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REMR Management Systems—Coastal/Shore Protection Structures

Condition and Performance Rating Procedures for Rubble Breakwaters and Jetties

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Preface

The program documented herein was authorized by Headquarters, U.S. Army Corps of Engineers (HQUSACE), as part of the Operations Management problem area of the Repair, Evaluation, Maintenance, and Rehabilitation (REMR) Research Program. The work was performed under Civil Works Research Unit 32672, “Development of Uniform Evaluation Procedures/Condition Index for Civil Work Structures,” for which Mr. Don Plotkin is Principal Investigator. Mr. Harold Tohlen (CECW-O) is the REMR Technical Monitor for this study.

Dr. Tony Liu (CERD-C) is the REMR Coordinator at the Directorate of Research and Development, HQUSACE. Mr. Tohlen and Dr. Liu serve as the REMR Overview Committee. Mr. William F. McCleese (CEWES-SC-A), U.S. Army Engineer Waterways Experiment Station (WES), is the REMR Program Manager. Mr. David T. McKay (CECER-FL-P), U.S. Army Construction Engineering Research Laboratories (USACERL), is the Problem Area Leader for the Operations Management problem area.

This work was conducted under the general supervision of Dr. Simon Kim, Chief of the Maintenance Management Division (FL-P), Infrastructure Laboratory (FL) at USACERL. The authors gratefully acknowledge the assistance of the Coastal Structure Advisory Group and many others throughout the Corps’ coastal community whose excellent ideas helped guide this work.

Dr. Michael J. O'Connor is Director of USACERL.

1 Introduction

Background

In an effort to improve maintenance techniques and practices for inland waterway and coastal structures, the U.S. Army Corps of Engineers (USACE) established the Repair, Evaluation, Maintenance, and Rehabilitation Research (REMR) program. Within the REMR program is a group of projects dedicated to the development of computerized maintenance management systems for coastal and inland waterway navigational structures. The general intent of these REMR Management Systems is to provide maintenance managers at all levels with tools to promote easier and more effective maintenance and budget planning. Additional objectives are to create uniform procedures for assessing the condition of structures and to create assessment methods that allow the condition of structures, and their parts, to be expressed numerically to take best advantage of the benefits available from the use of microcomputers in maintenance management.

The condition and performance rating procedures described here evolved over several years through the joint effort of a number of people throughout the Corps' coastal Operations and Management (O&M), engineering, and research community. Representatives of each coastal Engineer Division have been part of the advisory group guiding the project, and suggestions from people in every coastal Engineer District have been used to produce the rating system documented here. It is expected that field application of these condition rating procedures will lead to further refinement and improvement over time.

Objectives

The objectives of this phase of the project were to:

- a.* Establish a rational, standard procedure for evaluating the physical condition and performance of rubble breakwaters and jetties.
- b.* Create a method for determining numerical condition and performance ratings, which, in turn, would be used to produce Condition Index (CI) values for the structures.

This report describes the system created to accomplish these objectives. It also describes a process for collecting the information needed to make the condition and performance evaluations. Some of the required information is not used directly in producing condition index values, but is considered necessary for a good inspection, analysis, and evaluation.

Scope

The condition rating system described here represents the first stage in developing a maintenance management system for coastal navigation and protection structures. The computer software (currently called BREAKWATER) that will operate the management system is being developed to calculate the CI values, as described in Chapter 7, and ultimately perform other required management system functions.

The complete O&M budget planning process (and thus a complete maintenance management system) must incorporate the following major factors, generally evaluated in this sequence:

- a.* Structure condition
- b.* Structure performance
- c.* Risk/Reliability
- d.* Economics
- e.* Policies and priorities

The evaluation system described here covers the first two factors, mainly for breakwaters and jetties of rubble construction with either rock or concrete armor units. Results from this evaluation system are intended to feed methods for handling factors c, d, and e. Future efforts will include system features for breakwaters and jetties of non-rubble construction and also seawalls, bulkheads, and revetments.

Approach

The research for this project was conducted as a joint effort between USACERL and the Corps coastal divisions and districts. Assisting in development was the Coastal Structure Advisory Group (CSAG), which included representatives from each of the nine Coastal Engineer Divisions, the Coastal Engineering Research Center, and Corps headquarters.

Concepts for the condition rating procedures were generated by the authors, the CSAG, and other members of the Corps' coastal community. These concepts were refined through experience and field testing by the Engineer Districts. The procedures documented here were the result of many iterations of development and refinement. The intent was to produce a system specific enough so all structures would be assessed in the same manner, and yet broad enough to allow for the many variations inherent in coastal structures.

Mode of Technology Transfer

It is recommended that these evaluation procedures be distributed to the field through an Engineering Circular and incorporated into an Engineer Regulation.

2 REMR Management Systems

REMR Management Systems are intended to provide maintenance managers at all levels with tools to promote easier and more effective maintenance and budget planning. They are decision support tools to help managers determine when, where, and how to effectively allocate maintenance and rehabilitation dollars for Civil Works facilities. These systems are being developed to provide:

- a. More objective condition assessment procedures.
- b. Corps-wide consistency in structure assessment.
- c. A means for comparing the condition of facilities and tracking change in condition over time.
- d. A means for O&M project development based on consistent structure condition and performance criteria.
- e. Computer software for storing and organizing data, performing calculations, and producing a variety of reports (on structure condition, budgets, maintenance, repair records, etc).

The primary objective of the REMR Management Systems is to help managers obtain the best facility condition for a given budget level. The basic system features are shown schematically in Figure 1.

Application of the Maintenance Management Systems

The REMR Management Systems are intended to help determine when structures will warrant repair action, and the appropriate type and extent of repairs. Structure or project deficiencies that cannot be corrected through standard maintenance or repair actions are beyond the scope of these systems and must be handled through other processes.

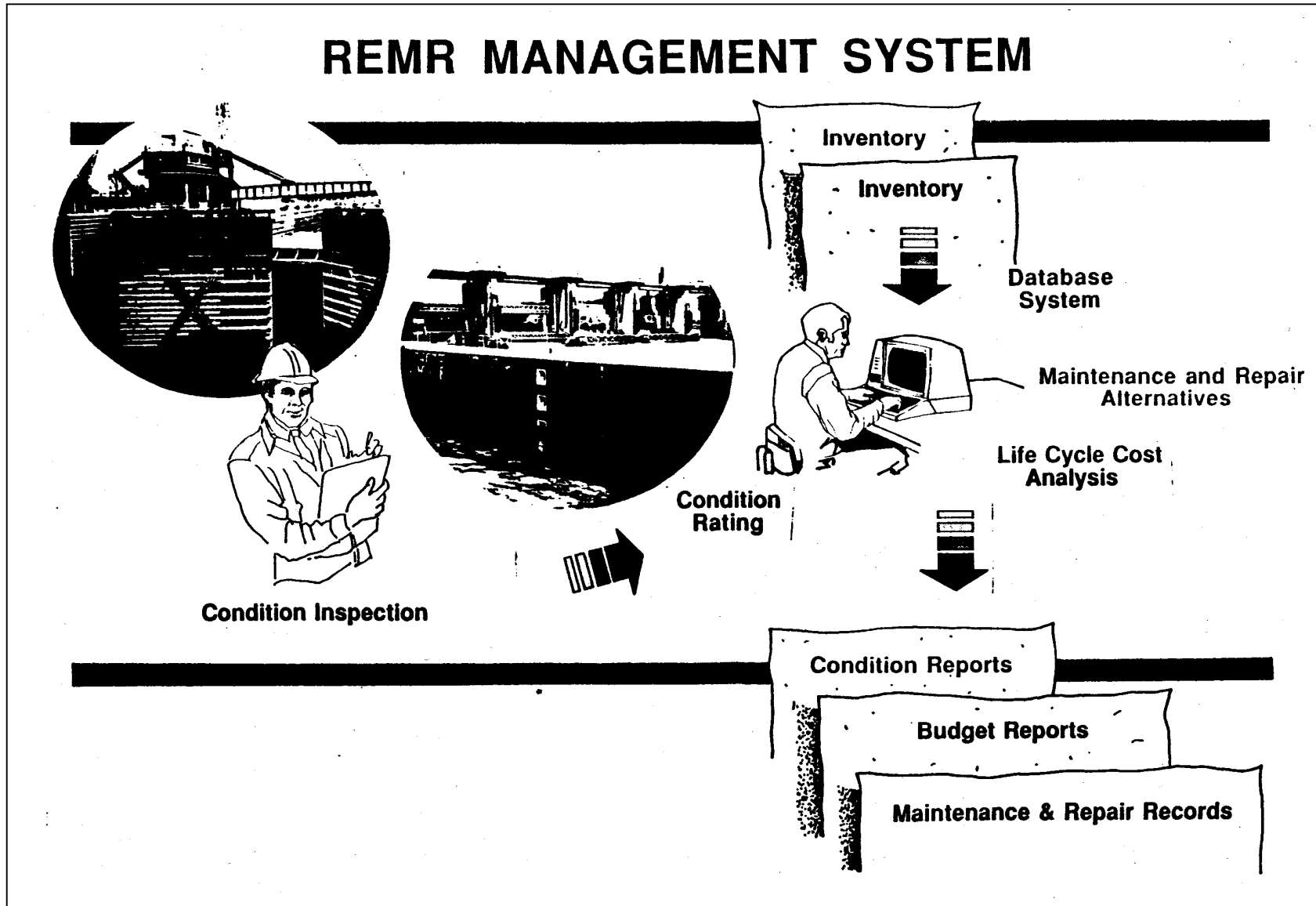


Figure 1. REMR Management Systems.

Performance-Based Evaluation

The evaluation process described in this manual is performance-based. Its main purpose is to answer the question: Is the structure in good enough condition to provide the intended performance? To answer this question it is essential to establish the performance requirements for each structure:

- a. What functions is the structure intended to perform?
- b. What level of performance is expected for each function?

Once these performance requirements are established, the physical condition of the structure is assessed. Any structural defects found are then evaluated according to their effect on loss of structure function, which in turn leads to a decision on the need for repair.

In a performance-based system, the difference between current structure condition and as-built (or "like new") condition is not, in itself, a deciding factor in the need for repair. Rather, it is a structure's documented loss of function as a result of structural deterioration that is most important.

The Condition Index

One objective of REMR Management Systems is to create assessment methods that will allow the condition of structures, and their parts, to be expressed numerically to take best advantage of the benefits available from the use of microcomputers in maintenance management. This "numerical language" for expressing the condition of facilities is the Condition Index (CI).

Index numbers (or condition ratings) for all structures covered by REMR Management Systems are based on the general condition index scale shown in Table 1. While each structure, structure part, or rating category has its own scale and corresponding condition descriptions, all condition index scales contain the same three zones and seven condition levels, and their general interpretation remains the same. Index values in all scales (from the most general to the most specific) are properly interpreted as representing the conditions found at the time the structure was inspected and rated.

The main objectives of the condition index system are to:

- a. Create a more uniform method for evaluating and then describing the condition of coastal structures.

- b. Create a concise reporting system that indicates the deficiencies a structure may have, which parts of the structure are deficient, and the relative severity of the deficiencies.
- c. Create a convenient means for comparing the condition of structures over long time periods.

Referring to the general CI scale (Table 1), structures rated within Zone 1 (70 to 100) are fully functional. Those rated in Zone 2 (40 to 69) have significant functional deficiencies, but their function is still considered adequate to perform their primary mission. Structures rated in Zone 3 (0 to 39) are functionally inadequate.

Table 1. General REMR Condition Index scale.

Observed Damage Level	Zone	Index Range	Condition Level	Description
Minor	1	85 to 100	EXCELLENT	No noticeable defects. Some aging or wear may be visible.
		70 to 84	GOOD	Only minor deterioration or defects are evident.
Moderate	2	55 to 69	FAIR	Some deterioration or defects are evident, but function is not significantly affected.
		40 to 54	MARGINAL	Moderate deterioration. Function is still adequate.
Major	3	25 to 39	POOR	Serious deterioration in at least some portions of the structure. Function is inadequate.
		10 to 24	VERY POOR	Extensive deterioration. Barely Functional.
		0 to 9	FAILED	No longer functions. General Failure or complete failure of a major structural component.

It is intended that this system conform with the assessment that knowledgeable inspectors would make based on the results of their own visual inspections (and additional data, when available).

Condition Index for Breakwaters and Jetties

For coastal structures, the CI is determined from a Functional Index (FI) and a Structural Index (SI). The FI indicates how well a structure (or reach^{*}) is performing its intended functions, while the SI for a structure or structural component indicates its level of physical condition and structural integrity.

Before the first inspection and ratings are made, each structure must be divided along its length into permanent reaches as discussed in Chapter 4. These reach boundaries will apply to all future CI inspections and ratings. In addition, structure performance requirements must be defined, as well as the minimum structural integrity level that will permit proper performance. (See “Steps in the Functional Rating Process” in Chapter 6).

The structural and functional rating and index process is diagramed in Figures 2 and 3. Starting at the bottom of Figure 2 and working upward, an inspector (or inspection/engineering group) produces ratings in structural categories for each reach of a breakwater or jetty. These ratings are determined primarily from visual inspections of the structure, along with the rating guidance provided in this report. (Additional information such as hydrographic surveys or underwater inspections may also be useful. The ratings for each reach are entered into the management computer program, which will calculate SI values for the crest, seaside, and channel/harborside, and then, an SI for the reach.

A functional analysis is then made, using field inspections, local reports, and other observations of how the structure performed during the last budget cycle. Functional ratings are based on the loss of function due to structural deterioration (which was documented during the structural rating process).

As with structural ratings, the functional ratings are also entered into the management computer program. From the SI and FI for each reach, the program will determine the SI, FI, and CI for the whole structure, as diagramed in Figure 3.

Interpreting and Using the Condition Index

The condition index is primarily a planning tool, with the index values serving as an indicator of the structure's general condition level. The CI values are also intended for monitoring the structure's change in condition over time and to serve as a means for comparing the condition of different structures.

* Reach: a specific segment of a structure, defined in terms of functional and structural characteristics.

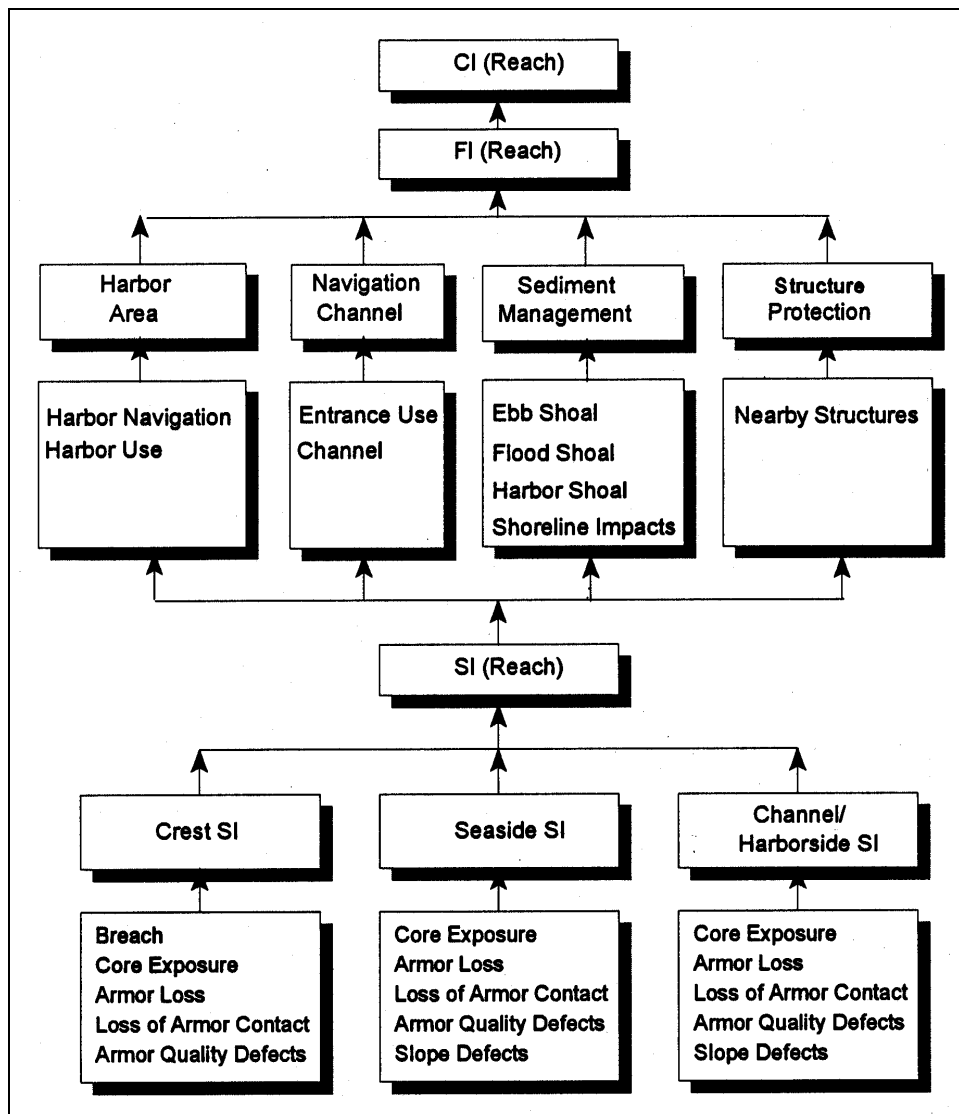


Figure 2. CI process for a reach.

For some purposes, there may be more interest in values at the lower end of the CI process (the structural ratings within each reach, as shown in Figure 2). For other purposes, there may be more need for the values nearer the top (the index values for whole reaches or structures, as shown in Figure 3). In either case, the CI values for any structure should be thought of as including all levels of detail.

One of the main uses of CI values is to track changes in condition over time, as illustrated in Figure 4. With historical trends, and knowledge of structure environment, future rates of deterioration may be estimated and used to plan the timing of repairs and corresponding maintenance expenditures. To achieve this purpose, it is essential that the ratings (and calculated index values) represent conditions as recorded at the time the structure was inspected (or, for functional ratings, proven by recent events). Any attempt to include expectations of future condition would distort the values and make them

useless as a record of actual structure condition, and thus useless for estimating future deterioration rates.

It is important to understand that the process of determining condition is different than the process of deciding what action, if any, to take because of structure condition. If two breakwaters (Structures 1 and 2, for example) are both in moderately good physical condition, they both may have SI values of about 65. If Structure 1 has shown progressive deterioration over the past 5 years and is in a heavy wave environment, it may

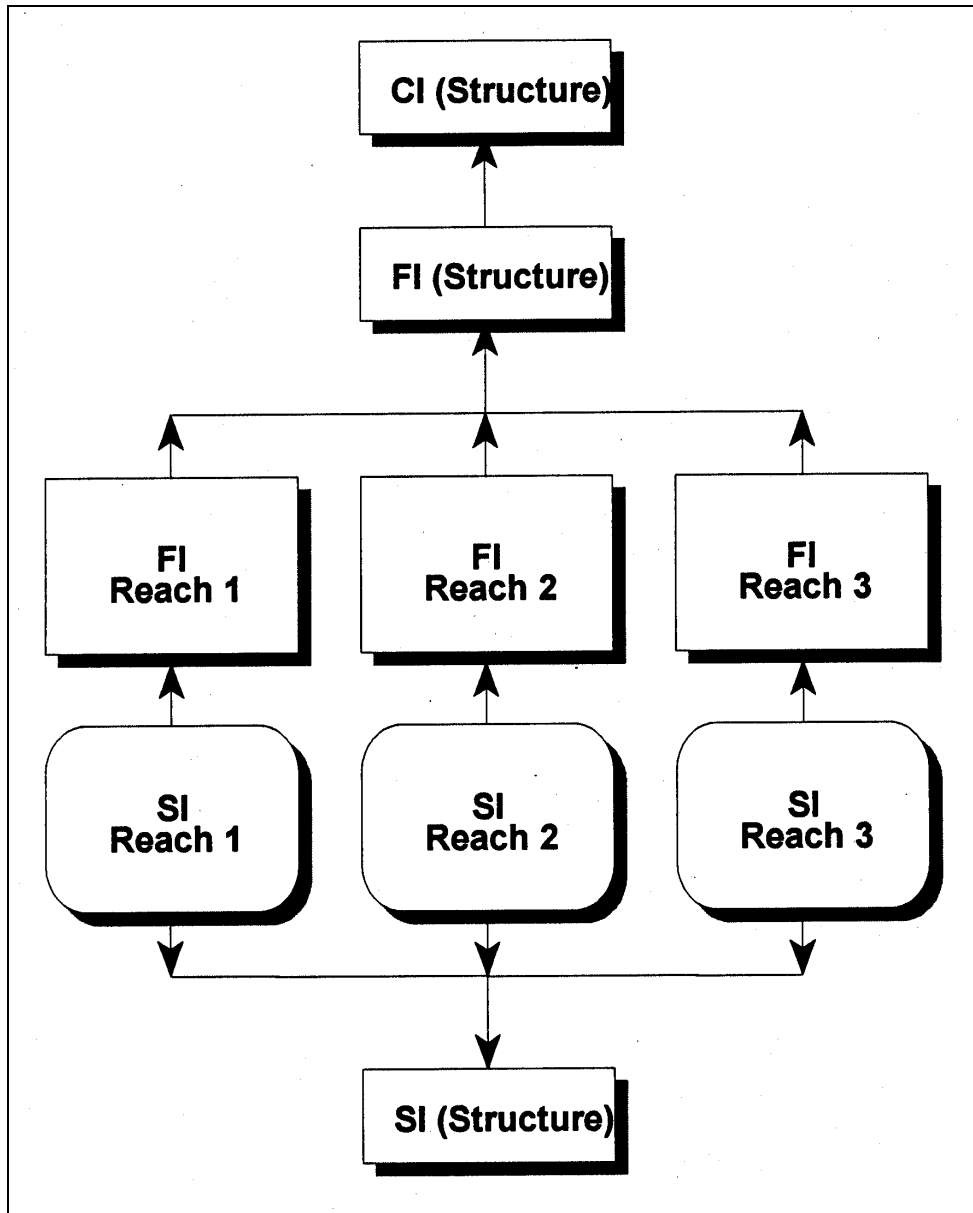


Figure 3. CI process for a whole structure.

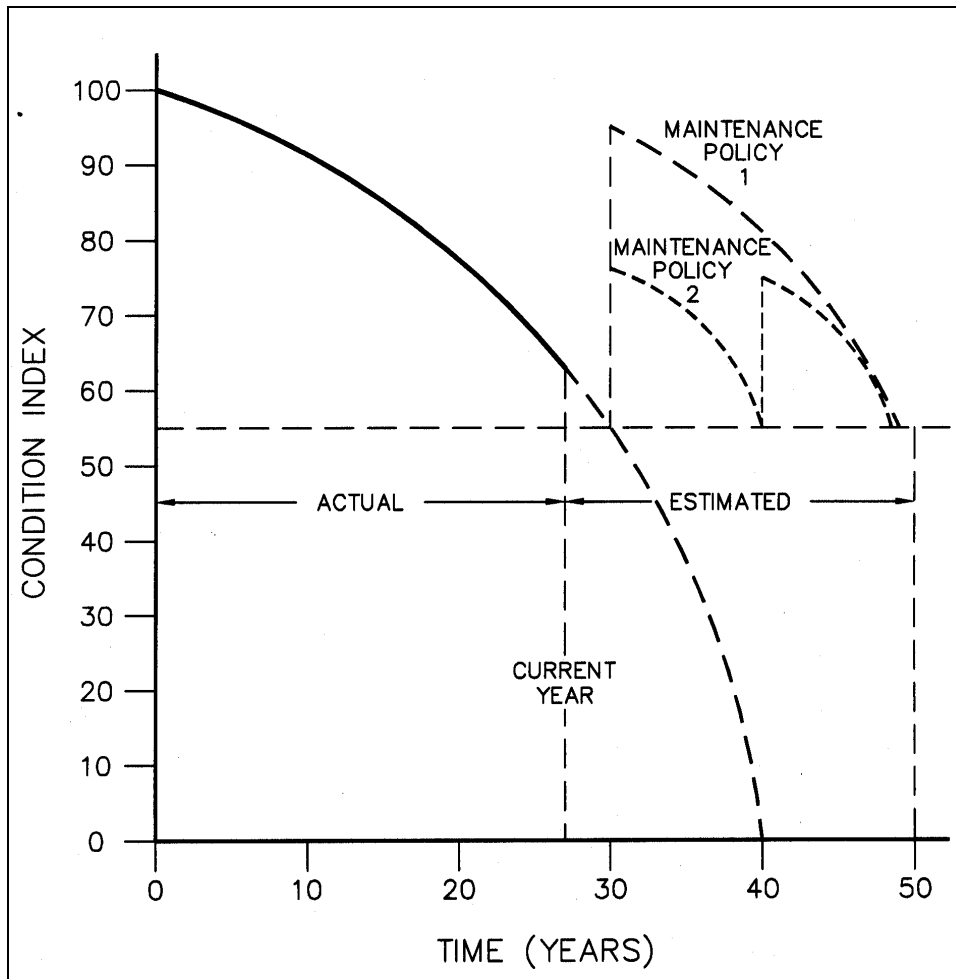


Figure 4. Using CI values to track condition changes over time.

warrant repairs in the near future. If Structure 2 is in a more moderate wave environment and its condition has been stable over the past 5 years, it may not warrant any action. The greater need for action does not make Structure 1's condition worse than that of Structure 2. Thus, it should be clear that condition influences maintenance and repair actions only in combination with additional information, such as knowledge of structure history, operating environment, budget levels, policies, etc.

The condition ratings and index values are simply a numerical shorthand for describing structure physical condition and functional performance, and they represent only one part of the information required to make decisions about when, where, and how to spend maintenance dollars. It must be emphasized that the CI system is not intended to replace the detailed investigations needed to fully document structure deficiencies, to identify their causes, and to formulate plans for correcting them.

Suggested Actions

Once the condition of structures is understood and documented, the next steps in the maintenance management process are to initiate action to correct unsatisfactory conditions and to begin planning for future maintenance and repair needs. For this purpose, the CI system for coastal structures includes a set of five suggested actions as part of the structural and functional rating process.

While the CI ratings and index values are used to describe and report conditions, the suggested actions allow inspectors and raters to indicate what they think should be done about those conditions. These action categories are explained in Chapters 5 and 6 in the sections covering the use of the rating forms.

3 System Instructions and Definitions

The 8-Step Process for Using the Rating System

Steps 1-5 are usually done one time only, during the initial phase of determining a Condition Index.

1. DETERMINE WHAT FUNCTIONS STRUCTURE SERVES

Use the 11 Functional Rating Categories described in Chapter 6.

2. DIVIDE STRUCTURE INTO REACHES BY FUNCTION

Decide which parts of the structure perform which of the 11 functions, and divide where major functional changes occur (see Chapter 4).

3. FURTHER DIVIDE REACHES INTO SUBREACHES, ACCORDING TO STRUCTURAL AND LENGTH CRITERIA

- Subdivide where differences in construction occur, such as cross section, armor size or type, underlayer, or core (see Chapter 4).
- Further subdivide to maximum size of 500 ft (200 ft minimum).

4. ESTABLISH FUNCTIONAL PERFORMANCE CRITERIA

- Decide what level of performance is expected for each function that applies to the structure. (See “Establishing Functional Performance Criteria” in Chapter 4, plus Chapter 6 and the Rating Tables.)
- Use Table 14, left side (see “Storm Events” in Chapter 6).
- Based on required performance levels, set minimum acceptable cutoffs for functional ratings as shown conceptually by dashed horizontal line in Figure 4.

5. ESTABLISH STRUCTURAL REQUIREMENTS

- Make an initial estimate of how much deterioration can be tolerated without either dropping below minimum required function levels or creating serious risk of structural instability. (See “Establishing Structural Requirements” in Chapter 4, plus Chapter 5 and Tables 3 through 8.)
- Use Table 14, center.
- Set minimum acceptable cutoffs for structural ratings, as shown conceptually by dashed horizontal line in Figure 4. (These trigger timing for repair evaluation.)

Steps 6 through 8 are repeated as required.

6. INSPECT STRUCTURE; PRODUCE STRUCTURAL RATING

- Determine current physical condition.
- Use the six Structural Rating Categories and their Rating Tables (see Chapter 5 and Tables 3 through 8). Use Structural Rating Form (one for each subreach).
- Calculate SIs (see Chapter 7).

7. ASSESS FUNCTIONAL PERFORMANCE; PRODUCE FUNCTIONAL RATING

- Determine to what extent structural deterioration has affected function (see Chapter 6).
- Use Table 14, right side.
- Use the Functional Rating Form (one for each full reach) and the Functional Rating tables (Tables 15 through 18).
- Calculate FIs (see Chapter 7).
- If significant loss of function has occurred due to structural deterioration, consider repair options.

8. REVIEW STRUCTURAL REQUIREMENTS

- Use Table 14, center. Relate Performance to Structural Deterioration (will be perfected through long-term, repeated analysis).
- Based on structural and functional evaluations (Steps 6 and 7), review structural requirements set in Step 4 and adjust as needed.

Basic Components

Breakwaters and jetties are constructed to maintain navigation channels across ocean inlets, control shoaling by preventing sediment from being driven into harbors and channels by waves and currents, create quiet waters for marinas and harbors, and provide shore protection along eroding coastlines. The following basic definitions are derived from those given in the *Shore Protection Manual* (U.S. Army Coastal Engineering Research Center, Vicksburg, MS, 1984).

Rubble-Mound Structure. This coastal structure is built largely or entirely as a somewhat irregular mound of quarried stones placed in a random fashion. A rubble-mound structure usually consists of one or two underlayers of smaller, graded stones covered by a primary layer of large armor stones of nearly uniform size or concrete armor units. In milder wave environments, the outer covering may consist of heavy graded riprap in lieu of uniform armor stones.

Breakwater. This structure is placed directly in the path of waves to create a quiet area of shelter, usually for a harbor, port, or marina. In some cases the sole purpose of a breakwater is to alleviate shoreline erosion by absorbing the energy of waves. A breakwater may be connected to shore at one end or entirely detached and more or less parallel to the shore.

Jetty. This structure has as its main purpose, the training and control of strong currents that flow through tidal inlets, harbor entrances, or the mouths of major rivers. Usually constructed in pairs, jetties serve both to confine the channel to a narrow location as well as to prevent sand and other sediments from collecting in the channel and forming shoals.

Weir Jetty. This structure is a variation on the jetty concept in which a section of the jetty near the shoreline is deliberately built low to allow sediments to pass over the weir and into a designated sand trap that was previously dredged to provide room for this inflow. This greatly facilitates subsequent maintenance dredging and bypassing of sand past the inlet.

Figures 5, 6, and 7 illustrate the use of these structures. Each of these is a schematic representation of an actual Corps of Engineers structure. Simple jetty systems of one or two structures are shown in Figure 5. Figure 6 shows two variations of the dual jetty system. The upper portion of the figure is a weir jetty system and sand trap. The combination of dual jetties and an offshore breakwater is a simplification of actual construction at Marina del Rey, CA.

Figure 7 presents typical breakwater configurations. The top illustration is a classic case of a shore-connected breakwater used to create a harbor at an open coast site. Santa Barbara Harbor, CA, is a well known representative of this category. The bottom portion of Figure 7 shows a two-segment detached breakwater system being used for shore protection with the characteristic resulting curvilinear shoreline that forms in the sheltered area. This is somewhat similar to the arrangement at Lakeview Park (Lorain, OH) where three breakwaters are used.

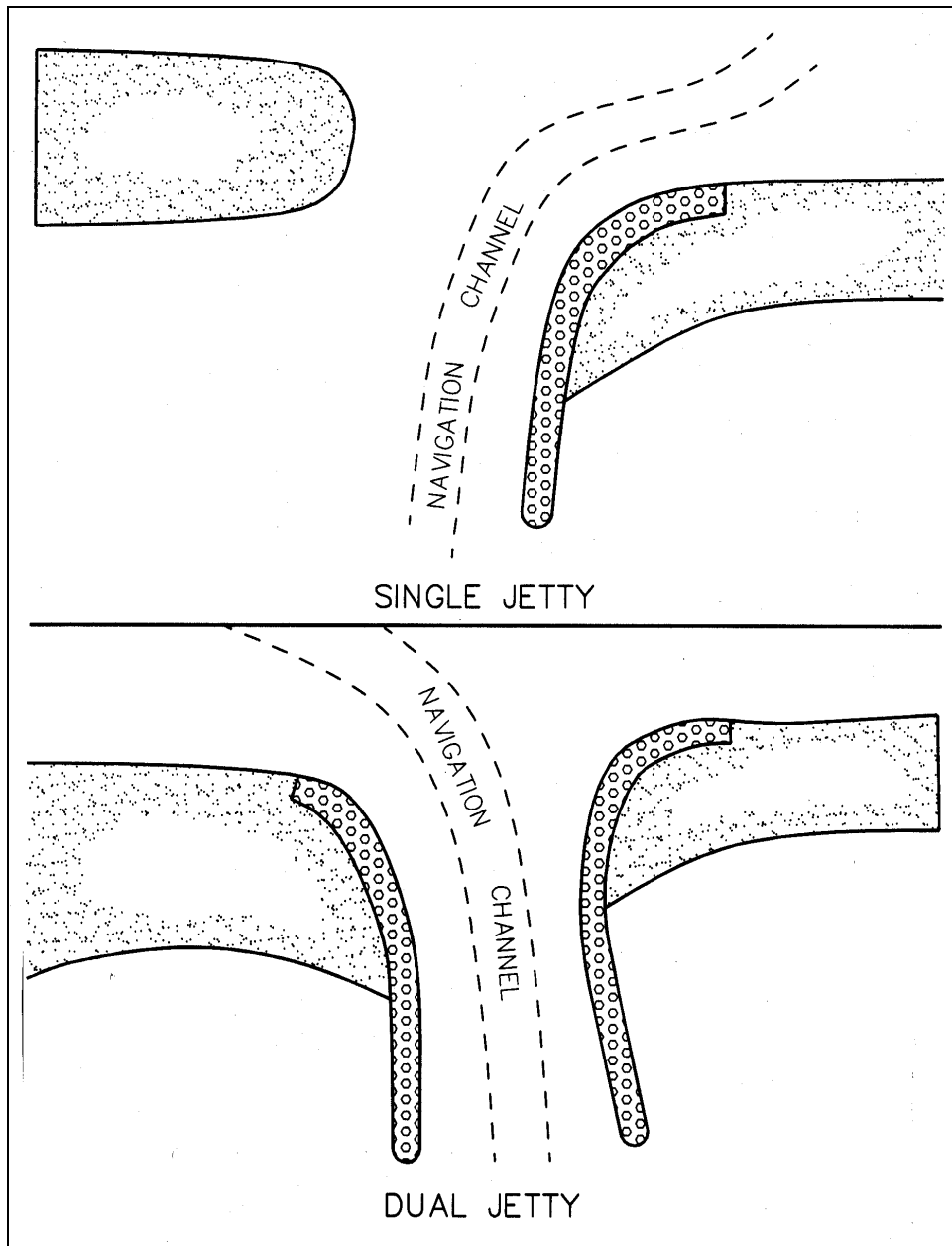


Figure 5. Jetty system.

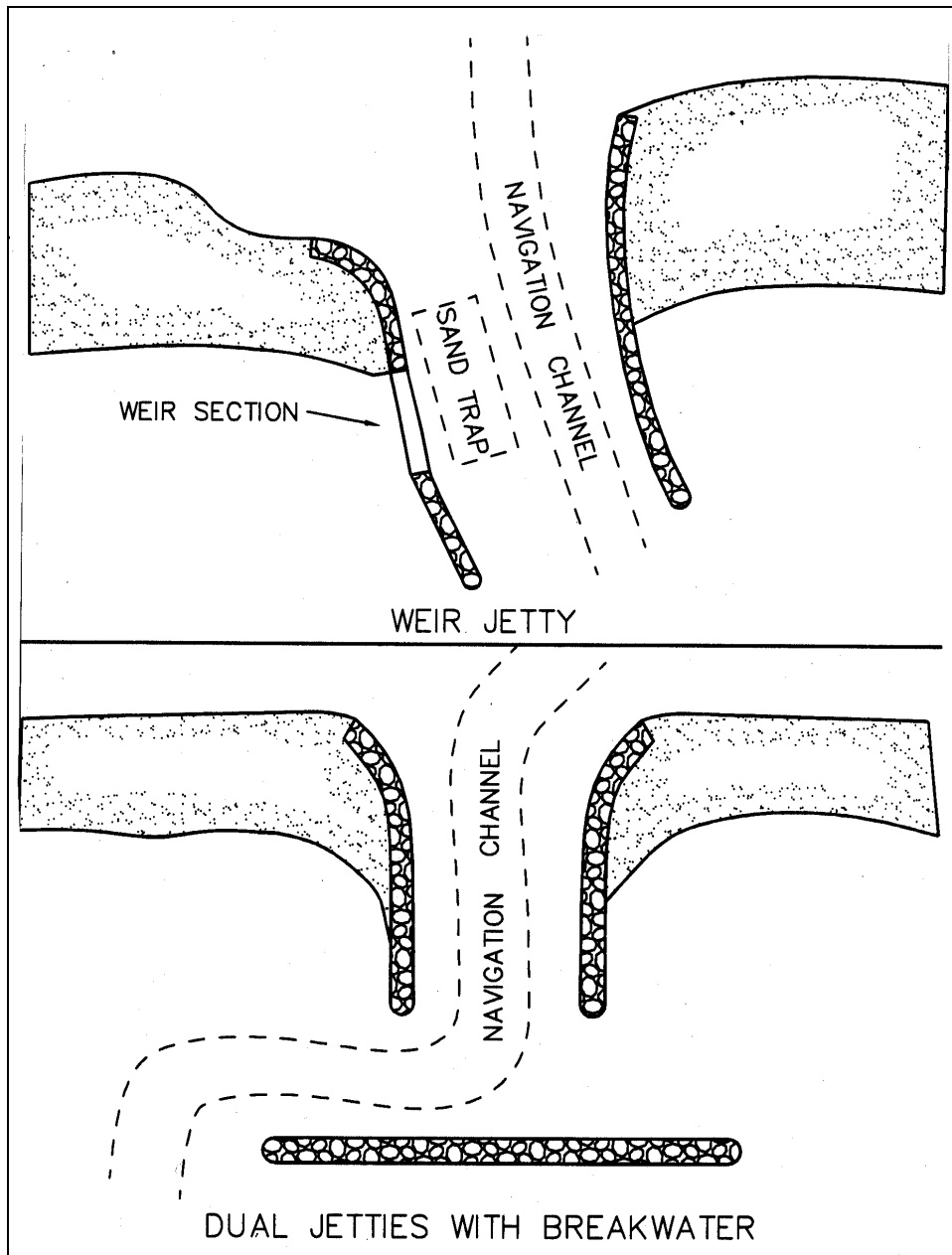


Figure 6. Jetty system variations.

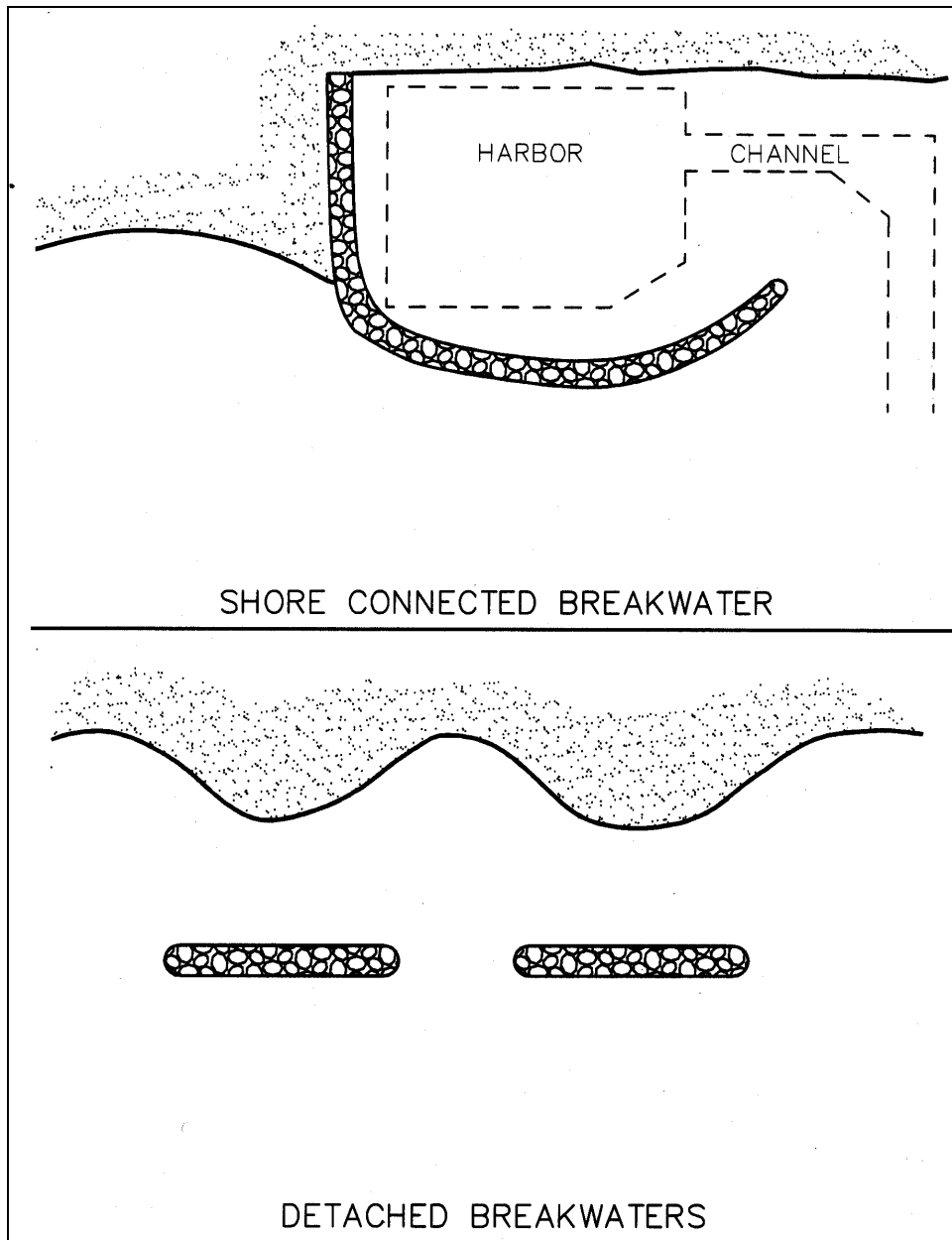


Figure 7. Breakwater systems.

Figure 8 illustrates the typical structural components of a rubble-mound structure; in this case, a shore-connected breakwater. It is important to note that construction and cross sectional composition of rubble structures may differ considerably from that shown in Figure 8. Where significant differences do occur, the inspector may need to adjust the interpretation of some rating categories and determine ratings accordingly. (Likewise, as-built drawings do not always reflect actual construction.) Definitions of key components shown on the figure are as follows:

Armor Layer. The armor layer is the outer layer of the structure, typically constructed with the largest stones, or with prefabricated concrete units. A rock armor layer commonly has a thickness of at least two armor stones. For structures constructed with uniform sized stone, the outer two layers will be considered as armor, with all underlying layers considered as core.

Channel/Harborside Slope. The side of a rubble-mound structure that is opposite (leeward) the primary direction of wave attack is the channel/harborside slope.

Core. The core is the interior portion of a rubble-mound structure. It generally consists of a widely graded mix of small stones. This widely graded mix makes the structure relatively impermeable to wave energy (which would otherwise pass directly through the voids in larger stones), prevents movement of sand through the structure, and creates a filter layer (or mat) to support the underlayer and armor stones on the foundation soils. For structures constructed with uniform sized stone, the outer two layers will be considered as armor, with all underlying layers considered as core.

Crest (or Cap). The top portion of the cross section of a rubble-mound structure is the crest or cap. It is usually constructed above the design water level.

Foundation Layer. The foundation consists of a layer of small graded stone, sometimes with geotextile underneath, placed on the in-situ soil to form a base on which the structure is built. The foundation layer helps reduce structure settlement and lateral movement at the base.

Head. A structure's head is the outer end or terminus of a rubble-mound structure. The head is often wider and somewhat higher than the structure trunk. A distinguishing feature of the head is that the individual armor stones must withstand large wave forces that may tend to sweep the units laterally off the structure as opposed to directly down the slope as on the trunk. For this reason, the armor stones on the head are often larger than those on the trunk. The general case assumed here is that the head does not have adequate length to materially impact waves and currents in the harbor or navigation channel - it is a sacrificial element that only protects the trunk.

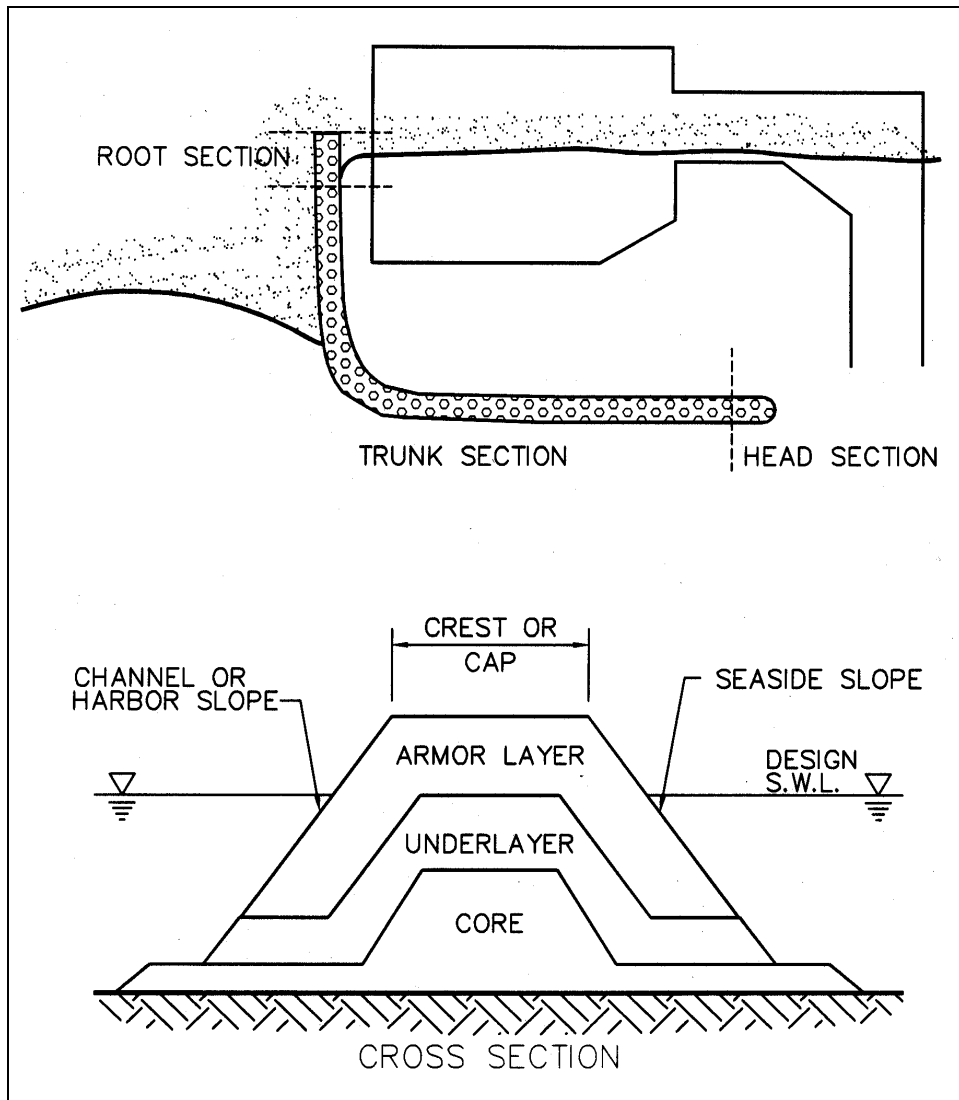


Figure 8. Components of a typical rubble-mound coastal structure.

Reach. A reach is a portion of a structure that is uniform in its functional purposes. Once defined, the number of reaches (and their limits) should remain constant over time, as they serve as primary references for functional rating.

Root. The landward reach or origin of a rubble structure which forms a permanent anchor or land connection. The root may be in contact with water on its channel/harborside, as in Figures 9 and 10.

Seaside Slope. The side of a rubble-mound structure that faces the main force of the waves is the seaside slope.

Subreach. For management purposes, reaches may be divided into subreaches due to changes in type of construction, cross sectional dimensions, or to maintain rated segments of relative uniform length throughout the structure. Once defined, the

number of subreaches (and their limits) should remain constant over time, as they serve as primary references for structural rating.

Toe. The lowest section of a side slope at the junction with the foundation. An outward extension of the side slope is often constructed at the toe, especially on the seaward side of a structure. This extension provides added protection against foundation erosion. The toe is critical to maintaining the stability and integrity of the side slope.

Trunk. The main body of the structure which extends between the root section at the landward end and the head at the seaward end.

Underlayer. The underlayer is a layer of smaller stones directly beneath the armor layer, commonly about one-tenth the weight of the units in the armor layer. The underlayer helps absorb the wave forces and prevents the smaller underlying core stones from being lost through voids in the armor layer. (Not all rubble structures have a separate underlayer).

Operations and Maintenance Items

The following items are considered in several functional rating categories (see Chapter 6), and thus are not rated separately. Because they have a great influence in the evaluation of structure performance, they warrant separate definition and explanation.

Dredging Costs. The decision to dredge (or do more frequent or additional dredging) is commonly an alternative to: (1) accepting actual or potential navigation delays or hazards, or (2) incurring the cost of structural repair or modification. Dredging costs serve as one means for evaluating structure performance.

Sand Bypassing. Without dredging, many improved navigation entrances would eventually reach an equilibrium state in which sand would naturally bypass the structures, deposit sediment in the channel (or at the channel entrance), and eventually nourish the downdrift beaches. Some projects have a structural configuration designed to facilitate sand bypassing or they incorporate a sand bypassing system to reduce channel sedimentation and protect the adjoining shoreline. The effectiveness of natural bypassing is included in the functional ratings for “Harbor Area,” “Navigation Channel,” “Sediment Management,” and “Structure Protection.”

Shoaling (Sediment). Shoaling is the buildup of excessive sediment in and around the channel or harbor. Shoaling may reduce the maximum available draft or reduce the channel to a width too narrow for safe passage, or may otherwise lead to navigation difficulties and delays. In addition, where depths are reduced due to shoaling, hazardous breaking wave conditions may develop in the channel.

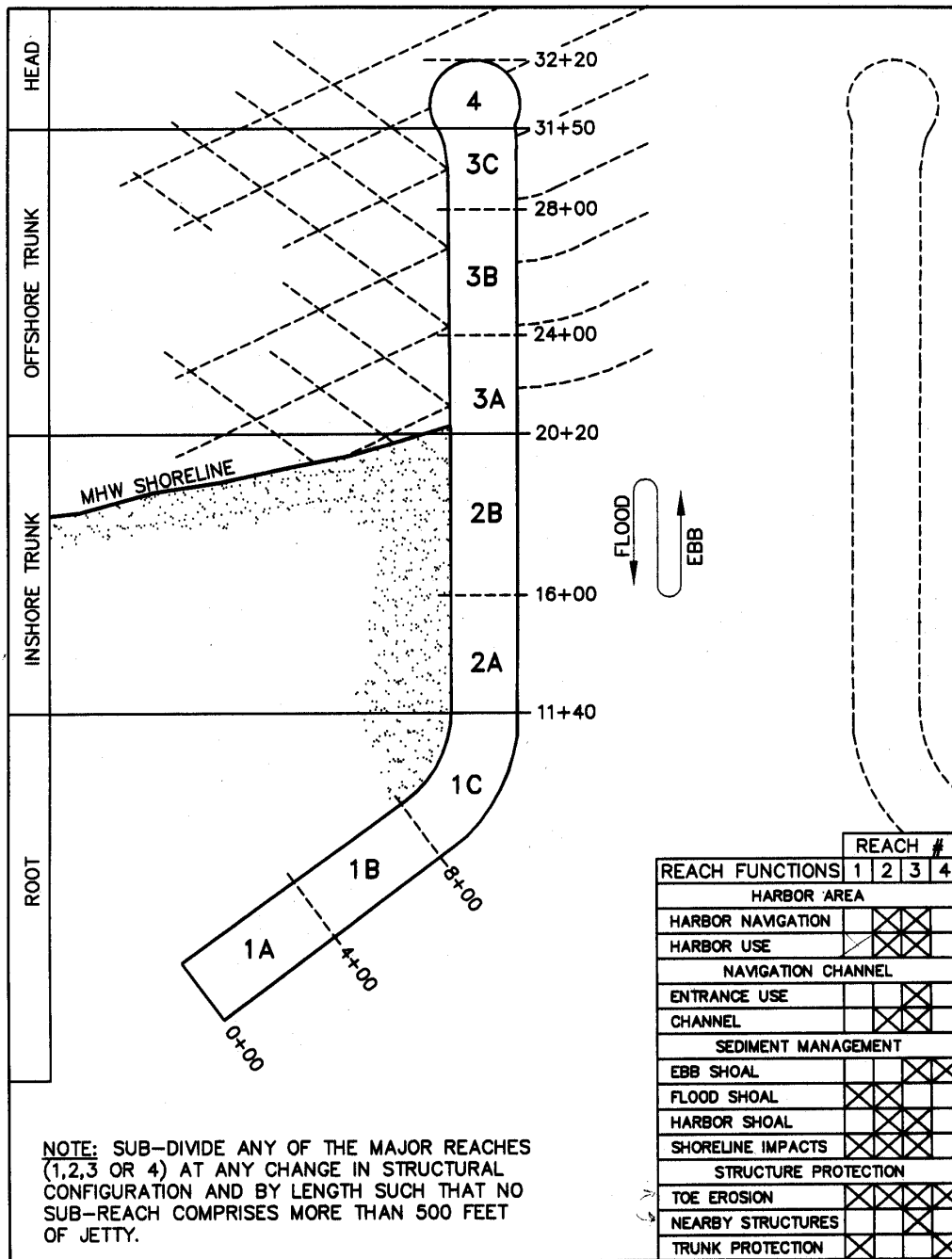


Figure 9. Typical reaches of a jetty.

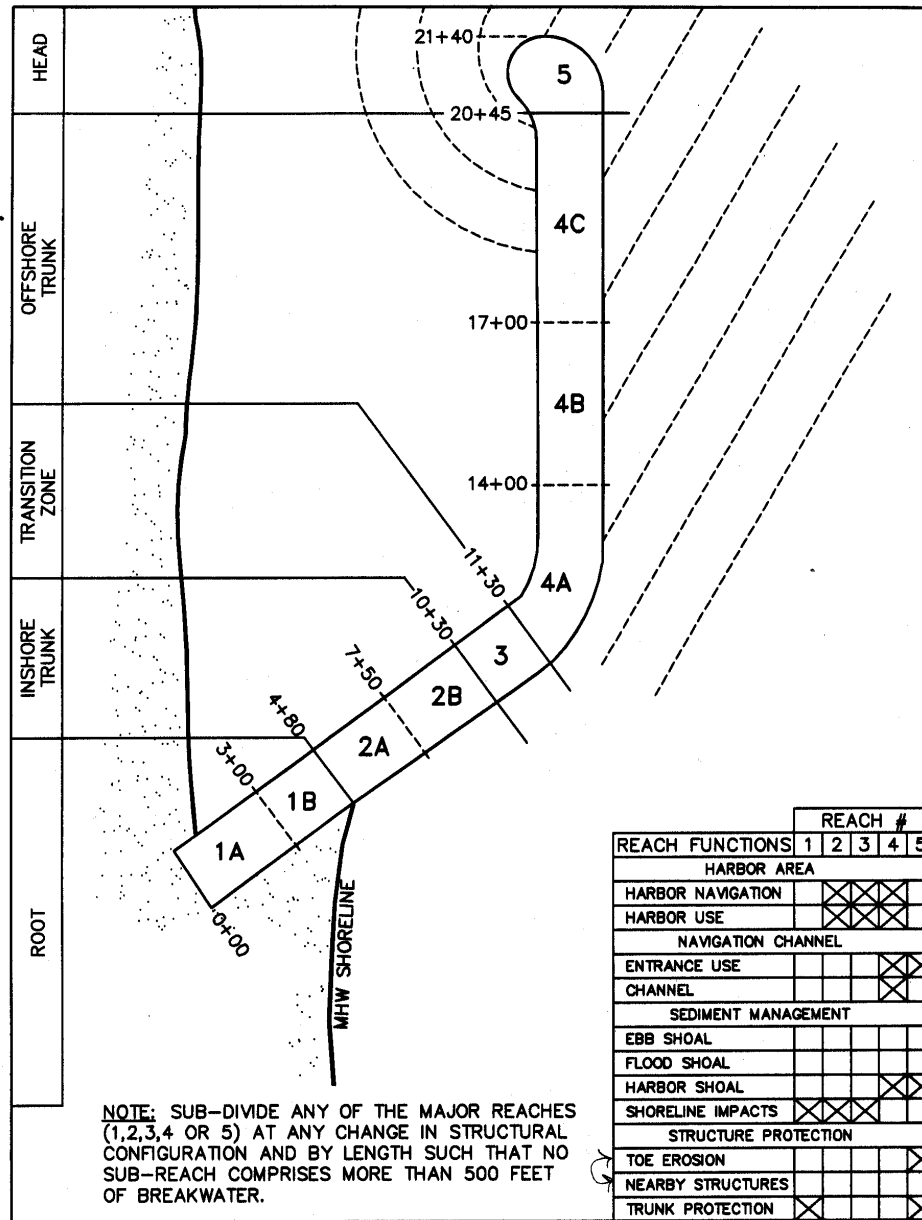


Figure 10. Typical reaches of a shore-connected breakwater.

Thalweg Location. The thalweg is the deepest portion of the navigation channel. The purpose of the navigation structures, particularly jetties, is to maintain the thalweg in a uniform and consistent position for predictable and safe passage by vessels. If the structures are only partially effective, the thalweg may tend to migrate and create a navigation hazard.

Design Storm

Performance in each functional rating category is measured in reference to three levels of storm events. The design storm is the largest storm (or most adverse combination of storm conditions) the structure (or project) is intended to withstand, without allowing disruption of navigation or harbor activities, or damage to the structure or shore facilities. The design storm is usually designated by frequency of occurrence or probability of occurrence. Authorizing documents, design notes, project history, and current requirements should be used to confirm the appropriate design storms for a project. Chapter 6 contains more detail on this subject.

Rating and Index

This evaluation system uses ratings and indexes. As used here, a rating is a value selected by an inspector or engineer, usually from a table of condition or performance levels. A rating category is an evaluation category requiring the selection of a rating.

An index, or index value, is a number calculated from several ratings. The calculation is made using a standard rule or formula. The index represents a summary or weighted average of the individual ratings.

4 Defining Reaches, Subreaches, and Structure Criteria

Defining Reaches and Subreaches

To implement the condition rating process, each structure must first be divided along its length into reaches, and further, into subreaches with permanent boundaries. This step need be done only once, as after reaches and subreaches are defined, their limits are not changed unless major structural or functional changes are made to the structure. Reach and subreach limits are based on three criteria and are chosen as described below. Figures 9, 10, and 11 show examples of applying these criteria.

- a. **By Function:** Determine the functions provided by different portions of the structure. This is done through an office study using authorizing documents and project history in combination with the functional descriptions in Chapter 6. Set the reach limits where functional changes occur. Structure functions are chosen from the list of 11 rating categories within the 4 main functional areas, as described in Chapter 6. Of the 11 rating categories, select only those on which the structure has a significant effect. As structure and reach purposes vary, it should be expected that different reaches will have a different number and different types of functions assigned to them. Further, the assigned functions need not include all of the four major functional areas or all of the categories listed within each functional area.
- b. **By Construction:** Further division into subreaches is made based on changes in structural characteristics. Using past inspection reports, photographs, and drawings (which have been field verified), note where there are significant changes in type of construction, type or size of armor, cross sectional dimensions, or geometry; these points should define further divisions.
- c. **By Length:** Final divisions are made based on length. Where function and construction are uniform over a long length, divisions should be made so that subreaches will not be overly long; 500 ft is a suggested maximum, and 200 ft a suggested minimum.

NOTE: Due to its unique function (and typically different construction), the head of a structure is always considered a separate reach. Where there is no difference

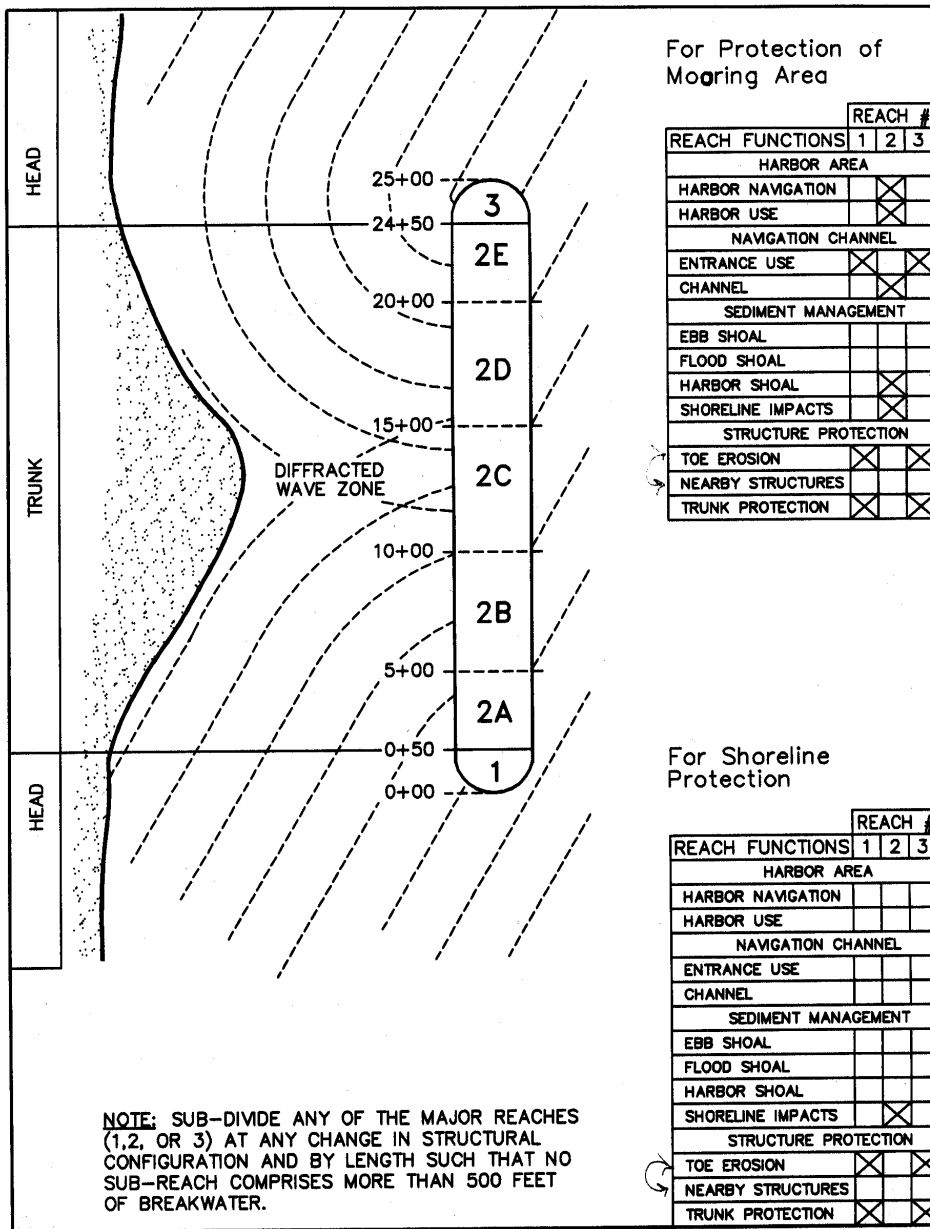


Figure 11. Typical reaches of a detached breakwater.

in construction at the outer end of a structure, a recommended length for the head reach is 50 to 100 ft. The general case assumed here is that the head does not have adequate length to materially impact waves and currents in the harbor or navigation channel - it is a sacrificial element that only protects the trunk. In exceptional situations where these assumptions may not apply, explanation should be given and other appropriate functions may be assigned to the head.

A convenient method for numbering reaches is to begin at the landward end and use both consecutive numbers and letters: 1A, 1B, 2A, 2B, 2C, etc., where the number indicates common function (a reach), and the letter indicates further division (a subreach) due to structural changes or maximum length requirements. This system is used in Figures 9, 10, and 11.

It is important to emphasize that the same reach definitions are to be used for both structural and functional ratings, so the reach limits should be selected with this in mind. In addition, permanent stationing markers should be applied to each structure to assure uniformity in reporting the location and limits of structure defects and to facilitate future inspections.

Establishing Functional Performance Criteria

Once structure functions have been determined, the next step is to determine the expected performance level for each rating category. These criteria must be based on how well the structure could perform when in perfect physical condition. Design deficiencies cannot be corrected through the maintenance and repair process and thus should not be considered in this analysis. Begin by reviewing the authorizing documents and structure history. Check if the original expectations have been changed, or if they need to be changed.

When defining performance requirements, refer to the section "Design Storm" and the rating tables in Chapter 6 to see how performance is measured in the different functional categories. Determine to what extent the structure should control:

- a.* waves, currents, and seiches
- b.* sediment movement
- c.* shoreline erosion and accretion.

To help decide required wave, current, and sediment control; determine the normal dredging frequencies and sand bypassing requirements; decide what size ships should be able to pass through the entrance and channel under normal conditions and during higher wave or storm conditions; and determine if any flooding of shoreline facilities should be expected during storm events, and if so, to what extent.

Establishing Structural Requirements

Structural ratings are produced by comparing the current physical condition, alignment, and cross sectional dimensions of a structure to that of a "like new" structure built as intended, according to good practice, and with good quality materials. Seldom, though, does a rubble coastal structure require full structural integrity to have continuity in function. In fact, most rubble structures are built with some allowance for damage before function is compromised, and many are overbuilt for constructability. Thus, structural damage does not automatically equate to loss of function.

After determining performance requirements, it is necessary to determine what minimum cross sectional dimensions, crest elevation, and level of structural integrity are needed to meet those requirements. Initial efforts in determining these dimensions can be aided by estimating the impact on functions if the reach under study were to be completely destroyed. Project history, authorizing documents, public input, and analysis may be required to identify these dimensions. As this is not an exact science, some engineering judgment will be necessary to produce a reasonable estimate. Once established, these structural requirements are used to help identify sources of functional deficiencies in the existing structure. Table 14 contains columns to record this information.

5 Structural Rating Procedures

Introduction

The structural rating procedures are used to determine the appropriate rating for six defect categories that apply to the crest and side slopes for each reach or subreach of a structure. From these ratings structural index (SI) values are calculated, as described in Chapter 7, for the crest and both side slopes, for each reach or subreach, and for the whole structure. The SI values are indicators of physical condition and structural integrity. These values are expressed as numbers from 0 to 100 and are interpreted according to the general SI scale shown in Table 2.

For each structural rating category, the inspector determines ratings from a field inspection, using the structural rating tables (Tables 3 through 8). Each of these tables follows the format and general interpretation of the SI scale in Table 2, but the wording is specific to the category being rated. The management computer program is then used to calculate index values from the field ratings entered into the program.

Table 2. Structural index scale for coastal structures.

Observed Damage Level	Zone	Structural Index	Condition Level	Description
Minor	1	85 to 100	EXCELLENT	No significant defects - only slight imperfections may exist.
		70 to 84	GOOD	Only minor deterioration or defects are evident.
Moderate	2	55 to 69	FAIR	Deterioration is clearly evident, but the structure still appears sound.
		40 to 54	MARGINAL	Moderate deterioration.
Major	3	25 to 39	POOR	Serious deterioration in some portions of the structure.
		10 to 24	VERY POOR	Extensive deterioration.
		0 to 9	FAILED	General failure.

Structural Rating Categories

Structural rating categories are described below. Lettered sections that accompany some of the rating categories correspond to the lettered items on the inspection form.

Breach/Loss of Crest Elevation

A breach, or a loss of crest elevation due to settlement, both result in a reduced structure height at the location where each occurs. A breach is a depression (or gap) in the crest of a rubble-mound structure to a depth at or below the bottom of the armor layer due to armor displacement. A breach is not present unless the gap extends across the full width of the crest. While having the same effect as a breach, loss of crest elevation is primarily due to settlement of the structure or foundation. Both may also be present to some degree at the same location.

Displaced Cap or Armor Stones. Figure 12 illustrates a breach; armor units have been dislodged across the full width of the crest, lowering the structure's top elevation.

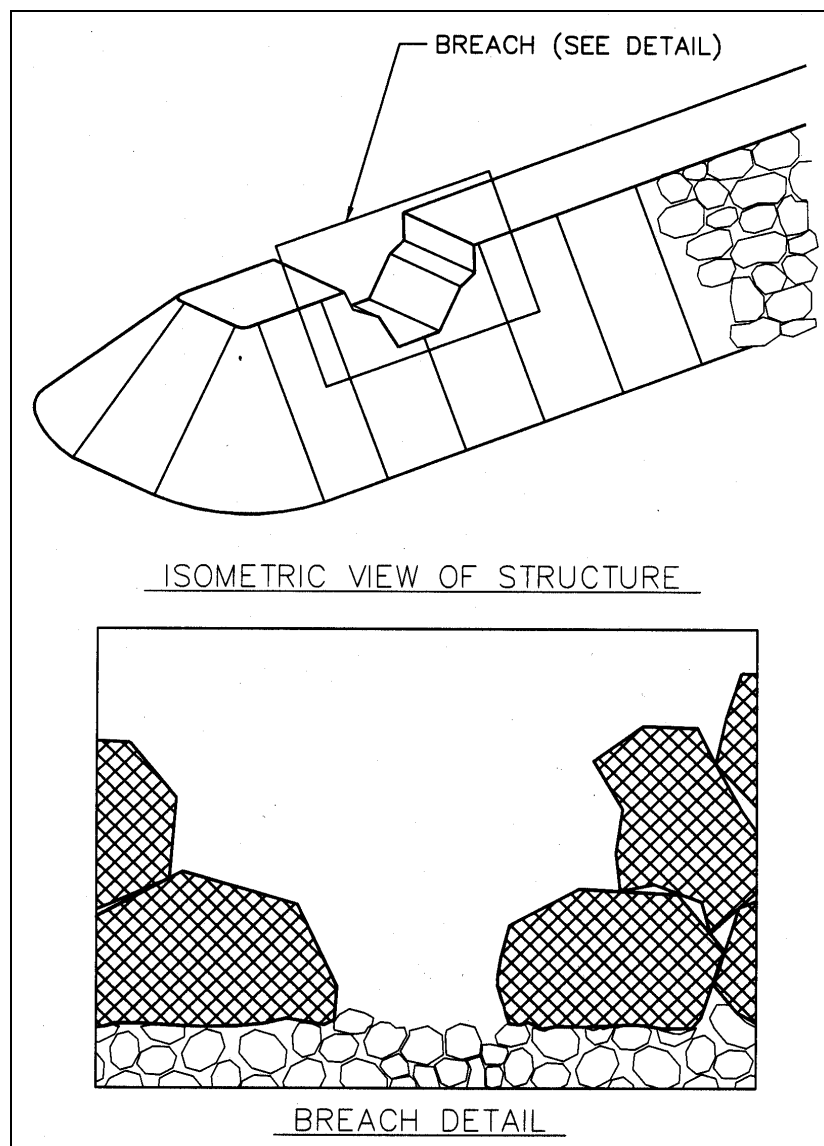


Figure 12. Typical breach.

Settlement of Cap or Armor Stones. Figure 13 illustrates loss of crest elevation from structure and foundation settlement. In this case the cap stones are still present on the crest of the structure.

Core (or Underlayer) Exposure or Loss

For condition rating purposes, all layers below the armor are considered to be core. For structures constructed with uniform sized stone, the outer two layers will be considered as armor, with all underlying layers considered as core.

Core Exposure. Core exposure is present when the underlayer or core stones can be readily seen through gaps between the primary armor stones.

Core Loss. Core loss occurs when underlayer or core stone is removed from the structure by waves passing through openings or gaps in the armor layer.

Movement and separation of armor often result in the exposure of the underlayer or core stone. If the exposed area is sufficiently large, core stone can be removed by waves, leading to a rapid disintegration of the structure (see Figure 14).

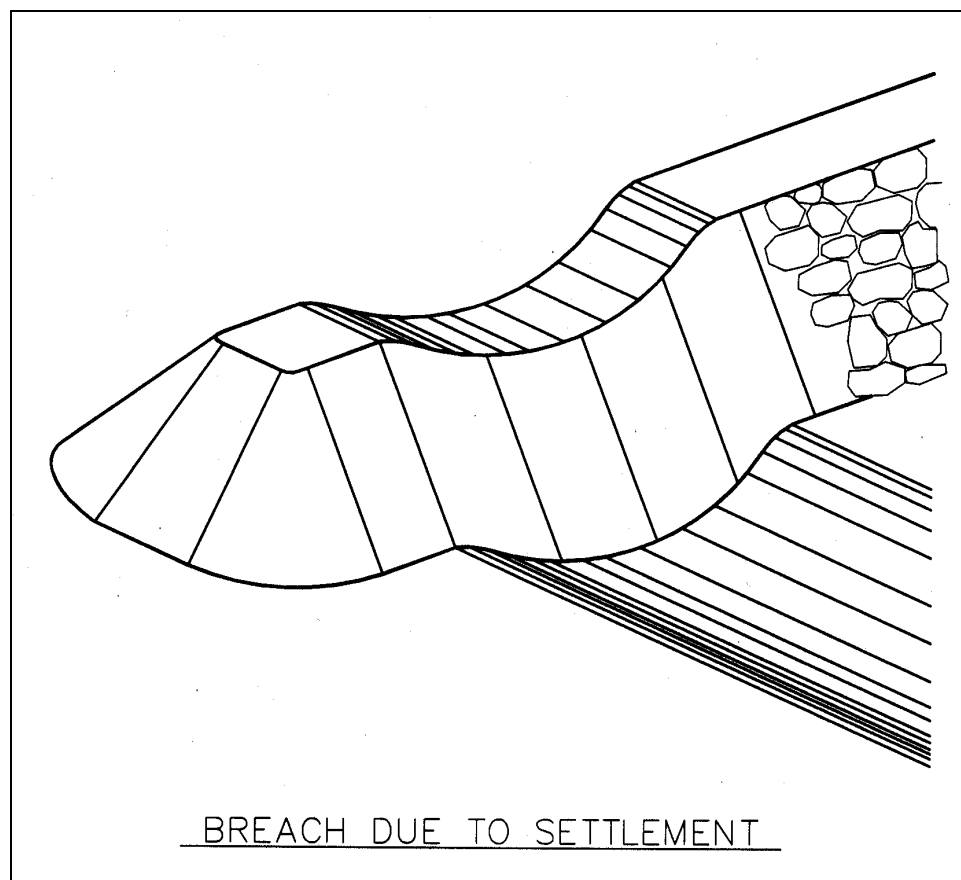


Figure 13. Loss of crest elevation.

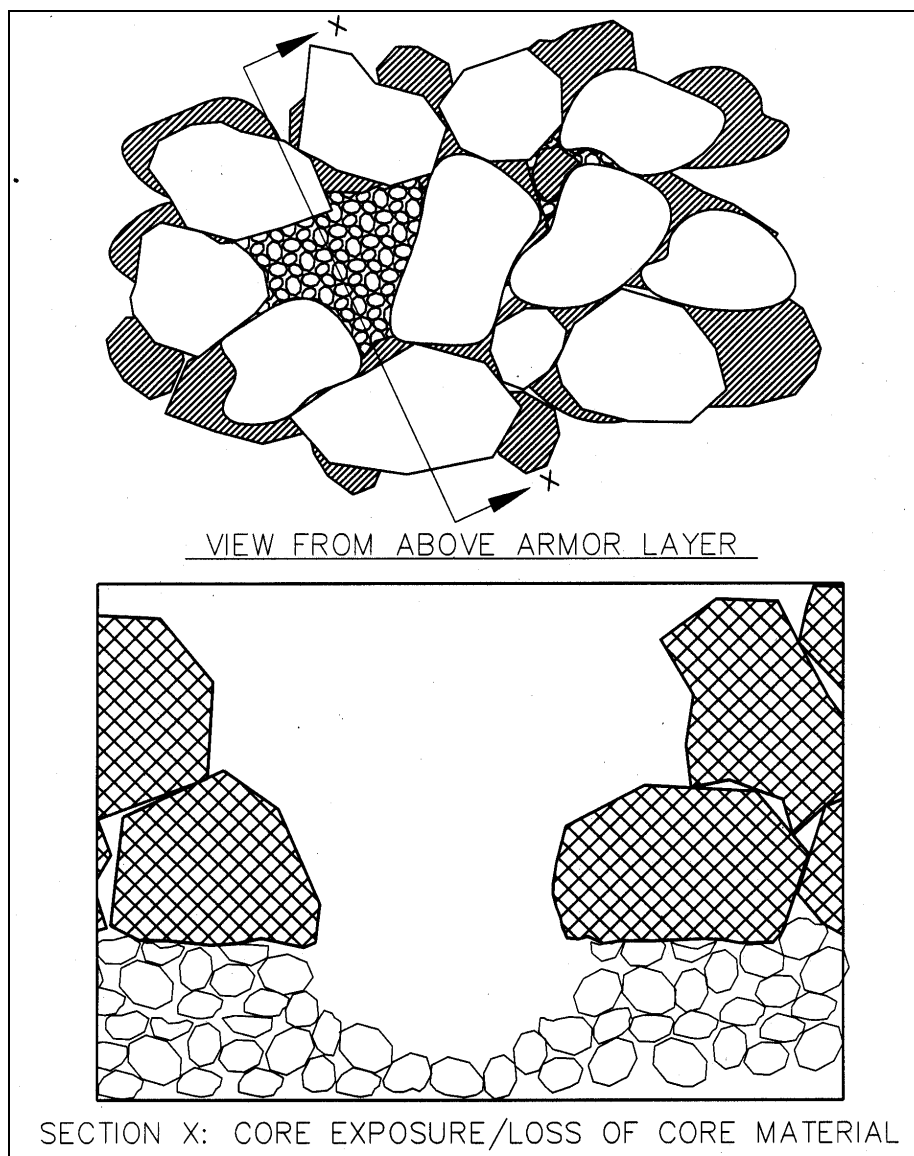


Figure 14. Core (or underlayer) exposure or loss.

Armor Loss

Three cases of armor loss are considered on the inspection form: displacement, settling, and bridging. Bridging may occur on either the crest or the side slopes of a rubble-mound structure. The Armor Loss category applies to localized losses of armor (up to 4 to 5 armor stones in length) from either side slope, or from the crest. If the displacement extends all the way across the width of the crest, the defect would be rated under Breach; if the area is longer than 4 or 5 armor stones, use the rating for Slope Defects. The individual cases are defined as follows:

Displacement. Figure 15 illustrates a typical case of displacement of armor stones from a side slope of a rubble-mound structure. This condition is most likely to occur near the still water line where dynamic wave and uplift forces are greatest. In this case, a pocket

is shown in the armor layer at the water line and the displaced stones, while not generally visible from above, have moved downslope to the toe of the structure.

Settling. Figure 16 shows settling on a side slope. The settlement may occur along or transverse to the slope and results from consolidation or settlement of underlayer stones, core, or foundation soils.

Bridging. Bridging is a form of armor loss that may apply to the side slopes or crest. Bridging occurs when the underlying layers settle but the top armor layer remains in position (at or near its original elevation) by bridging over the resulting cavity. In effect, the armor stones produce an arch. This is illustrated on Figure 17.

Loss of Armor Contact or Armor Interlock

Armor contact is the edge-to-edge, edge-to-surface, or surface-to-surface contact between adjacent armor units, particularly large quarriestones. Armor interlock refers to the physical containment by adjacent armor units. Good contact and interlock tie adjoining units together into a larger interconnected mass (see Figures 18 and 19). Certain types of concrete armor units are designed to permit part of one unit to nest with its neighbors. In this arrangement, one or more additional units would have to move significantly to free any given unit from the matrix.

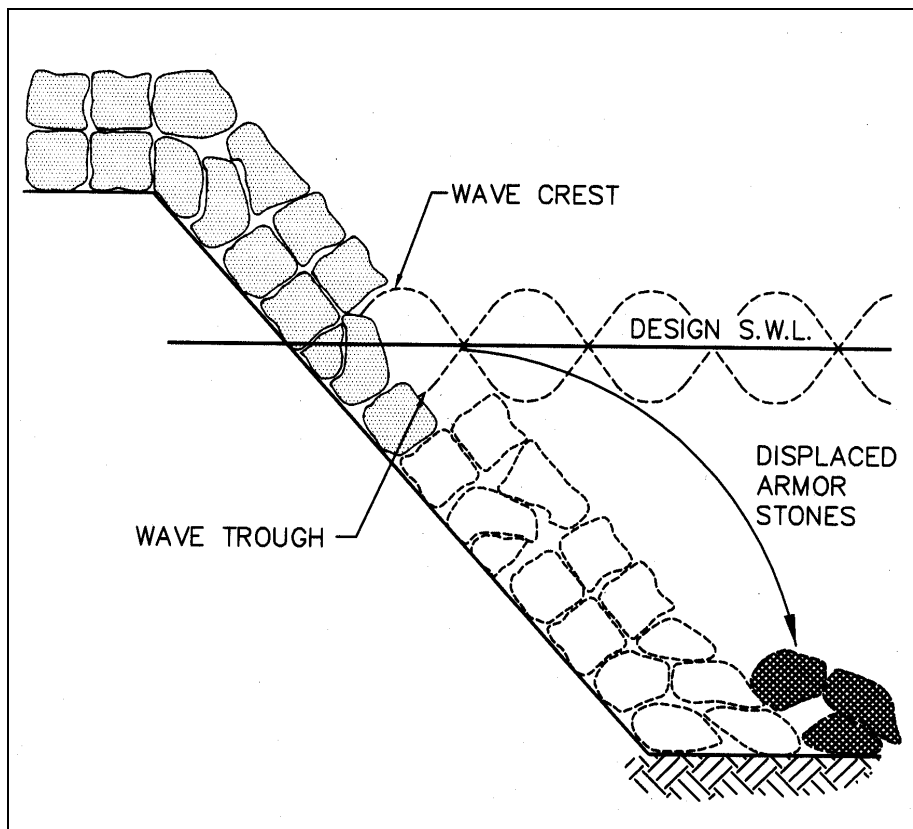


Figure 15. Armor loss on side slope by displacement.

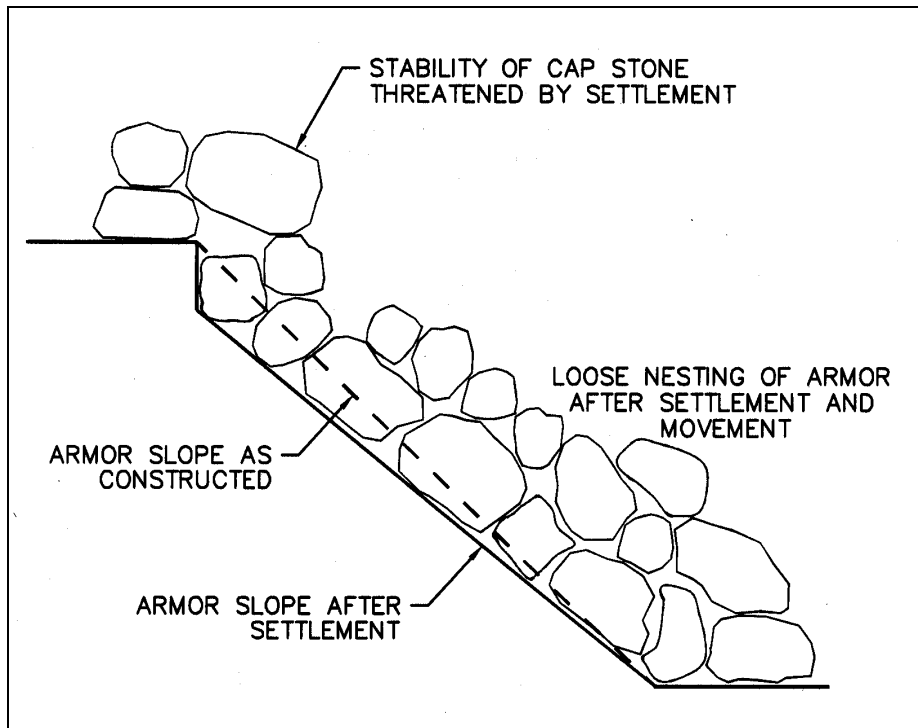


Figure 16. Armor loss due to settlement.

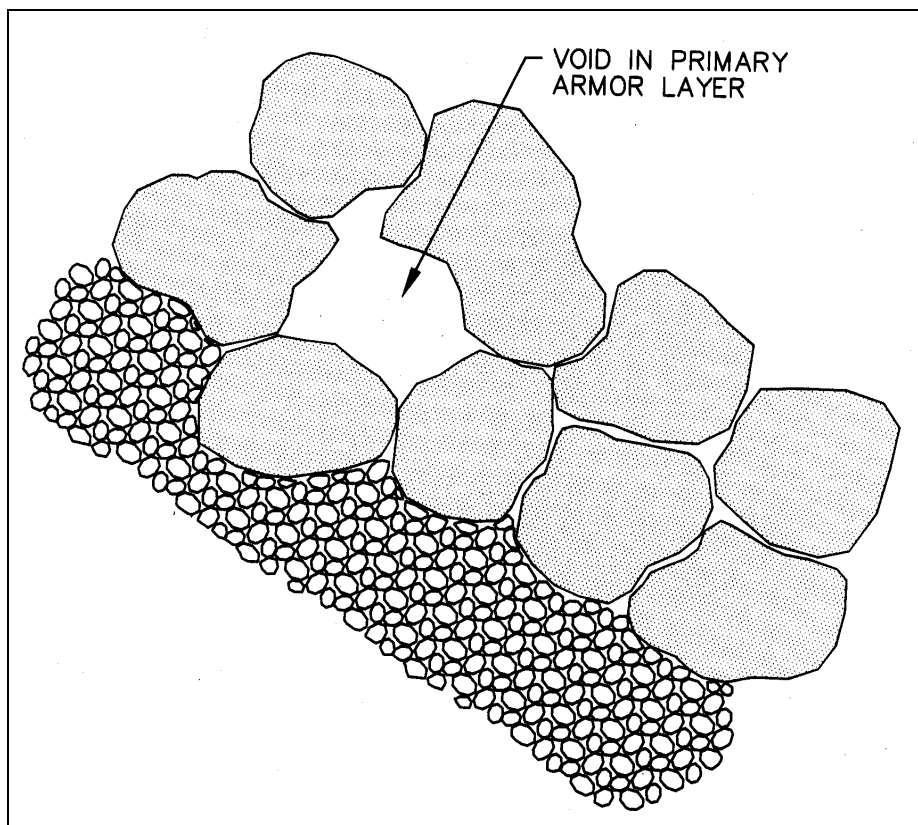


Figure 17. Loss of armor continuity caused by bridging a void.

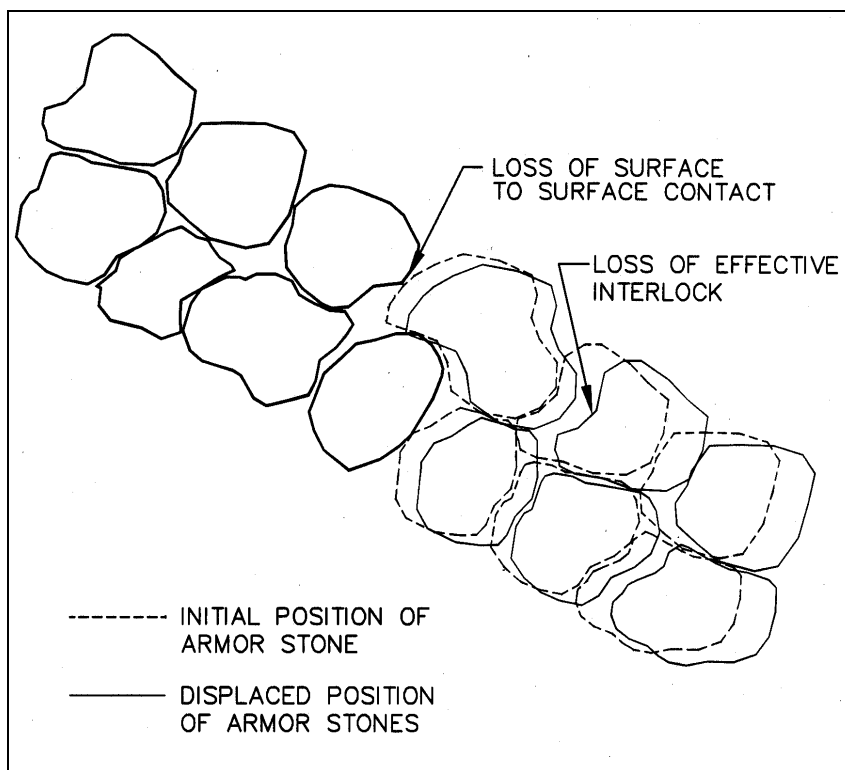


Figure 18. Loss of armor contact and interlock.

For many years, the Hudson armor stability coefficient has been used, in part, to identify armor interlock quality when designing structures with stone armor. A value of 3.5 represents good rock-to-rock contact, and this is the value on which the rating criteria in Table 6 are based. The actual design coefficient for the structure should be entered on the structural rating form, and ratings made accordingly. Any special armor placement should be stated in the inspection notes. For older structures, when the design criteria is not available, an assumed value of at least 3.5 should be used.

Armor Quality Defects

This rating category deals with structural damage to the armor units. It is not a rating of potential armor durability, but rather a reflection of how much damage or deterioration has already occurred. Four kinds of armor quality defects are defined below and illustrated in Figure 20.

Rounding. Armor stones, riprap, or concrete armor units with angular edges can be damaged by cyclic small movements or by abrasion. The softer sedimentary rock such as sandstone or limestone (and also reef material) is especially subject to this type of damage. The result is edges that are worn into smoother, rounded contours. This reduces the overall stability of the armor layer because edge-to-edge or edge-to-surface contact between units is less effective and movement is easier when the edges become rounded. Some concrete armor units such as tetrapods are little affected by this kind of damage since they consist almost entirely of rounded shapes and edges.

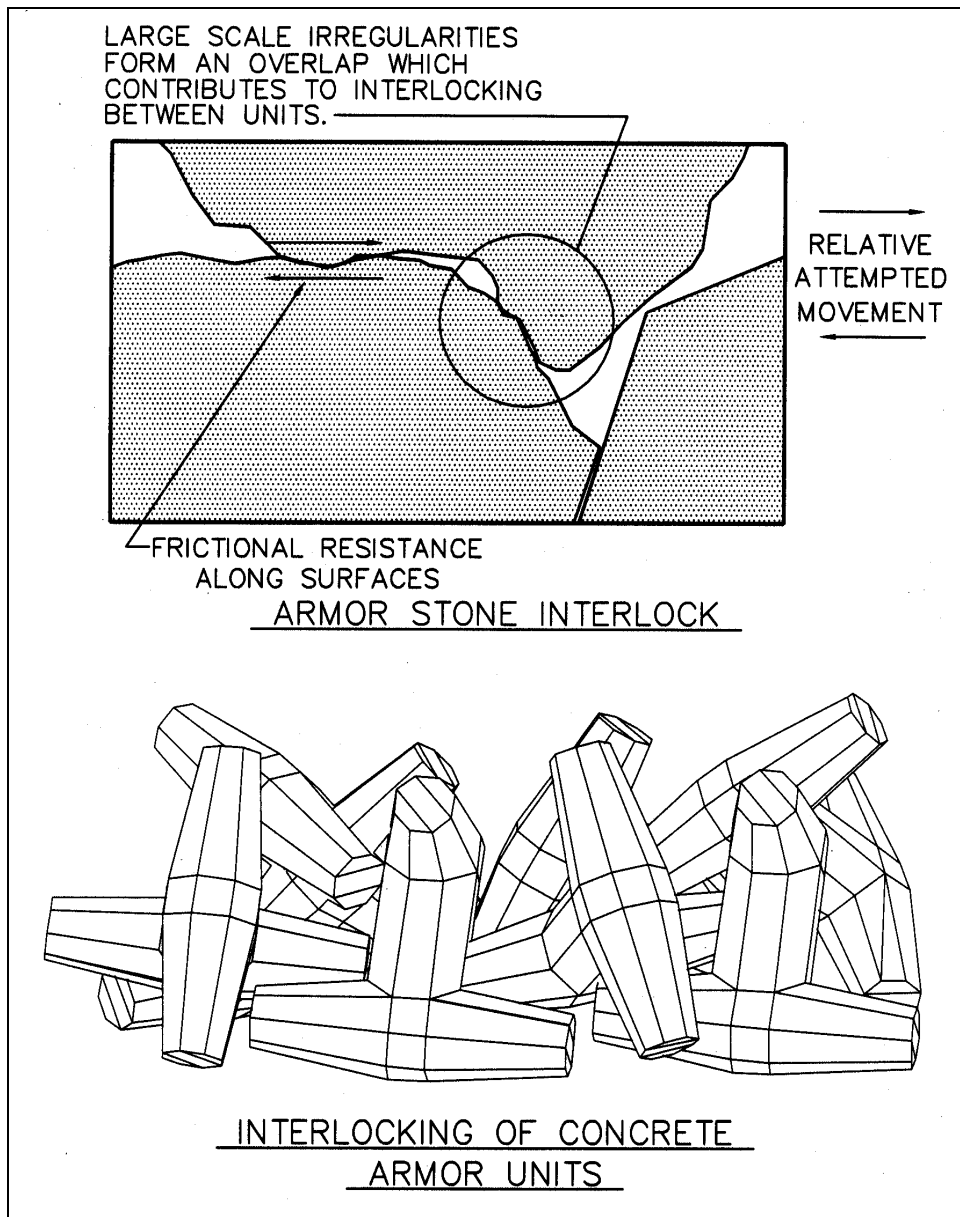


Figure 19. Armor unit contact and interlock.

Spalling. Spalling is the loss of material from the surface of the armor unit. Spalling can be caused by mechanical impacts between units, stress concentrations at edges or points of armor units, deterioration of both rock and concrete by chemical reactions in seawater, freeze-thaw cycles, ice abrasion, or other causes. Spalling because of a material defect that affects the entire armor layer is obviously more important than incidental spalling of an individual unit.

Cracking. Cracking involves visible fractures in the surface of either rock or concrete armor units. The cracks may be either superficial or may penetrate deep into the body of the armor unit. Cracking is potentially most serious in slender concrete armor units such as dolosse (either with or without steel reinforcement).

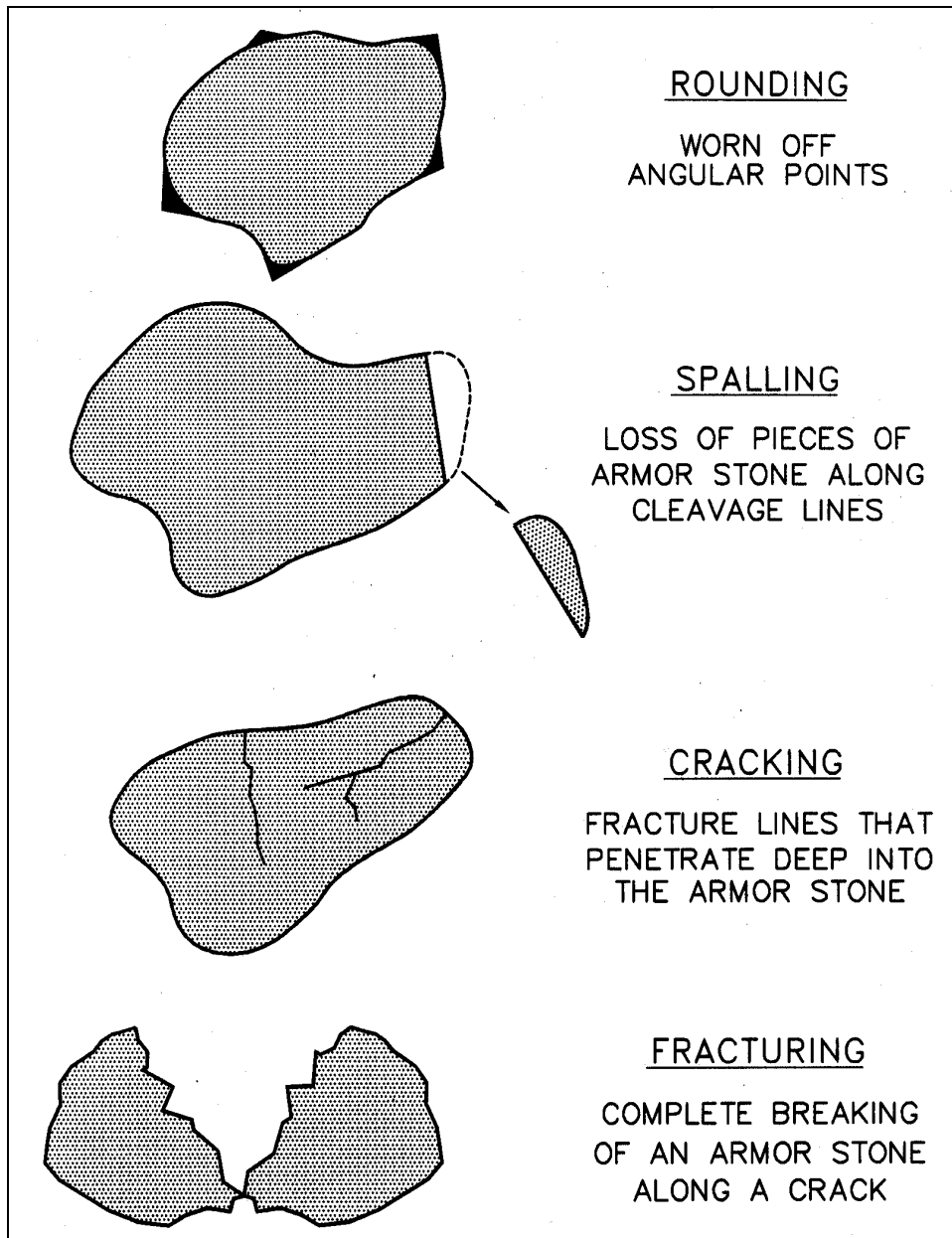


Figure 20. Armor quality defects.

Fracturing. As cracks progress, a critical condition is eventually reached and the unit will break into at least two major pieces. Because hydraulic stability is directly related to the weight of individual armor units, fracturing has serious consequences and it brings a risk of imminent and catastrophic failure.

Slope Defects

When armor loss or settlement occurs over a large enough area that the shape or angle of the side slope is effectively changed at that section, then a slope defect exists. Slope defects occur when many adjacent armor units (or underlayer stones) appear to

have settled or slid as if they were a single mass. Two forms of slope defects are described below.

Slope Steepening. Slope steepening is evidence of a failure in progress within a rubble structure. When present, the surface appears to have a steeper slope than for which it was designed or constructed. Slope steepening is a localized process that occurs on the surface of a rubble structure due to changes in the armor layer as shown on Figure 21.

Sliding. Sliding is a general loss of the armor layer directly down the slope. Unlike slope steepening, this problem is usually caused by more serious failures at the toe of the structure. Figure 22 illustrates a case in which deep toe scour has undermined the armor layer. If the scour is severe, the outer surface or even the entire armor layer could slide downward to fill the scour hole (as shown in the figure). This condition is possible along a jetty at a tidal inlet where strong currents are common. Another cause of sliding is a failure of the foundation soils near the toe when their shear strengths have been exceeded. This kind of failure can occur when a rubble structure is built over weak, cohesive soils.

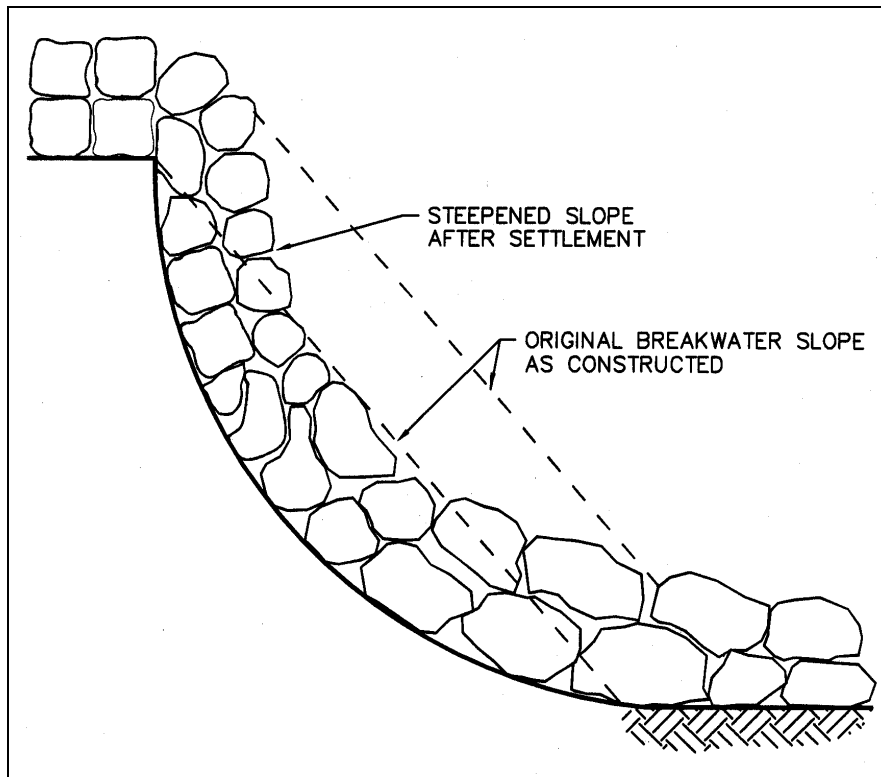


Figure 21. Slope steepening.

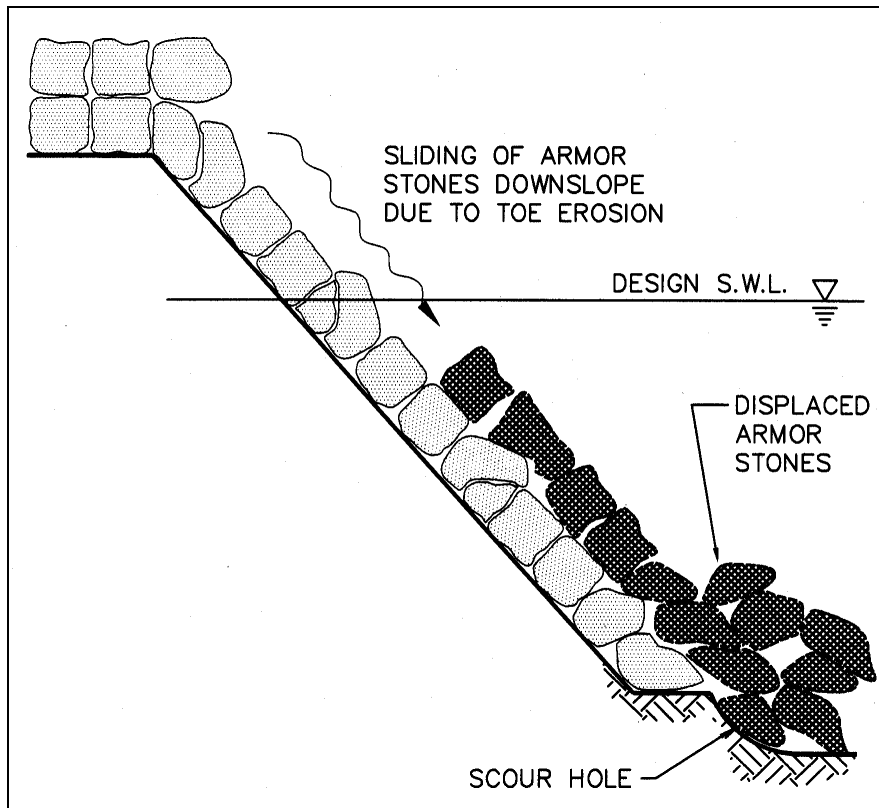


Figure 22. Slope defect caused by toe erosion and sliding of armor layer.

Using the Structural Rating Form

The structural ratings are made using the field form shown in Figures 23 and 24 (front and back, respectively). One form is needed for each reach or subreach in a structure. Figures 25 and 26 (front and back, respectively) show an example of a completed form.

For rating purposes, each reach or subreach cross section is divided into three areas: the crest (or cap), the seaside, and channel or harborside. Each cross sectional area is given 0 to 100 ratings in five rating categories, as shown in the center of the form. All categories must be rated (otherwise, a structural index cannot be calculated).

For reaches that form the head of a structure, all faces are considered to be the seaside; the channel/harborside section of the form is not used for these reaches.

Next to each rating block on the inspection form, is a space for comment number. This number may be keyed to a comment given in the bottom section, explaining the reason for the rating and describing what was observed, as well as station (or station range) for the defect location, and a column for "Suggested Action," referring to one of the five lettered actions listed above the comment block.

Four of the rating categories have a list of descriptors following them that serve to further characterize the defects found within a reach. If applicable, the inspector should circle the one (or more) that best characterizes the existing defects. Other descriptions may be supplied by the inspector in the comment space.

Below the rating block are additional items that should also be observed while inspecting a structure. The foundation fault items may require additional work before they can be completed. Related comments should be recorded in the comment section at the bottom of the form.

The importance of providing thorough comments cannot be overemphasized. Comments should note the location, character, size, and actual or potential effects of structure defects. The comments serve as backup and explanation for the ratings and suggested actions chosen by the inspector. Comments also provide a good record for future reference.

Five Suggested Actions are given on the structural rating form, just above the comment block. The inspector may use these to suggest what action may be appropriate for the recorded defects. As stated, A) Immediate Action means that repairs are required right away to preserve structural integrity — an emergency. B) Action Soon means defects should be corrected during the next budget cycle. C) Watch means no repairs are required currently, but the condition may be unstable or subject to rapid change and should be monitored regularly. D) Defer means that the affected area of the reach appears stable and does not appear to threaten structural integrity, even if condition should worsen somewhat. E) Investigate Further means more detailed inspection and analysis are needed to determine or verify the severity of the condition or the appropriate action to be taken.

Inspectors are encouraged to suggest an action for each defect area on the reach, but should follow local guidance in applying and reporting these. The action items do not affect ratings or index values.

The Inspection Process

Completion of the structural rating form is intended to be part of a regular, periodic structure inspection program conducted by the Coastal Engineer Districts. The field observations and recorded information needed to produce CI values are nearly the same as would be required as part of any routine inspection.

Preparation for determining structure ratings should be the same as for any regular, thorough inspection. The inspector (or inspection team) should be familiar with the structure and past inspection reports before the inspection begins. The beginning and end of each reach should also be known. A copy of the latest inspection report should be brought to the work site to help judge changes in condition.

SUGGESTED ACTIONS: A) Immediate Action B) Action Soon C) Watch D) Defer E) Investigate Further

Figure 24. Structural rating form - back.

STRUCTURAL RATING FOR RUBBLE BREAKWATERS AND JETTIES Page _____ of _____

PROJECT NAME: Example Harbor Reach 3A

STRUCTURE NAME: South Jetty Sta: From 20+20 To 24+00

INSPECTOR: J.O. Inspection Date: 8/30/95 Time: Begin 8:00 End 12:00

WAVE HEIGHT (ft) _____ WAVE ACTION ON: A. Overtopping B. Non-overtopping TIDE LEVEL: A. High B. Medium C. Low WEATHER DAY OF DAY OF INSPECTION: 3 ft. Stage: -2 MLLW feet A Fair B. Rain C. Fog D. Storming

TYPE OF INSPECTION A WALKING B. BOATING C. OTHER

RATING CATEGORIES: Rate all items (Circle applicable lettered items)	CREST / CAP		SEASIDE (or HEAD)		CHANNEL / HARBOR SIDE	
	Rating 0-100	Comment Numbers	Rating 0-100	Comment Numbers	Rating 0-100	Comment Numbers
Breach <u>A</u> Displaced Cap/Armor B) Settling Cap/Armor	10	1				
Core (or Underlayer) Exposure / Loss	10	1	10	1	10	1
Armor Loss: <u>A</u> Displaced B) Settling C) Bridging	10		10		10	
Loss of Armor Contact / Armor Interlock	10		10		10	
Armor Quality Defects: A) Rounding B) Cracking C) Spalling D) Fracturing	95		95		95	
Slope Defects: A) Steepening <u>B</u> Sliding			55		20	2

Comment Numbers FOUNDATION FAULT SUSPECTED IN: A) Armor Displacement B) Slope Steepening C) Slope Sliding Caused By: (a) Scour (b) Settlement (c) Shear (d) Liquefaction

2 Item A (B) C - (a) (b) (c) (d) Sta 20+40 to 23+40

3 Item A (B) C - (a) (b) (c) (d) Sta _____

WARNING SIGNS/GATES _____

AUXILIARY STRUCTURES (walkways, stairs, navigation lights, etc.) _____

AMOUNT OF DEBRIS IN ARMOR (rubble, trash, logs, etc.) _____

SUGGESTED ACTIONS: A) Immediate Action B) Action Soon C) Watch D) Defer E) Investigate Further

Comment Number	Suggested Action	Station Location(s)	COMMENTS AND SKETCHES
1	A		300 feet of reach has been breached to about MLLW.
2	A		Scour hole noted on last 2 annual surveys on channel side. Resurvey immediately.

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Figure 25. Example completed structural rating form - front.

SUGGESTED ACTIONS: A) Immediate Action B) Action Soon C) Watch D) Defer E) Investigate Further			
Comment Number	Suggested Action	Station Location(s)	COMMENTS AND SKETCHES
2	A		(Continued) Waves presently steepening at previous scour location. Thalweg shift apparent.
3	A		Warning signs needed, to alert public until reach is repaired.

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Figure 26. Example completed structural rating form - back.

Other items to help conduct an effective inspection and to document findings include: project maps and photographs, still and video cameras, tape measures, hand levels, and tidal information.

Ratings may be best determined by first walking the length of the structure and making notes of observed defects, their station location, and their severity. On the return walk, ratings may then be selected based on having seen the whole structure and on a second opportunity to observe defect sites.

Determining Structural Ratings

Structural ratings are selected from the appropriate rating table (Tables 3 through 8). These ratings are based on a comparison of the existing condition (at the time of inspection) with an "ideal" or "perfect" condition. Thus, even a brand new structure may not warrant ratings of 100 if, for example, some armor units were damaged during placement or armor placement did not fully meet design specifications.

When assigning ratings, choosing numbers in multiples of five is usually preferred. Ratings at the top or bottom end of a condition level may also be appropriate. The descriptions in the tables correspond to ratings at the center of the value range for each level. All ratings must be based on the condition of the structure at the time it was inspected.

For any rating category, it will be quite common that none of the condition levels lists a case exactly matching the situation found in the field. In such cases, the inspector selects the appropriate rating by first narrowing down the choice to the most appropriate one or two condition levels, and then selecting the final rating. The general SI scale (Table 2) should also be used to help judge the relative severity of the defect. The two most common situations are:

- a. The choice can be narrowed down to one condition level. The inspector must then determine if the most appropriate rating is near the top, bottom, or middle of the condition level. (Examining the condition levels just above and below will help in deciding.)
- b. Two adjacent condition levels look possible. The inspector must determine if the rating is most appropriate near the bottom of the higher condition level or near the top of the lower level.

For conditions or unique situations not covered in the rating tables, the general SI scale should be used to determine the most appropriate rating. The following two examples illustrate the thought process for selecting SI ratings.

Example 1

A reach has one spot where three adjacent armor stones have been rolled completely out of place. The second armor layer is still intact, although somewhat shifted. Armor units surrounding the void appear stable, with only a slight shift apparent. Core can be seen, but none has been lost, although the voids do appear just large enough to allow some loss. The rest of the reach is in very good condition, with at most, slight armor shifting.

Comparing this case to Table 5, note that none of the condition level descriptions match. Level 40 to 54 is close with respect to the core still being intact, but calls for much greater armor loss than the example. With respect to level 55 to 69, there is armor loss in only one spot, rather than several, but the space is three units large, rather than a single unit, as stated in the description. The sentence describing core exposure and loss does apply quite well. From this, it appears that the rating should be somewhere between the top of level 40 to 54 and the middle of level 55 to 69, or from 50 to 65.

In making the final choice, note that in both levels, no core has been lost. With three adjacent armor units missing, but surrounding units in place and appearing stable, the reach is closer to the lower end of level 55 to 69 than to the upper end of level 40 to 54. Thus, the most appropriate rating for Armor Loss would probably be 55.

Example 2

Consider the same reach used in Example 1. Looking at Table 4, we again find that none of the descriptions match. Level 55 to 69 is closest, although the reach does have a spot with three armor units completely out of place, but has only one place where voids would be large enough to permit core loss. With the main idea for this category as core exposure or loss, the defects appear to approximate the upper end of level 55 to 69 (one place where voids are large enough to allow core loss), thus the most appropriate rating is probably 65.

Rating Tables

Tables 3 through 8 provide guidance for assigning numerical ratings to the six structural rating categories. The descriptions in the tables correspond to ratings at the center of the value range for each level.

Table 3. Rating guidance for breach.

Structural Rating	Description
Minor or No Damage	
85 to 100	At most, slight settlement of crest or cap of less than 1/4 the diameter of a single armor stone or unit.
70 to 84	Along the reach there is some waviness in the crest profile, with settlement no more than ½ the diameter of an armor stone or unit. The cap is intact and no armor units have been lost.
Moderate Damage	
55 to 69	A breach has formed from the loss of the outer armor layer or the crest has settled a distance equivalent to about ½ - 1 diameter of an armor stone or unit. No underlayer stone has been lost. Repairs may be possible by the addition of a few armor units.
40 to 54	One or more short breaches have formed down to the underlayer or the crest has settled up to 2 armor stones or full armor layer in depth. A small amount of underlayer may have been disturbed or lost. Most repairs might be made by adding and repositioning armor units.
Major Damage	
25 to 39	A serious breach is present. Underlayer or core has been disturbed or lost. The reach is in a vulnerable state in which any overtopping wave could remove more underlayer or core stone and/or widen the breached area. Alternately, settlement is resulting in significant transmission of wave or current energy over the structure.
10 to 24	The core is exposed and much core material has been lost.
0 to 9	The cap or cap stones have moved out of position or been lost along most or all of the reach. The core is exposed and most of the reach is at or within the core.

Table 4. Rating guidance for core (or underlayer) exposure or loss.

Structural Rating	Description
Minor or No Damage	
85 to 100	No underlayer or core exposure or loss.
70 to 84	The underlayer stone can occasionally be seen through gaps in the armor layer. The gaps are smaller than the size of underlayer stone, and no underlayer loss is evident.
Moderate Damage	
55 to 69	The underlayer or core stone can often be seen through gaps in the armor layer. In some places the gaps are large enough to allow loss of underlayer or core stone, but no underlayer or core loss is yet evident.
40 to 54	Small losses of underlayer or core stone have occurred in some places, and armor stones may have shifted because of loss of underlying material. Structural stability is beginning to be affected.
Major Damage	
25 to 39	Some loss of underlayer or core stone has occurred in several places within the reach. Underlayer or core loss has caused armor stones to significantly shift in many places. Structural stability is clearly affected.
10 to 24	Large areas of underlayer and core are exposed. Enough core stone has been lost that very little support remains for the armor stones.
0 to 9	The core is exposed across the whole reach, and a large amount of core stone has been lost. No portion of the reach is still intact.

Table 5. Rating guidance for armor loss.

Structural Rating	Description
Minor or No Damage	
85 to 100	At most, slight movement of the armor in a few isolated spots. Movement has left a depression no larger than 1/4 of one armor stone (or unit) diameter.
70 to 84	Armor movement has caused some waviness along the slope surface with depressions less than 3/4 the armor layer thickness. Any bridging is over a void less than 1/2 of the armor diameter. Underlayer may be seen in spots, but none has been lost.
Moderate Damage	
55 to 69	Some loss of armor in spots, leaving voids or depressions about the size of an armor unit. Units surrounding the void may be rocking or gradually moving out of place. Underlayer or core might be seen at these spots, but armor position still prevents loss of this material. Bridging to a diameter of an armor stone may be visible in several places.
40 to 54	Armor units have been lost or displaced in some portions of the reach length. Voids are just large enough to allow loss of underlayer.
Major Damage	
25 to 39	Armor units have been fully displaced or lost. Voids are large enough to easily allow underlayer and core loss.
10 to 24	Armor units have been fully displaced or lost. Underlayer loss is evident.
0 to 9	Armor units are gone or fully displaced. Structure is unraveling.

Table 6. Rating guidance for loss of armor interlock.

Structural Rating	Description
NOTE: Interlock ratings based on Hudson Coefficient of at least 3.5.	
No or Minor Damage	
85 to 100	Loss of interlock is minimal.
70 to 84	A few armor units may have lost contact with adjacent units by up to 1/4 of the unit diameter.
Moderate Damage	
55 to 69	Loss of contact or interlock with adjacent units in some places, however separation rarely exceeds 1/2 of the unit diameter. Bridging of units may occur in isolated locations.
40 to 54	Many adjacent armor units are separated by up to 1/2 of the unit diameter. Some armor units are completely separated from adjacent units and are acting independently. Many of the loose units show signs of being easily rocked or shifted by normal or light storm waves.
Major Damage	
25 to 39	Many armor units are loosely nested and act alone. Separation between adjacent units commonly exceeds one unit diameter.
10 to 24	Most armor units are loosely nested and are acting alone.
0 to 9	Nearly all visible armor units are loosely nested and are acting alone. At this stage, many of the armor units have also been lost.

Table 7. Rating guidance for armor quality defects.

Structural Rating	Description
Minor or No Damage	
85 to 100	At most, some minor degradation (rounding of edges, small cracks or spalls) on some armor units.
70 to 84	Minor degradation (rounding of edges, small cracks or spalls) of armor units is common, but only a few armor units may have deep cracks. On concrete armor units, some corrosion staining may be visible, but no reinforcing steel is exposed.
Moderate Damage	
55 to 69	Some armor units have deep cracks. On concrete armor units, reinforcing steel may be visible on some units. In more severe cases, a few isolated units may have fractured completely.
40 to 54	Deep cracks in armor units are commonly seen; some may have completely fractured.
Major Damage	
25 to 39	Deep cracking of armor units is widespread, separation of smaller fractured pieces is common, and some units have fractured completely.
10 to 24	Most armor has deep cracks, and complete fractures are common. Numerous separated pieces are visible all across the reach.
0 to 9	Nearly all armor is seriously damaged or broken.

Table 8. Rating guidance for slope defects.

Structural Rating	Description
Minor or No Damage	
85 to 100	No detectable sliding or steepening of the slope.
70 to 84	Slight sliding of the slope. The slope surface may begin to appear wavy or uneven. No underlayer or core stone has been exposed.
Moderate Damage	
55 to 69	Sliding has occurred to the point that underlayer or core is beginning to be exposed, however the slope still seems relatively stable at these points. Adjacent slope sections may appear wavy or uneven.
40 to 54	Sliding has occurred to the point that the underlayer or core is clearly exposed in a few places. Overall stability is considered questionable at these locations.
Major Damage	
25 to 39	Steepening or sliding is readily apparent across much of the slope. Core is exposed in a few large areas or several small areas spread over the slope; these areas are considered very vulnerable to further storm damage.
10 to 24	The slope has generally deteriorated over most of the reach length, and much of the core or underlayer has been exposed. Storms of light to intermediate intensity cause continual additional damage.
0 to 9	Deformation of the slope is extensive. Stability has been lost.

6 Functional Rating Procedures

Introduction

The structure's functional performance is the most critical portion of the condition index for coastal structures, with the measure of physical condition (SI values) playing a subordinate role. As previously shown in Figures 2 and 3, the SI values supply information to assist in determining functional ratings, which then lead to functional index (FI) values and to the final condition index. FI values are expressed as numbers from 0 to 100 and have the general interpretation as shown in Table 9.

Part of implementing the Condition Index system is determining which major functions, and in turn, which rating categories apply to each reach of a structure. As with reach limits, once assigned, these functions should not change unless major changes are made to the structure or project. The functional index for the reach will then be based on the same selected functional rating categories every time a functional rating is done.

Functional ratings are produced using the rating tables (Tables 15 through 18) at the end of this chapter. While the wording in the descriptions for each rating table is specific to the category being rated, each table follows the format and general interpretation of the FI scale shown in Table 9.

Functional ratings are made for each reach of a structure after all the structural ratings are done and have been entered into the BREAKWATER computer program (which will calculate the Structural Index values). It is recommended, though, that the functional rating form be brought to the field during the structural inspection for observations and comments that may affect the functional rating produced back in the office.

Table 9. Functional Index Scale for coastal structures.

Functional Loss Level	Zone	Functional Index	Condition Level	Description
Minor	1	85 to 100	EXCELLENT	Functions well, as intended. May have slight loss of function during extreme storm events.
		70 to 84	GOOD	Slight loss of function generally.
Moderate	2	55 to 69	FAIR	Noticeable loss of function, but still adequate under most conditions.
		40 to 54	MARGINAL	Function is barely adequate in general and inadequate under extreme conditions.
		25 to 39	POOR	Function is generally inadequate.
Major	3	10 to 24	VERY POOR	Barely functions.
		0 to 9	FAILED	No longer functions.

Functional Rating Categories

Structure functions are divided into 4 major areas containing a total of 11 rating categories. The four functional areas indicate how well the structure performs the following:

- a. Controls waves and currents to permit full use of the harbor area.
- b. Controls waves and currents to permit full use of the navigation channel and entrance.
- c. Controls movement, build-up, and loss of sediment within navigation areas and along adjoining shorelines.
- d. Protects nearby structures, or portions of itself, from wave attack or erosion damage.

The self-protection aspects of functional area (d) are not used in determining the condition index, but are included as indicators of the potential for rapid loss of function in the other functional categories. Functional deficiencies that are not caused by structural deterioration are not included in the ratings. Design deficiencies should be identified in the development of the project spreadsheet and reported using the current guidance for that process.

When defining reaches (as outlined in Chapter 4), functions for each reach of a structure are determined from the 11 rating categories within the 4 main functional areas. A reach may have most of the 11 functions or only a few. (The rating process is covered in following sections.)

Tables 10 through 13 summarize the rating categories and corresponding process elements. Items in the Rating Categories column of the tables represent types of damage or adverse conditions (functional deficiencies). Items in the Process Elements column represent the potential causes of these conditions. When a functional deficiency is noted, an investigation of the process elements may help to further define the character and severity of the problem and to determine appropriate remedial actions.

In addition to the four major functional areas, there is a group called "Other Functions." These are considered secondary to the main functions and are not given numerical ratings, nor do they affect reach definitions or FI values. Instead, comments are provided when functional deficiencies exist in these categories.

Table 10. Harbor area.

Rating Categories	Process Elements
<u>Harbor Navigation</u> *Limitations on vessel size and draft. *Vessel maneuvering difficulties. <u>Harbor Use</u> *Delays due to wave or current conditions. *Limitations on vessel size and draft. *Reduced usable mooring area. *Reduced mooring density. *Vessel maneuvering difficulties. *Damage to structures. *Damage to other facilities. a. Moored Vessels *Damage from waves, currents, seiches. b. Harbor Structures *Damage or wear on piers, floating docks, and mooring systems. *Overstressed mooring buoys and dolphins. *Broken mooring lines. *Vessels dragging anchors. *Erosion or loss of backfill behind bulkheads, seawalls, revetments. *Scour at toe or excessive leaning of structures. *Direct structural damage. *Use restrictions c. Other Facilities *Flooding. *Erosion. *Direct structural damage. *Use restrictions.	<u>Wave Conditions</u> *Long period fluctuations or oscillations: - Harbor resonance. - Storm surge. - Seiching. *Storm waves: - Height. - Period. - Frequency. *Wakes from vessels. *Wave transformation: - Diffraction. - Reflection or standing waves. - Wave/current interactions. <u>Currents</u> *Tidal or fluvial: - Training. - Dispersion. - Deflection. *Alteration of natural flushing characteristics.

Table 11. Navigation channel.

Rating Categories	Process Elements
<u>Entrance Use</u> *Delays due to wave or current conditions. *Limited vessel size or draft, due to waves. *Difficulty or damage while navigating entrance.	<u>Wave Conditions</u> *Seiches of long period. *Storm waves: - Height. - Period. - Frequency. *Wave transformation: - Refraction and focussing. - Diffraction and crossing. - Reflection. - Breaking. - Wave/current interactions. - Waves at unfavorable angles.
<u>Channel</u> *Delays due to waves or current conditions. *Limited vessel size or draft. *Obstruction from displaced armor units. *Migrating thalweg. *Vessel collisions with structure or other vessels.	<u>Currents</u> *Tidal or fluvial: - Training. - Dispersion. - Deflection. *Excessive velocity. *Cross-channel currents.

Table 12. Sediment management.

Rating Categories	Process Elements
<u>Ebb Shoal</u> *Change in navigation channel dimensions. *Shift of channel location due to migrating thalweg.	<u>Sediment</u> *Shoaling: - Magnitude. - Rate. - Location.
<u>Flood Shoal</u> *Change in navigation channel dimensions. *Shift of channel location due to migrating thalweg.	* Loss of deposition. *Transformation of bedforms: - Ebb or flood tidal shoals. - Shore-parallel bars. - Sand waves.
<u>Harbor Shoaling</u> *Change in maneuvering channel dimensions. *Loss of depth in mooring areas.	<u>Wave Conditions</u> *Direction. *Refraction. *Diffraction.
<u>Shoreline Impacts</u> *Downdrift Erosion. - Flanking. - Interior bank erosion. *Updrift Accretion. *Adverse effect on sand bypassing operations. *Sediment losses from system.	<u>Currents</u> *Direction. *Velocity.

Table 13. Structure protection.

Rating Categories	Process Elements
<u>Nearby Structures</u> *Inner side of jetties or breakwaters. *Other jetties or breakwaters. *Jetty itself, in some cases, when armor is breached.	<u>Wave Conditions</u> *Wave transformation: - Diffraction. - Reflection. *Overtopping. *Wave runup. *Transmission through structure.
<u>Toe Erosion</u> *At structure head. *Seaward side. *Channel side.	<u>Current Conditions</u> *Rip currents on seaward side. *Ebb flow impingement. *Flow separation during flood with eddy forming and developing a scour hole at the head.
<u>Trunk Protection</u> (For Head or Root Only) *Damage to trunk due to inadequate protection from head or root reach.	

The 4 functional areas and 11 rating categories are:

Harbor Area

Harbor protection structures (usually breakwaters) are designed to protect or shelter an area from large waves, currents, seiches, and sedimentation, thereby forming a safe, navigable harbor. (Typical breakwater systems were illustrated previously in Figures 7 and 10.) Ratings within this main function are based on how well the structure provides and protects a harbor during all conditions and for all vessels, as compared with the design expectation or current requirements. Sedimentation is covered by the Sediment Management function under the Harbor Shoaling category.

Harbor Navigation. This category indicates how well navigable conditions are maintained within the harbor, as opposed to navigation outside the harbor. Difficulty in maneuvering and restrictions on vessel drafts or lengths are indications of problems. When these conditions are associated with waves or currents, in lieu of sedimentation, over-crowding, or designed channel width constraints, they indicate a deficiency in this category.

Harbor Use. Harbor use may be restricted by waves, currents, or seiches within the mooring area or at support facilities (i.e., fuel docks, unloading docks, dry docks, grids, etc.). Use restrictions may occur during certain wave conditions, which tend to be seasonal. For instance, frequent winter storms may lead to wave conditions inside the harbor that make the harbor unsafe for normal operations.

There are several facets to restrictions on harbor use. These are subcategorized in the following paragraphs and in the functional rating tables. The design storm events and structure performance expectations often differ among these subcategories, even though they are all part of harbor use. Likewise, all three subcategories may not apply to all harbors.

a. Moored Vessels

This subcategory indicates how well moored vessels are protected from damage by waves, currents, and seiches. Functional deficiency may be measured by the frequency and degree to which moored vessels sustain damage due to excessive wave or current energy. Also, areas of the harbor that cannot be used to their full potential may have reduced mooring density or may have been abandoned by that part of the fleet sensitive to the problems being encountered.

b. Harbor Structures

This subcategory indicates how well the harbor structures are kept usable and protected from damage. The berthing facilities used to dock or provide moorings for vessels are part of this subcategory. Berthing structures include fixed or floating docks, piers, mooring piles, dolphins or buoys, anchorages, and other areas set aside to receive vessels.

Functional deficiency may exist if waves or currents are strong enough to damage or impair the use of these facilities. Some indications of excessive wave and current energy are: damage or rapid wear to floating docks, chafing and wear on guide piles and mooring systems, overstressed mooring buoys and dolphins, and cases of vessels dragging their anchors.

Also included in this subcategory are those facilities that help form the harbor and allow its use for commercial and recreational navigation. Typical are structures that provide the land-water interface such as bulkheads, seawalls, and revetments. Certain kinds of repair facilities such as dry-docks may also be included in this category, and in some cases, even the breakwaters and jetties. Indications of damage by waves or currents include direct structural damage or erosion and loss of the backfill behind bulkheads and seawalls. Toe scour (determined from a diving inspection, sidescan, or other acoustic surveys) or excessive leaning of structures may also indicate damage by currents or seiches. Direct structural damage may not be the only indication of a problem. Use restrictions may indicate that waves and currents are excessive.

c. Other Facilities

Other facilities are those that are set back from the land water interface and which are part of the commercial and recreational activity surrounding the harbor. These facilities support cargo movements, commercial fishing, cruise vessels, recreational boating, etc. They include hard stand areas, transit sheds, warehouses, terminals, ship repair facilities, offices, stores, and restaurants. The condition of their foundations and surrounding property is an indication of adequate or inadequate protection.

Navigation Channel

This functional area includes all entrances and navigation channels within harbors, channels, maneuvering areas, and mooring areas. Ratings within this main function are based on how well the structure controls waves and currents to provide safe navigation during all conditions and for all vessels, as compared with design expectations or current requirements. Sediment control aspects are rated under Sediment Management. The channel is separated into two segments: the entrance, including approaches, and the channel between the harbor and entrance, if that segment is separable.

Entrance Use. This category indicates the ability of the structure to maintain a safe channel or harbor entrance by controlling waves and currents within the limits provided in the authorizing documents or by economic reality. Functional deficiencies are indicated if certain sizes or types of vessels are unable to safely pass through the entrance, or are delayed in entering. Another indication is a limit on allowable vessel draft, which can exclude vessels in either extreme of the fleet for which the harbor was designed. The impact of the ebb shoal and flood shoal on wave transformation can be a major source of difficulty and is to be rated here.

If structures are performing poorly in controlling channel depth, that portion of the problem is to be rated under Sediment Management (see “Operations and Maintenance Items” in Chapter 3.) If the entrance structures do not adequately reduce waves (or limit breaking wave conditions), the smallest vessels in the fleet may find it too hazardous to move through the entrance. Where the restriction is a function of wave activity and not caused by shoaling above project depth, it is properly rated here. Displaced armor from a structure may also create channel obstructions. (The angle that the entrance makes with prevailing winds and waves can also be a factor, particularly if recreational sailing is an important activity.)

Channel. This category indicates how well the structure controls waves and currents to provide a safe, navigable channel through which vessels may operate without difficulty, delay, or damage. Indications of functional deficiency include: strong cross channel currents or crossing wave trains that may delay vessels until more favorable conditions prevail; channel obstructions from displaced armor units; and reports of vessels impacting the bottom (grounding), vessels colliding with the navigation structures, or each other.

Sediment Management

The ratings in this main function indicate how well the structure controls the depth, character, and pattern of sedimentation in the navigation channel; the depth of ebb and flood shoals in tidal entrances; and the buildup or loss of sediments on nearby shorelines. For riverine or nontidal conditions, the rating should also cover the eddy shoal development that occurs at those entrances.

Breakwaters and jetties modify the pattern of sediment distribution in the waterways that are formed in conjunction with them and on the adjoining shorelines. A structure may cause ebb and flood shoals to shift dramatically and eventually stabilize in new locations if sediment supplies are stable. How well the structure is managing the depth of the ebb and flood shoal in the navigation channel can often be deduced by observing surveys and comparing them to dredging records. Secondary effects of ebb shoals and flood shoals such as wave steepening, cross channel currents, and erosion impacts are rated under Navigation Channel or Structure Protection.

Poor sediment management can also be discerned by unpredictable channel locations and unstable channel depths and widths. Shoreline erosion or accretion and oversteepening of shorelines are other indications of sediment management problems.

Ebb Shoal. The ebb shoal forms seaward of the structures and is a product of longshore currents and sediments interacting with the ebb flow currents including riverine contributions and sediments. Its position can affect navigation negatively by focusing waves in the channel, decreasing navigable depths, forcing the channel thalweg to migrate and forcing ebb flows to increase wave heights. The negative effects of in-channel sedimentation are largely managed by dredging, and a measure of the impact of the ebb shoal can often be partially deduced from dredging records. Other indications of ebb shoal impacts are vessel delays due to wave steepness or wave breaking in the entrance approach channel, vessel groundings, etc. To separate the Sediment Management portion of ebb shoal impacts from the Entrance Use category, only the loss of channel depth and width that can be corrected by dredging and the shift in thalweg requiring repositioning of aids to navigation are rated in this category. Other impacts of the ebb shoal are to be rated under Entrance Use and Structure Protection.

Flood Shoal. The flood shoal forms in the waterway landward of the structure head and, similar to the ebb shoal, is normally a product of longshore sediments and flood flow transfer of those sediments into the interior channel system. Riverine sediments may also contribute to this shoal. Deposition of the flood current sediments occurs at many locations and, to a large extent, is a product of loss of transport capacity at expansions. Normally the shoal can be found in two locations: immediately inside the contraction made by stagnation points at the jetty tips, and at the points where jetties terminate and an expansion occurs at the landward end.

The shoals can have significant affect on cross channel currents, waves in the channel, etc., even though they lie outside of the navigation channel. The only items that are rated in the Sediment Management functional area are a reduction in channel

dimensions that impact navigation, and a shift in channel thalweg that requires changes in aids to navigation. The relationship can normally be deduced by examining dredging records and surveys. Both the ebb and flood shoal can also be related to some structural damage as currents are shifted and erosion occurs at the toes of the structures. The toe erosion or scour aspect is to be rated under Structure Protection. Cross channel currents, crossing wave trains, oversteepened waves, etc., caused by the flood shoal are to be rated in the Channel category. Focusing of waves to the extent they disrupt harbor use is to be rated under Harbor Use.

Harbor Shoal. Sediment buildup in a harbor may be independent from the ebb and flood shoal. Density, currents, upland runoff, winds, short waves, and vessel agitation of sediments combined with very low velocity currents can all create sediment deposit in maneuvering areas and mooring areas. Where structures were placed to limit these types of shoals, a functional rating should be developed.

Shoreline Impacts. Breakwaters and jetties modify the natural pattern of sediment distribution in the surrounding area. They also affect the sediment supply, its location, and distribution on adjacent beaches. When these changes occur, the adjoining shoreline tends to adjust to the new conditions created by the structure's presence. This rating category indicates the ability of the structure to maintain adjoining shoreline profiles within acceptable limits. The structures also force large amounts of sediments to transfer to their seaward tips, thus much of the sediments associated with the ebb and flood shoal are related to shoreline impacts.

Breakwaters built primarily for shore protection should be judged on how well they succeed in stopping erosion of the protected shoreline without causing undesirable erosion on the adjoining shoreline on either side of the project. If a recreational beach is a part of the project, then some judgment must also be made about how well the sand is being retained.

Measures to minimize shoreline impact include: mechanical sediment transport systems, weir jetties with sand traps (in combination with dredging of the sand trap), shoreline-to-shoreline dredge pumps, or on-shore or near-shore disposal areas. These systems are separate from the structures and their performance is not considered here; however, a structure's adverse effect on these systems would be rated within this category.

Structure Protection

Ratings within this main function indicate how well the structure accomplishes the following, compared with design expectations, or in some cases, present requirements:

- a. Minimizes wave energy levels on adjacent structures.
- b. Protects itself from erosion (scour).

- c. For head reaches (and sometimes for a root section), protects the trunk from structural deterioration.

These ratings are used to help assess which structural repair actions are needed. Only item (a) is included in calculating the functional index for the structure; items (b) and (c) are usually already accounted for, in more detail, in the structural ratings.

Nearby Structures. This category indicates how well the structure protects nearby structures. With parallel jetties, one jetty may protect the inner side of the other jetty. For example, at the Umpqua River in Oregon, the south jetty protects both an inner training jetty and the inner side of the north jetty. Jetties or breakwaters may also protect structures that are within their diffraction shadow. A prime example of this is the main breakwater protecting an inner breakwater at St. Paul Harbor in Alaska. A modest loss of main breakwater length can cause structural failure of the inner breakwater.

Toe Erosion. This category indicates how well reaches control excessive removal of sediments around the structure foundation. The flow contraction around the heads of structures often creates a stagnation area and eddy near the head of the structure. When this occurs large holes form, which can undermine the foundation. Interaction between tidal currents, coastal and longshore currents, coupled with surges, can also cause scour. Periodic seasonal surveys should be adequate to determine the size of problem, and when coupled with a soils analysis, can be used to assess the severity of the condition.

Jetties and breakwaters are also subjected to flow concentrations at various locations throughout their length. Ebb flows may be shifted to the structure due to the relationship of its geometry to the tidal prism or to the flood shoal location. Conditions exist where both geometry and flood shoal combine to intensify the flow concentrations along the jetty and to minimize sediment entering the region. Under these conditions the depth of erosion can be severe. On the shore side of structures, rip currents and gyres form that can cause unexpected erosion, or in some cases, accretion. Wave turbulence when combined with semi-steadystate flows can intensify erosion. Erosion effects are sometimes visible on the structure as a breach due to settlement, or as slope defects. Side scan sonar imaging may be able to detect scour before the structure is affected.

Trunk Protection. This category mostly applies to a structure head but may also apply to root sections in some cases. It indicates how well the head (or root, if applicable) prevents unraveling of the structure's trunk.

Other Functions

In addition to the main functions described above, breakwaters and jetties often have secondary functions that are grouped together in this category. These categories are not given numerical ratings (and are not used in defining reaches), but are reported as comments on the functional rating form.

Public Access. Comments in this category should indicate any failure of structure features to permit safe public access as intended in the project plan, or to effectively limit public access where it is not desired. These features include walkways, handrails, bicycle paths, gates, barrier fences, warning signs, lights, markers, etc.

Recreational Use. Comments in this category should indicate any failure of the structure in permitting recreational use as intended in the project plan. These activities include: boating, fishing, swimming, etc. Conditions that degrade recreational use include dangerous wave or current conditions or shoals at a harbor entrance, or for shore protection structures, failure to maintain a stable public beach.

Environmental Effects. Comments in this category cover both positive and negative environmental impacts from a structure's presence. Negative impacts include any adverse effect the structure may have on the nearby environment or failure to provide expected environmental benefits. Such effects may include reduced water circulation and flushing in the protected area, resulting in poorer water quality. The structures may also degrade the local environment by accumulating trash and debris. In northern locations, particularly on the Great Lakes, the harbor structures could impede the passage of ice floes if a major stream or river discharges into the harbor; in severe cases, ice jam flooding could occur.

Positive impacts may include the shelter provided by a breakwater that protects wetlands from wave attack and provides opportunities for habitat enhancement. Other positive impacts include attachment of organisms (habitat), increased diversity of environment, enhancement of fishing, diving, bird watching, etc.

Aids to Navigation. Comments in this category should indicate any damage, deterioration, or displacement of aids to navigation, deficiencies in access to them for maintenance and inspection, and damage to their mooring systems.

Storm Events

Performance in each functional rating category is measured in reference to three levels of storm events. Generally, ratings should be based on structure performance during storms of the greatest intensity that have occurred during the last rating period. Using three storm levels allows ratings to be produced during intervals when only storms of less than design intensity have occurred. Storms are to include the impacts of both local and distant events (sea and swell).

Design Storm

The design storm is the largest storm (or most adverse combination of storm conditions) that the structure (or project) is intended to withstand, without allowing disruption of navigation or harbor activities, or damage to the structure or shore facilities. For systems designed for seasonal use or for interrupted use, the expected nonuse periods

must be allowed for in arriving at a design storm. Design storm conditions include: wave height, direction, and period; water level; storm duration; and combinations of these factors. The design storm is usually designated by frequency of occurrence or probability of occurrence.

The design storm typically varies from one project to another, and for different activities or areas within a single project. For example, disruption of cargo handling or limitations on channel entrance use might be tolerated more frequently than disruption in the harbor area. Thus the design storms for the navigation channel, damage to harbor facilities, vessel damage, and disruption of cargo handling are, or should be, at different return intervals.

Corps guidance is that channels and harbors will be safe and efficient. Safe implies that no vessel damage should occur when vessels are moored in accordance with good practice. Efficient implies reasonable economic tradeoffs. As an example, past Corps practice has often been to design small boat harbors to limit wave heights to 1.5 ft during storms that have a 50 percent probability of occurring during the economic life of the project. In this case, for a 50-year design life, the design storm would have a return interval of 73 years. Generally, the return interval allowed for facility or vessel damage is on the order of once every 50 to 100 years.

Authorizing documents, design notes, project history, and current requirements should be used to confirm the appropriate design storms for a project. Current requirements may show a need for new authorization to improve conditions, or current economic conditions may require dimensions and storm conditions that would decrease the use from the level anticipated during authorization.

For many harbor entrances, design depths and channel orientation are indications of design intent. For example, a 10-ft channel will have breaking waves at a wave height of 8 ft. At this wave height, about 4 ft of channel depth is lost at the wave trough and waves are steep enough to cause broaching of a craft with less than 5 ft of draft. Thus, with an 8-ft wave, the channel is impassable for all vessels due to either limited depth (for larger vessels) or excessive wave steepness (for smaller vessels). At this location, an 8-ft wave height can then be tied to a storm of a certain frequency or probability, and a tolerable frequency for closing the channel can then be determined. In a similar fashion, safety in the harbor berthing area and disruption to cargo handling could be analyzed.

Intermediate Storms (2X Design Storm Frequency)

This level refers to storms (or combinations of adverse conditions) of intermediate intensity that occur on the order of twice as often as the design storm. This level is intended to represent a midway point between the maximum storm levels (design storm) and small or minor intensity storms that may occur more frequently, especially during certain periods of the year.

Low Intensity Storm Conditions

This level refers to storms (or combinations of adverse conditions) of low intensity that may occur frequently throughout the year, and includes common rain storms or periods of above normal winds. This level is the next stage above normal nonstorm conditions.

Using the Functional Rating Form

The functional rating is made using the form shown in Figures 27 (front) and 28 (back). An example completed form is shown in Figures 29 (front) and 30 (back). One form is used for each reach in a structure. Numerical ratings are entered for those functional categories that apply to the reach. When a rating indicates a functional deficiency, a corresponding comment should be provided in the Comments and Sketches block at the bottom of the form to explain the rating.

As with the structural rating form, five suggested actions are listed above the comment block. A) Immediate Action means that repairs or actions are required right away to preserve structure function or public safety—an emergency. B) Action Soon means functional defects should be corrected during the next budget cycle. C) Watch means no repairs are required currently, but the condition may be unstable or subject to rapid change and should be monitored regularly. D) Defer means that the affected area of the reach appears stable and does not appear to threaten functional integrity, even if the condition should worsen somewhat. E) Investigate Further means more detailed analysis is needed to determine the degree of functional loss or the appropriate action to be taken.

Inspectors are encouraged to suggest an action for each rated function, but should follow local guidance in applying and reporting these. The suggested actions do not affect ratings or index values.

The two questions above the comment block should be answered by circling "Yes" or "No." When answering "Yes" to the first question, a corresponding comment should be made to identify the deficiency or changed conditions or requirements that support the response. A "Yes" answer to the second question also requires a comment and should correspond to a Suggested Action of A) Immediate Action or B) Action Soon.

FUNCTIONAL RATING FOR BREAKWATERS AND JETTIES						
FUNCTION		RATING 0-100		COMMENT NUMBER	PROJECT	
HARBOR AREA	Harbor Navigation				STRUCTURE	
	Harbor Use					
	a. Moored Vessels					
	b. Harbor Structures					
	c. Other Facilities					
NAVIGATION CHANNEL	Entrance Use				REACH	
	Channel					
SEDIMENT MANAGEMENT	Ebb shoal				RATER	
	Flood Shoal					
	Harbor Shoal					
	Shoreline impacts					
STRUCTURE PROTECTION	Nearby Structures				DATE OF RATING	
	Toe Erosion					
	Trunk Protection					
OTHER FUNCTIONS	Public Access				Has a structural inspection been recently completed ? YES NO	
	Recreational Use					
	Environmental Effects					
	Navigation Aids to					
					Comment No.	
Are there functional deficiencies which are <u>not</u> related to structural defects?					YES	NO
Is there risk of further loss of function within the next budget cycle?					YES	NO
SUGGESTED ACTIONS: A) Immediate B) Soon C) Watch D) Defer E) Investigate Further						
COMMENT NO.	ACTION	COMMENTS AND SKETCHES				

9/8/95

Figure 27. Blank FI form - front.

FUNCTIONAL RATING FOR BREAKWATERS AND JETTIES (CONTINUED)		
SUGGESTED ACTIONS: A) Immediate B) Soon C) Watch D) Defer E) Investigate Further		
COMMENT NO.	ACTION	COMMENTS AND SKETCHES

Figure 28. Blank FI form - back.

FUNCTIONAL RATING FOR BREAKWATERS AND JETTIES					
FUNCTION		RATING 0-100		COMMENT NUMBER	PROJECT
HARBOR AREA	Harbor Navigation	20		8	Example Harbor
	Harbor Use	30	30	9	STRUCTURE South Jetty
	a. Moored Vessels	35			
	b. Harbor Structures	35			
	c. Other Facilities	35			
NAVIGATION CHANNEL	Entrance Use	100			REACH 3
	Channel	30		3,10	
SEDIMENT MANAGEMENT	Ebb shoal	85			RATER J. O.
	Flood Shoal	—			
	Harbor Shoal	30			
	Shoreline impacts	75		6	
STRUCTURE PROTECTION	Nearby Structures	70		7	DATE OF RATING 9/8/95
	Toe Erosion	90			
	Trunk Protection	—			
OTHER FUNCTIONS	Public Access			1	Has a structural inspection been recently completed ? ☒ YES ☐ NO
	Recreational Use			2	
	Environmental Effects			None	
	Navigation Aids			3	
					Comment No.
Are there functional deficiencies which are <u>not</u> related to structural defects?				☒ YES ☐ NO	4
Is there risk of further loss of function within the next budget cycle?				☒ YES ☐ NO	5
SUGGESTED ACTIONS: A) Immediate B) Soon C) Watch D) Defer E) Investigate Further					
COMMENT NO.	ACTION	COMMENTS AND SKETCHES			
1	A	Access to outer end of jetty (across this reach) is hazardous at all tide levels.			
2	A	Pedestrian access needs to be blocked and danger signs posted. 8/95			

Figure 29. Example completed FI form - front.

FUNCTIONAL RATING FOR BREAKWATERS AND JETTIES (CONTINUED)		
SUGGESTED ACTIONS: A) Immediate B) Soon C) Watch D) Defer E) Investigate Further		
COMMENT NO.	ACTION	COMMENTS AND SKETCHES
3	A	Aids to navigation need to be shifted to identify channel location.
4	E	See project background information
5	A	Deterioration in function expected to increase.
6	A	Assessment of design and impact of intermediate storm levels needed as structure may be lost if major breach recession occurs.
7	A	Rating based on low intensity storm experience. Further evaluation may indicate a lower rating
8	A	Harbor navigation unsafe for small boats during low intensity storms
9	A	Low intensity storms stop commercial activities and cause vessel and facility damage.
10	A	Thalweg migration causes channel shift.

Figure 30. Example completed FI form - back.

Steps in the Functional Rating Process

Background/Data Collection

Obtain the information required for the functional analysis:

Items (a) through (c) of the following list establish baseline performance expectations for the project and structures:

- a. Review the original intent or expectation of the design as described in the authorizing documents (or as subsequently modified).
- b. Review the descriptions for the functions assigned to the different reaches.
- c. Review the structure's functional performance requirements and structural requirements (as outlined in Chapter 4).

Items (d) through (h) establish evidence of existing performance deficiencies and risk of near-term functional deterioration. (Use the lists in Tables 10 through 13 as a guide on what information to look for, what observations to make, and what questions to ask):

- d. Examine inspection reports, dredging records, project history, and other office records relating to project performance.
- e. Review the structural ratings, SI values, and comments made during the structural inspection. Note the lower ratings and any suggestion or evidence of structural instability.
- f. Examine the project site. Look for evidence of navigation difficulties or functional deficiencies (such as those listed in the descriptions of the functional categories above).
- g. Gather information from vessel operators, harbor masters, the Coast Guard, Corps staff, etc., on any known navigation difficulties, facility damage, or other project deficiencies.
- h. Review the environmental setting in and around the project: wave energy, water level variability, sediment transport, etc.

Analysis

Use the information obtained in the previous steps to analyze the structure's functional performance. Filling in the spreadsheet, as shown in Table 14, is recommended – one for each reach.

- a. Document the performance expectations, and the actual structure performance, when no structural defects have been present.
- b. Estimate the minimum cross sectional dimensions, crest elevation, and level of structural integrity needed to meet the performance requirements for the reach being examined. The center columns of Table 14 are used to estimate, first, the impact on structure performance if the reach was destroyed, and second, to record the minimum reach dimensions necessary to provide acceptable performance.
- c. Determine for each reach which functional deficiencies exist and estimate their severity. Use a table (similar to Table 14, in the following rating example) to compare performance with no structural defects to performance in the present condition.
- d. Determine the extent to which the structure's physical condition is responsible for functional deficiencies. (This is the criterion on which numerical ratings will be based.)
- e. Determine if changed requirements, site conditions, or design inadequacies have adversely affected structure performance. (This is used in responding to the questions below the rating section.)
- f. Determine if there is a significant risk of further functional deterioration before the next budget cycle can be completed. (This is used in responding to the questions below the rating section.)

Functional Rating

Determine the functional ratings and complete a functional rating form for each reach:

- a. Based on the functional analysis performed, the guidance presented in the next section, and Tables 15 through 18 determine the appropriate numerical rating for each function assigned to the reach.
- b. Check to ensure that each rating is made based only on a reduced performance due to structural deterioration. (As a reminder: desired structure or project modifications due to design deficiencies, major changes in usage, etc., are beyond the scope of maintenance and repair, and thus are not considered here.)

- c. Provide comments on the rating form to explain the reason for choosing the ratings and select the appropriate Suggested Actions.
- d. Answer the two questions above the comment block.

Determining Functional Ratings

Functional ratings are made in reference to structure performance criteria—either design intent or current requirements, as discussed in Chapter 4 and in the previous section. Design deficiencies are not rated here. Design deficiencies should become evident in the development of spreadsheets for the project and are to be noted there. The reporting of design deficiencies should then follow current guidance and be separated from this report.

Thus, to affect the ratings, functional deficiencies must be caused by structural deterioration, or in some cases, changed requirements. In any case, situations that a structure could not reasonably correct or control should not be taken into account. In addition, ratings must be based on the condition of the structure at the time it was inspected.

Ratings are made using the rating tables that appear in the following section. A rating of 100 indicates the structure is performing as well as it would when no structural defects are present. When assigning ratings, choosing numbers in multiples of five is preferred. Ratings at the top or bottom end of a condition level may also be appropriate. The descriptions in the tables correspond to ratings at the center of the value range for each level.

For any rating category, it will be quite common that none of the condition levels lists a case exactly matching the situation found in the field. In such cases, the inspector selects the appropriate rating by narrowing the choice to the most appropriate one or two condition levels, and then selecting the final rating. The general FI scale (Table 9) should also be used to help select the most appropriate rating. The two most common situations are:

1. The choice can be narrowed to one condition level. The inspector must then determine if the most appropriate rating is near the top, bottom, or middle of the condition level. (Examining the condition levels just above and below will help in deciding.)
2. Two adjacent condition levels look possible. The inspector must determine if the rating is most appropriate near the bottom of the higher condition level or near the top of the lower level.

For conditions or unique situations not covered in the rating tables, the general FI scale should be used to determine the most appropriate rating. The following example illustrates the process for selecting FI ratings.

Example

This example illustrates the type of information and observations needed to determine functional ratings, how the ratings are selected, and using a spreadsheet similar to Table 14 to aid in the analysis.

Background. A functional evaluation is being done for reach 3 (offshore trunk) of a jetty similar to the one in Figure 9. The jetty protects the shallow draft entrance and channel of a small commercial and recreational harbor, as shown in Figure 31. The channel is maintained to -15 ft Mean Lower Low Water (MLLW). Commercial vessels that use the channel are primarily fishing trawlers with the largest having a draft of 11 ft. In addition, the channel is heavily used on weekends by recreational sail and powerboats that originate from marinas within the harbor. The bulk of these pleasure craft have drafts of 6 ft or less. A few fixed-keel sailboats have drafts of up to 10 ft.

Field Observations of Structural Integrity and Functional Performance. A 300-ft breach has developed in reach 3, which was given a structural rating of 10, representing major damage. Large sections of core stone are exposed and it is easy to imagine that another major storm could devastate a much greater portion of the jetty in reach 3 and adjoining reaches. Waves overtop the jetty through the breach and spill over into the navigation channel extensively several times a year. When this happens the wave conditions in the channel are too dangerous to navigate for most of the vessels in the harbor. In addition, sand is carried over the breakwater through the breach so that a large shoal has developed adjacent to the breach. The shoal impinges on the channel, and groundings are probable when care is not exercised. Strong tidal flushing through the entrance has distributed the sand across broad areas of the channel, causing the channel thalweg to migrate. It should be noted that sand is available for transport across the jetty because of a large deposit on the updrift side of the project. The deposit is larger than expected during design. There has also been erosion on the downdrift side of the project, and additional sand was previously added to the north beach to prevent undermining of seawalls at one or two locations and to protect existing homes.

Prior to the breach, wave conditions could be severe within the entrance channel, but these conditions did not extend beyond the entrance except under unique storm events. Project history indicates that the unique events have been associated with long period swells approaching in a manner such that the crests of the swells are almost parallel to the shoreline and perpendicular to the jetty entrance. When these conditions occur, the waves have translated up the entrance channel and into the harbor. This creates a general disturbance within about 25 percent of the berths in the harbor that are the closest to the entrance channel. At the time of final project design, these areas of the harbor were identified as likely to experience disturbances during certain design conditions and moorings were excluded from the area. Despite recommendations otherwise, mooring

Figure 31. Example commercial and recreational harbor.

facilities were later built and have, in fact, experienced the predicted disturbances. During these events, mooring lines quickly become chafed and occasionally break. The boats, if unattended, will then drift from their moorings.

Wave reflection has historically been an occasional problem at one exposed bulkhead during the unique events, and "green" water and large amounts of white spray have overtopped the wall, particularly when wind conditions are right. No serious toe erosion or other problems have occurred during these conditions.

Shorter period storm waves may sometimes approach from the same direction. For small storms expected to occur every few years, there is not much difficulty except for vessels moving into the harbor through the entrance channel. The harbor area itself is fairly well protected because diffraction and refraction effects cause these waves to dissipate before they reach the inner harbor.

Since the breach in the structure, waves from storms frequently enter the channel, reflect and translate up channel, and cause severe disturbances in the harbor. During these periods, recreational vessels cannot leave their slips, even to cruise only within the protected portion of the harbor. Vessel damage occurs, mooring lines chafe through, and docks are damaged. Commercial fishermen who might return to the harbor ahead of the storm have difficulty unloading their catch at the commercial dock and usually are hindered until conditions subside.

The exposed bulkhead area that faces the entrance channel is now subjected to heavy wave pounding on a more frequent basis. In these cases, larger amounts of green water overtop the wall and flood the area behind the bulkhead. Vehicles that normally park behind the bulkhead must be moved to avoid damage, and a material storage area has to be emptied.

Functional Rating. Functional ratings are performed separately for the harbor area itself, the navigation channel, sediment management, for self-protection of the jetty, and for other functions. The resulting functional ratings appear in the example completed functional rating form, shown as Figures 29 and 30.

The ratings were determined after completing a Spreadsheet for Functional Evaluation, shown as Table 14. This spreadsheet is used initially to guide the choice of ratings from the functional rating tables (Tables 15 through 18), and then again, if the initial rating process indicates the need for further analysis in any of the rating categories.

The spreadsheet summarizes structural performance under three conditions: when there are no structural defects present (in "like new" condition), if the reach were

substantially destroyed, and under current conditions when structural defects are present. The first column lists the functional rating categories. The lefthand section (Without Structural Defect) summarizes structure performance as intended when designed and then as experienced when built. This section also includes a column (Non Str. Def.) to indicate if there are functional deficiencies that are not related to structural deterioration.

The center section (If Reach Were Destroyed), not used in this example, is intended to aid in evaluating the With Structural Defect case and for determining reach functions when the system is first implemented. It can also aid in cross checking for correct reach functional assignments and in determining (in the column to the right) the minimum structure dimensions needed to provide satisfactory functional performance.

The righthand section (With Structural Defect) summarizes structural performance as presently experienced and, as needed, when recent changes in physical condition have occurred and analysis is required to estimate current performance. The column titled Analyzed Storm Disruption Period is not used in the initial analysis but is reserved for times when additional analysis is suggested. If suggested actions are undertaken, the performance effects are entered in this column, and a revised rating is then determined for that functional category.

The righthand column is used to show the increase in frequency of disruptions compared to the performance of the structure when in excellent condition. This entry assists the rater in locating the appropriate rating in the functional rating tables (Tables 15 through 18). The disruption frequency increase is based on the Analyzed Storm Disruption Period whenever this additional analysis is done for a functional category.

If the numbers shown in the last column indicate $>>2$, disruptions are said to occur even in low intensity storms. If the disruption frequency is about 2, then intermediate storm conditions must be present to cause disruption. A 0 or 1 entry indicates that design storm conditions are required to cause disruption.

Table 14 shows no problems under Without Structural Defect conditions, except when long period swells are approaching directly in line with the entrance channel. However, damage under these conditions was anticipated during design and should not affect the rating. Jetties were not intended to offer complete protection when waves approach in line with the opening between the structures. The other project defect under Shoreline Impacts has been remedied by a project modification made in 1989. In all cases, functional defects not associated with structural defects are not to be considered in the ratings.

To determine proper ratings, it is necessary to consider existing conditions—when structural deterioration is present. Since actual experience of the impact of the structural defects is often limited, it may be necessary to expand the data base through analysis—estimating the probable effects in cases where structure performance in present condition is not well known. If estimated impacts are used, the If Reach Were Destroyed section must be filled in before judgments on these impacts are made. The example uses only experienced impacts, as should be the case for all projects during the first iteration

of the rating. The need for further analysis is a local decision and should be based on economic, environmental, safety, and other factors.

In the example, the data from Table 14 suggest ratings from 10 to 54 for Harbor Area categories (Table 15). Harbor Navigation is curtailed to a large extent and receives a rating of 20 due to virtual cessation of use by pleasure craft during low intensity storm conditions. (Table 14 shows a Disruption Frequency Increase of much greater than 2). In the Harbor Use category and its three subcategories, several evaluations must be made. In the general paragraph describing harbor use, it is noted that cargo handling is hindered during storms of 2X the design storm frequency, which would put the rating between 25 and 39. A value of 30 is assigned. Moored vessels are suffering damage during low intensity storm events, but curtailment of operation is not yet being experienced. This would suggest a rating between 25 and 39 (say 35). Some evaluation of the expected damage during a design storm and intermediate level storm is appropriate as those conditions could control the rating. This is also true for the remaining categories under Harbor Use. Harbor structures are being damaged but the damage is moderate. This places the Harbor Structure subcategory in the 25 to 39 range and 35 is chosen. Other facilities are being damaged to a moderate degree and this category is also given a rating of 35. As the lowest rating found under the Harbor Use category is 30, the overall rating for Harbor Use is 30.

Under Navigation Channel, Entrance Use has not been affected and is given a rating of 100 from Table 16. The channel inside the entrance has certainly been affected by waves, resulting in two to three closures per year. Even though these closures exceed twice the frequency of the design storm, they are not frequent enough to be considered as low intensity storm events. Therefore, the intermediate storm level is appropriate, and this column (in Table 16) is used to evaluate the Channel rating category. Delays and nonuse periods appear best described by the 25 to 39 range. The lower end of this range is used and the Channel category is rated at 30.

Sediment Management (Table 17) has been compromised, but only for the Flood Shoal. Ratings for Ebb Shoal and Harbor Shoal remain high and are given an 85. From the description of the project, updrift shoreline impacts should be significant during major and intermediate storm levels, but no impact of consequence is evident at this time other than minor shore recession as material is taken out of storage and deposited in the navigation channel. This suggests a rating for Shoreline Impacts in the 70 to 84 range, and a 75 is chosen. A note is added to the evaluation indicating immediate need to evaluate higher intensity storms. The rating should be modified if the evaluations indicate that a problem will occur with higher level storms. The Flood Shoal rating falls in the 25 to 39 range. A rating of 30 is given as the shoaling requires significant effort to keep track of the migrating thalweg and significant effort by navigators to avoid vessel damage.

Under Structure Protection (Table 18), the evidence of erosion is slight and of no consequence, thus Toe Erosion is rated at 90. However, protection of nearby harbor structures may have been seriously compromised. The rating of 70 for Nearby Structures is based on the observed low intensity storm experience, and it is noted that the impacts

of more severe storms should be evaluated. (The final rating for Nearby Structures could be as low as 20 after these evaluations are made.)

Although Other Functions are not given numerical ratings, these items should be given considerable thought and attention as they concern public safety and environmental effects of the project. As noted in the comments section, immediate action to alleviate public hazard may be needed.

Rating Tables

Tables 15 through 18 on the following pages are used to select the appropriate functional ratings. The descriptions in the tables correspond to ratings at the center of the value range for each level. Ratings should be selected with respect to the worst storm or wave/current/wind conditions experienced at the project.

Table 14. Example functional evaluation spreadsheet.

SPREADSHEET FOR FUNCTIONAL EVALUATION Structure/Reach: Example Jetty - Reach 3 Date: 3/26/96 Evaluator: J. O.									
FUNCTION	WITHOUT STRUCTURAL DEFECT			IF REACH WERE DESTROYED		ESTIMATED DIMENSIONS WHEN STRUCTURE FUNCTION IS DISRUPTED	WITH STRUCTURAL DEFECT		
	EXPECTED DESIGN STORM DISRUPTION PERIOD	REALIZED STORM DISRUPTION PERIOD	NON STR. DEF.*	EXPECTED DESIGN STORM DISRUPTION PERIOD	DISRUPTION FREQUENCY INCREASE	ELEVATION, WIDTH, OR OTHER DIMENSIONS	OBSERVED STORM DISRUPTION PERIOD OR CONDITION	ANALYZED STORM DISRUPTION PERIOD	DISRUPTION FREQUENCY INCREASE
HARBOR AREA									
Harbor Navigation	70 year event	70 year event	No				2 to 3 per year	Analysis suggested	>>2
Harbor Use	1 per year for cargo unloading	1 per year for cargo unloading	No				2 to 3 per year for cargo unloading		2
a. Moored Vessels	70 year event	70 year event	No				2 to 3 per year	Analysis suggested	>>2
b. Harbor Structures	70 year event except at harbor bulkhead where wave reflection problems were anticipated on a 1 to 3 year basis	70 year event except at harbor bulkhead where wave reflection occur 1 to 3 times per year	No				2 to 3 per year	Analysis suggested	>>2
*Are There Functional Deficiencies Which Are Not Related To Structural Defects?									
c. Other Facilities	10 year event except where wave oversplash was anticipated on a 1 to 3 year basis	10 year event except where wave oversplash was anticipated on a 1 to 3 year basis	No				2 to 3 times per year	Analysis suggested	>>2

NAVIGATION CHANNEL									
Entrance Use	5 times per year	5 times per year	No				5 times per year		0
Channel	1 per year	1 per year	No				3 to 4 per year		>2
SEDIMENT MANAGEMENT									
Ebb Shoal	Annual dredging cycle	Annual dredging cycle	No				Annual dredging cycle		0
Flood Shoal	Annual dredging cycle	Annual dredging cycle	No				Dredging cycle must be modified or navigation aids moved on a frequent basis to maintain safe navigation		Severe change
Harbor Shoal	10 year cycle	10 year cycle	No				10 year cycle anticipated		No observed change
Shoreline Impacts	50 year project life	Project modified for beach nourishment at 5 year interval in 1989	No				50 year project life with beach nourishment as under- taken in 1989		No change
STRUCTURE PROTECTION									
Nearby Structures	Minor damage in project life	Minor	No				Significant change in the level of protection	Analysis suggested	Significant change in frequency of structural stress
Toe Erosion	Minor	Minor	No				Minor		No change
Trunk Protection									
OTHER FUNCTIONS									
Public Access	2 per year	2 per year	No				Continuous		>>>2
Recreational Use	2 per year	2 per year	No				Continuous		>>>2
Environmental Effect	None	None	No				None		0
Aids To	None	None	No				None		0

Navigation									
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Table 15. Rating guidance for harbor area.

Rating (based on worst storm conditions)	Rating Category	Design Storm Conditions	Intermediate Storms (2X Design Storm Frequency)	Low Intensity Storm Conditions
MINOR OR NO FUNCTIONAL LOSS				
85 to 100	HARBOR NAVIGATION	Recreational boats and other vessels can be maneuvered without interruption in the protected part of the harbor. Vessels can enter or leave the harbor immediately when outside conditions warrant.	Recreational boats and other vessels can be maneuvered without interruption in the protected part of the harbor. Vessels can enter or leave the harbor immediately when outside conditions warrant.	No difficulties or impacts for navigation.
	HARBOR USE	Cargo loading operations, and other maritime activities can continue without interruption.	Cargo loading operations, and other maritime activities can continue without interruption.	Operations within the harbor occur at optimum design levels at all locations.
	a. Moored Vessels	Vessels at moorings, at berths, or within slips experience no difficulty.	Vessels at moorings, at berths, or within slips experience no difficulty.	There are no problems at mooring, berths, or within slips.
	b. Harbor Structures	The harbor structures and docks can remain fully occupied without jeopardizing vessels. No erosion, toe scour, wave overtopping, or other problems.	The harbor structures and docks can remain fully open with no damages to structures or vessels. No erosion, toe scour, wave overtopping, or other problems.	The harbor structures and docks are in optimum condition and occupancy is not limited. No erosion, toe scour, wave overtopping, or other problems.
	c. Other Facilities	No erosion or flood damages to facilities within the harbor.	No erosion or flood damages to facilities within the harbor.	No erosion or flood damages to facilities in the harbor.
70 to 84	HARBOR NAVIGATION	Recreational boats, and other vessels can be maneuvered without interruption within the protected portion of the harbor. Minor problems may exist at a few spots. Nearly all vessels can enter or leave the harbor immediately when outside conditions warrant, although the deepest draft vessels may have to exercise some caution in a few isolated locations.	Recreational boats, and other vessels can be maneuvered without interruption within the protected portion of the harbor. Vessels can enter or leave the harbor immediately when outside conditions warrant. There are no limitations on vessel draft throughout the harbor and there are no maneuvering difficulties that could be attributable to wave or current conditions.	Navigation within the harbor is close to design levels at all locations. No difficulties due to waves or currents are generally evident. Nearly everyone interviewed about local conditions would praise the harbor.

Rating (based on worst storm conditions)	Rating Category	Design Storm Conditions	Intermediate Storms (2X Design Storm Frequency)	Low Intensity Storm Conditions
		Waves or currents may cause difficult maneuvering conditions in one or two places within the harbor.		
70 to 84	HARBOR USE	Cargo loading operations and other maritime activities can continue without interruption within the protected portion of the harbor. Minor problems may exist at a few spots.	Cargo loading operations and other maritime activities can continue without interruption within the protected portion the harbor.	Operations within the harbor are close to design levels at all locations during normal conditions. No difficulties, damages, or impacts due to waves or currents are generally evident. Nearly everyone interviewed about local conditions would praise the harbor.
	a. Moored Vessels	A few vessels may experience minor damages while in the harbor. An occasional vessel may drag anchor.	Generally, there will be no damages to moored vessels within the harbor.	Moored vessels in the harbor have no problems and would not suffer damages.
	b. Harbor Structures	Moorings, berths, slips and other facilities within the harbor can remain fully occupied without jeopardizing structures. In a few cases, some minor damages to docks or mooring systems may occur. No erosion, toe scour, wave overtopping, with the exception of minor amounts at scattered locations.	No erosion, toe scour, wave overtopping, or other problems.	No erosion, toe scour, wave overtopping, or other problems.
	c. Other Facilities	No erosion or flood damages to facilities within the harbor, except minor problems at scattered locations.	No erosion or flood damages to facilities within the harbor.	No erosion or flood damages to facilities within the harbor.
MODERATE FUNCTIONAL LOSS				
55 to 69	HARBOR NAVIGATION	The smaller boats in the recreational fleet would not leave their slips in such conditions. Nearly all vessels can enter or leave the harbor immediately when outside conditions warrant although many vessels may have to exercise caution in a few isolated locations. Waves or currents may cause difficult maneuvering	Recreational boats can continue without interruption. Nearly all vessels can enter or leave the harbor immediately when outside conditions warrant, although the deepest draft vessels may have to exercise some caution in a few isolated locations. Waves or currents may cause difficult maneuvering conditions in one or two places within the harbor.	Vessels can enter or leave the harbor freely. There are no limitations on vessel draft throughout the harbor and there are no maneuvering difficulties that could be attributable to wave or current conditions. Recreational boating can continue without interruption.

Rating (based on worst storm conditions)	Rating Category	Design Storm Conditions	Intermediate Storms (2X Design Storm Frequency)	Low Intensity Storm Conditions
		conditions in one or two places within the harbor.		
55 to 69	HARBOR USE	Generally, there are only minor damages within the harbor. In one or two isolated locations, more damage may occur. Cargo loading operations can largely continue without interruption within the protected portion of the harbor.	Generally, there are no damages within the harbor, except in one or two isolated locations. Cargo loading operations, other maritime activities can continue without interruption within the protected portion of the harbor, although minor problems may exist at a few spots.	There are no damages within the harbor. Cargo loading operations, and other maritime activities operate daily without interruption within the protected portion of the harbor.
	a. Moored Vessels	Some berths may have to curtail operations because of excessive vessel movements or difficulties in remaining at the mooring. Many vessels may suffer minor or incidental damage. A few vessels may have more damage. No vessel would be expected to have severe damage.	A few vessels may suffer minor damages. The majority of vessels would be unscathed.	No damages to moored vessels would be expected.
	b. Harbor Structures	Moorings, berths, and slips within the harbor can remain fully occupied with only minor damages during major storms. In a few cases, more than minor damages to docks or mooring systems may occur. An occasional vessel may drag anchor. Minor erosion, toe scour, wave overtopping, or other problems throughout the harbor. Problems can be more important in localized areas.	The mooring area can remain fully open with only minor damages occurring occasionally to moorings or vessels. No erosion, toe scour, wave overtopping, or other problems, although localized minor problems may exist.	The mooring areas or berths would not be expected to suffer damages and occupancy is not limited by wave or current conditions. No erosion, toe scour, wave overtopping, or other problems.
	c. Other Facilities	Minor erosion or flood damages within the harbor. Damages can be more important in localized locations.	No erosion or flood damages to facilities within the harbor. Minor localized damages could occur in a few areas.	No erosion or flood damages to facilities within the harbor.

Rating (based on worst storm conditions)	Rating Category	Design Storm Conditions	Intermediate Storms (2X Design Storm Frequency)	Low Intensity Storm Conditions
40 to 54	HARBOR NAVIGATION	Most boats in the recreational fleet would avoid going out in such conditions. Maneuvering conditions are difficult in number of places within the harbor.	The smallest boats in the recreational fleet would not leave their slips in such conditions. Maneuvering conditions may be difficult in one or two places within the harbor.	Vessels can generally enter or leave the harbor freely. There are some limitations on vessel draft within the harbor and there are a few places where maneuvering is difficult.
	HARBOR USE	Generally, some damages occur throughout the harbor. In several locations, moderate damages may occur. Cargo loading operations can continue in most berths but are somewhat hindered.	Generally there are only minor damages within the harbor. In one or two locations more extensive damage may occur. Cargo loading operations can continue without interruption in most instances.	There are few damages within the harbor. Cargo loading operations, and other maritime activities generally operate without interruption. There are, however, a few locations where operations are often limited. A few recreational boat slips may be unusable because of wave action.
	a. Moored Vessels	Many berths may have to curtail operations because of excessive vessel movement. Some vessels may experience moderate levels of damage while at moorings or within berths. Large numbers of recreational craft could suffer significant damages.	Some berths may have to curtail operations because of excessive vessel movements or difficulty in remaining at the mooring. A few vessels may suffer minor damages. Some recreational craft could suffer moderate damages.	Minor damages could be suffered by vessels within the harbor. The majority of damage would be to smaller boats. Incorrectly moored recreational boats would be the most susceptible to damage.
	b. Harbor Structures	Mooring, berths, and slips can remain fully occupied with some damage. Moderate damages to docks or mooring systems may occur in a few cases. An occasional vessel may drag its anchor or a mooring line may part. Some erosion, toe scour, wave overtopping, or other problems that can threaten structural stability of bulkheads, revetments, wharves, and other structures may occur in a few locations.	Minor damage to mooring systems within the harbor should be expected. In some cases damages could be more than minor. Minor erosion, toe scour, wave overtopping or other problems can occur at a few locations.	The moorings systems may suffer minor damages at times in a few isolated cases. No erosion, toe scour, wave overtopping or other problems except for minor problems in isolated locations.

Rating (based on worst storm conditions)	Rating Category	Design Storm Conditions	Intermediate Storms (2X Design Storm Frequency)	Low Intensity Storm Conditions
	c. Other Facilities	Some erosion or flood damage to facilities including moderate damages in some areas.	Minor erosion or flood damage to facilities which can be moderate at a few locations.	No erosion or flood damage to facilities within the harbor with the exception of minor problems at a few locations.
MAJOR FUNCTIONAL LOSS				
25 to 39	HARBOR NAVIGATION	Difficult maneuvering conditions prevail throughout the harbor.	Most boats in the recreational fleet would avoid going out in such conditions. Difficult maneuvering conditions are common in a number of places within the harbor.	Vessels must generally exercise care when entering or leaving the harbor. There are limitations on vessel draft and many places where maneuvering difficulties occur.
	HARBOR USE	Generally, moderate damage occurs throughout the harbor. In several locations, damage is significant. Cargo loading operations can continue in some berths, but are significantly hindered.	Generally, some damage occurs throughout the harbor. In several locations, moderate damage may occur. Cargo loading operations can continue in most berths, but are somewhat hindered.	Minor damage often occurs within the harbor. Cargo loading operations and other maritime activities can usually operate daily without interruption. In a few places wave action often limits operations. Conditions are normally poor for recreational vessels and many slips cannot be leased. Damage to mooring lines and docks is common and persistent.
	a. Moored Vessels	Most berths have to curtail operations because of excessive vessel movements or difficulties in remaining at the mooring. Most recreational boats have problems at the slips. Some may be lost and many boats will suffer significant damage.	Many berths may have to curtail operations because of excessive vessel movements or difficulties in remaining at the mooring. Overall, a large number of vessels, particularly recreational craft, suffer moderate damage. In a few cases, this damage is significant.	Only minor to moderate damage is suffered by vessels within the harbor. The majority of damage is to smaller boats, particularly recreational vessels whose lines are not closely tended.

Rating (based on worst storm conditions)	Rating Category	Design Storm Conditions	Intermediate Storms (2X Design Storm Frequency)	Low Intensity Storm Conditions
25 to 39	b. Harbor Structures	Moorings, berths, and slips within the harbor can remain fully occupied, but with moderate damage. In a few cases, significant damage to docks or mooring systems may occur. Some vessels may drag their anchors, mooring buoys may be displaced, and parted mooring lines may be common. Moderate erosion, toe scour, wave overtopping, or other problems occur, which can be significant in places.	Moderate damage to mooring systems within the harbor is common. A few vessels may drag their anchors and there may be occasional parting of mooring lines or displacement of mooring buoys. Some erosion, toe scour, wave overtopping, or other problems occur, which can, in a few locations, threaten structural stability of bulkheads, revetments, wharves, and other structures.	The mooring systems may suffer minor damages. It would be unusual, however, for a vessel to drag anchor, a mooring line to part, or similar incidents to occur. Minor erosion toe scour, wave overtopping, or other problems, which can, in a few locations, threaten structural stability of bulkheads, revetments, wharves, and other structures.
	c. Other Facilities	Moderate erosion or flood damage occurs to facilities within the harbor, which can be significant in places.	There is some erosion or flood damage to facilities within the harbor. In a few locations, the level of damage can be moderate.	Minor erosion or flood damage occurs to facilities within the harbor. In a few locations, moderate levels of damage may occur.
10 to 24	HARBOR NAVIGATION	Maneuvering conditions are hazardous throughout the harbor.	Maneuvering conditions are difficult throughout the harbor.	Vessels must always exercise care when entering or leaving the harbor. There are significant limitations on vessel draft and maneuvering difficulties prevail.
	HARBOR USE	Generally, significant damage occurs throughout the harbor. In several locations, damage is severe. Cargo loading operations cease because of excessive vessel movements or difficulties in remaining at the mooring. Any recreational boats within their slips would be in extreme jeopardy. Most or nearly all would be lost as well as the docks.	Generally, significant damage would occur throughout the harbor. Cargo loading operations cease with the possible exception of one or two berths. Most berths have to curtail operations because of excessive vessel movements or difficulties in remaining at the mooring. Most recreational boats have problems at their slips. Some will be lost and many boats and docks will suffer significant damage.	Moderate damage often occurs within the harbor. Cargo loading operations and other maritime activities must usually be timed to allow for favorable conditions. Most berths are normally vacant. Permanently occupied recreational ships are out of the question in nearly all cases. Docks are in poor condition.

Rating (based on worst storm conditions)	Rating Category	Design Storm Conditions	Intermediate Storms (2X Design Storm Frequency)	Low Intensity Storm Conditions
10 to 24	a. Moored Vessels	Nearly all vessels within the harbor suffer significant to major damage and there would be a number of total losses. Smaller craft would be particularly hard hit.	Most vessels within the harbor suffer significant damage, and there would be occasional total losses of smaller vessels.	Damage to vessels within the harbor is common. Damage is so severe that few, if any, small recreational boats use the harbor.
	b. Harbor Structures	Moorings, berths, and slips within the harbor suffer significant damage. In a few cases, major damage or complete losses to docks or mooring systems occur. Vessels dragging anchors, displacement of mooring buoys, and parted mooring lines are a widespread problem.	Significant damage to mooring systems within the harbor occurs. Vessels dragging anchors, displacement of mooring buoys, and parted mooring lines are a common problem. Significant erosion, toe scour, wave overtopping, or other problems occur, which can, in a few locations, threaten the structural stability of bulkheads, revetments, wharves, and other structures. Structural failures can be expected in a few locations.	The mooring systems may suffer moderate damage. It would be common for a vessel to drag anchor, a mooring line to part, or other similar incidents to occur. Moderate erosion, toe scour, wave overtopping, or other problems occur, which can, in a few locations, threaten the structural stability of bulkheads, revetments, wharves, and other structures. Structural failures can be expected in a few locations.
	c. Other Facilities	Significant erosion or flood damage occurs to facilities within the harbor. In a few locations, the damage is severe and total losses to some facilities may occur.	Significant erosion or flood damage occurs to facilities within the harbor.	Moderate erosion or flood damage occurs to facilities within the harbor. Significantly greater damage may occur in a few locations.
0 to 9	HARBOR NAVIGATION	Navigation extremely hazardous.	Navigation is generally hazardous.	Navigation is possible at some risk.
	HARBOR USE	No prudent mariner would remain in this harbor. Massive damage to vessels and facilities would be expected and losses would be catastrophic.	Remaining in or using this harbor would be hazardous. Virtually no essential activities could occur and severe damage would be expected.	This is a minimal harbor that supports few activities, and those inadequately. From a functional viewpoint, it is barely superior to no harbor at all.
	a. Moored Vessels	Damage or losses to moored vessels would be catastrophic.	Damage or losses to moored vessels would be severe. Many vessels would be lost.	Any boat that uses this harbor would be subject to damage whenever wave activity picks up.

Rating (based on worst storm conditions)	Rating Category	Design Storm Conditions	Intermediate Storms (2X Design Storm Frequency)	Low Intensity Storm Conditions
0 to 9	b. Harbor Structures	Damage to mooring systems would be heavy. Total destruction of various elements would be expected. Severe erosion, toe scour, wave overtopping, or other problems occur in the harbor. Structural failures can be expected in many locations throughout the harbor.	Damage to mooring systems would be heavy. Total destruction of various elements would be expected. Severe erosion, toe scour, wave overtopping, or other problems occur in the harbor. Structural failures can be expected in many locations throughout the harbor.	Mooring systems are in poor condition. Fendering systems, mooring dolphins, lines, buoys, and other elements are distressed and heavily worn due to excessive working hand movements of vessels when secured. Persistent erosion, toe scour, wave overtopping, or other problems occur in the harbor. Structural failures in locations throughout the harbor are not uncommon.
	c. Other Facilities	Severe erosion or flood damage occurs to facilities within the harbor. Destruction of some facilities may be expected.	Severe erosion or flood damage occurs to facilities within the harbor. Destruction of some facilities may be expected.	Persistent erosion or flood damage to facilities occurs within the harbor. Many locations throughout the harbor can no longer support these facilities because of the threat of damage.

Table 16. Rating guidance for navigation channel.

Rating (based on worst storm conditions)	Rating Category	Design Storm Conditions	Intermediate Storms (2X Design Storm Frequency)	Low Intensity Storm Conditions
MINOR OR NO FUNCTIONAL LOSS				
85 to 100	ENTRANCE USE	There are no delays. The largest and smallest vessels may transit without broaching or touching bottom. Vessels experience no difficulties in the entrance.	There are no delays. Vessels experience no difficulty in the entrance.	There are no delays. Vessels experience no difficulty in the entrance.
	CHANNEL	There are no delays in the channel within the shelter of the breakwaters or jetties. The largest and smallest vessels using the harbor are not limited by insufficient depth or severe wave conditions.	There are no delays in the channel within the shelter of the breakwater or jetties. The largest and smallest vessels using the harbor are not limited by either insufficient depth or severe wave conditions.	There are no delays in the channel within the shelter of the breakwaters or jetties. Vessel operations are not limited by either depths or hazardous wave conditions.
70 to 84	ENTRANCE USE	Vessels generally have no difficulty in the entrance when seeking shelter in the harbor.	Vessels normally experience no difficulty in the entrance.	Vessels experience no difficulty in the entrance.
	CHANNEL	There are generally no vessel delays in the channel within the shelter of the breakwater or jetties. Small vessels may have some problems with wave conditions within exposed parts of the harbor.	There are no vessel delays in the channel within the shelter of the breakwater or jetties. The largest and smallest vessels using the harbor are not limited by either insufficient depth or severe wave conditions with only a few exceptions in unusual circumstances.	There are no vessel delays in the channel within the shelter of the breakwater or jetties.

Rating (based on worst storm conditions)	Rating Category	Design Storm Conditions	Intermediate Storms (2X Design Storm Frequency)	Low Intensity Storm Conditions
MODERATE FUNCTIONAL LOSS				
55 to 69	ENTRANCE USE	Vessels generally have little difficulty in the entrance when seeking shelter.	Vessels generally have no difficulty in the entrance when seeking shelter.	Vessels experience no difficulties in the entrance.
	CHANNEL	There are generally few vessel delays in the channel within the shelter of the breakwaters or jetties, except in a few exposed locations. Some vessels using the harbor do not have enough water under the keel to go safely. Small vessels have some problems with conditions at exposed locations.	There are generally no vessel delays in the channel within the shelter of the breakwater or jetties, except at exposed locations.	There are no vessel delays in the channel within the shelter of the breakwaters or jetties. No vessels using the harbor are limited by either insufficient depth or by severe wave conditions.
	ENTRANCE USE	Vessels generally have some difficulty in the entrance when seeking shelter. Vessel entrance may be delayed until flood tide.	Vessels generally have no difficulty in the entrance when seeking shelter.	Vessels have little or no difficulty in the entrance.
	CHANNEL	There are vessel delays in the channel within the shelter of the breakwaters or jetties. In a few locations the delays can be significant for larger vessels that do not have enough water under the keel to proceed safely. Small vessels have problems with wave conditions at a number of locations. In a few exposed locations conditions may be too hazardous for small vessels to safely venture.	There are some vessel delays in the channel within the shelter of the breakwaters or jetties. A few vessels that would normally use the harbor are limited by either insufficient depth or severe wave conditions.	Vessels experience little or no difficulty in the channel.
40 to 54				

Rating (based on worst storm conditions)	Rating Category	Design Storm Conditions	Intermediate Storms (2X Design Storm Frequency)	Low Intensity Storm Conditions
MAJOR FUNCTIONAL LOSS				
25 to 39	ENTRANCE USE	Vessels often have difficulty in the entrance when seeking shelter in the harbor. Crossing during ebb tide is seldom a possibility.	Vessels generally have some difficulty in the entrance while seeking shelter. Entry may be delayed until flood tide.	Vessels generally have no difficulty in the entrance when seeking shelter.
	CHANNEL	There are vessel delays in the channel within the protected areas of breakwater and jetties that may continue for a considerable period before and after the peak of the storm. In several locations in the harbor the delays can be significant, especially for larger vessels. Larger vessel may not have enough water under the keel to proceed safely. Small vessels have problems with wave conditions within the harbor and channel before, during, and after storm peaks. In many locations conditions may be too hazardous for small vessels to safely venture.	There are vessel delays in the channel within the shelter of the breakwater or jetties leading up to, during, and after storm peaks. Numerous vessels using the harbor may not have enough water under the keel to proceed safely during the storm. Small vessels generally have problems with wave conditions within the shelter of the harbor.	There are occasional vessel delays. A few large vessels using the harbor may have to wait for favorable tide conditions before proceeding. Wave conditions may limit use of exposed portions of the channel by small craft on some days.

Rating (based on worst storm conditions)	Rating Category	Design Storm Conditions	Intermediate Storms (2X Design Storm Frequency)	Low Intensity Storm Conditions
10 to 24	ENTRANCE USE	Vessels generally seek shelter in other harbors. Entrance is hazardous even during flood tide. Ebb shoal may be focusing waves. Flood shoal may be focusing currents.	Vessels often have difficulty in the entrance when seeking shelter. Crossing during ebb tide is seldom a possibility. Ebb shoal may be focusing waves. Flood shoal may be focusing currents.	Vessels generally have some difficulty in the channel while seeking shelter. Entrance must often be delayed until flood tide.
	CHANNEL	The channel is hazardous for all vessels for a long time before and after the peak of the storm. Throughout the harbor there are normally significant delays after the passage of the storm before it is again safe to enter or leave. Many vessels have problems with wave conditions in the harbor and channels. In most locations the wave conditions are too hazardous for small vessels. Ebb and flood shoal may be influencing wave and current regime.	Delays are common leading up to, during, and immediately after the peaks of storms. Many vessels using the harbor may not have enough water under the keel to proceed safely. Small vessels generally have problems with wave conditions throughout the harbor and channels. In some locations conditions may be too hazardous for small vessels to safely venture. Ebb and flood shoal may be influencing wave and current regime.	Delays are common. Most of the larger vessels using the harbor have to wait for more favorable tide conditions before entering or leaving the harbor. Wave conditions limit use of the channel by small craft on many days.

Rating (based on worst storm conditions)	Rating Category	Design Storm Conditions	Intermediate Storms (2X Design Storm Frequency)	Low Intensity Storm Conditions
0 to 9	ENTRANCE USE	Vessels avoid the harbor. Entrance is extremely hazardous. Wave steepness makes small boat broaching a possibility during all tide phases. Ebb shoal focuses waves.	Vessels generally seek shelter in other harbors. Entrance is hazardous even during flood tide. Ebb shoal has an impact on wave focusing.	Vessels often have difficulty in the entrance when seeking shelter. Crossing during ebb tide is seldom possible.
	CHANNEL	The channel is extremely hazardous for all vessels. Most vessels have problems with wave conditions within the channels. Flood shoal impacts wave and current regime.	Long delays are normal and extend through the period leading up to, during, and immediately after the peaks of storms. Many vessels using the harbor will not have enough water under the keel to proceed safely. Many vessels will have problems with wave conditions. Flood shoal has an impact on wave and current regime.	Delays are the normal mode of operation. Most vessels must await favorable tide conditions before entering or leaving the harbor. Wave conditions limit use of exposed portions of the channel by small craft on most days.

Table 17. Rating guidance for sediment management.

Rating (based on worst storm conditions)	Rating Category	Design Storm Conditions	Intermediate Storms (2X Design Storm Frequency)	Low Intensity Storm Conditions
MINOR OR NO FUNCTIONAL LOSS				
85 to 100	EBB SHOAL	The channel is stable, does not migrate and is not deflected or impaired. Shoals that would threaten navigation safety do not form in the channel.	The channel is stable, does not migrate, and is not deflected or impaired. Shoals that would threaten navigation safety do not form in the channel.	The channel is stable, does not migrate, and is not deflected or impaired. Maintenance dredging requirements are minimal and infrequent. There are no hidden or dangerous shoals in the channel.
	FLOOD SHOAL	The channel is stable, does not migrate, and is not deflected or impaired. Shoals that would threaten navigation safety do not form in the channel.	The channel is stable, does not migrate, and is not deflected or impaired. Shoals that would threaten navigation safety do not form in the channel.	The channel is stable, does not migrate, and is not deflected or impaired. Maintenance dredging requirements are minimal and infrequent. There are no hidden or dangerous shoals in the channel.
	HARBOR SHOAL	Shoaling is insignificant and does not affect harbor navigation or mooring areas. Build-up is very gradual and easy to manage with widely time-spaced periodic dredging.		
	SHORELINE IMPACTS a. Navigation Structures OR	The project has had no discernible impact on littoral processes. There is no unexpected accretion on the updrift side of the project and no unexpected erosion on the downdrift side. If there is a sand management plan in place for the project, the amount of material that needs to be moved to maintain shoreline equilibrium is well within the projected amount. Sediment is not being lost from littoral system (e.g., no offshore dumping of material dredged from the channel).		
	b. Shoreline Protection Structures	Adequate amount of sediment is maintained to prevent upland structure or flood damage from a subsequent intermediate level storm. Recovery of beach to original conditions is expected.	Insignificant sediment loss.	No indication of shoreline distress.

Rating (based on worst storm conditions)	Rating Category	Design Storm Conditions	Intermediate Storms (2X Design Storm Frequency)	Low Intensity Storm Conditions
70 to 84	EBB SHOAL	The channel is generally stable, does not migrate significantly, and is not deflected or impaired significantly by large storms. Dangerous shoals generally do not form in the channel.	The channel is generally stable, does not migrate significantly, and is not deflected or impaired significantly by large storms. Dangerous shoals generally do not form in the channel.	The channel is stable, does not migrate, and is not deflected or impaired. Shoals or shifting bars are not an important concern since they are minor in size and area. Channel maintenance requirements are minimal in quantity but occasionally are needed.
	FLOOD SHOAL	The channel is generally stable, does not migrate significantly, and is not deflected or impaired significantly by large storms. Dangerous shoals generally do not form in the channel.	The channel is generally stable, does not migrate significantly, and is not deflected or impaired significantly by large storms. Dangerous shoals generally do not form in the channel.	The channel is stable, does not migrate, and is not deflected or impaired. Shoals or shifting bars are not an important concern since they are minor in size and area. Channel maintenance requirements are minimal in quantity but occasionally are needed.
	HARBOR SHOAL	Shoaling is evident but has no impact on harbor navigation and is only a minor inconvenience in the mooring area.		
	SHORELINE IMPACTS a. Navigation Structures OR	The project has had a barely discernable impact on littoral processes. On the updrift side there may be a small amount of accretion beyond what was expected, but this presents no problem. The downdrift side of the project may be experiencing a small amount of localized erosion, but it is inconsequential. If there is a sand management plan in place for the project, the amount of sand that needs to be moved annually to maintain shoreline equilibrium is close to design projections. No important losses of sand from the system are occurring (e.g., offshore dumping of hopper dredged material).		
	b. Shoreline Protection Structures	Amount of sediment maintained is barely adequate to prevent upland structure or flood damage from a subsequent low intensity storm. Beach recovery without damage is expected.	Adequate sediment is maintained to prevent upland structure or flood damage from a subsequent design storm. Full recovery of the beach is expected.	Sediment loss is not significant.

Rating (based on worst storm conditions)	Rating Category	Design Storm Conditions	Intermediate Storms (2X Design Storm Frequency)	Low Intensity Storm Conditions
MODERATE FUNCTIONAL LOSS				
55 to 69	EBB SHOAL	The channel is fairly stable, does not seriously migrate, deflect, or become impaired. Some potentially hazardous shoals often form in or along the channel, but these are in isolated locations and can be readily avoided by most mariners.	The channel is generally stable and does not migrate significantly. A few minor shoals may form in or along the channel, but these are not a significant problem for prudent mariners.	The channel is generally stable and does not migrate significantly. Small shoals form over time and these are removed from the channel through maintenance dredging operations that are small in scale, but are needed on an annual basis.
	FLOOD SHOAL	The channel is fairly stable, does not seriously migrate, deflect, or become impaired. Some potentially hazardous shoals often form in or along the channel, but these are in isolated locations and can be readily avoided by most mariners.	The channel is generally stable and does not migrate significantly. A few minor shoals may form in or along the channel, but these are not a significant problem for prudent mariners.	The channel is generally stable and does not migrate significantly. Small shoals form over time and these are removed from the channel through maintenance dredging operations that are small in scale, but are needed on an annual basis.
	HARBOR SHOAL	There is some impact on navigation. Spot shoals may require periodic removal and avoidance by deeper draft vessels in the navigation fairways. Shoaling at docks may require shifting of vessels between maintenance cycles.		
	SHORELINE IMPACTS a. Navigation Structures	The project has had a minor affect on littoral processes. There has been a little more accretion on the updrift side than expected but this presents only a minor problem (e.g., slightly more channel maintenance dredging due to sand bypassing the end of the updrift jetty). The downdrift side of the project has experienced some localized erosion, but it can be handled by adding small quantities of additional sand at the impacted area. There is still enough beach width to provide for recreation and storm protection. If there is a sand management plan in place for the project, the amount of sand to be moved annually is larger than design projections. Some sand is periodically lost from the system by offshore dumping of dredged material.		
	OR b. Shoreline Protection Structures	Supplemental beach nourishment would be needed to prevent upland structure or flood damage from a following low intensity storm.	Sediment maintenance is barely adequate to prevent structure or flood damage if a subsequent intermediate level storm occurs.	Adequate sediment is maintained to prevent upland structure or flood damage if a design storm should occur.

Rating (based on worst storm conditions)	Rating Category	Design Storm Conditions	Intermediate Storms (2X Design Storm Frequency)	Low Intensity Storm Conditions
40 to 54	EBB SHOAL	The channel tends to migrate so that care is required by mariners. Hazardous shoals and bars are numerous.	The channel is fairly stable and does not migrate, deflect, or become impaired. A few potentially hazardous shoals often form in or along the channel, but are usually in isolated locations and can be readily avoided by most mariners.	The channel is stable, does not migrate, and is not deflected or impaired. Shoals are a persistent problem in a few sections of the channel. A moderate amount of maintenance dredging is needed on an annual basis.
	FLOOD SHOAL	The channel tends to migrate so that care is required by mariners. Hazardous shoals and bars are numerous.	The channel is fairly stable and does not migrate, deflect, or become impaired. A few potentially hazardous shoals often form in or along the channel, but these are usually in isolated locations and can be readily avoided by most mariners.	The channel is stable, does not migrate, and is not deflected or impaired. Shoals are a persistent problem in a few sections of the channel. A moderate amount of maintenance dredging is needed on an annual basis.
	HARBOR SHOAL	Shoals are an encumbrance to navigation. Minor loss of facility use occurs between dredging cycles.		
	SHORELINE IMPACTS a. Navigation Structures	The project has had a moderate affect on littoral processes. More accretion than expected has occurred on the updrift side, creating a problem (e.g., channel maintenance requirements are increasing because sand is bypassing the end of the updrift jetty). The downdrift side has measurable erosion over a long length of shoreline, with some pockets of moderate erosion. Trouble spots have demanded occasional remedial filling with sand. Beach width is barely adequate for recreation and some storm protection. If a sand management plan exists for the project, the annual movement of sand for maintaining shoreline equilibrium is significantly larger than design projections. Sand may be periodically lost from the system in offshore dumping of hopper dredged material.		
	OR b. Shoreline Protection Structures	Supplemental beach nourishment is required to prevent upland structure and flood damage from a subsequent low intensity storm.	Supplemental beach nourishment is required to prevent upland structure and flood damage from a subsequent intermediate level storm.	Sediment maintainance is barely adequate to prevent upland structure or flood damage if a design storm should occur.

Rating (based on worst storm conditions)	Rating Category	Design Storm Conditions	Intermediate Storms (2X Design Storm Frequency)	Low Intensity Storm Conditions
MAJOR FUNCTIONAL LOSS				
	EBB SHOAL	The channel tends to migrate significantly so that great care is required by most mariners. Hazardous shoals and bars are widespread.	The channel tends to migrate and develop shoals. Mariners must proceed with caution.	The channel tends to migrate. Shoals are a fairly widespread problem. Channel maintenance dredging is needed annually.
	FLOOD SHOAL	The channel tends to migrate significantly so that care is required by most mariners. Hazardous shoals and bars are widespread.	The channel tends to migrate and develop shoals. Mariners must proceed with caution.	The channel tends to migrate. Shoals are a fairly widespread problem. Channel maintenance dredging is needed annually.
25 to 39	HARBOR SHOAL	Shoaling trends require significant effort by the harbor master to prevent vessel damage. Significant loss of facility use between dredging cycles is common.		
	SHORELINE IMPACTS a. Navigation Structures OR	The project has had a significant impact on littoral processes. There has been more accretion on the updrift side than expected. Channel maintenance dredging requirements have increased significantly because sand is bypassing the end of the updrift jetty. The downdrift side of the project is experiencing significant erosion over a long length of shoreline, with some pockets of intense erosion. Trouble spots have demanded emergency remedial filling with sand after low intensity storms. Beach width is less than desirable. Recreation use has been compromised and the storm protection properties have suffered. Private property owners have begun trying to build bulkheads and revetments to protect waterfront property where permitted. If there is a sand management plan in place for the project, the amount of sand that needs to be moved annually to maintain shoreline equilibrium is much larger than design projections. Operational or budgetary reprogramming is required to meet project needs. A significant volume of sand may be lost from the system during offshore dumping of dredged material.		
	b. Shoreline Protection Structures	Some structural damage or flooding occurs. Supplemental beach nourishment is needed to prevent continued damage and flooding in upland area from a low intensity storm.	Significant supplemental beach nourishment is needed to prevent damage and flooding in upland area from an intermediate level storm.	Supplemental beach nourishment is needed to prevent damage and flooding in upland area from a design storm. Chronic sediment deficit is evident.

Rating (based on worst storm conditions)	Rating Category	Design Storm Conditions	Intermediate Storms (2X Design Storm Frequency)	Low Intensity Storm Conditions
10 to 24	EBB SHOAL	The channel migrates widely after large storms. Shifting shoals are common and dangerous. Great care is required to negotiate the channel.	Storms cause the channel to shift significantly and shoals are common.	The channel tends to migrate and hazardous shoals appear in numerous places. Extensive channel maintenance dredging is needed annually.
	FLOOD SHOAL	The channel migrates widely after large storms. Shifting shoals are common and dangerous. Great care is required to negotiate the channel.	Storms cause the channel to shift significantly and shoals are common.	The channel tends to migrate and hazardous shoals appear in numerous places. Extensive channel maintenance dredging is needed annually.
	HARBOR SHOAL	Shoaling is extensive and management by the harbor master can no longer prevent navigation conditions from becoming hazardous. Major loss of facility use between dredging cycles is common.		
	SHORELINE IMPACTS a. Navigation Structures	The project has had a major impact on littoral processes. There is major accretion on the updrift side, which presents a problem (e.g., intense channel maintenance dredging efforts are needed to offset the sand bypassing at the end of the updrift jetty). These efforts are not enough to maintain a safe open channel in the aftermath of storm events. There has been serious erosion on the downdrift side of the project over a long length of shoreline. Trouble spots have demanded emergency filling with sand after low intensity storms. There is little beach width remaining to provide for recreation and storm protection. Existing dune systems have been over washed and destroyed. Private property owners have begun trying in earnest to build bulkheads and revetments where permits for structures can be obtained. Homes and other shorefront structures have been lost in storms and some existing bulkheads and revetments have been destroyed. If there is a sand management plan in place for the project, the amount of sand that needs to be moved annually to maintain shoreline equilibrium far exceeds design projections. An important volume of sand may be lost from the system during the offshore dumping of dredged material.		
	OR b. Shoreline Protection Structures	Significant flooding and damage occur on shore. Significant supplemental beach nourishment is needed to prevent damage and flooding in upland area from a low intensity storm.	Some flooding and damage occur on shore. Major supplemental beach nourishment is needed to prevent damage and flooding in upland area from an intermediate level storm.	Significant supplemental beach nourishment is needed to prevent damage and flooding in upland area from a design storm. Large, chronic sediment deficit is evident.

Rating (based on worst storm conditions)	Rating Category	Design Storm Conditions	Intermediate Storms (2X Design Storm Frequency)	Low Intensity Storm Conditions
0 to 9	EBB SHOAL	The main body of the channel may migrate dramatically, or close entirely.	Storms cause the channel to shift dramatically or to close. As a minimum, dangerous shoals are widespread.	The channel is difficult to maintain. Hazardous shoals occur in many places. Extraordinary maintenance dredging effort is needed to keep the channel open.
	FLOOD SHOAL	The channel thalweg may shift, requiring repositioning of navigation aids and/or emergency dredging before the channel can be safely navigated.	Dangerous shoals are widespread.	The channel is difficult to maintain and there are hazardous shoals in many places. Extraordinary maintenance dredging effort is needed to keep the channel open.
	HARBOR SHOAL	Dredging cycles are repetitive and interfere with normal harbor use. The harbor may not be economically competitive without modification.		
	SHORELINE IMPACTS a. Navigation Structures	The project has had a catastrophic impact on littoral processes. Enormous accretion of sand has occurred on the updrift side, stretching far upcoast. Intense channel maintenance dredging efforts are needed to offset the sand bypassing the end of the updrift jetty. Low intensity storms move enough sand to close or seriously impair use of the entrance channel. There has been major erosion on the downdrift side of the project along vast lengths of shoreline. Trouble spots have routinely demanded emergency filling with sand and revetment stone following low intensity storms. There are no beaches left at high tide and beach storm protection properties are negligible. The dune system has overwashed and is almost destroyed. Private property owners have armored the shoreline with bulkheads and revetments where not constrained by permit processes. Houses have been moved back from the shoreline and/or abandoned. Numerous homes and other shorefront structures have been lost in storms and bulkheads and revetments have been destroyed. If a sand management plan exists, the annual volume of sand required to maintain shore equilibrium far exceeds design projections. Huge volumes of sand may be lost from the system during offshore dumping of dredged material.		
	OR b. Shoreline Protection Structures	Structures are ineffective. Major damage occurs to upland areas. Major beach nourishment or other remedies are needed.	Significant flooding and damage occurs. Significant supplemental beach nourishment is needed to protect against a subsequent low intensity storm.	Significant supplemental beach nourishment is needed to prevent damage and flooding in upland area from a subsequent intermediate level storm.

Table 18. Rating guidance for structure protection.

RATING	RATING CATEGORY	DESCRIPTION OF CONDITION
MINOR OR NO FUNCTIONAL LOSS		
85 to 100	NEARBY STRUCTURES	Wave energy levels on adjacent structures are within design intent, and nearby structures are fully protected.
	TOE EROSION	No erosion at the toe or adjacent to the structure.
	TRUNK PROTECTION	Head reach fully protects structure trunk.
70 to 84	NEARBY STRUCTURES	Wave energy passing structure is somewhat higher than intended, but nearby structures are still fully protected.
	TOE EROSION	Only minor erosion at the toe or adjacent to the structure. Structural stability is not threatened.
	TRUNK PROTECTION	Condition of the head reach has resulted in minor armor movement or shifting on the trunk, but the trunk is still considered to be fully protected.
MODERATE FUNCTIONAL LOSS		
55 to 69	NEARBY STRUCTURES	Segments of the structure allow enough wave energy to pass to be of concern. Some minor damage to nearby structures has resulted.
	TOE EROSION	Erosion is clearly evident along the toe or adjacent to the structure, but has not resulted in damage higher up on the structure. Structural stability is not seriously threatened.
	TRUNK PROTECTION	Condition of the head reach has resulted in minor damage to the trunk.
40 to 54	NEARBY STRUCTURES	Nearby structures are suffering moderate damage, but their functions are not yet compromised.
	TOE EROSION	Moderate erosion along the toe or adjacent to the structure has resulted in some slumping of the armor higher up on the slope. Structural stability is still considered adequate.
	TRUNK PROTECTION	Condition of the head reach has resulted in moderate level damage to the trunk.

RATING	RATING CATEGORY	DESCRIPTION OF CONDITION
MAJOR FUNCTIONAL LOSS		
25 to 39	NEARBY STRUCTURES	Nearby structures have incurred significant damage from lack of protection, and as a result, their functions have been moderately compromised.
	TOE EROSION	Significant erosion along the toe or adjacent to the structure has resulted in significant armor slumping higher up on the slope. Core is exposed and structural stability is marginal. Structure is vulnerable to heavy damage from subsequent intermediate level or design storm.
	TRUNK PROTECTION	Condition of the head reach has resulted in moderate level damage to the trunk. Trunk receives direct wave attack due to improper protection from head.
10 to 24	NEARBY STRUCTURES	Nearby structures have incurred major damage from lack of protection, and as a result, their functions have been seriously compromised.
	TOE EROSION	Widespread erosion along the toe or adjacent to the structure has resulted in some slope failure along the structure. Core is exposed and slopes are unstable. Structure is vulnerable to additional damage from subsequent low intensity storm.
	TRUNK PROTECTION	Condition of the head reach has resulted in major damage to the trunk. Trunk receives little protection from head.
0 to 9	NEARBY STRUCTURES	Nearby structures are being destroyed from lack of protection, and as a result, their functions have been largely lost.
	TOE EROSION	Toe erosion has undermined most of the structure, resulting in massive structural failure. Core has washed away and the crest is planed off near the waterline. The whole structure is compromised.
	TRUNK PROTECTION	Head reach no longer provides any protection to the trunk.

7 How Index Values Are Calculated

The BREAKWATER Computer Program

The BREAKWATER computer program calculates index values for each reach or subreach and structure. The program accepts all information (including comments) from the structural and functional inspection forms. The input screens are set up much like the field forms to simplify the transfer of information from the forms to the computer. The index values are obtained when creating the desired reports from the Reports menu.

Structural Index

After the inspection forms are completed, the ratings are entered into the BREAKWATER computer program, which will calculate the structural index values as follows.

Cross Section Component Index

The 0 to 100 ratings assigned by the inspector for the structural rating categories are weighted as follows to produce a structural index for the crest/cap, seaside, and channel/harborside for each reach or subreach:

$$CR = R_5 + 0.3(R_1 - R_5) \left[\frac{R_2 + R_3 + R_4}{300} \right]$$

$$SE = R_5 + 0.3(R_1 - R_5) \left[\frac{R_2 + R_3 + R_4}{300} \right]$$

$$CH = R_5 + 0.3(R_1 - R_5) \left[\frac{R_2 + R_3 + R_4}{300} \right]$$

where:

CR = Structural index for Crest/Cap

SE = Structural index for Seaside

CH = Structural index for Channel/Harborside

R_5 = Lowest of the five ratings for the cross section component

R_1 = Highest of the five ratings for the cross section component

R_2, R_3, R_4 = Values for the second, third, and fourth highest ratings.

For a reach that forms a structure head, the channel/harborside (CH) index does not apply.

Reach/Subreach Index

The three cross-sectional indexes will be combined as follows to create a structural index for the reach or subreach:

$$SI = I_L + 0.3(I_H - I_L) \frac{I_M}{100}$$

SI = Structural index for the reach or subreach

I_L = Lowest of the three cross sectional indexes

I_H = Highest of the three cross sectional indexes

I_M = Middle value of the three cross sectional indexes

For a reach that forms a structure head, there will be just two cross sectional index values, and the term $I_M/100$ becomes 1.

Structure Index

The structural index for a whole structure is determined from the reach and subreach SI values in the following manner:

$$SI = I_L + 0.3(I_H - I_L) \left[\frac{\%1}{100} * \frac{S1}{100} + \frac{\%2}{100} * \frac{S2}{100} + \frac{\%3}{100} * \frac{S3}{100} + \dots(etc.) \right]$$

SI = Structural index for the structure

I_L = Lowest of the reach or subreach structural indexes

I_H = Highest of the reach or subreach structural indexes

%1, %2, %3, ... = Percentage of the structure length occupied by reaches or subreaches 1, 2, 3, etc.

S1, S2, S3, ... = Structural Index for reaches or subreaches 1, 2, 3, etc.

Functional Index

After the functional rating forms are completed, the ratings are entered into the BREAKWATER computer program, which will calculate the functional index (FI) values as shown below. Only the ratings for categories within Harbor Area, Navigation Channel, Sediment Management, and Nearby Structures (within Structure Protection) are used to produce FI values.

Reach Index

The functional ratings will be combined as follows to create a functional index for the reach:

$$FI = R_L + 0.3(R_H - R_L) \frac{[R_2 / 100 + R_3 / 100 + R_4 / 100 + \dots (etc.)]}{N}$$

FI = Functional index for the reach

R_L = Lowest of the functional ratings for the reach

R_H = Highest of the functional ratings for the reach

$R_2, R_3, R_4, \dots$ = Values for the second, third, and fourth, etc., highest ratings. (Maximum is 7).

N = Number of rated functions for the reach. (Maximum is 9).

Structure Index

The functional indexes for each reach will be combined as follows to create a functional index for the whole structure:

$$FI = I_L + 0.3(I_H - I_L) \frac{[I_2 / 100 + I_3 / 100 + I_4 / 100 + \dots (etc.)]}{N}$$

FI = Functional index for the structure

I_L = Lowest of the reach functional indexes

I_H = Highest of the reach functional indexes

$I_2, I_3, I_4, \dots$ = Values for the second, third, fourth, etc., highest reach indexes

N = Number of reaches in structure

Condition Index

The condition index for a reach or structure is the same as its FI.

8 Summary and Recommendations

The general intent of REMR Management Systems is to provide maintenance managers with tools to promote easier and more effective maintenance and budget planning. This report contains a rational, standard method for evaluating the physical condition and performance of rubble breakwaters and jetties. The method includes processes to determine numerical condition and performance ratings that are used to produce an overall Condition Index, which indicates the relative need for structural repair.

It is recommended that this method be distributed and applied Corps-wide. Further, it is also recommended that the method periodically be reevaluated and refined to incorporate improvements suggested by users.

Bibliography

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