRICAL METHODS FOR THE FUNCTIONAL DESIGN OF DETACHED BREAKWATERS FOR SHORELINE STABILIZATION

PURPOSE: To present an overview of empirical relationships available for the design and prediction of beach response to single or segmented detached breakwater systems. Several of these relationships have shown to predict prototype response fairly well. This CETN summarizes information presented in Rosati (1990), and supplements the general information on detached breakwaters presented in CETN III-22 (1984).

BACKGROUND: Design techniques for detached breakwaters can be classified into three categories: physical and numerical models, empirical methods, and prototype assessment. Dally and Pope (1986) suggest a three-phase breakwater design process: first, a desk-top study employing various empirical relationships to relate proposed structural and site parameters to shoreline response and identify design alternatives; second, a physical or numerical model study to assess and refine alternatives; and finally, if feasible, a prototype test to verify and adjust the preliminary design.

Empirical relationships are somewhat limited due to their inherent simplicity; however, they can be used as reasonable methods prior to detailed studies to quickly assess prototype response to several design alternatives. Empirical design methods can also provide a means of assessing model results.

SUMMARY OF EMPIRICAL RELATIONSHIPS: Various empirical relationships are presented and evaluated in Rosati (1990). Table 1 presents a summary of these studies, which have been used to design both US and foreign detached breakwater projects.

Table 1
Empirical Relationships for Detached Breakwater Design

Inman and Frautschy (1966)	predicts accretion condition; based on beach response at Venice in Santa Monica, CA
Toyoshima (1972, 1974)	recommends design guidance based on prototype performance of 86 breakwater systems along the Japanese coast
Noble (1978)	predicts coastal impact of structures in terms of offshore distance and length; based on California prototype breakwaters
Walker, Clark, and Pope (1980)	discusses method used to design the Lakeview Park, Lorain, OH segmented system for salient formation; develops the Diffraction Energy Method based on diffraction coefficient isolines for representative waves from predominant directions

(continued)

Table 1 (concluded)

Gourlay (1981)	predicts beach response; based on physical model and field observations
Nir (1982)	predicts accretion condition; based on performance of 12 Israeli breakwaters
Rosen and Vadja (1982)	graphically presents relationships to predict equilibrium salient and tombolo size; based on physical model/prototype data
Hallermeier (1983)	develops relationships for depth limit of sediment transport and prevention of tombolo formation; based on field/laboratory data
Noda (1984)	evaluates physical parameters controlling development of tombolos/salients; especially due to on-offshore transport; based on laboratory experiments
Shore Protection Manual (1984)	presents limits of tombolo formation from structure length and distance offshore; based on the pattern of diffracting wave crests in the lee of a breakwater
Dally and Pope (1986)	recommends limits of structure-distance ratio based on type of shoreline advance desired and length of beach to be protected
Harris and Herbich (1986)	presents relationship for average quantity of sand deposited in lee and gap areas; based on laboratory tests
Japanese Ministry of Construction (1986); also Rosati and Truitt (1990)	develops step-by-step iterative procedure, providing specific guidelines towards final design; tends to result in tombolo formation; based on Japanese breakwaters
Pope and Dean (1986)	presents bounds of beach response based on prototype performance; response given as a function of segment length-to-gap ratio and effective distance offshore-to-depth at structure ratio; provides beach response index classification
Seiji, Uda, and Tanaka (1987)	predicts gap erosion; based on performance of 1,500 Japanese breakwaters
Sonu and Warwar (1987)	presents relationship for tombolo growth at the Santa Monica, CA breakwater
Suh and Dalrymple (1987)	gives relationship for salient length given structure length and surf zone location; based on lab tests and prototype data
Berenguer and Enriquez (1988); see also Ahrens (unpublished)	presents various relationships for pocket beaches including gap erosion and maximum stable surface area (i.e., beach fill); based on projects along the Spanish coast
Ahrens and Cox (in press)	uses Pope and Dean (1986) to develop a relationship for expected morphological response as function of segment-to-gap ratio

<u>EVALUATION OF METHODS:</u> Evaluation of the empirical design methods consisted of compiling data from five US breakwater projects, and comparing the prototype response with empirical predictions where possible. These projects encompass a range of structural and site parameters and beach response, from salient formation (Lakeview Park, Lorain, OH and Redington Shores, FL), to no sinuosity (Lakeshore Park, OH), to periodic tombolo formation (Colonial Beach, VA, Central and Castlewood Park Sections).

In general, the simplicity of the empirical methods evaluated and the lack of a large prototype database tended to result in widely varying predictions for most design relationships. However, several of the evaluated relationships have shown to be reasonable predictors, as long as their limitations are realized throughout the design process. A number of these relationships are presented herein. Rosati (1990) presents additional evaluations and provides correlation coefficients for the various comparisons. Parameter definitions are provided in Table 2.

Table 2
Parameter Definitions

L_g	Gap distance between adjacent breakwater segments
L_s	Breakwater segment length
X	Breakwater segment distance from original shoreline
X_g	Erosion/accretion opposite gap, measured from original shoreline
X_{gi}	Erosion/accretion opposite gap, measured from initial beach-fill shoreline
X_i	Breakwater segment distance from initial beach-fill shoreline
X_s	Salient/tombolo length in on-offshore direction measured from original shoreline
X_{si}	Salient/tombolo length in on-offshore direction measured from initial beach-fill shoreline

<u>Shoreline Response</u>. The most investigated effect of detached breakwaters is the relationship between project accretion, in particular, morphological response (salient or tombolo), and structural parameters. An evaluation of these relationships showed an apparent trend in the prototype data for deposition to increase as the structure length-to-distance offshore ratio increases (Rosati, 1990).

Suh and Dalrymple (1987) developed the following relationship for the prediction of salient length, X_s by combining movable-bed laboratory results with prototype data:

$$X_s = X\,(14.8)\,\frac{L_g\,X}{L_s^2}\;e^{\left(-2.83\sqrt{\frac{L_g X}{L_s^2}}\right)} \tag{1}$$

Tombolos usually formed for single prototype breakwaters when

$$\frac{L_s}{X} \geq 1.0 \qquad (2)$$

For multiple offshore breakwaters, tombolos formed when

$$\frac{L_g\, X}{L_s^2} \sim 0.5 \qquad (3)$$

For evaluation, Equation 1 was applied to all segmented projects. The relationship tends to overpredict the seaward excursion of the spit for the majority of prototype data evaluated; but, appears to accurately predict for pocket-beach type structures with periodic tombolo formations (Figure 1).

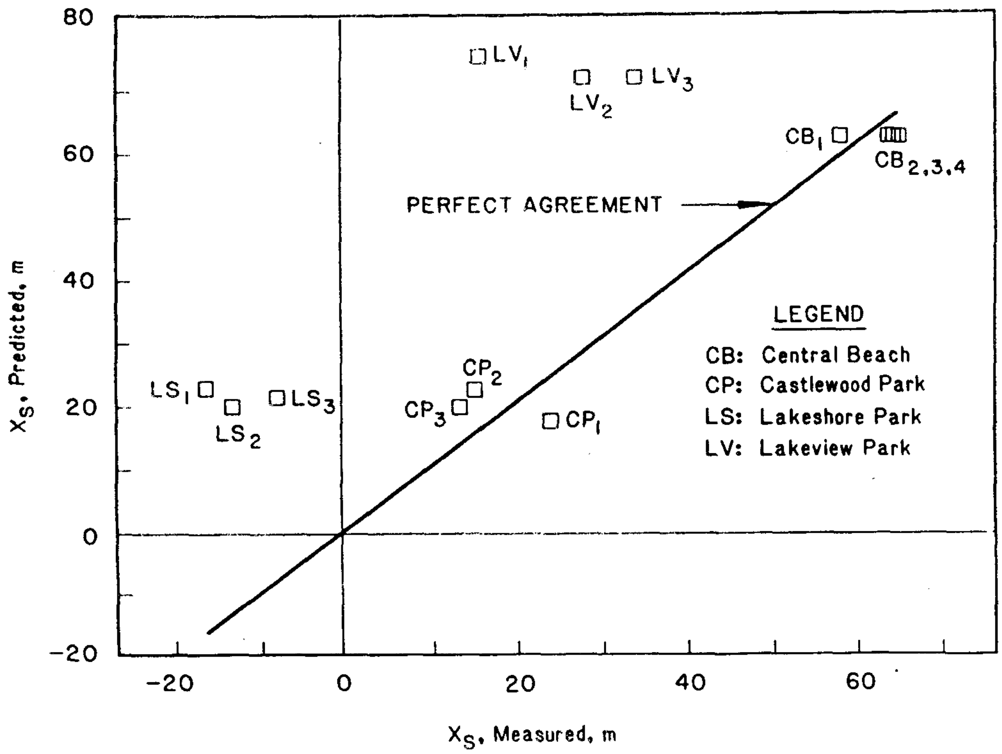

Figure 1. Evaluation of Suh and Dalrymple's (1986) relationship for salient length (Rosati, 1990).

Gap Erosion. Seiji, Uda, and Tanaka (1987) predict the following gap erosion relationships, where gap erosion is defined as the retreat of shoreline to the lee of the gap from the initial (pre-project) shoreline position:

$$\frac{L_g}{X} < 0.8 \quad \textit{no erosion opposite gap} \qquad (4)$$

$$0.8 \leq \frac{L_g}{X} \leq 1.3 \quad \textit{possible erosion opposite gap} \qquad (5)$$

$$\frac{L_g}{X} \geq 1.3 \quad \textit{certain erosion opposite gap} \qquad (6)$$

These relationships were evaluated with prototype data (Figure 2). The lower boundary for no erosion ($L_g/X < 0.8$) was a good predictor of either accretion or very little erosion. Gap erosion occurred for ratios of L_g/X greater than 0.8.

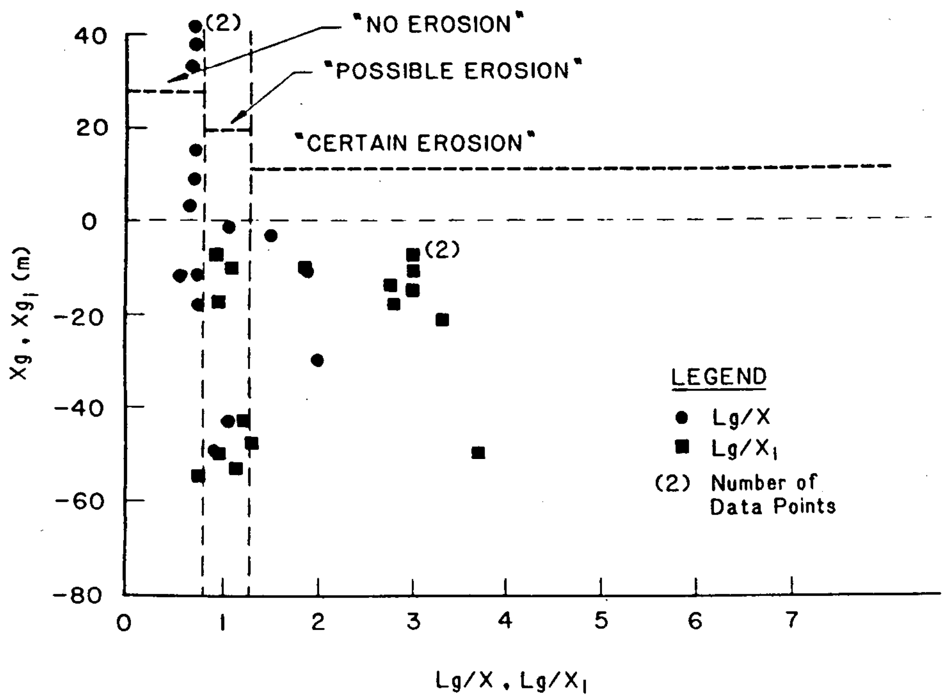

Figure 2. Evaluation of Seiji, Uda, and Tanaka's (1987) limits for gap erosion (Rosati, 1990).

<u>Structure Depth</u>. Hallermeier (1983) recommends the following depth as a guide for positioning detached breakwaters when tombolo formation is deemed undesirable:

$$d_{sa} = \frac{2.9\ H_e}{\sqrt{(S - 1)}} - \frac{110\ H_e^2}{(S - 1)\ g\ T_e^2} \quad \textit{depth for salient formation} \qquad (7)$$

where

d_{sa} = annual seaward limit of the littoral zone
H_e = deepwater wave height exceeded 12 hr per year
S = ratio of sediment to fluid density
g = acceleration of gravity
T_e = wave period corresponding to H_e

For headland structures (tombolo formation), structures should be sited near

$$d = \frac{d_{sa}}{3} \quad \textit{headland structures} \qquad (8)$$

where d = depth at the structure

This relationship was evaluated using the recommended depth for salient formation for all sites except for Colonial Beach, where the recommended depth for tombolo formation was used. An excellent correlation between depth at the structure and Hallermeier's recommended depth exists for all but the Lakeshore Park data (Figure 3).

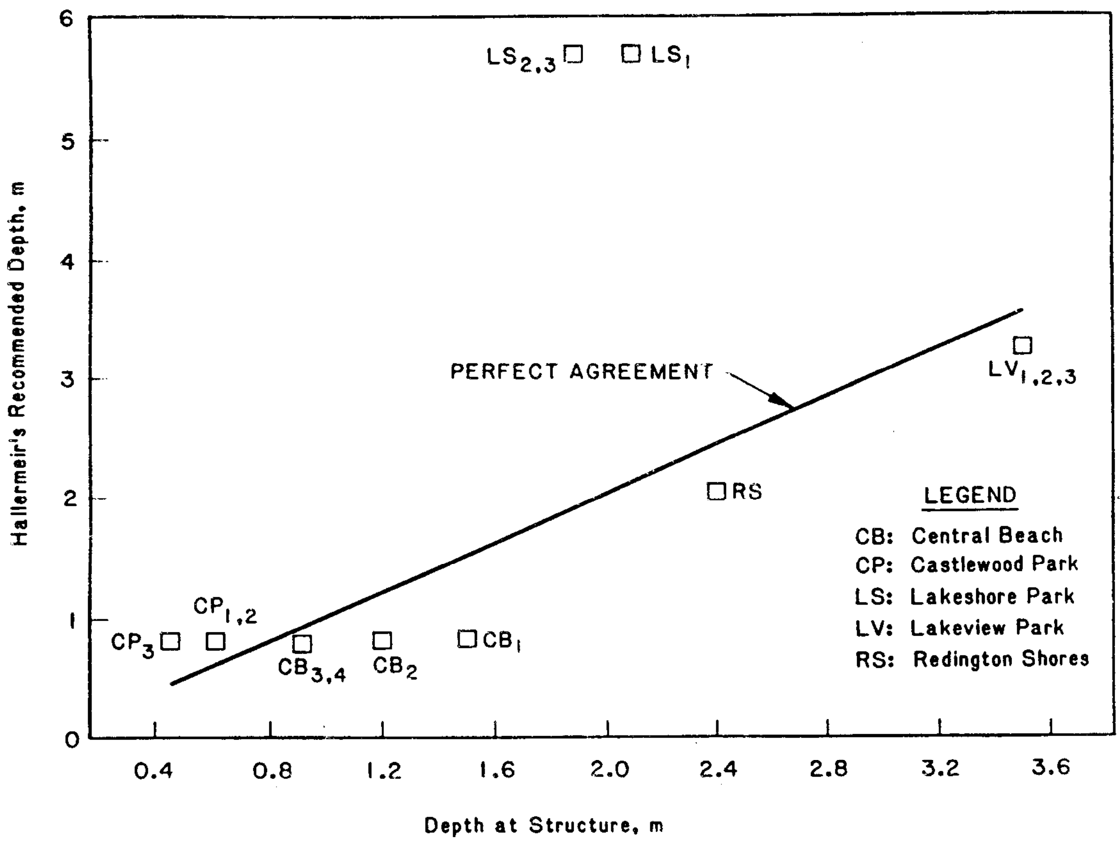

Figure 3. Evaluation of Hallermeier's (1986) relationship for structure design depth (Rosati, 1990).

Other Relationships. A comparison of the Japanese Ministry of Construction (JMC) method and the design from the Lakeview Park project was conducted by Rosati and Truitt (1990). For the four example problems and the site parameters evaluated, use of the JMC design tended to result in more numerous, shorter length segments with a decreased gap width. Additionally, these structures are placed closer to shore than observed in US projects.

The Lakeview Park project was used to intercompare relationships and further assess their validity (Rosati, 1990). The Diffraction Energy Method (Walker, Clark, and Pope, 1980) was used to design this project, which has been successful in terms of shoreline protection. A comparison of as-constructed project parameters to those recommended by the JMC method and Toyoshima's median-depth system was conducted. Both of these methods resulted in segment lengths and gap distances smaller than the constructed project, with structures positioned closer to shore than indicated by the Diffraction Energy Method.

SUMMARY: A desk-top study using empirical relationships is recommended as the first step in the design of a detached breakwater system. This CETN summarizes empirical methods available in the literature, and should aid the engineer in identifying a subset of methods to be considered for a particular project design.

ADDITIONAL INFORMATION: Continuing research at the Coastal Engineering Research Center (CERC) is developing additional desk-top guidance and improved methods for detached breakwater design. For further information on breakwater design guidance, contact Monica Ippolito, CERC, Coastal Structures and Evaluation Branch, (601) 634-2072.

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