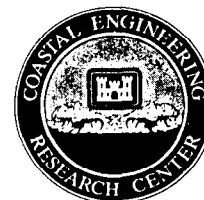




Coastal Engineering Technical Note



SIZING OF TOE BERM ARMOR STONE ON RUBBLE-MOUND BREAKWATER AND JETTY TRUNKS DESIGNED FOR DEPTH-LIMITED BREAKING WAVES

PURPOSE: To provide design guidance for sizing toe berm armor stone on breakwater and jetty trunks exposed to depth limited breaking waves whose crests approach at or near parallel to the structure.

DISCUSSION: Under the Repair, Evaluation, Maintenance and Rehabilitation (REMR) Research Program, the Coastal Engineering Research Center (CERC) conducted a field experience survey of the Corps of Engineers coastal districts (Markle, 1986) which revealed that design guidance based on research for toe berms fronting rubble-mound structures was nonexistent. It was discovered that the rubble-mound toe berm designs were usually based on one of the following; (a) field experience, (b) weight of toe berm armor should be at least one-tenth the primary armor weight (SPM, 1984), or (c) research by Brebner and Donnelly (1962) and Tanimoto, Yagyu and Goda (1982) on foundation and toe berm materials lying beneath and/or in front of vertical structures, i.e. caissons, timber cribs, etc.

TESTS: Under the REMR work unit "Rehabilitation of Rubble-Mound Structure Toes" a series of two-dimensional, physical model, wave stability tests were developed and conducted by CERC during the 1985-86 time period. The purpose of the tests was to develop guidance to aid in sizing toe berm armor stone for rubble-mound breakwater and jetty trunks which will be exposed to depth-limited breaking waves whose wave crests approach at or near parallel to the structures.

RESULTS: For rubble-mound structures similar to the one shown in Figure 1, toe berm stability is strongly related to the ratio d_1/d_s , where d_1 is depth of water over the toe berm and d_s is water depth the structure is constructed in. Toe berm armor stone stability can be defined in terms of the nondimensional stability number, N_s , defined as follows:

$$N_s = \left(\frac{\gamma_r}{(W_3)_{50}} \right)^{1/3} \frac{H_D}{(S_r - 1)} \quad (\text{SPM, 1984}) \quad (1)$$

where

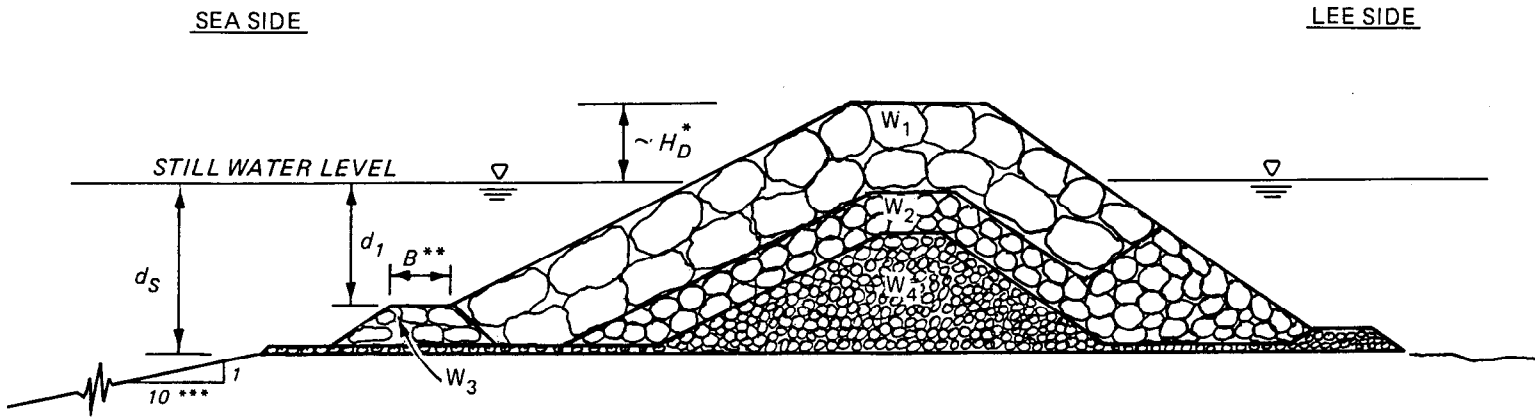
- $(W_3)_{50}$ = median weight of individual toe berm stone, lb
 (See Figure 1)
- γ_r = unit weight of toe berm stone, pcf
- H_D = design wave height (breaking wave defined at depth d_s),
 ft (minimal stone movement)
- S_r = specific gravity of toe berm stone relative to the water
 in which the structure is situated ($S_r = \gamma_r/\gamma_w$)
- γ_w = unit weight of water, pcf

Solving for the median weight of individual toe berm armor stone, $(W_3)_{50}$, from Equation (1),

$$(W_3)_{50} = \frac{\gamma_r H_D^3}{N_s^3 (S_r - 1)^3} \quad (\text{SPM, 1984}) \quad (2)$$

For a given prototype design, N_s^3 is the only unknown in the above equation that is needed to determine W_{50} . A plot of N_s^3 as a function of d_1/d_s measured during the two dimensional tests is presented in Figure 2. All data points on Figure 2 represent acceptable levels of damage on the toe berm armor stone. The vertical spread of N_s^3 at a specific value of d_1/d_s appears to be a function of water depth and wave period (d/L) but the trend was not developed well enough to define a contour plot. For this reason, a lower limit line was added to Figure 2 which defines the lower boundary of the data. It is recommended that values of N_s^3 equal or less than those defined by this line be used for depth-limited breaking wave design unless site specific tests are conducted to justify larger (less conservative) stability numbers. The values of N_s^3 recommended by this test series can be compared to those

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CONSTRUCTION MATERIALS

$W_1 = 1.25 (W_1)_{50}$ TO $0.75 (W_1)_{50}$	PRIMARY ARMOR STONE
$W_2 = W_1/10 = 1.3 (W_2)_{50}$ TO $0.7 (W_2)_{50}$	UNDERLAYER STONE
$W_3 = 1.3 (W_3)_{50}$ TO $0.7 (W_3)_{50}$	TOE BERM ARMOR STONE
$W_4 = W_1/200$ TO $W_1/4000$	CORE AND BEDDING STONE

* H_D = DESIGN WAVE HEIGHT. ** $B = 3t$ WHERE $t = ((W_3)_{50}/\gamma)^{1/3}$ AND γ = SPECIFIC WEIGHT OF STONE

*** ALL TESTS WERE CONDUCTED WITH 1:10 FORE SLOPE.

Figure 1. Typical multilayered rubble-mound structure designed for depth-limited breaking waves with little or no overtopping

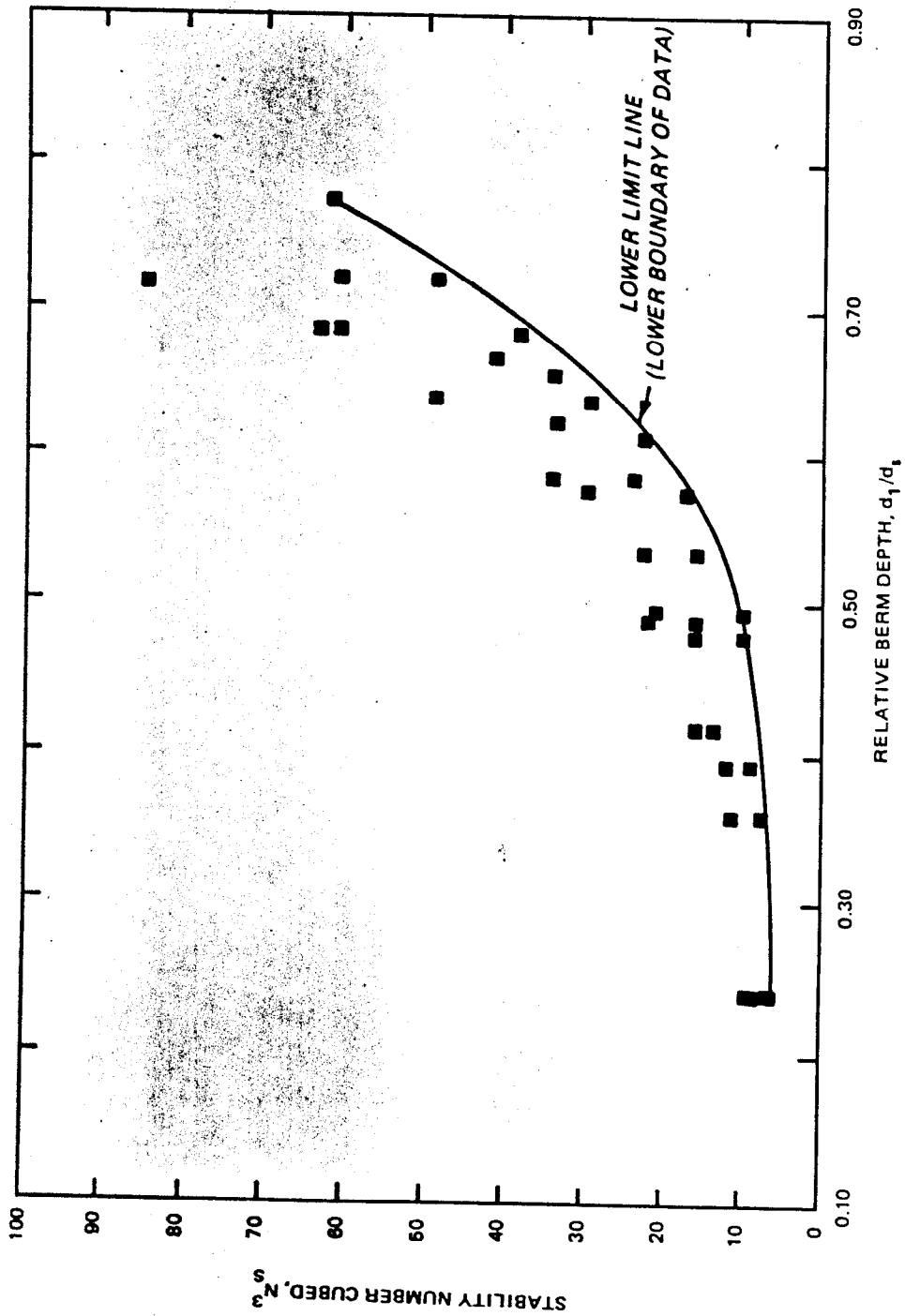
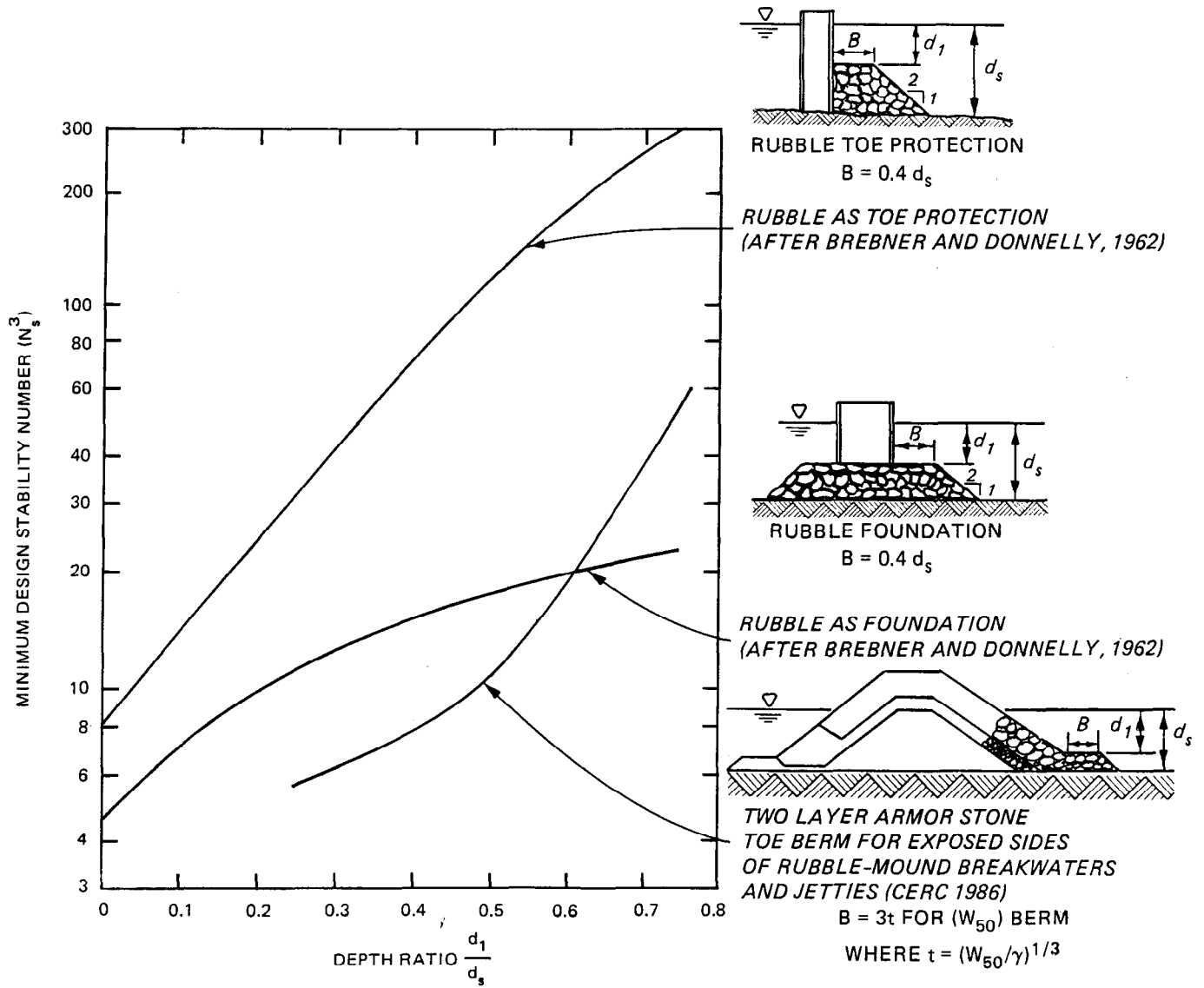


Figure 2. Stability number cubed versus relative berm depth for toe berm stone designed for depth-limited breaking waves whose crests approach at or near parallel to the structure.

Figure 3. Stability number cubed versus depth ratio for rubble toes and foundations for vertical structures and armor stone berms fronting rubble-mound structures



NOTE: N_s^3 VALUES FOR TOE BERMS FRONTING RUBBLE-MOUND STRUCTURES ARE FOR BREAKING WAVE DESIGN CONDITIONS.

recommended by Brebner's et.al (1962) data by plotting the data together as presented in Figure 3. It can be seen that in cases where d_1/d_s is less than approximately 0.62, design for depth limited breaking waves on rubble-mound trunks requires larger stones than recommended by Brebner et.al for foundation and berms fronting vertical structures. (Brebner's et.al tests did not use a steep foreslope and critical depth-limited breaking waves).

DISCUSSION: When toe berm stones are used on a structure being constructed on an erodible bottom material, adequate thicknesses and gradations of filter or bedding layers need to be incorporated into the design to prevent the leaching of foundation material. Failure to do this could result in the ultimate failure of the entire structure.

The toe berm armor stone stability numbers recommended herein are for use on rubble-mound breakwater and jetty trunks designed for depth-limited breaking waves whose crests approach at or near parallel to the structure. Preliminary test results for ongoing three dimensional tests addressing toe berm armor stone designed for trunks under oblique wave attack and structure heads are showing that these latter incident wave conditions are less severe and will most likely not require as large a toe berm stone. These latter tests are scheduled for completion in 1988 at which time a comprehensive report will be prepared and published and information will be available to update EM-1110-2-2904, "Design of Breakwaters and Jetties."

For toe berms being designed for nonbreaking waves the SPM (1984) recommends that the toe berm armor stone should be one tenth the weight of the primary armor stone. It is recommended that this guidance continue to be followed and for critical structures, the design adequacy should be checked through site specific model tests.

ADDITIONAL INFORMATION: A more comprehensive description of the two-dimensional tests discussed herein are presented in a draft ETL (Markle, unpublished). For further information please contact Mr. Dennis G. Markle of CERC, Wave Research Branch at (601)634-3680 or FTS 542-3680.

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Brebner, A. and Donnelly, P. 1962. "Laboratory Study of Rubble Foundation for Vertical Breakwaters," C. E. Research Report No. 23, Queens University, Kingston, Ontario.

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