Coastal Engineering Technical Note

COMPUTER PROGRAM: TOEPRO (MACE-21) DESIGN OF RUBBLE TOE PROTECTION FOR A COASTAL STRUCTURE

PROGRAM PURPOSE: TOEPRO uses design wave height, wavelength, depth of breaking, depth of penetration of sheet piles, coefficient of passive earth pressure for soil at toe and water depth at site of structure and calculates toe stone sizes for a number of section geometries of toe protection for a coastal structure using equations and a graph based on Tanimoto's method (will be presented in revised pages of Shore Protection Manual and EM 1110-2-1614 (USACE).

PROGRAM CAPABILITY: TOEPRO investigates a number of alternative stone sizes and section geometries and produces a tabular printout of median weight of toe stone, width of toe apron, height of toe apron, and depth of water over toe apron. A check is also made in the program to establish that the water depth at the structure is greater than the breaking depth, and a warning is given if the water depth at the structure is less than the breaking depth.

BACKGROUND: Anchored bulkheads, (retaining walls of waterfronts) are classified into two types on the basis of use. Design benefits to be achieved for the first type (the waterfront operational facility) are optimal discharge and receipt of cargo. Design benefits to be achieved for the second type (shore protection structure) are stabilizing shoreline and preventing erosion. Bulkheads are normally constructed with a vertical face, and wave reflection is maximized. Wave reflection increases the height of waves at the structure inducing scour at the toe. Since excessive scour causes failure, toe protection may be necessary to insure stability.

TOEPRO can be also used for determining armor stone size and examining geometries of toe protection for sheet pile wall and vertical gravity wall breakwaters and for determining armor stone size and examining geometries of rubble foundations for composite breakwaters.

Should toe stone be insufficiently sized, removal by action of waves begins as wave disturbance is felt by toe stone during the elliptical orbital motion of water particles under a wave. Fluid flow results in a vertical wave force, which is the sum of vertical inertia and vertical drag forces. The vertical force lifts up on an individual toe stone and reduces its effective buoyant weight. At the same time, or slightly thereafter, the horizontal wave force associated with the wave (which is the sum of horizontal inertia and horizontal drag forces) pushes toe stone of reduced weight to an adjacent location.

Insufficiently sizing toe stone could be disastrous and calculating toe stone weights by hand for various alternative toe apron geometries is tedious and time consuming.

PROGRAM APPLICATION: By examining various alternative toe stone weights and section geometries calculated by TOEPRO, selection of toe protection design that will most nearly satisfy the requirement of scour protection at the lowest practicable cost is facilitated. TOEPRO computes toe apron width, varies the depth of water over the toe apron, calculates toe apron thickness, and calculates median toe stone weight corresponding to each alternative geometry.

TOEPRO computes toe stone weights corresponding to values of depth from 1 to 9 feet, in increments of 0.5 foot. Calculated toe stone weights should be considered approximate values which serve as guidelines. Toe stone weights might require doubling to be conservative, as suggested in the Shore Protection Manual. Conservatism is necessitated due to possible errors inherent in use of an empirical method (developed by using physical model results) to design the prototype and due to two quality control considerations. The first quality control consideration relates to stability number being a function of shape of stone. Shapes attained in the field can vary significantly within limits set by specifications. The commonly encountered clause in the specifications constraining shape is that "Neither breadth nor thickness of any rock shall be less than 1/3 of its length". The construction contractor can utilize quite a variety of toe stone shapes and still construct toe apron in compliance with this specification. The second quality control consideration relates to the stability number being a function of the placing method of the stone. Use of the method of end dumping to place toe stone atop filter rock several feet below mean low water results in segregation of toe stone. Controlling quality by assuring attainment of an even distribution of toe stone by construction inspectors is difficult unless underwater inspection is performed. Underwater inspection of toe stone by special television cameras is rarely used because it is costly and time consuming.

TOEPRO only works for input values that might reasonably be encountered at the structure site. For instance, erroneously large values of the coefficient of passive pressure may result in excessively large values of toe apron width and unrealistic values of toe stone weight being calculated. Even though the method upon which TOEPRO is based is the best available, only input values normally encountered at the shoreline will give realistic results. For the case of toe protection for scour caused by tidal or riverine currents alone, it is suggested that the engineer consider utilization of EM 1110-2-1601.

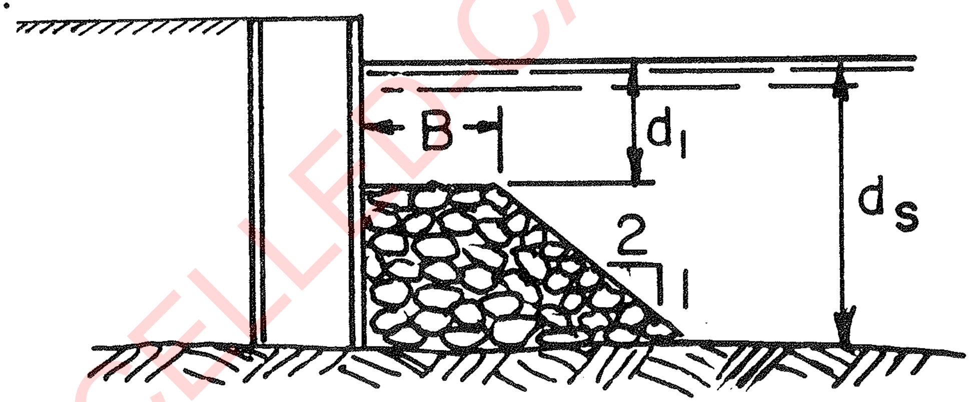
PROGRAM AVAILABILITY: TOEPRO is available for the IBM PC on a 5-1/4-in. diskette or as a printed program listing and may be obtained from Ms. Gloria J. Naylor at (601) 634-2581 (FTS: 542-2581), Engineering Computer Programs Library Section, Technical Information Center, US Army Engineer Waterways Experiment Station, P.O. Box 631, Vicksburg, MS 39180-0631. Questions concerning the application of TOEPRO can be directed to

Mr. Gordon E. Staab at (601) 634-2139 (FTS 542-2139) of the Coastal Engineering Research Center's Coastal Design Branch.

INPUT: It is necessary to provide 6 input parameters to use TOEPRO: design wave height associated with water depth at site of structure, design wavelength, depth of breaking, depth of penetration of sheet piles, coefficient of passive earth pressure for soil at toe, and water depth at site of structure. For the water depth at site of structure, the minimum depth should be used; it is the low water level correlated with large waves that creates the worst scour condition.

Deepwater design wave height may be estimated according to the procedure found in Chapter 7 of the Shore Protection Manual, and a value between H1 and H10 may be used as suggested in both the Shore Protection Manual and EM 1110-2-1614. Design wave height and wavelength that occur in the depth of water at the structure site in absence of toe protection can be estimated from the deep water wave height and wavelength using MACE program SINWAVES.

The depth of breaking also may be estimated by using SINWAVES. Depth of breaking is needed because the design procedure upon which the algorithm is based works only for nonbreaking waves. It should be noted that the ratio of apron width to incident wave length is sufficiently small, (as indicated in unpublished wave data collected by Camfield) therefore the wave will not have time to react to the toe apron and break before reaching the coastal structure.



Rubble Toe Protection

OUTPUT: TOEPRO prints width of toe apron (B) median weight of toe stone, height above existing bottom of toe apron (d_s-d_1), and depth of water over toe apron (d_1), in tabular form.

SAMPLE PROBLEM What is toe stone weight and thickness of toe apron if the significant wave height is 6 feet, wavelength is 288 feet, depth of sheet pile penetration is 6 feet, coefficient of passive earth pressure is 1.5, depth of water in absence of toe protection is 10 feet and depth of breaking wave is 8.1 feet?