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Construction Engineering Research Laboratory

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Navigation Systems Program

Condition Assessment Aspects of an Asset Management Program

Stuart D. Foltz and David T. McKay

January 2008

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Condition Assessment Aspects of an Asset Management Program

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Final report

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Under Project C93K59, Condition Assessment for Asset Management

Abstract: Central to a comprehensive asset management program is the ability to evaluate and know the condition and performance characteristics of all inventoried assets in the real property inventory (Federal Real Property Council [FRPC] Guidance, Section 4 "Operations of Real Property Assets"). In the case of the U.S. Army Corps of Engineers (USACE) Civil Works business area, this inventory includes an enormous array of multipurpose dams, locks, levees, and hydropower generation facilities (as well as buildings, roads, and bridges).

This report is a digest of condition assessment methodologies for Civil Works infrastructure. Included in the digest are insights and observations collected by the research team over the duration of the Repair, Evaluation, Maintenance, and Rehabilitation (REMR) Program that are pertinent to any organization interested in developing an asset management program. This digest is intended to be used in creating a USACE asset management program that also follows FRPC guidance.

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Preface

This study was conducted for the Operations Division of Headquarters, U.S. Army Corps of Engineers (HQUSACE) under Project C93K59, "Condition Assessment for Asset Management." The technical monitor was James E. Clausner, CEERD-HV-T.

The work was performed by the Engineering Processes Branch (CF-N) of the Facilities Division (CF), U.S. Army Engineer Research and Development Center – Construction Engineering Research Laboratory (ERDC-CERL). At the time of publication, Donald K. Hicks was Chief, CF-N; L. Michael Golish was Chief, CF; and Martin J. Savoie was the Technical Director for Installations. The Deputy Director of ERDC-CERL was Dr. Kirankumar V. Topudurti and the Director was Dr. Ilker R. Adiguzel.

The Commander and Executive Director of ERDC was COL Richard B. Jenkins and the Director was Dr. James R. Houston.

Unit Conversion Factors

Multiply	By	To Obtain
feet	0.3048	meters
inches	0.0254	meters
miles (U.S. statute)	1,609.347	meters
square ft	0.09290304	square meters

1 Overview of Asset Management and Condition Assessment

Background

In 2002 the federal government began using the Program Assessment Rating Tool (PART) to evaluate the efficiencies and successes of various government programs. PART revealed lower than expected performance effectiveness for many federal programs. One of the many programs where performance did not meet the goals is the U.S. Army Corps of Engineers (USACE) Inland Waterway Navigation Program. Subsequently, in February 2004, Executive Order 13327, "Federal Real Property Asset Management," mandated a pragmatic and consistent approach to federal agency management of real property. That order created the Federal Real Property Council (FRPC) to provide guidance to agencies for improved agency accountability and performance through the application of defined asset management business procedures. The guidance includes principles and strategic objectives, an asset management plan template with required components, and a framework for defining property inventory data elements and performance measures.

Central to a comprehensive asset management program is the ability to evaluate and know the condition and performance characteristics of all inventoried assets in the real property inventory (FRPC Guidance Section 4, "Operations of Real Property Assets"). In the case of the USACE Civil Works business area, this inventory includes an enormous array of multipurpose dams, locks, levees, and hydropower generation facilities (as well as buildings, roads, and bridges).

In the early 1970s ERDC-CERL began developing Condition Index (CI) products for airfield and highway pavements. By the 1980s this effort expanded to other installation infrastructure including buildings and utilities. These CIs would also be applicable to Civil Works assets.

From 1984 to 1998 USACE invested approximately $6 million developing condition assessment techniques for a large number of components in the Civil Works inventory. Condition inspection routines were developed using subject matter experts (usually USACE engineers and operations per-

sonnel responsible for the design, construction, or safe and continuous operation of a given component) who identified component distresses of the greatest concern. Levels of severity and relative importance factors were developed for each family of distresses associated with any given component. Methodologies were subsequently developed to make objective measurements and literally gauge the magnitudes of distresses. Algorithms compare field measurements against allowable maximums (determined by expert consensus) and generate component CIs that can be used to represent a snapshot of component condition. These indices were developed under the Repair, Evaluation, Maintenance, and Rehabilitation (REMR) Program, a research program sponsored by the USACE Directorate of Civil Works from 1984–1998, and are known as REMR Condition Indices.

Later in the research phase of the REMR work, another CI approach was developed at the system level rather than for components. It uses similar distresses and severities for the components, but the approach included an alternative framework for assigning component importance that relies more on intimate and expert knowledge of Civil Works component infrastructure than on field inspections per se. Whether at the component or system level of evaluation, all CIs enable stakeholders to pragmatically identify the most important sub-units that are in the worst condition.

Objective

A completed body of condition assessment procedures resulting from the REMR program identifies Civil Works component distresses, allowable magnitudes, relative importance criteria (weighting factors) and the means to measure them. The objective of this effort is to create a digest of these methodologies and similar methods for Civil Works infrastructure developed by other organizations. Included in the digest are insights and observations that the research team collected over the duration of the REMR program that are pertinent to any organization interested in developing an asset management program. This digest is intended to be employed in creating an USACE asset management program that also follows FRPC guidance.

Description

Condition assessment technologies were developed for approximately twenty components and groups of related components of USACE Civil Works infrastructure. Accordingly, there are a corresponding number of

technical reports that discuss CI development and provide specifics on using the CI procedure. Each of the 19 technical reports will be condensed to a 2- or 3-page fact sheet and compiled into a single reference designed to be useful to the asset management program required by the FRPC. This reference will include component type (name), a brief description, a list of component distresses and importance factors (weight coefficients) that most affect condition and performance, and assorted tables, pictures, and diagrams. For detailed descriptions of the inspection process, the Appendix provides readers with a hyperlink to the complete technical report. Similar descriptions will be included for non-REMR condition assessment systems that have also been developed for Civil Works infrastructure.

According to the Permanent International Association of Navigation Congresses (PIANC) and the American Society of Civil Engineers (ASCE), essential asset management (AM) includes:

- hierarchical asset register including classification and attributes
- a simple lifecycle approach
- AM plans based on the best available current inspection data (not necessarily complete) and assumptions where it does not exist
- meeting existing levels of service
- long term financial predictions based on local knowledge and options for meeting the current levels of service
- financial and service performance measures so that trends can be monitored.

The advanced approach will optimize activities and programs to meet agreed or aspirational service standards in the most cost-effective way through the collection and detailed analysis of key data on asset condition profiles, performance, deterioration rates, usage, lifecycle cost management, risk analysis and refurbishment options. It leads to optimization and true asset management strategies. It will usually involve lifecycle AM.

While other definitions of asset management may vary in the details, they all focus on similar lists of good management steps and processes to conscientiously care for built infrastructure. This report focuses on only a few aspects common to most asset management plans concerning inspection and condition assessment. While inspection may vary from the most cursory consideration to very detailed invasive and costly investigations, the meaning of inspection is relatively clear. The same cannot be said for condition. The word generically implies some measure compared to new, perfect, or optimal but the measures of condition vary not only in the level of detail but also in kind. Condition can be defined in terms of financial, safety, operational, functional,

> deterioration, aesthetic, adequacy, occupancy rate, and numerous other possibilities or combinations of metrics. This is important to note: condition can mean different things to different people. Condition assessment can only meet the need if the metric used meets the objective of the user. A single condition assessment procedure, no matter how robust, cannot meet all needs of all users. A particular condition assessment technique should not be denigrated for not meeting an objective it was not designed for.

While this view from PIANC emphasizes the importance of condition assessment, a more rounded approach that includes other considerations besides condition should lead to better decisions. Plotkin et al. (1991) proposed five primary factors in the decision process for maintaining infrastructure assets:

1. infrastructure condition
2. infrastructure performance
3. risk
4. economics
5. policies and priorities (national, Corps, and local).

Each of these factors has varying importance for different AM concerns.

By looking at condition assessment within this broader view, one can see that it would be difficult if not impossible to manage infrastructure solely using assessment data. Likewise, it is unlikely that any other factor could stand alone as an asset management tool. Ignoring any of the factors is likely to result in a sub-optimal management plan.

General discussion of condition index

The first CI was developed for airfield pavements by ERDC-CERL in the 1970s. Condition Indexes for other pavements and other infrastructure followed. These CIs focus on physical condition by identifying distresses, assigning severity levels, and quantitative measurement. Algorithms were developed to rate the distresses based on these distress types, severities and quantities. The initial CI work used the scale shown in Figure 1. When detailed data are needed, these standards are a significant improvement over subjective descriptive inspection reports. In addition to uniform reporting of inspection information, the ratings can be managed in a database, which has allowed the development of numerous predictive and

budgetary planning capabilities. Such capabilities have not been developed for the REMR CIs.

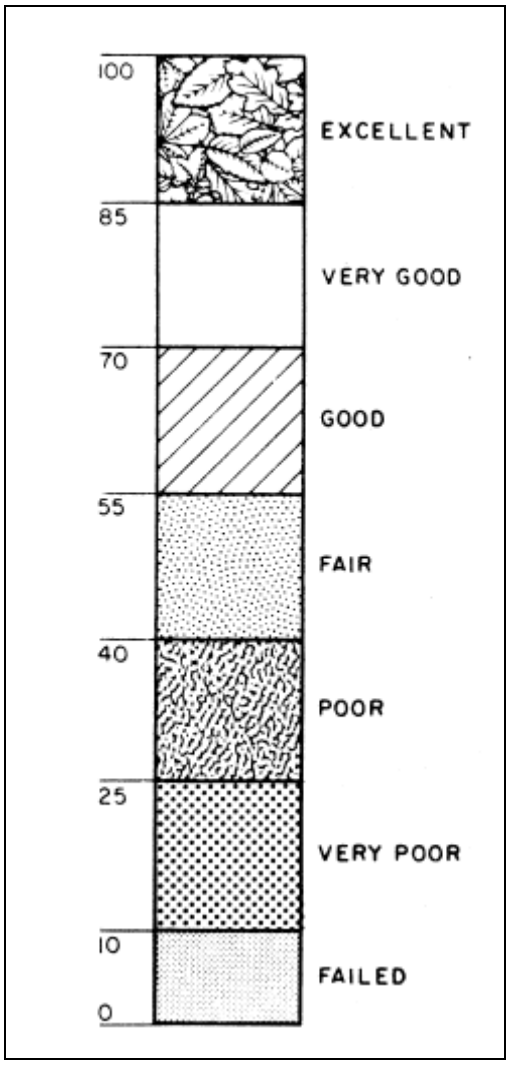


Figure 1. Condition index scale.

More recently, CIs developed by ERDC and other organizations included consideration of function (performance) within the CI or in a separate Functional Condition Index (FCI, not to be confused with the Facility Condition Index, also denoted as FCI). It is recognized that function is not always compromised equally by different defects in physical condition. Additionally, function can be compromised by other causes such as poor design. The Breakwater and Jetties CI and BUILDER both describe different methods of considering function within the CI process.

Sintef (http://www.sintef.no/content/page1____2212.aspx) has defined a technical CI to be "the degree of degradation relative to the design condition. It is a mean

value aggregated by a selected set of technical, financial and statistical parameters." This is a further divergence from the original CI definition as a measure of physical condition. A definition of CI as a financial measure has been gaining significant visibility and recognition. This financial measure was originally proposed by the National Association of College and University Business Officers as the ratio of repair costs divided by asset value. The FRPC has included "condition index" as one of their required metrics for federal facilities. Clearly, a shared understanding of meaning has become very important when using CIs to communicate condition data.

2 Overview of REMR Detailed CIs

REMR Management Systems (REMR-MSs) are decision-support tools for determining when, where, and how to effectively allocate maintenance and repair (M&R) dollars for Civil Works structures. These systems were developed to provide:

- objective condition assessment procedures
- means for comparing the condition of facilities and tracking change in condition over time
- an information source to assist in the budget prioritization process.

The objective of REMR-MSs is to provide uniform and objective condition assessment procedures and to help managers and engineers obtain the best facility condition for a given budget level.

REMR condition index scale

REMR maintenance management systems are based on the CI, a numerical rating system that indicates facility condition and function level. The core CI scale for all REMR tools is shown in Figure 2. By providing a quantitative and consistent means for condition description, the CI makes it possible for the facility conditions to be compared and monitored over time. With sufficient data collected, predictions about future facility conditions can also be made.

Zone	Condition Index	Condition Description	Recommended action
1	85 to 100	**Excellent:** No noticeable defects. Some aging or wear may be visible.	Immediate action is not required
	70 to 84	**Good:** Only minor deterioration or defects are evident.	
2	55 to 69	**Fair:** Some deterioration or defects are evident, but function is not significantly affected.	Economic analysis of repair alternatives is recommended to determine appropriate action.
	40 to 54	**Marginal:** Moderate deterioration. Function is still adequate.	
3	25 to 39	**Poor:** Serious deterioration in at least some portions of the structure. Function is inadequate.	Detailed evaluation is required to determine the need for repair, rehabilitation, or reconstruction. Safety evaluation is recommended.
	10 to 24	**Very poor:** Extensive deterioration. Barely functional.	
	0 to 9	**Failed:** No longer functions. General failure or complete failure or a major structural component.	

Figure 2. The REMR CI scale and recommended actions.

Condition index development process

While not all CIs are developed exactly according to the steps outlined here, the uniformity in the development process is relatively high. The general steps are as follows:

1. Identify components being rated and desired benefits of the target CI. These objectives may change during the development process, but it is important to keep them in mind throughout.
2. Collect experts on the design, construction, and operation of the topic components. These experts will provide the expertise and understanding of the components' behavior under varying operating environments throughout USACE.
3. A strawman of distresses and descriptions may be presented to the experts, but their input will be essential in refining the list. The distress list and descriptions will likely change throughout the development process.
4. Develop methodologies for quantifying the distresses. This may be based upon measurements, quantities, or descriptive criteria. Depending on the distress and how it is quantified, it is also useful to determine minimum/maximum for the measurements and/or excellent and failed state criteria. Some distresses will have multiple indicators of distress, which may require multiple methods of measuring and quantifying.
5. Condition rating algorithms are determined in order to weight the impact of each distress on the overall component condition. For most CIs these distress weights are pre-determined by the initial expert panel and applied uniformly to all like components. These "black box" distress weightings are frequently based on an algorithm that varies the weight depending on the distress condition rating. The Embankment and Spillway CIs add an additional level of information by determining the relative importance of each component of these structures (filters, drains, motors, wire rope, etc.). This is accomplished by a pre-developed framework that is tailored to the specific project and the relative importances are determined by the users. In addition to CI ratings, the process also results in priority ranking for each component's distresses based on the condition and the component's relative importance.
6. Software enhances data management capabilities and simplifies calculations. DOS-based software developed under REMR is unlikely to run on most modern computers. Spreadsheets could be set up for most CIs

to make calculations, but they are problematic for larger implementations and network-level activities. Robust software is needed for effective implementation.

Condition assessment procedures

The critical component of condition inspection is the condition assessment criteria. The criteria form the basis of a standardized inspection process. By guiding the inspector to specific areas of concern, the inspection will be more thorough. Criteria used in REMR CIs ranges from moderately detailed to subjective methods without much detail at all. At one extreme, the miter gate CI is arguably the most detailed and time consuming inspection process. The cost and benefits of any inspection should be considered carefully when determining how frequently to perform an inspection. At the other extreme, many REMR CI inspections use subjective criteria that can be evaluated based on current knowledge or a quick visual verification. Although the miter gate CI is technically rigorous and very sound, there is a misperception that all CIs require that level of effort. This is but one example of perceived uniformity in CI lore that does not exist.

One of the planned activities under the Operation and Maintenance (O&M) Management Tools Research Program was to develop a multi-level inspection capability where quick and rough CI ratings were made on a frequent schedule and more detailed inspection and ratings were only used when better information was needed. A similar capability has been developed (ERDC 2006) and incorporated in the latest release of BUILDER. Besides reducing the cost and effort required for most CI inspections, this would also set a CI inspection frequency plan that would not otherwise exist. The lack of such a policy created difficulties in implementing CIs.

Measurements

Although measurements can be time consuming, they are a desirable assessment method due to their quantitative and objective nature. The effort needed to make measurements also increases the likelihood of discovering unknown problems. It can be difficult to judge whether the measurements will be worth the required effort and expense. Using miter gates as an example, there has been some investigation under the USACE O&M Management Tools Research Program as to how to perform CI inspection more quickly without losing significant rigor and accuracy. Although prelimi-

nary, this effort delivered promising results. For example, forgoing close-up inspections by boat reduces inspection times by more than 50 to 70%, but observations (with binoculars if possible) obviously become more subjective; and the overall representation of condition through data is less objective. These trade-offs must be considered in balance with the desired objectives of the inspection.

Checklists

A checklist approach is often used to increase consistency where subjective information is used. The checklist categories may be based on estimated quantities, generic descriptions of condition or other subjective descriptions of distress and deterioration. Checklists and other subjective criteria tend to require less effort and expense to complete but the results can be less consistent and more ambiguous than measurements.

Condition rating procedures

While the condition assessment criteria may have greater importance, engineering and planning evaluations can also be assisted by quantifying the condition on a relative scale. Engineering tasks tend to be assisted the most by ratings for distresses and individual components. These ratings are the simplest and clearest in meaning. Planning needs are more often met using a combined rating for multiple distresses, components, and systems. Valuable details can be lost as information is combined. Methodologies for combining ratings and processes for using these ratings must consider the impact of the lost detail in these higher level ratings. The two primary methods of combining the detailed ratings are (1) a “black box” that makes the calculations according to a pre-determined algorithm and (2) a hierarchical model in which the user assigns relative weights.

Black box calculation

Most REMR CIs use a “black box” calculation to weight the distresses and other condition indicators for rating the condition of a component. Pre-determined methods for combining individual ratings offer greater simplicity and uniformity. They allow inspection and rating by less knowledgeable and less experienced engineers since they are only rating condition against pre-determined criteria. While inspection may still be time consuming, the calculation of condition ratings can be done quickly. If the calculations are complex, they can be automated within a spreadsheet or

other software. Black box calculations work best where the components being inspected and rated have the greatest uniformity. It may be a cumulative advantage or disadvantage that black box calculations are less subject to bias and manipulation by the inspector.

Expert system assessment

The alternative to black box calculations is to allow the evaluator to assign relative rankings to each component in a system. This is best accomplished by providing the strongest framework possible within which the evaluator can assign relative weightings to the distresses and other condition indicators at each level of a hierarchy. Similar to an event tree or fault tree, the system can be modeled within a framework where each comparison is on a single criterion so the meanings of the weightings are not ambiguous. These frameworks for system assessment have been developed for dam embankments and for spillway systems. This method also allows a further step not taken with most component CIs using black box CI calculations. The importance of components within a system can also be customized to the specific spillway.

Many considerations should be carefully assessed when deciding whether to have the user assign facility-specific component weightings or use a black box calculation:

- The uniformity between components and facilities is important. For example, most tainter gates share many attributes, the major variable being size. When looking at a spillway system, the variation in design is much greater, and it is more difficult to capture the uniqueness of a particular site within a black box weighting scheme. While it does take longer to create site-specific weightings, this effort is relatively minor if it results in a better understanding of the facility condition.
- It is also much easier to update on subsequent inspections than to create the weightings on the first inspection.
- This approach requires knowledgeable evaluators. If they are not available, it will be difficult to implement the approach. While the process is more likely to create greater understanding of the behavior and performance of the facility, this may not be important if the end objective is to create budget estimates for a large portfolio.
- It may be more important to obtain consistent results by a black box calculation than to generate the details and understanding by incorporating more of the site-specific attributes. For this reason, the size of

the portfolio can have an impact on which type of weightings work best, but consistency should not override technical quality when determining the best process.

3 REMR Inspection Criteria and Rating Procedures

This chapter describes condition assessment aspects and criteria of the REMR-MSs developed between October 1984 and September 1998. This discussion is neither a history of the REMR R&D Program, a discourse on the benefits (or deficiencies) of the systems, nor a narrative on how the systems should be used; but a simplified description of what was measured and the relative importance of each distress in assessing overall condition. Individual technical reports provide detailed descriptions on how the inspections are accomplished.

A general description is provided for the development process common to the majority of the systems. This description is followed by a section for each system with the following cited: the structure considered, the related distresses, the condition rating algorithm and relative importance of the distresses, and how each distress is measured. The Appendix lists web links and postal addresses where the original technical reports can be obtained.

The primary goal for the REMR-MSs was to provide the means for objective condition assessment. By using pragmatic procedures, based upon repeatable measurements, performed by local project personnel, it was hoped that structural conditions could be quantified. The systems produced CIs, a numeric range from 0 to 100 with definition provided in a CI scale. The scale shown in Figure 2, used for all structures, is divided into seven *condition zones* and three *action zones*. Through time, the raw data, CIs, and the trends tracked by this information could be used to support the decision process in prioritizing work packages in O&M budgets.

The first phase of development began with the formation of a panel of experts; most often USACE personnel who were responsible for maintaining the structure in question. A new panel was formed every time a new REMR-MS was developed. The panel was assembled and queried concerning which features and characteristics of the structure required the most attention to keep the structure functional in accordance with mission and safety. Their responses resulted in a list of distresses common to the structure, with an associated range of allowable/maximum magnitudes (e.g.,

displacements) for each, by consensus, representing failure to operational modes. Each distress was then weighted by its importance in contribution to the overall condition of the structure. Normalizing the weights yields relative importance factors for each distress category that, more often than not, were mathematical constants. When these were not constant (e.g., where a given distress' importance might dramatically increase if the structure were very close to failure), a sliding scale as a function of distress magnitude may have been used to modify the weights. It is notable that age was rarely considered as a contributing factor in determining condition. A means for consistently measuring each distress was planned; generally a variation of plus or minus 10 points was considered acceptable. An algorithm was developed to take distress information as input and produce CIs that were consistently meaningful as described by the REMR CI Scale.

Implicit in the discussion above is the concept that performance and condition mean much the same thing; most often this assumption is correct. Performance is based on condition and function. If the design is appropriate for the function, then condition will be the dominant factor in performance. However, as a class of structures apart from the rest, performance was considered separately from condition in the cases of breakwaters, jetties, riverine dikes, and riverine revetments constructed in wood and stone. Very often these structures can be in poor condition but perform excellently; and structures in as-built condition can perform miserably. This performance variance was attributed to the dynamically changing environments in which the structures existed. Changing environments prescribe changing required performance parameters. Hence, in these classes of structures, performance was measured and characterized in addition to condition and may have an entirely different connotation.

Field tests by the development team and expert panel and local District personnel were conducted via site visits at numerous structures for each system. Results validated or disproved assumptions, and the resulting organization of weights, measurements, and algorithms was finalized. In the 1980s the first system took 2 years to complete and field. By the mid-1990s, some individual systems were being produced in less than a year.

In the field, ordinary rulers and tape measures, see-through plastic crack comparators capable of measuring 0.01 in.–0.10 in. (0.25 mm–2.0 mm), magnetic dial gauges, and feeler gauges capable of measuring 0.001 in. displacements or gaps were the only required equipment in most cases.

For more complicated structures like miter gates, a rod and transit is used. Sometimes a boat is required to get close enough to measure the distress. However, an experienced inspector with binoculars may be able to obtain acceptable data, too. Often a large chalk or crayon is needed to mark locations. More experienced crews developed mechanical leveling and centering systems for the dial gauges and had an "erector set" style collection of lightweight angle bars, C-clamps, and other tools to facilitate the miter gate inspection. In the mid-1990s the cost for this equipment set was approximately $2,500.

After a system was developed, training exercises for Corps personnel were conducted. People were taught how to perform the inspections and how to use the software that was designed for each system. The software provided the basic inventory of projects and related infrastructure components. Inspection data could be stored and CIs automatically calculated. Note that many of the technical reports cited in this paper contain user guides for the various pieces of CI software; but the applications were written and compiled in pre-Windows DOS-based environments which are now, for all practical purposes, obsolete. Since the CI program was mandated such a short time before becoming voluntary, data were not systematically collected. Locating data would be difficult.

Finally, every variety of gate was considered (for condition assessment purposes) separately from the gate operating equipment. Since the operating equipment for gates is fairly common to most gate types, operating equipment was considered as a system with its own unique REMR-MS.

Refer to the technical reports listed in the References to see examples of completed inspection forms. Each REMR-MS is described in the following text, presented in the chronological order in which it was developed.

Steel sheet pile (REMR-OM-03 and REMR-OM-09)

Illustration 1. Steel sheet pile.

Description: Steel sheet pile is used for many purposes. It is used most often by USACE as retaining walls, lock chamber walls, lock guide walls, lock transition walls (lock chamber or guide walls to natural bank), cut off walls (retarding or stopping flow), and circular mooring cells or protection structures. Sheet pile comes in a variety of shapes. In nearly all cases the piles comprise cantilevered structures, driven into earth, interlocked together, tied or waled for stability, and backfilled with earth, stone, or concrete.

Distresses: The criteria for condition assessment considered safety, structural integrity (factor of safety) and the ability of the structure to function as designed. Early in the development process, data were taken to calculate the existing factor of safety and compare it to the original design factor of safety. This was called a structural CI. However, this was eventually deemed too expensive and complicated for local project crews to perform. The process was simplified to produce just the functional CI, which was designed to agree with the ratings assigned by the panel of experts. This CI is based on the following categorical distresses; the percentages in parentheses represent the normalized importance of each distress in terms of its importance to the overall structure's functional condition. Steel sheet pile distresses and unadjusted weight coefficients (W_is) are shown below:

- Misalignment (24%) – deviations of wall or cell from design
- Corrosion (15%) – loss of cross section
- Settlement (12%) – vertical displacement of fill
- Cavities (12%) – loss of backfill material behind the piling
- Interlock separations (12%) – interlocking failure

- Holes (8%) – in the steel
- Dents (6%) – depressions without rupture
- Cracks (11%).

Procedural narrative: An inspection form is provided. Having as-built drawings is required for some of the inventorial data. A crew with prepared inspection forms visits the structure by land and boat making visual observations for any of the distresses cited above from all possible vantage points. Sizes, relative sizes, and locations of all distresses are recorded. In this case a tape measure is all that is needed. Measurements are taken to the closest inch. Cracking or spalling of concrete around embedded steel is indicative of excessive motion. No underwater measurements or observations are made based upon the assumption that underwater distresses will be manifested in visible above-water distresses such as misalignment or loss of fill.

Rating algorithm: This algorithm will be referred to several times in this report. All of the distresses are sorted according to category and considered for both their singular and collective contribution to overall condition. Each distress is first considered in regard to its importance relative to the other distresses (e.g., misalignment is considered to be twice as important as a crack and four times as important as a dent). These relative importance factors are called w_i. These w_i are then normalized and become W_i (where the sum of the W_is is unity). These weights, importance factors, or scalar coefficients for each distress are known as the unadjusted weights for each distress (the W_is shown parenthetically in the distresses listed above).

Recall that relative allowable maximums for each category of distress had already been determined by expert consensus; these maximums were defined as $X_{i\text{-max}}$. The actual magnitudes measured in the field are defined as X_i. All distress measurements and the frequency of each distress category are considered in relation to these maximums. The algorithm asks "What would the overall condition index of the structure be if no other distresses were present?" This calculated result is called a "sub CI" or CI_i for the given distress category. The formula used for the sub-CIs is

$$CI_i = 100(0.40)^{Xi/Xi\text{-max}}$$

Note that, as the measured magnitudes approach the maximum allowable as determined by expert consensus, the sub-CI approaches 40, a CI indicative of a failed component. The algorithm then considers each category of distress and weights its contribution to the overall CI of the entire structure. The overall CI for the structure is calculated by the formula:

$$\text{CI} = \sum W_i CI_i$$

where the CI_is are the individual category sub-CI contributions and the W_is are the normalized weights (percentage values shown in the parentheses above) or coefficients for each distress category.

As selected distresses became more severe, approaching their maximum allowable value, it became apparent that the associated scalar coefficients (weights) had to be readjusted; i.e., certain (not all) distresses become more important relative to the other distresses (as when one or more particular parts of the structure are in very poor condition). An example may be that, if misalignment nears its maximum allowable magnitude (indicating imminent failure), its importance would grow relative to the other weights (e.g., now misalignment is eight times more important than a crack or a dent). A sliding scale was developed to adjust certain relative importance scalars w_i; in such cases the w_i are scaled by multipliers obtained from a curve given in the technical report, and subsequently renormalized to obtain new importance coefficient W_is. For this reason, the tables of distresses described in this report list only the *unadjusted* weights. Readers can refer to the original technical reports for the adjustment factors for recalculating the new W_is.

Other: The basic format of the algorithm employed here was used consistently for other structural types where possible. Sometimes, however, it made more sense to perform the calculations using a different algorithm. Later in this document the reader will be referred to this section where the algorithms used were identical.

Also refer to Technical Report REMR-OM-09 “Maintenance and Repair of Steel Sheet Pile Structures.” This report is the same as REMR-OM-03 but has an additional chapter on how to use the software that was developed for this REMR-MS. Although the software is obsolete, the REMR-OM-09 report is available on-line in Portable Document Format (PDF).

Concrete lockwall monolith (REMR-OM-04)

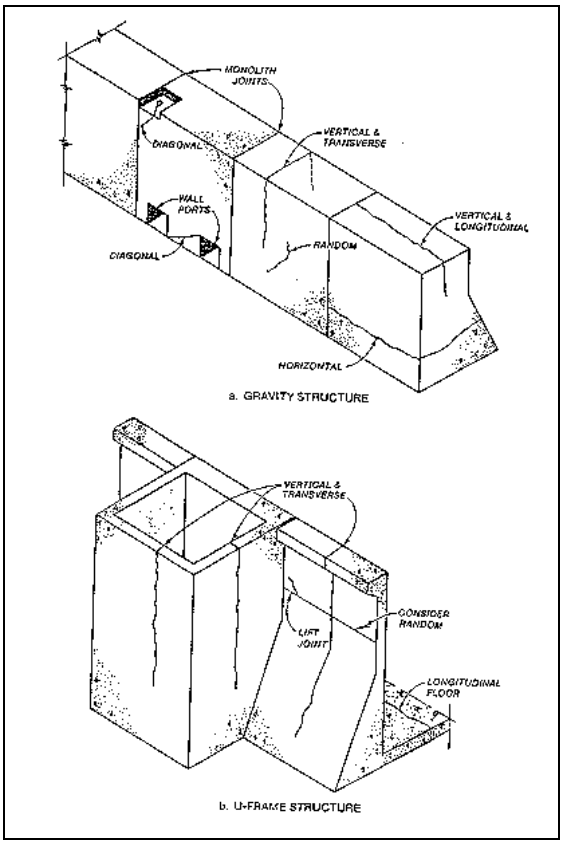


Illustration 2. Examples of concrete distresses in lock chamber monoliths.

Description: Lock chamber walls are constructed of singular large reinforced concrete monoliths that rely essentially on their own weight (gravity) for structural performance. They vary in size from low lift to high lift locks but generally are of the same construction (20 x 40 x 40 ft up to 90 x 40 x 130 ft). They sometimes contain galleries for electrical raceways or mechanical equipment, conduits for filling and emptying, slots for valves and bulkheads, and support gate structures at each end of the lock chamber. Typically they are rubber-sealed on the upstream and downstream ends with the neighboring monoliths to prevent leakage. Structurally they are similar to gravity monoliths in spillways, dam piers, and retaining walls.

Distresses: Cracking is the primary distress in any concrete structure. The categorization of the cracking is based upon the American Concrete Institute's ACI 201.1R-92, *Guide for Making a Condition Survey on Concrete In Service*. The importance of each type of cracking was determined by expert consensus. Cracking or spalling of concrete around embedded steel is indicative of excessive motion. Different kinds of cracking are treated with

varying levels of scrutiny because the location and orientation of the cracking carries different interpretations regarding the structure's ability to function as designed. Cracks are measured for width at the widest point where a clean measurement is possible. It is recommended to look for cracks on vertical surfaces where weathering or raveling has had little to no effect (e.g., underneath the grating over a bulkhead slot). Cracks are categorized into four categories by their maximum width as follows:

- Very fine (width ≤ 0.01 in./0.25 mm)
- Fine (0.01 in./0.25 mm < width ≤ 0.04 in./1.0 mm)
- Medium (0.04 in./1.0 mm < width ≤ 0.08 in./2.0 mm)
- Wide (width > 0.08 in. or 2.0 mm)

Figure 3 shows these crack widths drawn approximately to full scale.

Some cracking is volumetric in nature where the concrete crumbles, erodes, or simply pops out due to constrained expansion. The deduct values (DV) of this type of cracking are proportional to the relative amounts of volume lost from the cross section. The maximum DV assumes that 12% of section thickness can be lost before overturning becomes a concern. Deduct values are assigned to crack types and increase with increasing crack width and carry more importance where undesirable loading conditions are indicated. Monoliths supporting gates are given additional DVs when cracking is present. Only the largest crack of each type is measured. No record of the frequency or concentration of the cracks is made, but a variety of crack types are considered. In addition to cracking, spalled joints, corrosion stains, exposed steel, damaged armor, leaks, and calcium deposits are tabulated. In cases where monoliths are misaligned, this indicates that the monument is moving dramatically and a DV is assigned. The DV forces the CI to a maximum of 40, with the intent of bringing it to the immediate attention of O&M managers.

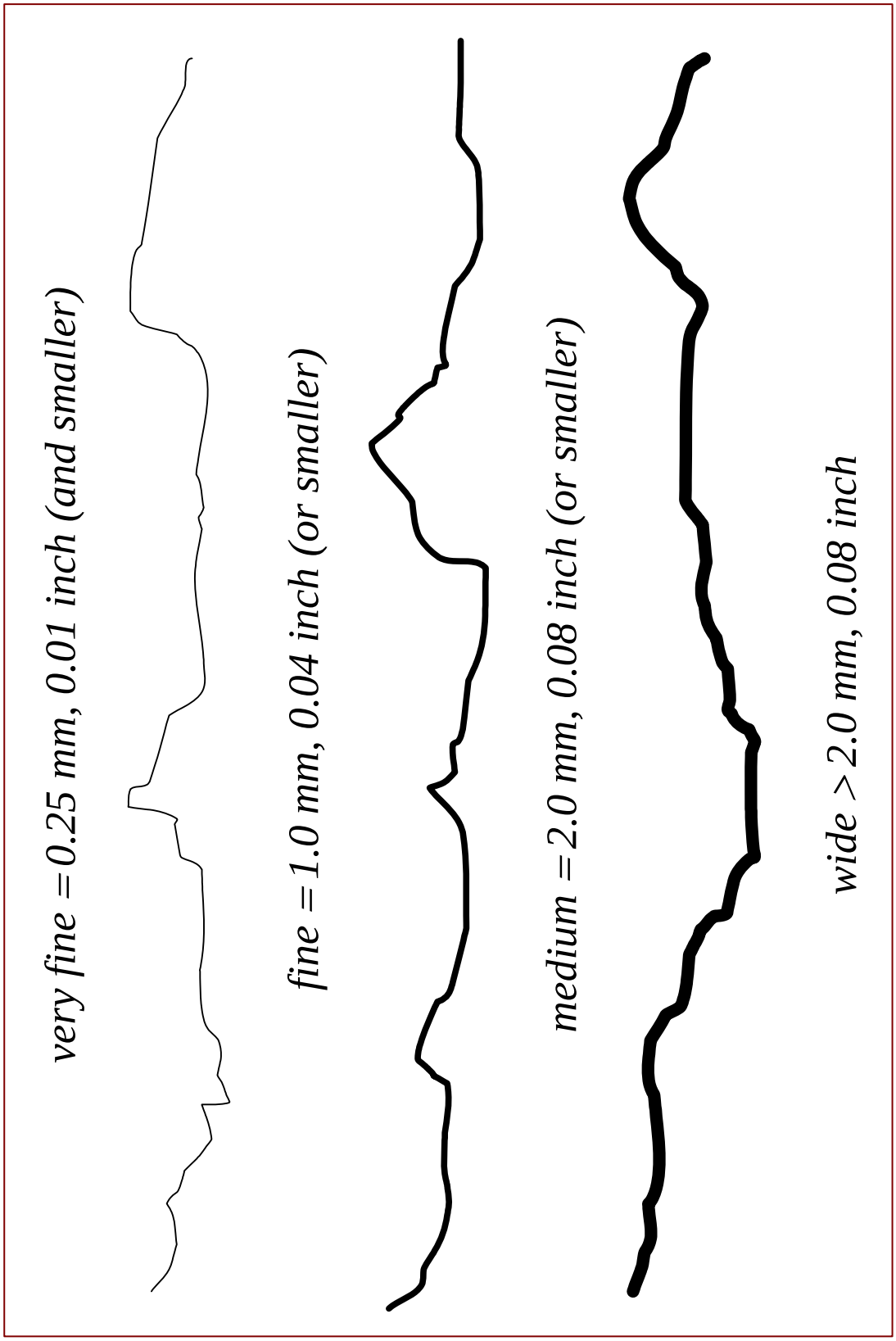


Figure 3. Crack width size categories (approximate actual sizes).

The distresses and their associated DVs are listed below:

- Alignment Problems* (DV = 60, I.E. CI Max = 40)
- Horizontal Cracks (10 < DV < 40)
- Vertical & Transverse Cracks (10 < DV < 40)
- Vertical & Longitudinal Cracks (10 < DV < 70)
- Diagonal Cracks (20 < DV < 70)
- Random Cracks (10 < DV < 60)
- Longitudinal Floor Cracks (10 < DV < 40)
- If Gate Block Additional (5 < DV < 70)
- Volume Loss (Checking, Spalling, Pattern, etc.) DV Proportional to Volume Material Lost Compared to Section Design Thickness at Same Elevation (2 < DV < 50)
- Exposed Steel (30 < DV < 60)
- Conduit Abrasion or Cavitation (10 < DV < 60)
- Spalled Joints (5 < DV < 10)
- Corrosion Stain (5 < DV < 10)
- Damaged Armor (5 < DV < 20)
- Leakage (5 < DV < 20)
- Deposits (5 < DV < 20)
- Damage To Decks (5 < DV < 20).

Procedural narrative: Inspectors armed with as-built drawings should look at a minimum of 10% of the lockwall monoliths and must include all monolith supporting gates. Only the worst need to be inspected. Originally a boat inspection was required where the vertical surfaces were inspected while the chamber was raised and lowered, but this added a minimum of 2 hours to the inspection time so it was decided that visual inspection with a good pair of binoculars would suffice. Widths, relative location, orientation, and monolith ID numbers are recorded on a prepared form. Aside from preparation and subsequent analyses, the inspection time can be honed down to under 2 hours with practice. The procedures are the same for dewatered locks and apply to the filling and emptying chambers when the opportunity arrives.

Rating algorithm: Deduct values are provided on a table in ACI 201.1R-92. Diagrams like the one shown in Figure 3 enable the inspector to discern crack types; transparent crack comparators allow crack width meas-

* A CI of 40 indicates a failed condition and should be brought to the immediate attention of O&M managers. If misalignment is deemed negligible, the DV can be changed to zero.

urements. Generally, crack widths are very small with the largest upper width being 0.08 in.; above this size cracks are considered "severe." The largest distress of each category is considered. The ACI table gives instructions (and limits) on how to combine the DVs into a single CI for the lockwall monolith, but generally the DVs are subtracted from 100 with certain distress types becoming more important in prescribed circumstances. No roll up procedure or algorithm has been developed for calculating a CI for the lockwall or the lock chamber based on the individual monolith CIs.

Other: Algorithms for concrete monoliths and piers in spillways, dams, and retaining walls are very similar to this one.

Timber dikes – Columbia River (REMR-OM-05)

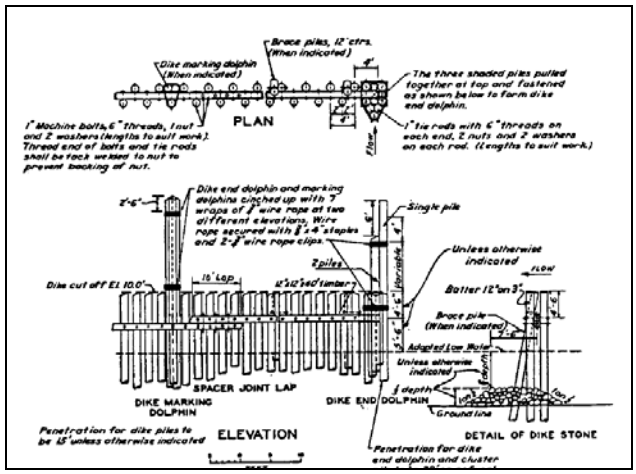


Illustration 3. Typical Columbia River timber dike.

Description: This REMR-MS was developed specifically for the structures along the lower Columbia River. Timber dikes are riverine training structures made of timber piles and stone placed in a direction either parallel to or nearly perpendicular to flow. In nearly all cases along the Columbia, the timber pile dikes resemble cantilevered structures with an end connected to the river bank, with all piles driven into earth, bolted and tied together, braced and battened with more piles for stability, stabilized by horizontal wood spreaders, and protected by a layer of stone on the river bed. The pieces are held together with steel connectors and wire rope. They are permeable structures with piles placed on 2 ft centers on either side of a horizontal wood spreader. The perpendicular dikes constrict the cross-sectional area of the river, thus increasing flow past the dike ends and reducing the flow where the dike connects to the bank. Reduced flow also occurs between the bank and a dike constructed parallel to it. The increased flow near the channel results in a scouring effect, promoting sediment transport downstream. The design functions are to align the navigation channel and decrease the amount of periodic dredging required to keep the channel in navigational compliance. Clusters of piles wrapped at the top with wire rope, called dolphins, are evenly spaced along the length of the dike with an additional dolphin on the riverward end. The structures considered here are unique to the Columbia River, but concepts could be transferred to similar structures if desired. Very little variation is found in the construction of these dikes, which makes condition assessment considerably easier.

Distresses: Distresses result from the forces acting on the dike due to wave motion, watercraft collision, and deterioration due to exposure. Exposed portions deteriorate much more rapidly than portions that are underwater. Rotten timbers, usually due to wood fungi or marine borers, are the leading cause of component failure. Generally these structures deteriorate slowly and somewhat uniformly, lasting about 25 to 30 years for untreated timber. As soon as a critical level of decay is realized, however, deterioration accelerates rapidly to failure within a couple of years. The primary distresses for timbers and their connectors are as follows:

- Loose Timbers
- Rotten Timbers
- Missing Timbers
- Missing Connectors Or Wire Wrapping
- Length Of Structure Affected & Location
- Depth Of Water At Location (Shallow < 30 Ft < Deep)
- Normalized Age Of Component

Procedural narrative: Original drawings, knowledge of the structure's maintenance and repair history, a tape measure, and a shallow draft boat are required for inspection. The critical condition is easily recognized when timber around a connector that joins the pile to the spreader has deteriorated enough to allow relative movement between the pile and spreader that is visible to the naked eye. The data captured for the rating process is the same that is usually noted in the regularly scheduled periodic inspections. No underwater inspections are made; no ratings based on the loss of stone are included.

Rating algorithm: To a small degree the CI algorithm for this REMR-MS is based on the ability of the dike to perform its design function. For rating condition, however, the algorithm is based primarily on structural integrity and safety as determined by the integrity of its parts. In addition, because these structures do behave somewhat uniformly and predictably, age is considered as an indicator of condition for planning purposes by a normalized parabolic curve. For piles and spreaders, a visual observation is made for a given distress and the length of the structure under this effect is noted.

The algorithm considers the location, length affected (% of structure), distress severity, and calculates the CI for the structure. Distresses are given

more importance or weight if they are located farther away from the channel. The reason for this is that the structure is intended to slow flows near the bank and increase flows toward the channel; so a deteriorated dike near the bank defeats its purpose. The algorithm makes use of the uniform construction of these dikes to compute conditions of each pile and spreader based on the data taken during the inspection.

Other: This CI system was designed for the approximately 120 timber dikes that exist between mile 20 and mile 136 on the Columbia River.

Miter lock gates (REMR-OM-08s, supplement)

Illustration 4. Downstream miter gate.

Description: Miter gates are called such because of their likeness to a miter headdress or because, when they close, they form a beveled surface where the miter blocks meet and seal. The gates are made of vertical and horizontal girders, skin plates, diaphragms, intercostals, quoin blocks, miter blocks, seals, pintles, diagonals, embedded anchorages, anchorage links, and gudgeon pins and bushings (Figure 4). At the upstream and downstream ends of a lock chamber, they hold back or contain water as the chamber fills and empties. A simple looking but complicated structure, miter gates leak, vibrate, groan, stretch, compress, bend, jump, corrode and break under a variety of loading profiles that range from minimum to maximum head, from their open to closed configurations, and in between. The miter gate inspections are probably the most measurement intensive of all REMR CIs. If the boat inspection is skipped, however, and barring river traffic, an experienced and equipped crew of two or three can accomplish an inspection of two sets of gates in under 3 hours.

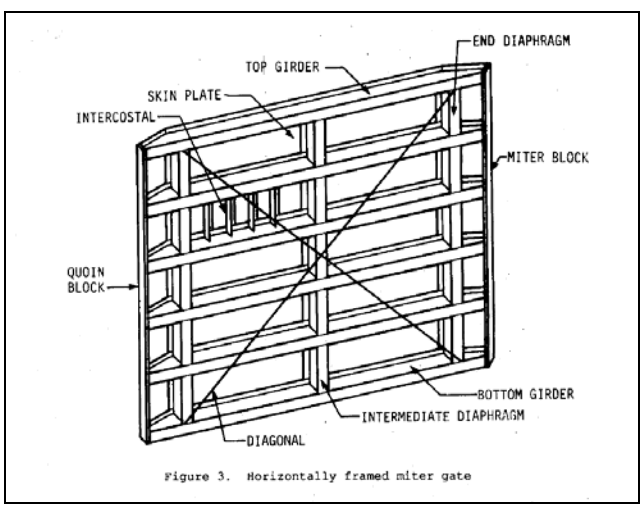


Figure 4. Components of a miter gate leaf.

Distresses: The gates are considered under a variety of static loads. Beginning at fully recessed, to partially closed, to fully closed with a 2 ft head water, and finally fully closed with a full head of water. Every measurement described here occurs at each loading condition. Given enough crew and equipment, both gates can be measured at the same time but measuring one at a time does not affect the outcome. A transit measures relative downstream movement of the fully mitered gates after a 2 ft head and full head are applied. The transit also measures changes in elevation (measured by rod) at the quoin and miter points as the gates are swung from fully recessed to partially closed to fully closed and under low and full head. Cracking or spalling of concrete around embedded steel is indicative of excessive motion. A series of dial gauges arrayed along the gate anchorages measure relative displacements along the axial directions to one-hundredth of an inch. (Figure 5). Play between the brass bushings and the gudgeon pins and pintles are deduced by the various readings. How well the gates mate at the miter point is checked visually and measured to the quarter inch. Vibrations are noted, as are unusual sounds. Cracks and dents in the components are recorded for severity and location; leaks (in the skin plate and at the quoin block and miter block mating surfaces) are recorded as are boils (leaks from under the seals). The condition of concrete housing the anchorage bars is checked for spalling (indicating excessive movement of the anchorage). Miter gate distresses and unadjusted weights (W_i) are as follows:

- Top Anchorage Movement (18%)
- Elevation Change (14%)
- Miter Offset (8%)
- Bearing Gaps (13%)
- Downstream Movement (11%)
- Cracks (10%)
- Leaks/Boils (5%)
- Dents (2%)
- Noise/Vibration (11%)
- Corrosion (8%).

Figure 5. Preparations for measuring bushing wear around axis of rotation.

Procedural narrative: The procedure is designed to be conducted on gates in service, requiring occasional and brief disruptions to river traffic. No underwater observations or measurements are required. Dial gauges are set up according to instructions in the technical report. Relative displacement between the anchor bar and concrete are measured. Relative displacement between the anchor bar and the bar supporting the gudgeon pin and bushing is measured relative to true vertical (a special machined tripod supporting a smooth steel cylinder) displacements are measured in the bushing and bushing pin which directly relate to bushing wear. A boat trip was required to measure gaps between the quoin and miter bearing surfaces using common feeler gauges. A plastic 12 in. ruler was firmly attached to one of the armor timbers (see yellow ruler on third timber in Illustration 4) for the purpose of measuring relative downstream displacement with the transit from the concrete deck. The gates were swung open and closed and unusual sounds, jumps or vibrations were recorded (somewhat subjective but guidance is given). Gate alignment at the miter point is measured visually to the closest quarter inch.

Rating algorithm: The list of distresses is the same for all types of miter gates, but there are various types of miter gates to account for within the algorithm. Depending on the anchorage system (rigid versus flexible) and whether the lock is considered a low lift or high lift lock (determined by the width to height ratio of one gate), the algorithm is modified accordingly. Also considered is whether the gate is horizontally framed (principal loads are borne by the concrete monoliths holding the anchorage) or vertically framed (principal loads borne by the concrete sill monoliths directly under and in contact with the gates). Upstream and downstream gates are treated differently because of the different load profiles.

The calculation of sub-CIs for each distress and an overall composite CI for one gate leaf is identical to that described in the rating algorithm section on steel sheet piles.

Other: The first miter gate report was distributed as REMR-OM-08. A supplemental report REMR-OM-08s was published to cover required changes in the algorithm after subsequent discoveries in extended field trials.

Rubble and nonrubble breakwaters and jetties (REMR-OM-11 and OM-24 for rubble; REMR-OM-26 for nonrubble)

Illustration 5.Hybrid breakwater.

Description: 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 (Figure 6).

Rubble mound structures are 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 under-layers of smaller, graded stones covered by a primary layer of large armor stones of nearly uniform size. In milder wave environments, the outer covering may consist of heavy graded riprap in lieu of uniform armor stones.

Nonrubble structures include concrete and other nonrubble units as well as hybrid construction, employing stone, timber, and other materials. The overall approach and execution for hybrid breakwaters and jetties is similar to that for rubble mound structures. Older rubble structures may also be repaired using other materials, making the structure hybrid.

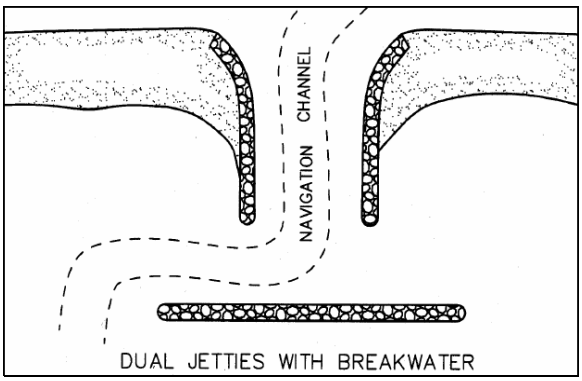


Figure 6. Breakwater with dual jetties.

Breakwaters are 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 the shore at one end or entirely detached and more or less parallel to the shore.

Jetties are mainly for 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.

Structures like breakwaters, jetties, dikes, and revetments must be considered for both condition and performance. Unlike most other structures discussed in this section, condition and performance do not always have a 1:1 correlation. Because they exist in ever-changing environments, it is possible for these structures to exist in as-built conditions but perform poorly; or the opposite may be true, structures in poor condition may be functioning well. Hence performance history and the consideration of risk (predicted performance) play increased roles in evaluation of these structures.

Condition distresses: Performance requirements are determined by considering what the structure is designed to control, such as waves, currents, seiches, sediment movement (navigation), shoreline erosion or accretion. Structural distresses include breaches, loss of elevation, displaced caps or armor, settlement, changes in slope, interlocking (Core-Loc), spalling, cracking of stone or armor.

Functional rating categories: The rating categories listed below are the basis for rating the function of the structures. Each structure will perform one or more of these functions. The structure's functional condition will be evaluated against the applicable functions. Each rating category includes more detailed items representing the types of damage or adverse conditions (functional deficiencies):

- Harbor area
  - navigation
  - use (vessels, facilities)

- Navigation channel
  - entrance
  - channel
- Sediment management
  - ebb shoal
  - flood shoal
  - harbor shoal
  - shoreline impacts
- Structure protection (relative to design expectations)
  - minimize wave energy
  - defend against erosion, scour
  - trunk deterioration
- Risk of damage to nearby structures
  - toe erosion
  - trunk protection
- Other functions
  - public access
  - recreational use
  - environmental effects
  - aids to navigation
- Storm events (history and prediction, frequency)

Procedural narrative: Each structure is first considered by determining the functions the structure serves. The structure is then divided into management sections called reaches. Reaches are further divided into sub-reaches according to structural length and other criteria. Functional performance criteria and structural requirements are determined according to provided guidance. Most of these pre-inspection procedures are relatively time consuming the first time they are performed. Subsequent reviews will take significantly less time. A physical inspection follows, making use of tables created in this process. Nearly all notations are based on visual observations above the waterline; underwater defects will make themselves known by changes in slope of the stone. Guidance for judgments on whether distresses are minor, moderate, or major is provided. After a complete inspection, the user is led to probable actions to be effected for operational or safety issues.

Rating algorithm: The rating algorithm and the weights for distresses are a function of the pre-inspection evaluation of the structure's structural and performance criteria (Table 1) and are used for assigning numerical rat-

ings to each of the structural concerns. However, the performance rating is considered the most critical portion of the CI for coastal structures. The structural ratings help determine the functional ratings, which are determined by entering inspection and evaluation data into forms; tables and formulae lead to the rating.

Other: None

Table 1. Example structural condition rating table.

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.

Hydropower equipment

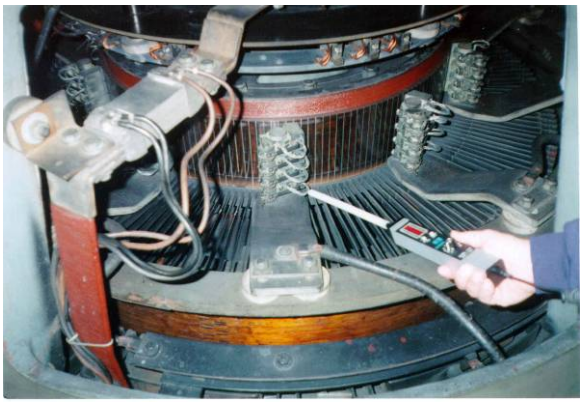


Illustration 6. View of a hydropower generator.

Description: The hydropower equipment CI developed under REMR funding was distributed in an unpublished binder that was updated during REMR. The content was later incorporated into hydroAMP, a tool that is described in Chapter 4. REMR condition assessment methodology was incorporated into hydroAMP, but a multilevel inspection approach was also added after the conclusion of the REMR program.

Lock sector gates (REMR-OM-13)

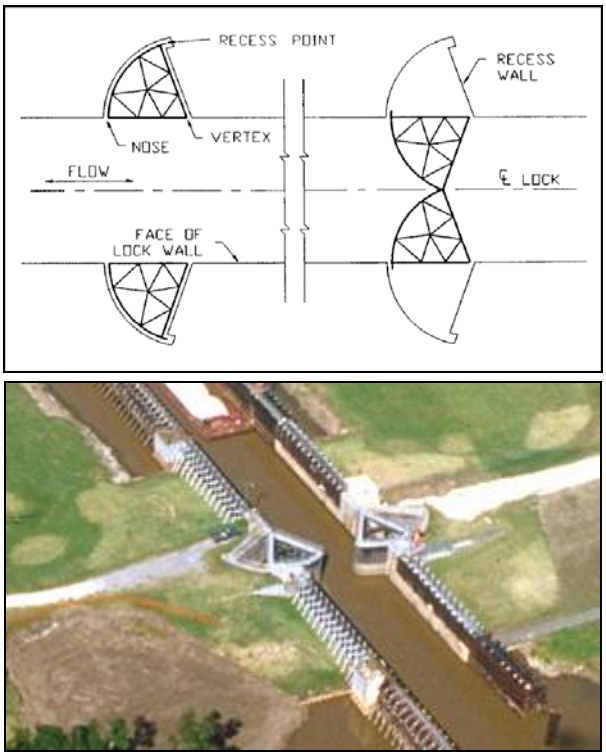


Illustration 7. Plan diagram of sector gate operation (top) and aerial view of lock with sector gates (bottom).

Description: Sector gates perform the same function as miter gates and consist of many of the same pieces. This combination of girders, skin plates, pintles, bearing surfaces, and seals suffer the same distresses as miter gates, and the rating algorithms and formulae are very similar. However, the inspection process is slightly different from that of the miter gate because of the obvious differences in their design, construction, operation, and maintenance.

Distresses: The basic family of distresses (e.g., misalignment, corrosion, undesirable anchorage movements, large changes in elevation, cracks, and leaks) are the same as other gates described herein. There are minor process changes to account for the different design and construction. The fact that the gates are usually smaller and simpler than miter gates makes them easier to inspect. A sector gate problem not encountered in miter gates is the binding of the hinge pin with its bushing as the gate moves around its axis of rotation. This distress is difficult to measure objectively, and the inspection process is somewhat subjective. A means for measuring this was developed, requiring an accuracy of measuring displacement to the closest 1/8-in. The same measurement also can indicate normal wear of the pin and bushing, pin or pintle problems, or gate structure problems.

The measurement considers how much the nose of the gate displaces before the hinge pin actually moves from a state of rest. Cracking or spalling of the concrete around embedded steel is indicative of excessive motion. Sector gate distresses are listed here with their unadjusted normalized importance coefficients (weights, W_i) shown in parentheses.

- Top Anchorage Movement (17%)
- Gate Deflection/Hinge Binding (10%)
- Levelness (9%)
- Cracks (9%)
- Dents (2%)
- Noise, Jump, Vibration (9%)
- Corrosion (12%)
- Hinge Wear (14%)
- Incremental Wear Thrust Bushing/Pintle (12%)
- Leaks and Boils (6%)

Procedural narrative: A crew of two is required. The inspection is performed on gates in service. With the exception of the hinge binding problem, the gates are inspected much the same way as the lock miter gates. The reader is referred to that section for discussion.

Rating algorithm: The rating algorithm is identical in most respects and so similar in others that the reader is referred to the discussion on the rating algorithm in the section on steel sheet piles.

Other: None.

Tainter and butterfly valves (REMR-OM-14)

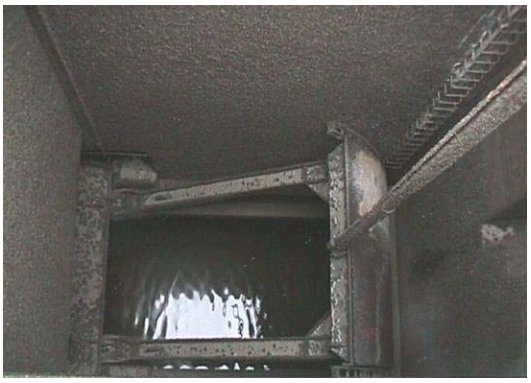


Illustration 8. A lock chamber tainter filling/emptying valve.

Description: Tainter and butterfly valves are critical components of the filling and emptying system of a navigation lock. Two valves are required in each culvert on either side of the lock. The filling valve is located between the upper pool intake and chamber intake ports. The emptying valve is located between the chamber outlet port and the downstream discharge. They are located at the bottom of lockwall monolith valve pits like that shown at the right, they are usually hinged within or just above the culvert, and they act as moveable stoplogs which allow or prevent water from passing into or from the culverts and laterals. Most often they are lifted and dropped by a linkage system controlled from the deck of the lock wall. There are many styles of valves designed for this purpose (e.g., sluice, cylindrical, wagon body, slide gates). To date, however, butterfly valves are used only in the Pittsburgh District and the tainter type valves are used almost to exclusion of all other types by the rest of USACE. Procedures were developed for both a “dry” inspection (where the culvert is dewatered by placing stoplogs in the culvert upstream and downstream of the valve) and “wet” inspection where the valve is in service. The “wet” inspection does not yield results as informative as the “dry” inspection. The “dry” inspections entail the cost of stoplogs, safety equipment, and a means to lower the inspection crew into the pit, which has scaffolding surrounding the valve. Therefore, the “dry” inspections should be planned to coincide with periodic lock dewatering.

The tainter valves can be positioned with the skin plate upstream or down stream of the trunnion assembly, which is anchored into the concrete of the slotted monolith (Figure 7). The case shown to the right, where the convex surface of the skin plate and seal faces the flow with trunnions downstream, was redesigned in 1975. The “reverse” valve has the convex

surface facing downstream with trunnions upstream of the skin plate. The inspection procedure considers both types of tainter valve setup.

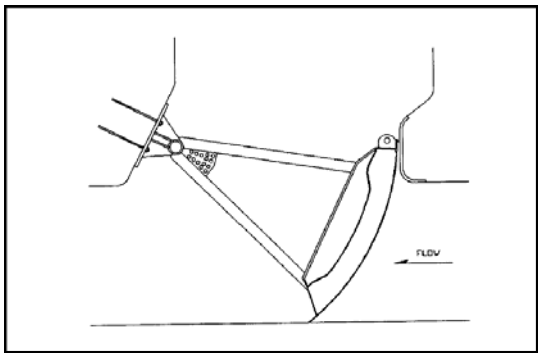


Figure 7. Plan view of tainter valve.

Butterfly valves were designed in a variety of shapes and sizes, some circular, some rectangular; some rotate about a vertical axis and others about a horizontal axis. The majority of butterfly valves in service are rectangular with rotation about the horizontal axis (Figure 8). This is the only type of butterfly valve addressed in this REMR-MS.

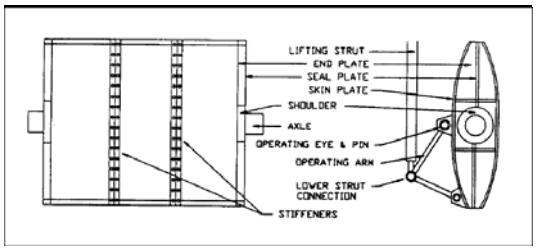


Figure 8. Diagram of a butterfly valve (front and side views).

Distresses: All pieces that are critical to the valve's operation and function are considered with the exception of operating equipment that is addressed by another REMR-MS. The tainter valve rotates about a horizontal axis through the trunnions welded to an anchor plate that is bolted to an embedded frame (like an "I" beam) within the concrete. Dial gauges are used to measure movement of the anchor plates relative to the concrete surface. Dial gauges are also used to measure the play in the trunnion pins and bushings surrounding the axis of rotation. Sometimes it is necessary to use a hydraulic jack to observe play in the trunnion system, but caution is required to avoid damaging the pins and bushings. For butterfly valves, gauges are used similarly at the valve's shoulder. Cracks, leaky seals, corrosion, damaged girders, and skin plate are recorded. Cracking or spalling of concrete around embedded steel is indicative of excessive motion. Because the waters around a valve can be more turbulent due to the confined

space, special consideration is paid to abrasion or cavitation in the concrete, skin plate, girders, and intercostals. For components in a valve, the following distresses are cataloged, with the unadjusted (see "*Other*" in this section) importance coefficients (weights) shown in parentheses. Tainter valve distresses and weights (W_i), unadjusted, dry inspection:

- Anchorage deterioration (25.0%)
- Cracking (23.1%)
- Trunnion assembly wear (15.6%)
- Lifting bracket / bushing wear (15.6%)
- Seal condition (10.0%)
- Cavitation/erosion/abrasion (8.2%)
- Corrosion (2.5%)

Tainter valve distresses and weights (W_i), unadjusted, wet inspection:

- Anchorage deterioration (27.9%)
- Lifting bracket / bushing wear (17.5%)
- Trunnion assembly wear (17.5%)
- Noise/jump/vibration (11.1%)
- Seal condition (10.0%)
- Cavitation/erosion/abrasion (9.2%)
- Corrosion (2.8%).

Butterfly valve distresses and weights (W_i), unadjusted, dry inspection:

- Cracking (34.6%)
- Lifting bracket wear (23.4%)
- Axle assembly wear (23.4%)
- Seal condition (14.9%)
- Corrosion (3.7%).

Butterfly valve distresses and weights (W_i), unadjusted, wet inspection:

- Axle assembly wear (27.9%)
- Lifting bracket (27.9%)
- Noise/jump/vibration (22.1%)
- Seal condition (17.7%)
- Corrosion (4.4%).

Procedural narrative: Effort is made to get as much information as possible on the valve without having to descend into the valve pit for an instrumented inspection. For the wet inspection, the use of subjective terms such as poor, average, good, and excellent are unavoidable but guidance is given to reduce the subjectivity as much as possible. Tools include ruler, tape measure, level, and magnetic dial gauges. For the dewatered dry inspection, after stoplogs have been placed in the culvert above and below the valve, scaffolding must be erected in order to take the dial gauge measurements. The inspection crew is lowered down the valve pit by a crane. A hydraulic jack is used to check the play in the trunnion pins and bushings.

Rating algorithm: The rating algorithm is the same as for steel sheet piles. The reader is referred to that section for a description of the algorithm used.

Other: Another approach was developed to assess the condition and performance of tainter gates. This approach did not rely specifically on objective measurements but on a facilitated group consensus. Refer to the spillway CI entry in this chapter.

Concrete gravity dams, retaining walls, and spillways (REMR-OM-16)

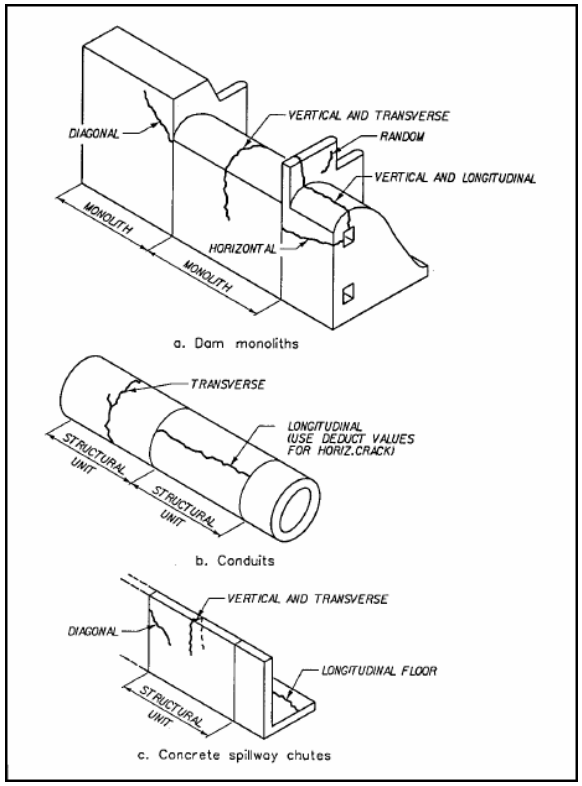


Illustration 9. Concrete distresses in dam and spillway monoliths and retaining wall.

Description: Concrete gravity dams, spillways, retaining walls, and piers supporting overhead bridge decks are constructed in lifts and generally function as structural units much the same as the lock wall monoliths previously described. The condition assessments for these structures are based on the earlier work completed on the lockwall monoliths.

Distresses: The primary distress in any concrete structure is cracking. The categorization of the cracking is based on American Concrete Institute (ACI) 201.1R-92, *Guide For Making a Condition Survey On Concrete In Service*. The importance of each type of cracking was determined by expert consensus. The discussion of the distresses is so similar to that of lockwall monoliths that the reader is referred to that section of this report. However, there were some variations in the DVs as determined by the expert panel, due to the variation in potential loads and usage (e.g., axial loads in bridge piers). Decks are treated slightly different for additional safety purposes. The list of distresses and associated DV is presented below:

- Alignment problems* (DV = 60, i.e., C_i max = 40)
- Horizontal cracks (5 < DV < 35)
- Vertical & transverse cracks (5 < DV < 35)
- Vertical & longitudinal cracks (10 < DV < 60)
- Diagonal cracks (15 < DV < 65)
- Random cracks (10 < DV < 50)
- Longitudinal floor cracks (10 < DV < 40)
- Volume loss (checking, spalling, pattern, d-cracking, alligator, disintegration, etc.) DV proportional to volume material lost compared to section design thickness at same elevation
- Exposed steel (30 < DV < 60)
- Retaining wall reinforcement (10 < DV < 20)
- Conduit abrasion (10 < DV < 30)
- Conduit cavitation (20 < DV < 60)
- Spalled joints (5 < DV < 10)
- Damaged armor (5 < DV < 10)
- Corrosion stain (5 < DV < 10)
- Damaged armor (5 < DV < 20)
- Leakage as function of gpm (10 < DV < 20)
- Leakage affecting operation of dam (DV = 40)
- Deposits (5 < DV < 20)
- Damage to decks (5 < DV < 10)

Procedural narrative: The procedures involve visual inspection of no less than 20% of the structural units. Instructions for evaluating cracks within a circular conduit are provided. All units are in service and do not require dewatering. Crack widths are measured from 0.01 – 0.1 in., cracks of more than 0.1 in. are simply considered "wide" cracks with a corresponding maximum DV for the crack category. Where cracking cannot be observed and measured by hand, an experienced inspector with binoculars will be above to conduct an assessment — for example, cracking on a bridge pier from the deck it supports.

Rating algorithm: The rating algorithm is very similar to that for concrete lockwall monoliths with the following changes: More attention for volumetric-type cracking in decks is accounted for. Curves (see Figure 9) are provided for obtaining DVs as a function of distress magnitude. The four

* A CI of 40 indicates a failed condition and should be brought to the immediate attention of O&M managers. If misalignment is deemed negligible, the DV can be changed to zero.

largest DVs identified during the inspection are used in the calculation of overall CI as:

$$CI = 100 - (DV1 + 0.4*DV2 + 0.2*DV3 + 0.1*DV4)$$

where the DVs are sequenced in descending magnitudes.

Other: None.

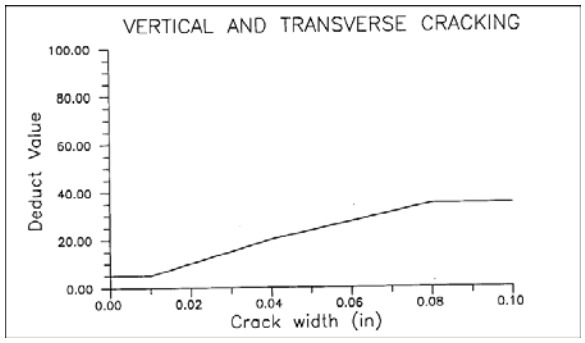


Figure 9. Correction curve for wide cracking.

Tainter dam and lock gates (REMR-OM-17)

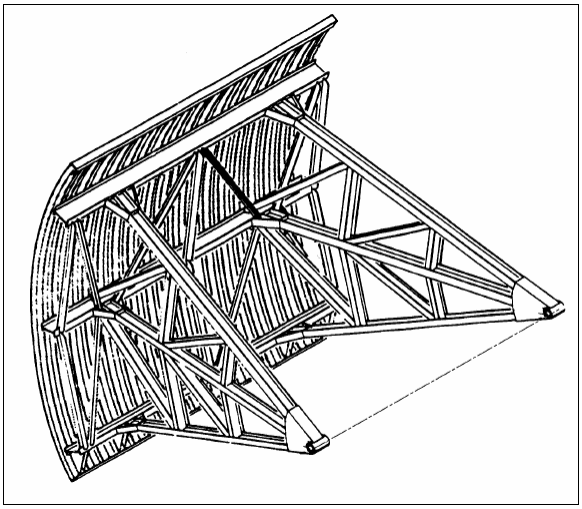


Illustration 10. Dam or lock tainter gate.

Description: Tainter gates (and valves) operate as a moveable damming surface and are made of steel skin plate and structural beam-column members. Various components make up the trunnion around which the gate rotates. The trunnion assembly is welded to anchor plates attached to an embedded frame within the concrete that supports it. Often a trunnion girder braces the trunnions on opposite sides of the dam pier. The two primary uses for tainter gates are for navigation or flood control projects where they control flow over spillways; however, tainter gates are found on multi-purpose projects as well. Tainter gates rarely achieve maximum loading (e.g., from flood events – in this case they are often lifted out of the water), whereas tainter valves see maximum loads all the time. The gates normally rest on or just above the concrete sill with the convex skin plate surface bearing the force of the water, which is allowed to pass (by design) only under the gate as it is lifted by chain or wire rope from above. (Chain and wire rope are considered under the REMR-MS for operating equipment.) Depending on the breadth of the spillway, a USACE spillway can have from one to more than 40 tainter gates. In a few cases, single tainter gates are used on the upstream end of lock chambers, and the gate is lowered for traffic to pass over it. The load profiles for all cases are so similar that the same REMR-MS is used for these tainter gate applications. The operating environment is not much different from the tainter valves and the REMR-MS for these components are also similar. It is possible to inspect tainter gates in the dry by installing a stoplog upstream of the gate and dewatering.

Distresses: As with all hydraulic steel, the gates are subject to cracking, dents, corrosion, poor seals, worn bushings and trunnion pins, anchorage movement, etc. The list of distresses is nearly the same as for tainter valves and miter gates. Cracking or spalling of concrete around embedded steel is indicative of excessive motion. One notable difference with tainter gates is their known ability to warp under operation. This can cause the projection of the convex surface to change from a perfect rectangle into a parallelogram with no right angles. This type of warping causes undue stresses on structural members as well as leakage. Tainter gate distresses and unadjusted weights (W_i) are shown below:

- Noise, jump and vibration (10.6%)
- Vibration with flow (11.2%)
- Misalignment (8%)
- Anchorage assembly deterioration (19.3%)
- Trunnion assembly wear (16.4%)
- Cracks (11.3%)
- Dents (1.6%)
- Corrosion/erosion (13.2%)
- Cable/chain plate wear* (5.8%)
- Leaks (2.6%).

Procedural narrative: The inspections are conducted on gates in service. The gates need to be opened and closed for intervals during the inspection. The gate may be stoplogged (bulkheaded) for inspection on the upstream face of the convex skin plate. It is not recommended for anyone to climb on the gate. However, the trunnions are approached from the concrete pier, and dial gauges are set up to measure movements in the trunnion assembly that can be related to wear in the bushing and trunnion pin or wear in the trunnion girder and its attachment to the concrete. It is desirable to place reference or benchmarks for comparison purposes during future inspections. The rectangular distortion (misalignment) is measured by using a tape measure weighted with heavy magnets, from the bridge deck to opposing ends along the upper edge of the gate. This measurement is not always possible because the distance from the bridge deck to the gate is sometimes too great for the tape to reach or it may be too windy for the magnets to make contact. In these cases, guidance is provided for subjective judgments.

* If cable/chain plate wear is not measurable, then the unadjusted W_i's must be renormalized.

Rating algorithm: The rating algorithm is the same as that used for steel sheet piles, and the reader is referred to that section for discussion.

Other: None.

Roller dam gates (REMR-OM-18)

Illustration 11. A dam constructed with roller gates.

Description: Roller gates are used almost exclusively for navigation projects. They are most often used in conjunction with tainter gates (in the unique case of the dam at Rock Island, IL, roller gates are used exclusively). The roller gates are usually located closer to the lock chamber than the tainter gates. Lock operators say they are better able to control outdraft (current pulling tows away from the lock and toward the dam) with roller gates. Roller gates are tubular structures that roll up or down a ramp. One or two aprons are attached to the tube, which acts as a moveable damming surface to the water below the gate (Figure 10). The gate can be lowered until the apron stops flow under the gate, but it can also allow water to pass over the gate if conditions allow. In flood situations it is possible to lift the gate and its attached apron to a point above the water. The gates are operated by a motor from the overhead bridge deck that uses a lifting chain to lift or lower the gate from one of the ends that follow a toothed rack. The other end, usually free of lifting chains, also follows a toothed rack. Operating equipment is treated under a separate REMR-MS.

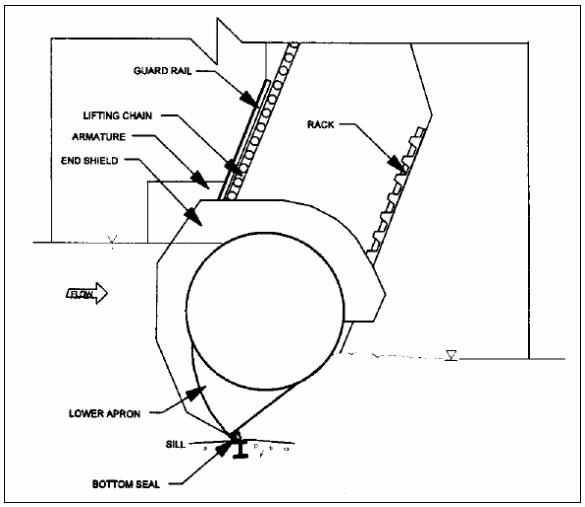


Figure 10. Components of a roller gate.

Distresses: Distresses common to hydraulic structures such as corrosion, cracks, dents, etc. are common to roller gates. Cracking or spalling of concrete around embedded steel is indicative of excessive motion. There are distresses unique to roller gates as well. As in the tainter gate, where rectangular distortion is common, torsional distortion occurs in roller gates (Figure 11). This becomes apparent when the gate is moving up the rack embedded within the concrete piers on either end of the gate; the elevations of the gate on either end are unequal. A complex of truss frames inhabit the interior of the tube, but it is decidedly too hazardous to include an inspection of a roller gate interior in this REMR-MS. Essential pieces of the roller gate include the steel rack of "steps" on which the gear-toothed rim of the gate climbs. These pieces are considered integral to the roller gate and are therefore not treated as part of the operating equipment REMR-MS.

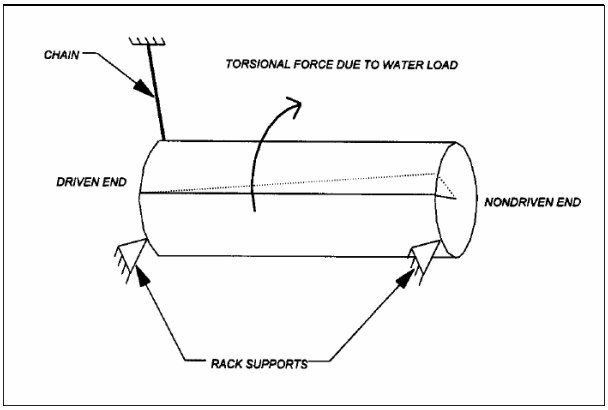


Figure 11. Torsion in a roller gate.

Like the miter and tainter gates, a downstream deflection under different loads is measured to assess excessive bending in the gate due to buckled skin plate, internal failure of truss frames, or other causes. However, downstream deflection can be measured only when the gate is stoplogged and in the closed position. If the gate is stoplogged and closed, torsional misalignment cannot be measured. Because it is impossible to measure both downstream deflection and torsional misalignment at the same time, different unadjusted weight coefficients were calculated. If critical cracking is found in selected critical members, the CI is limited to 30 points, indicating imminent failure. The purpose is to bring the crack to the immediate attention of O&M managers. Roller gate distresses and unadjusted weights (W_i*), (W_i†) are as follows:

- Noise, jump, vibration (11.0%), (10.3%)
- Vibration with flow (12.5%), (11.7%)
- Torsional misalignment (10.4%), (0%)
- Rack deterioration (10.8%), (10.2%)
- Rim deterioration (13.0%), (12.2%)
- Seal & end shield damage (7.6%), (7.1%)
- Cracks (20.3%), (19.1%)
- Dents (2.7%), (2.5%)
- Corrosion/erosion (11.7%), (11.0%)
- Downstream deflection (0%), (15.9%).

Procedural narrative: The inspection is conducted on in-service roller gates. The crew descend the ladders on the concrete pier to the gate but do not venture past the end shields. No inspection is required for the inside of the tube because trouble inside the tube should be evident in the way the gate behaves under observation. The gate is raised and lowered for measurements and observation. Relative torsional displacements between the driven end (chain) and the free end are measured by making reference marks on the concrete pier and marked points on both ends of the gate when the gate is closed and again after the opening under the gate is at 6 ft. The distance between beginning and end points is measured on both ends. The difference in the resulting lengths is proportional to the torsional rotation. Inspections of the center sections are conducted from a crew bucket suspended by the lock crane. Inspections on the rack and

* Downstream deflection excluded (in service inspection).

† Torsional misalignment excluded (stoplogged inspection, gate closed only)

geared rim include observations on tooth wear, cracks, corrosion, and spalled concrete. Reference marks are made in the concrete by non-destructive means for benchmarking future inspections.

Rating algorithm: The rating algorithm used on roller gates is identical to the approach used for steel sheet piles. Please refer to that section.

Other: None.

Lock and dam operating equipment (REMR-OM-19)

Illustration 12. Lock and dam operating equipment.

Description: A host of operating equipment is used to open and close the various gates and valves that have been described in this report. Not all operating systems are alike. There are variations but during development of the CI, nine basic assemblies were identified. Since electric and fuel powered motors are routinely maintained, it was decided not to develop a CI for motors; however, the pieces connected to the motor do need a consistent means for describing their condition. It was often difficult to devise purely objective measurements that were precise enough to be repeatable by different crews. It was necessary, therefore, to rely on subjective observations, but guidance was developed to reduce the variation in results as much as possible. The nine basic operating equipment assemblies are:

- Exposed gears
- Enclosed gears
- Gear rack
- Strut arm
- Rocker arm
- Cable (wire rope)
- Chain
- Hydraulic cylinder
- Coupling.

Distresses: Each of the nine assemblies has a unique family of distresses, and a sub-section is dedicated to each after this introductory text.

Procedural narrative: As with all other REMR-MS, the intent was to keep the measurements simple requiring only tape measures, rulers, dial gauges, calipers, pry bar, etc. Nearly all observations require getting close to the

components, which are often under bridge decks or within recesses of concrete monoliths. In some cases, for instance very large exposed gears, it was necessary to use hydraulic jacks to measure play in gear housings caused by wear in trunnion or gudgeon pins and bushings. Care is taken in all cases not to damage the equipment.

Rating algorithms: The rating algorithms for operating equipment use the same format as that used and described in the section for steel sheet piles presented earlier. However, there are notable additions for operating equipment.

Note that, if cracks are discovered, the word "critical" is displayed in the table of distresses. This means that, if a crack is discovered in these systems, it is deemed imperative that it be brought to the immediate attention of O&M managers. The CI will be forced to zero until a judgment on the crack is determined. Otherwise, cracks do not have weight coefficients (the other coefficients still add to unity).

With nine assemblies, more than 350,000 combinations are possible. Obviously, not all nine assemblies need be part of the system being inspected. It was decided nonetheless to develop CIs for each of the nine assemblies and leave an overall CI for any given system of assemblies as a project for future work.

The final power train is generally dictated according to the component (gate or valve) it operates or how it was originally designed. A procedure is presented in the technical report where the final connectivity of the individual operating equipment assemblies for a given structure is described in terms of how power is transferred from the motor to the gate or valve. This facilitates the process of describing overall condition for each component and unambiguously describes its location within the train. Generally, every gate leaf and individual valve will have an independent set of operating equipment.

Other: Inspection forms and procedural descriptions for each of these assemblies are provided in REMR-OM-19. Since several of the criteria for assessing condition of operating equipment were taken from safety regulations, there was no expert consensus or calibration of certain maximum allowable magnitudes of certain distresses.

Operating equipment: exposed gear (REMR-OM-19)

Illustration 13. An exposed gear.

Description: Exposed gears operate in the vertical or horizontal planes and are readily accessible by the inspection crew. A system of gears is usually in the gear train; but sometimes a large gear can be driven by a single linear gear rack. In the former case, each gear is assigned a number according to its position within the power train. For the simple single gear and rack (most often found operating lock miter or lock sector gates) the process is much simpler.

Distresses: The list of distresses for an exposed gear is similar to those measured for gates but there is additional attention paid to the condition of the gear teething. Cracking or spalling of concrete around embedded steel is indicative of excessive motion. Exposed gear distresses and unadjusted weight factors (W_i) are as follows:

- Noise, jump, vibration (27.5%)
- Anchorage movement, deterioration (26.8%)
- Bearing/bushing wear (12.3%)
- Roller support wear or damage (7.0%)
- Cracks (critical)
- Tooth wear (2.6%)
- Reduced tooth contact (9.0%)
- Damaged teeth (14.8%)

Procedural narrative: The gears are visually inspected. Sometimes special access hatches must be unlocked to be able to approach the gear. Guidance is provided for assessment of the wear patterns of the individual teeth.

Rating algorithm: The rating algorithms used for operating equipment is the same as that used and described in the section for steel sheet piles described earlier in this report.

Other: None.

Operating equipment: enclosed gear (REMR-OM-19)

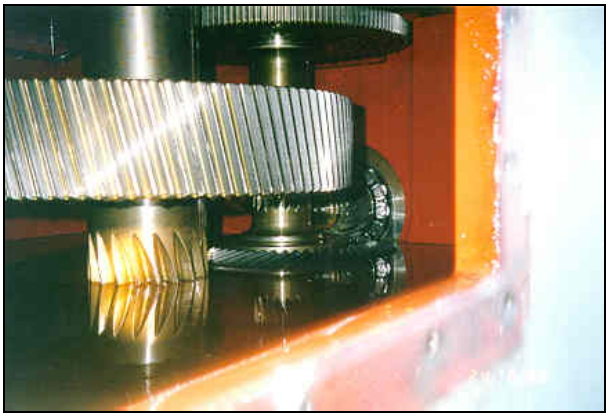


Illustration 14. Inspection view of enclosed gears and oil bath.

Description: Enclosed gears are encased, usually requiring a cover to be removed before inspection can occur. Access is also hampered because only a portion of the gear can be seen from the hatch access. Caution is used because the gears sit in an oil bath. Each gear is assigned a number according to its position in the power train. This number assists in keeping track of which gear is being assessed.

Distresses: Similar procedures are used for enclosed gears and for exposed gears. In addition to the distresses common to the exposed gears, the oil is considered for leakage and is tested for contamination. Spalled or cracked concrete around the housing of the gear case indicates excessive movement. Enclosed gear distresses and unadjusted weights (W_i) are as follows:

- Noise, jump, vibration (24.1%)
- Anchorage movement, deterioration (21.5%)
- Cracks (critical)
- Tooth wear (2.6%)
- Reduced tooth contact (9.0%)
- Damaged teeth (14.8%).

Oil contamination – definition and causes: All rotating equipment parts and machinery require lubrication to function properly. Over time the oil

becomes contaminated and breaks down. The oil contamination distress is the reduction of the useful life of the lubrication oil. Oil contamination is caused by the collection of dirt, rust, water, and metal particles in the oil.

Measurement and limits: Oil distress is measured at two different levels. The first level involves visually checking the oil consistency for: (1) water, (2) dirt or rust, and (3) metal. If water is present, the CI is reduced by a factor of 0.85. Likewise, if dirt or rust is present, a reduction factor of 0.85 is applied to the CI. If metal is in the oil, the CI is 40. In the second level of inspection, a representative sample is examined in the laboratory for extended chemical analysis to check for particulates such as dirt, water, and rust on a more precise scale. The results of this test should be included in any inspection report that is generated. If the oil does not meet the specifications set by the manufacturer or laboratory, the CI is 40.

Procedural narrative: Visual inspection is made. Oil samples are sent to a laboratory for contamination assessment.

Rating algorithm: The rating algorithm is the same used for steel sheet pile structures earlier in this report.

Other: None.

Operating equipment gear rack (sector gates) (REMR-OM-19)

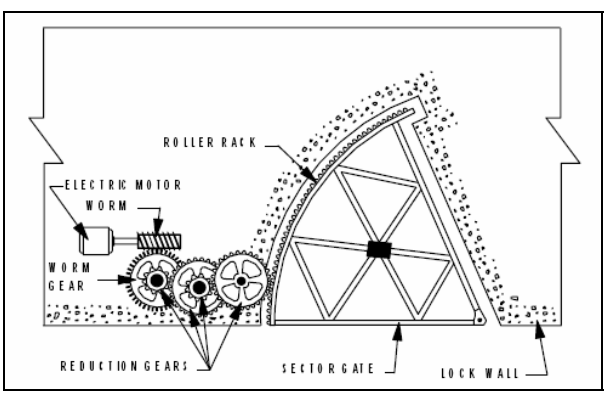


Illustration 15. Operation of a roller gate rack.

Description: The roller gear rack for sector gates is a toothed steel arc attached to the convex surface of a sector gate. It is driven by a series of reduction gears usually operated by a motor with a coupled transmission or worm gear. They are most often found in assemblies using horizontal exposed circular gears in the recess of a concrete monolith.

Distresses: Corrosion and wear are the usual distresses, but the roller rack must maintain gear meshing between the rack and gear. Gear rack distresses (sector gate) and unadjusted weights (W_i) are as follows:

- Noise, Jump, and Vibration (34.3%)
- Cracks (CRITICAL)
- Rack Attachment Deterioration (25.1%)
- Tooth Wear (6.4%)
- Reduced Tooth Contact (14.3%)
- Damaged Teeth (19.9%).

Procedural narrative: Tape measures, calipers, rulers, dial gauge, pry bars and a hydraulic jack are used. The gear rack is in service and must be operated for the assessment process. Dial gauges are mechanically held to concrete where the anchor plate is fastened. If, during the operation of the rack, a displacement greater than 0.002 in. is recorded, then the anchorage is considered to be loose. Gear tooth wear is recorded according to guidelines cited in the technical report.

Rating algorithm: The rating algorithm for gear racks uses the same formulae as the algorithm for the steel sheet pile algorithm discussed earlier in this report.

Other: None.

Operating equipment linear gear rack (REMR-OM-19)

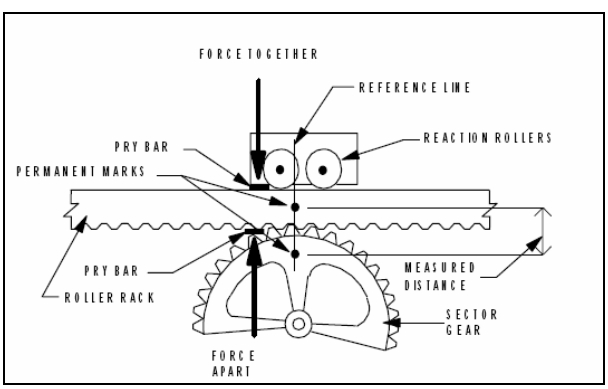


Illustration 16. Operation of a linear gear rack.

Description: The linear gear rack for other gates is composed of linear pieces of steel equipped with exposed gear teeth. It is usually driven by a hydraulic piston. It mates with a horizontal sector gear witch pushes either

a gate, strut arm, or rocker arm. They are most often found in the recess of a concrete monolith.

Distresses: Corrosion and wear are the usual distresses; however gear racks must be guided by rollers and maintain gear meshing between the rack and gear. Because of the difference in loading and operation, the weight coefficients are slightly different than for sector gate racks. Gear rack distresses (other uses) and unadjusted weights (W_i) are as follows.

- Noise, Jump, and Vibration (29.0%)
- Cracks (CRITICAL)
- Reaction Roller Wear/Damage (10.2%)
- Reaction Rollers Anchorage Movement/Deterioration (15.4%)
- Gear/Rack Displacement (9.0%)
- Rack Wear (3.2%)
- Tooth Wear (4.9%)
- Reduced Tooth Contact (11.4%)
- Damaged Teeth (16.9%)

Procedural narrative: Tape measures, calipers, rulers, dial gauge, pry bars, and a hydraulic jack are used. The gear rack is in service and must be operated for the assessment process. Dial gauges are mechanically held to concrete where the anchor plate is fastened. If, during the operation of the rack, a displacement greater than 0.002 in. is recorded, then the anchorage is considered to be loose. Gear tooth wear is recorded according to guidelines cited in the technical report.

Rating algorithm: The rating algorithm for gear racks uses the same formulae as the algorithm for the steel sheet pile algorithm discussed earlier.

Other: None.

Operating equipment strut arm (REMR-OM-19)

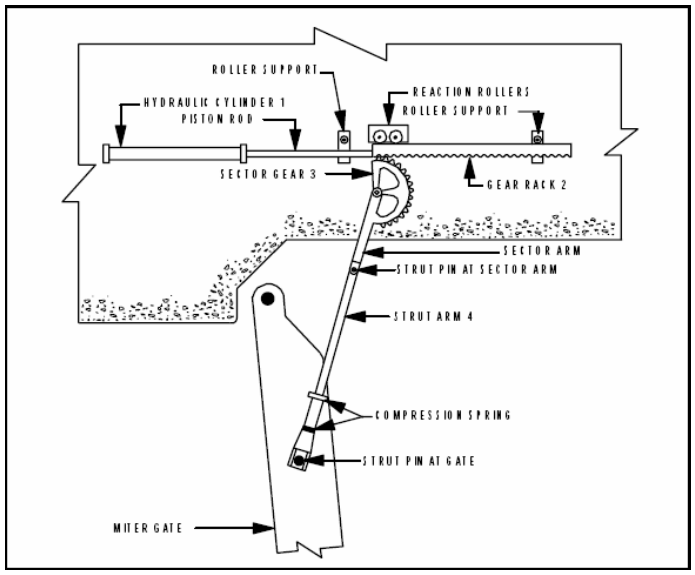


Illustration 17. Operation of a strut arm.

Description: The strut arm usually connects to a miter gate leaf. Often a compression spring there is at the gate attachment point. It can be powered in various ways but it usually acts as a rigid boom.

Distresses: The compression spring and attachment points are an obvious concern. If the spring shows no ability to compress, then it cannot act as a shock absorber and should be replaced. Noise, jumps, or vibration would indicate poor connections. Cracks cannot be tolerated. Otherwise, the strut arm suffers corrosion and bending. Strut arm distresses and unadjusted weights (W_i) are as follows:

- Noise, Jump, Vibration (44.5%)
- Strut Connection Movement (20.6%)
- Compression Spring Movement (27.7%)
- Corrosion (7.2%)
- Cracks (CRITICAL).

Procedural narrative: The strut arm must be inspected while in service. It is usually easy to observe from the lock gate catwalk. Most observations are subjective, but written guidance is provided to make the observations more repeatable.

Rating algorithm: The rating algorithm for strut arms uses the same formulae as those used in the section on steel sheet pile.

Other: None.

Operating equipment rocker arm (REMR-OM-19)

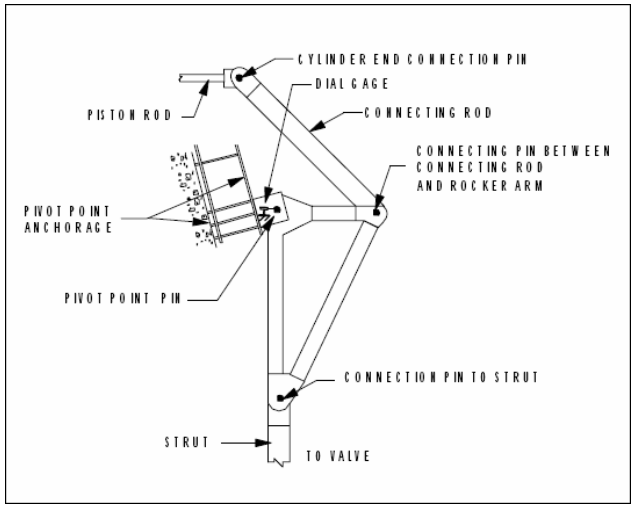


Illustration 18. Operation of a rocker arm.

Description: The rocker arm consists of steel arms that are joined with connecting pins. It transfers and redirects a horizontal load produced most often by a hydraulic cylinder to a vertical strut arm assembly. Besides pivot points, the rocker arm assembly may have a connecting rod. Rocker arms are used by USACE to open and close lock chamber tainter and butterfly valves.

Distresses: Movement in embedded anchorages is not acceptable but could be evidenced by cracked or spalled concrete. Motion of 0.002 in. is considered movement. Wear will first be obviously visible with pivot points. Relative motion between the rocker arm and connecting rod(s) is of concern since it indicates worn pins or fittings. Corrosion is also measured. The presence of cracks is not tolerated. Rocker arm distresses and unadjusted weights (W_i) are as follows:

- Noise, Jump, Vibration (27.7%)
- Rocker and Connecting Rod Connection Movement (19.3%)
- Pivot Point Anchorage movement/Deterioration (38.9%)
- Pivot Point Pin Movement (4.9%)
- Corrosion (9.2%)
- Cracks (CRITICAL).

Procedural narrative: Since rocker arms are often positioned over open valve pits, they are not always easy to get close to but are usually visible

from the monolith deck. If a safe means of getting close to the component is possible, then that is recommended. However, the motions and movements that are checked for can be estimated with reasonable accuracy and repeatability with experience.

Rating algorithm: The rating algorithm for rocker arms uses the same formulae as those used in the section on steel sheet piles.

Other: None.

Operating equipment cable (REMR-OM-19)

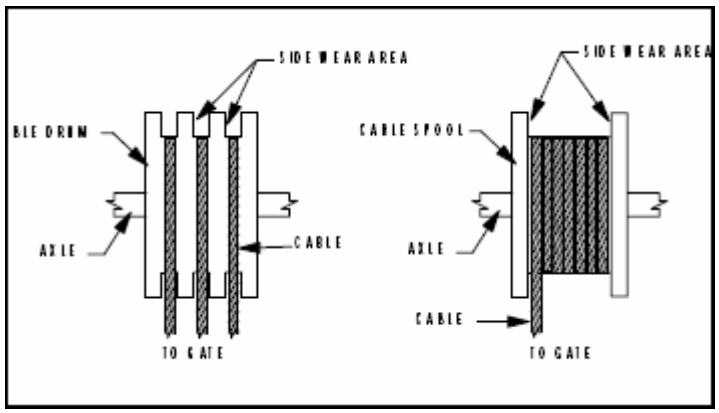


Illustration 19. Cable (wire rope) on drum (left) and spool (right).

Description: The cable is made of several wire strands usually wound in one of two ways: regular or lang lay. The wires of a regular lay are twisted to make the strands, and the strands are then twisted in the opposite direction to make the rope. The wires in the regular lay run in the longitudinal direction. In a lang lay, the wires and strands are twisted in the same direction so individual wires angle across the rope. Cable or wire rope is used for many purposes but, in the context of operating equipment for Civil Works, it is usually used to pull or lift loads that open and close gates. Safety procedures in place for the use of wire rope and the condition assessment for cable relies heavily upon well-established and understood facts about the engineering behavior of wire rope.

Distresses: Cable must be properly lubricated for use. Reductions in diameter affect load carrying capability. Often wear on the drum around which the cable is wrapped will show effects of worn and damaged cable. Worn drums are noted and the depth of wear is estimated; groove templates are available for this purpose. Drum bushing wear can be revealed if there is play in the bushing when using a pry bar. Evidence of unwrapping

such as "birdcage" (Figure 12), kinks, or a protruding core is critical. This rope should be replaced immediately. Broken wires are noted and the number of affected layers recorded. Tension in the cable should be constant; if the cable is binding in the drum, it is recorded. Cable distresses and unadjusted weights (W_i) are as follows:

- Noise, Jump, Vibration (9.1%)
- Outer Wire Wear (7.5%)
- Reduction in Rope Diameter (14.1%)
- Corrosion (8.8%)
- Bird Cages, Kinks, and Protruding Core (CRITICAL)
- Unlayed Strands (10.5%)
- Wire Breakage (CRITICAL)
- Unequal Tension (7.0%)
- Drum Wear (1.3%)
- Drum Anchorage Movement/Deterioration (10.6%)
- Sheave Wear* (2.7%)
- Sheave Bearing/Bushing Wear* (4.1%)
- Sheave Anchorage Movement/Deterioration* (10.6%)
- Idlers/rollers wear* (3.4%)
- Gate or Valve Connection Movement† (10.5%).

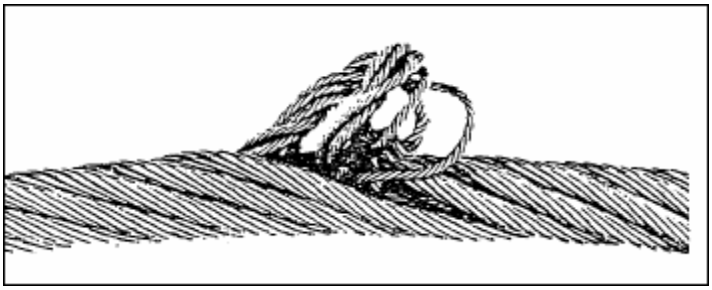


Figure 12. "Bird cage" failure in wire rope).

Procedural narrative: Crews must approach the cable to be as close as possible. The cable is in service and needs to be operated and observed.

Rating algorithm: The rating algorithm for cable and wire rope uses the same formulae as those used in the section on steel sheet piles.

Other: None.

* If not applicable, W_i for this distress is zero.

† If not observable, W_i for this distress is zero (weights must be renormalized).

Operating equipment chain (REMR-OM-19)

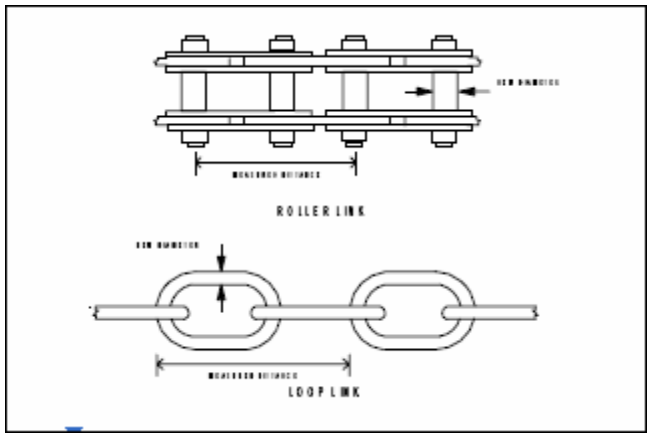


Illustration 20. Examples of chain links.

Description: A chain is a series of links connected to one another. Chain lifting systems are sometimes used to raise or lower dam or lock structures. The chain is lifted and wound over a sprocket type device during the operation of the assembly. A roller chain consists of roller bushings, side plates, and pins. The roller bushings turn on the pins, thereby reducing the friction between the chain and the sprocket. The rollers fit between the sprocket teeth. The links of a round chain are oval shaped and permanently fitted into one another. The sprocket is specially designed for the chain it receives. Chains are used most often to lift dam tainter or roller gates.

Distresses: The chains are heavy enough to always be under load. Some link elongation may occur, which is measured relative to its center and design length. Often a chain may not been moved for long periods of time, resulting in kinks or poor fit over the sprocket. Sprocket wear is included and evidence of anchorage motion relative to concrete is recorded. Cracks in the chain are not tolerated, but cracks in the sprocket are treated the same as they are for exposed gears (presented earlier). The connection point between the gate and the chain are of obvious concern. Chain distresses and unadjusted weights (W_i) are:

- Noise, jump, vibration (16.3%)
- Linkage wear/elongation (12.3%)
- Cracks (CRITICAL)
- Frozen Links (23.6%)
- Corrosion/Pitting (9.7%)
- Sprocket Anchorage Movement/Deterioration (21.8%)

- Sprocket Wear (2.9%)
- Gate Connection Movement* (13.4%).

Procedural narrative: Crews must approach the chain to be as close as possible. The chain is in service and needs to be operated and observed.

Rating algorithm: The rating algorithm for cable and wire rope uses the same formulae as those used in the section on steel sheet piles.

Other: None.

Operating equipment hydraulic cylinder (REMR-OM-19)

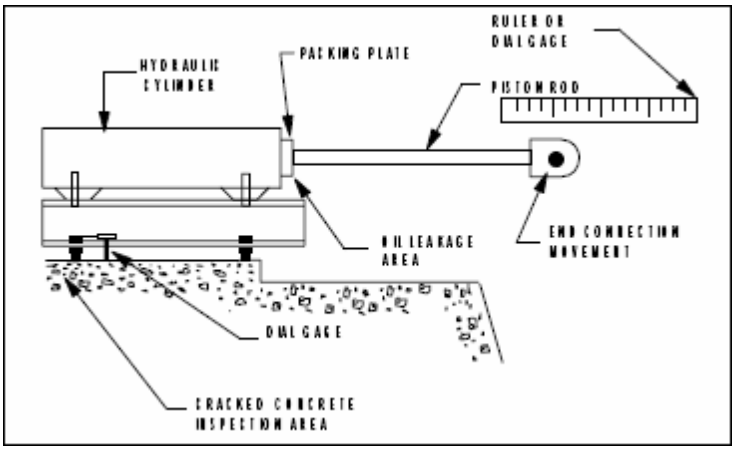


Illustration 21. Operation of a hydraulic arm.

Description: Hydraulic cylinders produce the force required to move the gate structure or lift and lower the valve structure. Hydraulic cylinders are often used horizontally in gate structures. Hydraulic cylinders are also used horizontally in conjunction with the rocker arm assembly in valve structures. In some cases, the hydraulic cylinders are used vertically directly above a vertical lift valve (i.e., therefore, a rocker arm is not needed). The assembly is made up of a packing plate, through which the piston rod passes without leaking fluid, and an end connection. In some cases guides are needed to support the cylinder.

Distresses: The concrete near where the anchor plate is embedded is checked for signs of cracking or spalling, which would indicate anchorage movement. The piston rod is coated with highly polished metal; corrosion or pitting allows hydraulic fluid to leak causing loss of pressure and drift

* If not observable, W_i for this distress is zero (weights need to be renormalized).

(piston moves with change in applied load). End connections and relative movements are noted. Hydraulic cylinder distresses and unadjusted weights (W_i) are:

- Noise, Jump, Vibration (18.1%)
- Anchorage Movement/Deterioration (21.0%)
- Rod End Connection Movement (13.1%)
- Corrosion/Pitting of Rod (12.3%)
- Damage of Rod (14.8%)
- Oil Leakage (7.4%)
- Drift (11.2%)
- Damaged Guide* (2.1%).

Procedural narrative: Crews must approach the hydraulic cylinder to be as close as possible. The hydraulic cylinder is in service and needs to be operated and observed.

Rating algorithm: The rating algorithm for hydraulic cylinder uses the same formulae as those used in the section on steel sheet piles.

Other: None.

* If not observable, W_i for this distress is zero (weights need to be renormalized).

Operating equipment coupling (REMR-OM-19)

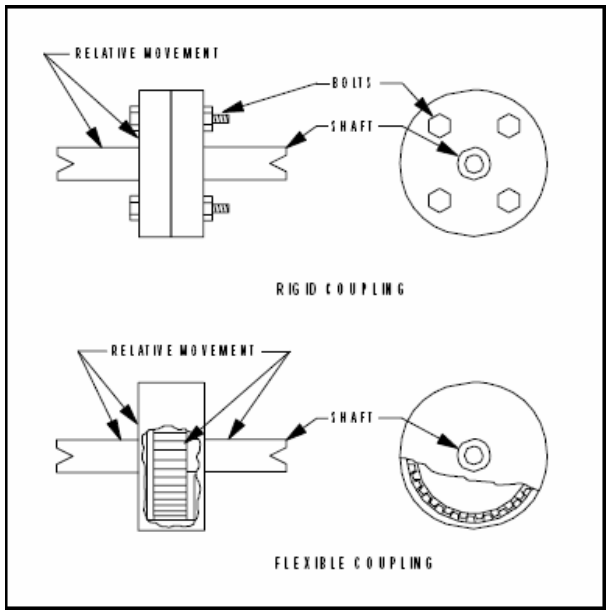


Illustration 22. Examples of coupling equipment

Description: A coupling is a joint between input and output shafts that generally contains meshing teeth to transfer torque from one shaft to another. The meshing teeth are enclosed in a hub. The shaft transfers force from one set of gears to another set of gears or to other equipment such as a cable drum. The input shaft is the shaft on the power end. The hub is the casing that contains the meshing teeth of the coupling. The keyway enables the transmission of torque from a shaft to the shaft-supported element. A flexible coupling is an internal gear. A small amount of lateral movement of the coupling may occur in a flexible type coupling. A rigid coupling is one for which no movement should occur, either in the lateral direction or with respect to the shaft. Rigid couplings are often bolted together.

Distresses: The coupling is one of the simpler assemblies to inspect. Cracks are not tolerated. Of all things indexed, the coupling CI depends more on noise, jump, and vibration than any other component. The operation of couplings should be smooth and free of vibrations. Observations are made when the shaft and hub come to rest after operation. If there is relative motion between the two, the keyway is loose and needs to be replaced or tightened. Coupling distresses and unadjusted weights (W_i) are:

- Noise, Jump, Vibration (89.3%)
- Cracks (CRITICAL)

- Corrosion (10.7%)
- Input Shaft and Hub Movement (CRITICAL)
- Output Shaft and Hub Movement (CRITICAL).

Procedural narrative: Crews must approach the coupling to be as close as possible. The coupling is in service and needs to be operated and observed.

Rating algorithm: The rating algorithm for coupling uses the same formulae as those used in the section on steel sheet piles.

Other: None.

Riverine stone dikes and revetments (REMR-OM-21)

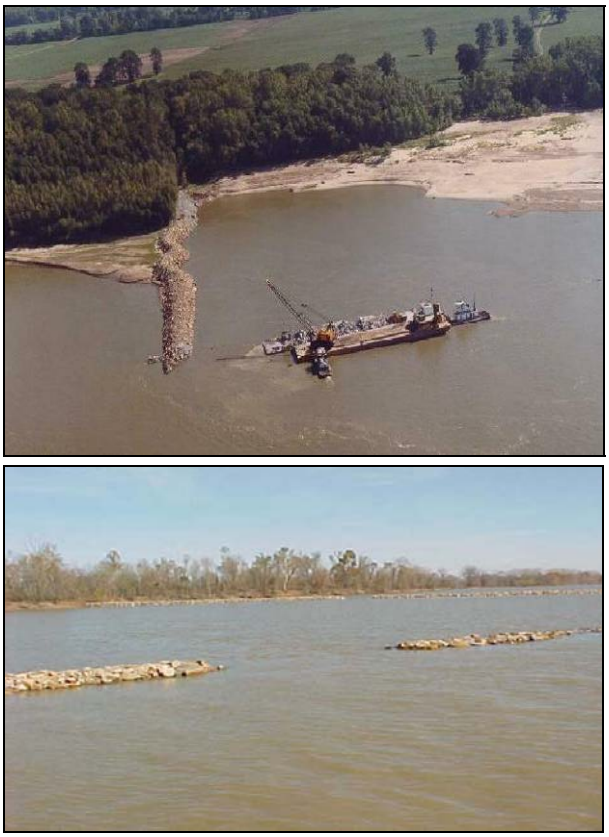


Illustration 23. Riverine spur dike (top) and offbank dike (bottom).

Description: Dikes and revetments are riverine training structures made primarily of stone, although some have timber dike structures rooted within. They train the river by forcing flow conditions that favor bank protection and/or improved navigability within the navigation channel. They are designed and positioned in directions either parallel to or nearly perpendicular to flow and all positions in between. They are designed to dam flow but are nonetheless permeable structures, and sometimes they are purposely breached or notched to produce favorable environments for riverine species closer to the bank. The perpendicular dikes constrict the cross-sectional area of the river and thus increase flow past the dike ends and reduce the flow where the dike connects to the bank. Reduced flow also occurs between the bank and a dike constructed parallel to it. The increased flow near the channel results in a scouring effect, promoting sediment transport downstream. Over time, the navigation channel more or less stabilizes and the river bank grows outwards along dikes by accretion. Revetment structures are stone structures in which rocks are carefully laid upon the bank to reduce scour and erosion (Figure 13). The design functions of dikes and revetments are to align the navigation channel, protect

the river banks, and decrease the amount of periodic dredging required to keep the channel in navigational compliance. USACE maintains more than 11,000 dike structures and untold miles of revetment structures.

Figure 13. Bank line revetment structure.

Structures like breakwaters, jetties, dikes, and revetments must be considered for both condition and performance. Unlike most other structures discussed here, condition and performance do not always have a 1:1 correlation. Because they exist in ever-changing environments, it is possible for these structures to exist in as-built conditions but perform poorly; or structures in poor condition may be functioning well. Hence, performance history and the consideration of risk (predicted performance) play increased roles in evaluation of these structures.

Distresses: After a major weather event, it is possible that a dike or revetment may have been entirely washed away. For those that remain, existing structures are compared to as-built designs, but their ability to meet original design goals must be reevaluated periodically. For instance, if a new power plant has been constructed downstream of a dike, flow conditions and customer requirements may have been dramatically altered since the original design was completed. The condition assessment considers physical characteristics of the dike and, by expert consensus, these characteristics coincide with conditions that most often trigger O&M action. In most cases this happens when 2 ft or more are lost from the designed dike elevation or if an area of revetment has been washed away to reveal bare bank. If a dike is flanked (the river's flow has actually circumvented the rooted end), the structure has failed regardless of its condition otherwise. Stone dike and revetment structures have five fundamental distresses, with vary-

ing degrees and special cases for each. Stone dike and revetment distresses are as follows:

- Dike Missing (self explanatory)
- Dike Flanked (flow behind point where dike was originally rooted)
- Loss of Grade (generally a maximum of 2 ft is allowed)
- Holes (unintended breaches)
- Adequacy of Navigation in Channel
- Bank Erosion (scallops)
- Any Bare Bank Exposed (revetment only).

As with coastal breakwaters and jetties, a structure in good condition but functioning poorly warrants more attention. In the previously mentioned instances, condition and function do not always have a 1:1 correlation. A dike in great condition can cease to function if ambient variables allow it. Similarly, a dike in poor condition can be functioning exceptionally well. For these reasons, a measure of consideration is given to risk. If a structure has a history of performing poorly after the spring rise, the expectation that it can fail is allowed in the assessment. Apart from a pure structural condition CI, a repair priority index (RPI) was developed that allows functional assessment of dike and revetment structures. The RPI is a separate and independent index. The RPI considers the performance of neighboring dikes or revetments in a field of these structures. It also considers the safety of surrounding property and the navigability of the channel.

Procedural narrative: It is preferred that technically knowledgeable personnel familiar with this structure conduct the inspection. Inexperienced personnel are entirely capable, but it will take much longer and they will require the original construction drawings. Current river elevation is checked at the closest gauge. Dike and revetment structures are visited and inspected visually. If the top of the dike is underwater, then a rod is used to measure the depth to the top stone at several locations along the structure's length. These depths are compared to the gauge elevation and construction drawings to determine if more than a 2 ft loss of grade has occurred anywhere.

Rating algorithm: Field data and calculations are entered into the provided tables. For dikes more or less perpendicular to the shore, damage has more importance at the shore end as opposed to the channel end. This

is because damage closer to the shore will have the greater detrimental impact on the function of the dike in maintaining a safe and navigable channel. The condition of the upstream and downstream bank lines are also considered; a poorly functioning dike can lead to scallops (removed earth) in the bank line above and below the dike root just prior to a flanked condition. Magnitudes and quantities of damages are compared to pre-set expert consensus to calculate a structural condition CI and functional RPI.

Other: A table is included for assessing the quality of timber pile dikes that may be embedded in the stone dikes. Similar in quality to the Columbia River timber dikes, this rating system considers missing piles, rotten piles, broken piles, missing horizontal spacers, and broken wire rope for pile clusters.

Earth and rockfill embankment dams (REMR-OM-25)

Illustration 24. Embankment dam.

Description: This management system is based primarily on existing inspection data and contains an evaluation framework and condition rating procedures. This CI evaluation is intended to elicit the engineers' knowledge about the performance of the embankment dam and provide quantitative information to aid in prioritizing M&R for an embankment dam. It provides the engineers an opportunity to think about the dam as a system and helps them organize their knowledge. A computer application employing this condition rating system has been created to provide an automated decision support tool to engineers and managers who plan REMR activities for embankment dams. The computer program includes data storage and handling capabilities, automated calculations, and reports for work planning and budgeting purposes. The "defense systems" and "monitoring system" are evaluated separately but share part of the same evaluation hierarchy. The hierarchy for defense groups is shown in Figure 14. The defense group actively works to prevent failure of the structure. The monitoring system provides information that warns of impending failure of the defense groups and information necessary to develop repair strategies.

Distresses: Distress ratings are presented in a checklist style, and the evaluator selects the CI rating from a suggested range for that indicator and its distress level. See Table 2 for an example.

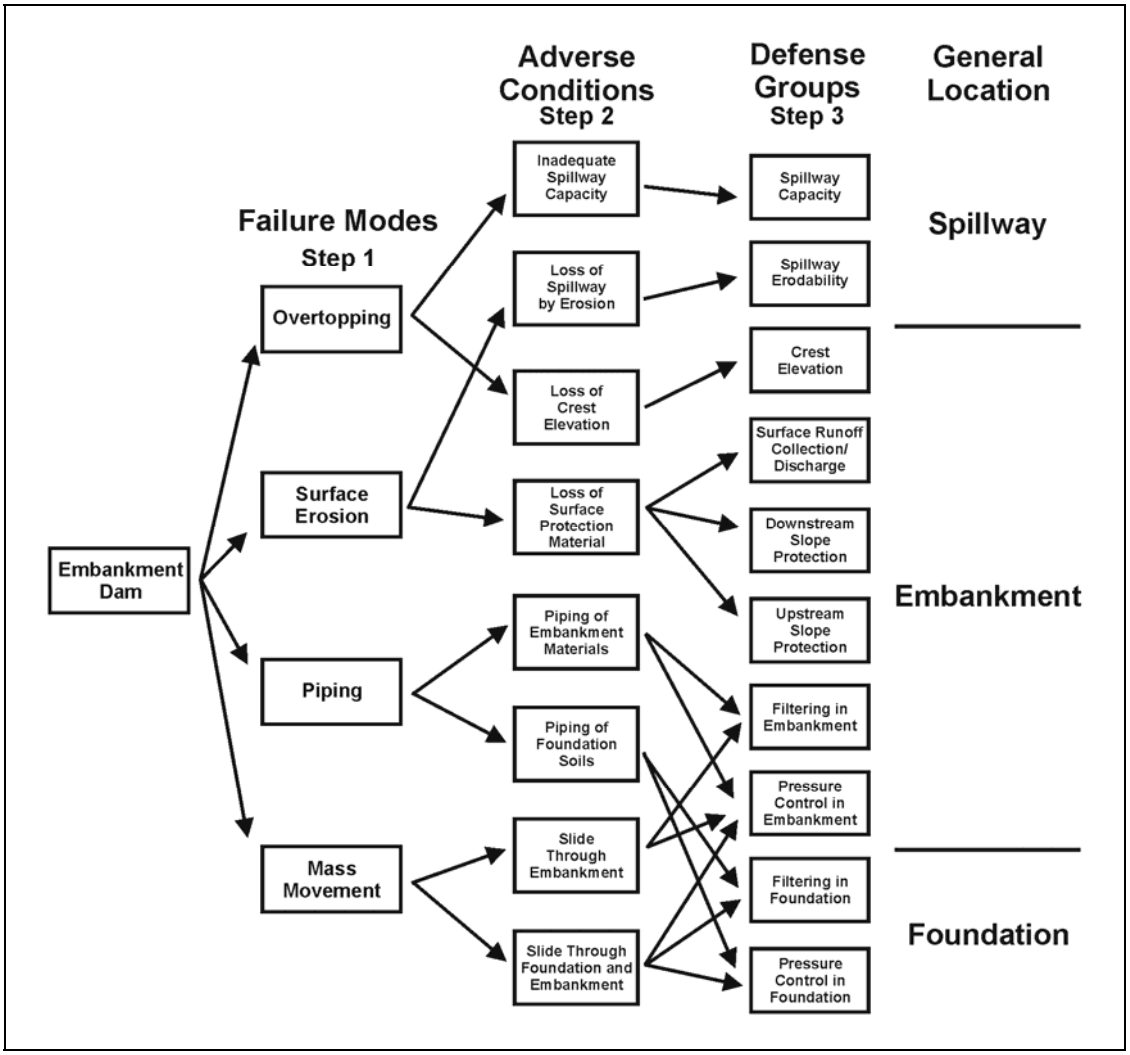


Figure 14. Embankment defense group hierarchy

Procedural narrative: Analysis of the dam begins (with engineers who are knowledgeable about the dam) by prioritizing the subsystems and components and developing importance weightings in a guided process using "interaction matrices." Application of this management system is based on the knowledge and experience of the responsible engineers and on existing inspection information. These importance weightings are more subjective than “black box” weightings, but they allow consideration of the unique factors present for each embankment dam. Failure modes, adverse conditions, and defense groups are compared against each other on a relative scale to identify and quantify the most important dam safety issues.

Rating algorithm: The CI for the embankment is calculated by multiplying the component CIs by their importance and summing these quantities.

Table 2. Embankment pressure control rating checklist.

Pressure Control in Embankment							
Ideal Condition	Magnitude of pressures within design parameters projected at design pool.						
Failed Condition	Pressures sufficient to result in FS < 1 at design pool for mass movement.						
Indicators	0-9	10-24	25-39	40-54	55-69	70-84	85-100
Piezometric levels at or below design levels (a)							
constant						X	X
increasing				X	X	X	X
Piezometric levels above design level (a)							
constant		X	X	X	X		
increasing	X	X	X				
Uncontrolled seepage							
changes in surface vegetation					X	X	X
soft/wet areas				X	X	X	
constant flow			X	X	X		
increasing flow	X	X	X				
Change in controlled seepage		X	X	X	X	X	
Differential movement (e.g., cracking, shallow slides, bulging, between fixed and floating structures)							
minor / localized			X	X	X	X	
major / extensive	X	X	X				
F.S. mass movement							
F.S.≥ Design F.S. (b)							X
1.0 < F.S. ≤ Design F.S. (b)		X	X	X	X	X	
F.S. < 1.0	X						
Known defect (no indicators of distress)						X	X

(a) Projected in relationship to design pools.

(b) Required design minimum factor of safety.

Example of known defect: Improperly designed drains.

In addition to calculating the CI for the embankment, the system also uses the collected information to produce priority rankings for the components. These numerical priority rankings are based on the condition and importance of the components and can be used to assist in prioritizing specific M&R tasks based on their effect on the performance of the dam.

The condition ratings and importance weightings are entered into the system to compute the CI and priority rankings. The results should reflect the engineers' understanding of the dam.

Other: The rating checklists are "simplified" and do not require detailed inspection or measurement. It is usually possible to complete the rating based on preexisting knowledge and past site visits.

The summary CI for embankment dam defense groups provides a measurement of relative risk. The priority rankings are also good approximations of the relative risk associated with distresses.

Spillways

Illustration 25. View upstream at a dry spillway.

Description: This CI contains an evaluation framework and condition rating procedures. This CI evaluation is intended to elicit the engineers' knowledge about the performance of the spillway system and provide quantitative information to aid in prioritizing M&R for a dam. It provides the engineers an opportunity to think about the dam as a system and helps them organize their knowledge. The system evaluates structural, mechanical, electrical and operational components of the spillway. Rating criteria are included for spillway tainter and lift gate structural components. Operational components include gathering information, decision process, and access & operation. A partial hierarchy for the system is shown in Figure 15.

Distresses: Distress ratings are presented in a checklist and the evaluator selects the CI rating from a suggested range for that indicator and its distress level. See Table 3 for an example. These CI rating checklists are "simplified" in that they are not up to the rigor of prior REMR CIs. The tainter gate CI and some of the operating equipment component checklists are simplified alternatives to CIs previously developed.

Procedural narrative: Analysis of the dam begins with engineers knowledgeable about the spillway prioritizing the subsystems and components by developing importance weightings in a guided process using "interaction matrices." Application of this management system is based on the knowledge and experience of the responsible engineers and on existing inspection information.

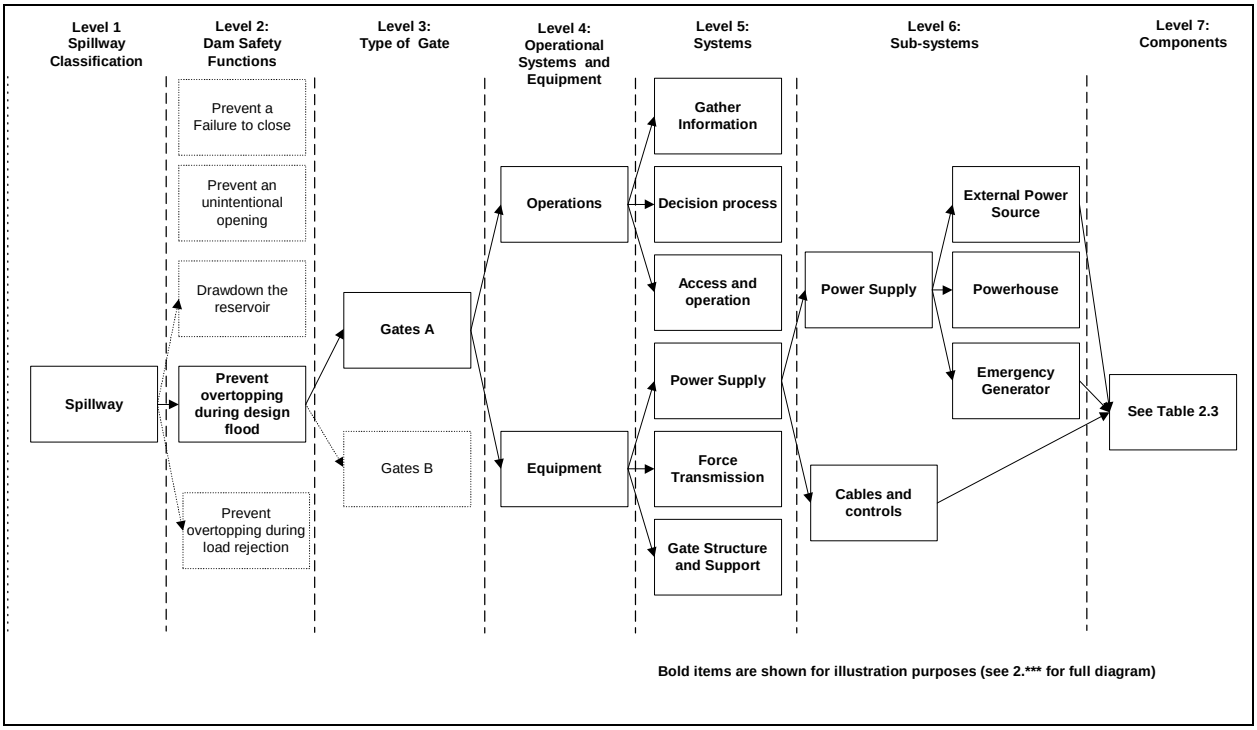


Figure 15. Partial importance hierarchy for spillway gate components

Rating algorithm: The CI for the spillway is calculated by multiplying the component CIs by their importance and summing these quantities.

In addition to calculating the CI for the spillway and its components, the system also uses the collected information to produce priority rankings for the components. These numerical priority rankings are based on the condition and importance of the components and can be used to assist in prioritizing specific M&R tasks based on their effect on the performance of the dam.

The condition ratings and importance weightings are entered into the system to compute the CI and priority rankings. The results should reflect the engineers' understanding of the spillway.

Other: The rating checklists are "simplified" and do not require detailed inspection or measurement. While it may be possible to complete the rating based on pre-existing knowledge and past site visits, it is not advisable. A large number of individual components should be compared to the rating checklists based on a concurrent visual inspection. When possible, gate operation is also advised.

The priority rankings provide good approximations of the relative risk associated with distresses for each component. The summary CI for spillways is not a particularly good measurement of relative risk.

Table 3. Condition rating checklist for transformers.

Transformer									
Function	Supply power at correct voltage level								
Excellent	Built to current codes and standards, and maintained to provide continuous service at correct voltage level.								
Failed	Cannot supply correct voltage level.								
Indicator	0 -- 9	10 -- 24	25 -- 39	40 -- 54	55 -- 69	70 -- 84	85 -- 100	Score	Comments
Dielectric (oil)									
Oil according to specifications							X		
Contaminated oil (presence of foreign matter, e.g.; moisture)		X	X	X	X				
Degraded oil (by arcing, aging, acidity)	X	X	X	X					
Dissolved gases	X	X	X	X					
Insulation									
Performs the function and/or passes the standard testing procedures (insulation resistance and power factor, etc.)						X	X		
Does not perform the function nor passes the standard testing procedures	X	X							
Windings									
Performs the function and/or passes the standard testing procedures (resistance and turns-ratio)						X	X		
Does not perform the function nor passes the standard testing procedures	X	X							
Cannot supply power	X								
Tank									
No leaks							X		
Inadequate oil level or oil leak	X	X	X	X	X				
Service life (based on utility standard practices)									

Comments: The evaluation of the condition of a transformer is done by performing tests and by performing a visual inspection. The visual inspection is performed to determine the condition of the tank while tests are performed to control the quality of the oil, and the state of the insulation and the windings. Considering the wide variety of possible tests, outcomes are described qualitatively and must be evaluated by considering the recommendations of each specific manufacturer of testing devices.

4 Other Established Inspection and Rating Systems

hydroAMP

hydroAMP is being developed jointly by the USACE Hydroelectric Design Center (HDC), Bonneville Power Administration (BPA), U.S. Bureau of Reclamation (USBR), and Hydro Quebec. It is based on work originally accomplished by HDC under the REMR program. The CI methods developed by HDC under REMR included some tests and measurements that were labor and time intensive. The hydroAMP tool has mitigated this problem by developing two tiers of inspections. Tier 1 inspections can generally be completed without costly efforts and give a good indication of areas of concern. Further tests can be accomplished under the Tier 2 inspections. Tier 1 inspection ratings also include a small number of "condition indicators" that usually include operation and maintenance history and age, rated on a scale of zero to three. The condition indicator ratings are multiplied by weighting factors to sum to a score on a 0 – 10 scale. See Figure 16 for an illustration and further details. Strictly speaking, these two indicators in particular often are not considered to be measures of condition, but they are considered important for completing the next step, which is to estimate risk. This risk estimate is based on condition, as a proxy for failure likelihood, in conjunction with the consequences of failure. It is important to understand the limits of the method. The resulting CI scores on a 0 – 10 scale are a combination of overlapping and distinct factors. This can further distort any relation that condition has to failure probability. That considered, hydroAMP offers a rough measure that can be used for prioritization and planning. Use of hydroAMP will allow data collection that can be used to improve the process. In particular, some subjective steps in the process can be modeled on the data.

hydroAMP
Asset Management Partnership

A Strategic Approach to Making Hydropower Investment Decisions Based on Equipment Condition and Risk Management Principles

Bureau of Reclamation, Hydro-Québec, Corps of Engineers and Bonneville Power Administration

Successful strategic planning for capital investments in existing hydropower facilities requires consideration and balancing of many factors, including the risks and consequences of equipment failure. The goal of hydroAMP (the Hydropower Asset Management Partnership) is to create a framework to streamline and improve the evaluation of equipment condition to enhance asset management and investment decision-making. Condition assessments support:

- Prioritization of capital investments
- Development of long-term investment strategies
- Coordination of O&M budgeting processes and practices
- Identification and tracking of performance goals

Technical teams comprised of experts from the hydroAMP organizations have developed condition assessment guides for circuit breakers, emergency closure gates and valves, generators (and large pump motors), governors, GSU transformers, surge arresters, and turbine runners. Assessment guides for compressed air systems, cranes, exciters, and station batteries are also currently being developed. A two-tiered approach for assessing equipment condition is used. Tier 1 relies on test data, inspection results, and other information that is readily available or easily obtained during routine operation and maintenance activities. A low condition index may indicate the need for a Tier 2 evaluation, comprised of specialized tests and a higher level of expertise, to refine the condition rating.

Equipment condition indices assist management and other personnel involved in making decisions on replacement or rehabilitation when faced with competing demands and limited resources. The simplest approach involves using condition indices to prioritize, rank and sort equipment needs. This analysis may be done horizontally across an organization to determine the replacement order for similar types of equipment (e.g., to develop a transformer or circuit breaker replacement program). Condition indices can also be combined vertically into an integrated generating unit (i.e., turbine, generator, circuit breaker, and transformer) index or into an overall facility index (including batteries and plant other equipment). Condition indices may be used to formulate a business case that addresses a wide range of factors such as risk of failure, efficiency, safety, economic, environmental, political and regulatory consequences, as well as other considerations. The analysis tools being designed by hydroAMP will be open and flexible to fit into existing maintenance, planning, budgeting, and decision-making structures.

A pilot project is currently being coordinated at select powerplants in the Corps' Pacific, Central, and Atlantic regions to perform Tier 1 assessments of their turbines, generators, circuit breakers, and transformers. In addition, powerplants in the Federal Columbia River Power System (FCRPS) in the Pacific Northwest will perform Tier 1 condition assessments during FY04. Experience from these applications will be used to improve the condition assessment procedures and outputs.

Several condition assessment tools are now available for testing and field validation. Use of these "draft" guides is encouraged, and feedback on ways to improve the guides is essential for further development of the condition assessment and asset management tools being created by the hydroAMP teams.

Example: Tier 1 Analysis of a GSU Transformer

Transformer Condition Summary

No.	Condition Indicator	Score	× Weighting Factor	= Total Score
1	Oil Analysis	3	1.143	3.429
2	Power Factor and Excitation Current Tests	2	0.952	1.904
3	Operation and Maintenance History	2	0.762	1.524
4	Age	2	0.476	0.952
	Condition Index (Sum of individual Total Scores)			7.8

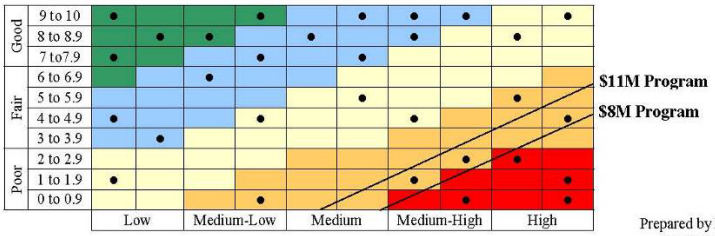
Condition-Based Alternatives

Condition Index	Suggested Course of Action
≥ 7.0 and ≤ 10 (Good)	Continue O&M without restriction. Repeat condition assessment as needed.
≥ 3.0 and < 7.0 (Fair)	Continue operation but reevaluate O&M practices. Consider using appropriate Tier 2 tests. Conduct full risk-economic assessment. Repeat condition assessment process as needed.
≥ 0 and < 3.0 (Poor)	Immediate evaluation including additional Tier 2 testing. Consultation with experts. Adjust O&M as prudent. Begin replacement/rehabilitation process.

1 Perform Tier 1 assessment to score condition indicators and calculate the Condition Index.

2 Use the Condition Index to rate condition and determine a course of action.

Risk Map



Consequences
(Based on Risk to Revenue or other factors)

3 Use the Condition Index to evaluate risks and establish investment priorities.

Prepared by HDC
May 2004

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Figure 16. HyrdoAMP literature.

Simplified Tier 1 condition assessment and rating

Condition assessment guides have been developed for the following equipment:

- batteries
- circuit breakers
- compressed air systems
- cranes
- emergency closure gates and valves
- exciters
- generators
- governors
- surge arrestors
- transformers
- turbines.

As an example, the guide for transformers is presented in Table 4. An overall rating for each transformer was calculated using the following weighting factors provided by the technical group:

- oil analysis (1.2)
- power factor (1.0)
- O&M history (0.8)
- age (0.5).

Detailed Tier 2 assessment

According to the hydroAMP guidebook, "each condition assessment guide describes a 'toolbox' of Tier 2 inspections, tests, and measurements that may [be] performed, depending on the specific issue or problem being pursued. A Tier 2 assessment is considered non-routine. Tier 2 inspections, tests, and measurements generally require specialized equipment or expertise, may be intrusive, or may require an outage to perform."

A Tier 2 assessment is used to improve the accuracy and reliability of the Tier 1 CI or to evaluate the need for more extensive maintenance, rehabilitation, or equipment replacement. Table 4 shows an example of how Tier 2 results are used to adjust the CI according to criteria.

Table 4. Transformer condition assessment guidelines.

Condition Indicator (oil analysis)	Score			
	3	2	1	0
1. DGA (dissolved gas analysis)				
a. Generation Rate (ppm/mo)				
TDCG	<30	30-60	50-80	>80
Individual CG	<10	<15	<25	>50
CO	<70	<150	<350	>350
Acetylene	0	0	<5	<10
b. Level (ppm)				
Hydrogen	<100	100-350	350-700	>700
Oxygen	<5000	5k-10k	10k-15k	>15k
Methane (CH4)	<75	75-200	200-400	>400
Acetylene (C2H2)	<5	5-20	20-40	>40
Ethylene (C2H4)	<30	30-60	60-100	>100
Ethane (C2H6)	<30	30-60	60-100	>100
Carbon monoxide	<200	200-400	400-600	>600
Carbon dioxide	<1000	1k-3k	3k-5k	>5k
TDCG	<450	450-900	900-1800	>1800
2. Oil Quality				
IFT	>35	30-35	25-30	<25
Acid Neut. No.	0-0.05	0.05-0.15	0.15-0.5	>0.5
Moisture	0-10	10-15	15-20	>25
Furans	0-75	75-150	150-250	>50
*3. Power Factor (Doble)***	*Normal (0.10 - 0.50)*	*Minor Degradation (0.50 - 0.80)*	*Significant Degradation (0.8 - 1.0)*	*Severe Degradation (>1.0)*
O&M History/ Physical Condition	Normal	Some abnormal ops or additional maintenance	Significant abnormal ops or additional maintenance	Forced outages, major leaks, severe problems, sister unit failures
Age (years)	*<30*	*30-45*	*>45*	-
*Overall oil score is lowest of individual scores for each category. Weight "Level" scores less than "Generation Rate" scores by increasing individual gas "Level" scores by one point. In addition, if the Level of a gas is high but unchanged for 4 to 5 years, reduce weight of individual gas score for each such gas by increasing score by one point.				
**Values refer to percent power factor on overall tests. Review overall, excitation, and TTR results. Defer to test engineer's assessment if present on report.				

Types of analysis

Not to be confused with condition assessment, hydroAMP also includes a simplified and a more detailed method for analyzing the priorities for repairs. Tier 1 and Tier 2 analysis are not covered in this report. The reader is referred to the hydroAMP literature.

RecBEST

The RecBEST documentation (http://corpslakes.usace.army.mil/employees/recbest/recbest.html) summarizes the primary objective of the tool.

> The U.S. Army Corps of Engineers Recreation Budget Evaluation SysTem (RecBEST) is a tool designed to satisfy the Office of Management and Budget (OMB) requirement to link performance and budget. It is intended to provide a means for quantifying performance outputs as well as ranking incremental recreation budget packages in a consistent manner throughout the Corps. This system incorporates the ability to rank incremental budget packages at the project, district, and division, and national levels. There are three measures being used for development of the FY 2008 Recreation O&M Budget: (1) Recreation Unit Day Availability (RUDA), (2) Recreation Facility Condition Index, and (3) Recreation National Economic Development (NED) Benefits. Additional measures may be incorporated in future budget years.

RecBEST documentation explains that each of the three measures is compared to the budget package cost, with the FCI also multiplied by the visitation days. Additional but incomplete details about how this is used to prioritize are also in the documentation. Current service levels are recorded, but the documentation does not describe how this information is used to evaluate and prioritize recreation areas or budget packages.

Recreation funding levels are submitted for three levels, as defined by the RecBEST documentation.

> For FY 2008, the initial funding level for recreation will provide funds to operate and maintain recreation areas and facilities to accommodate 75% of the existing visitation at an acceptable level of service. The Increment 2 Budget Package is to serve the remaining 25% of the existing visitation by choosing the most efficient way. For each recreation project site there will be only one budget package included in the initial funding level, and one included in the increment 2 level. Each project will then have up to nine increment 3 budget packages to address Budget packages beyond the initial and increment 2 funding levels.

The Recreation Facility CI is determined based on standardized criteria provided within the RecBEST tool. Ratings similar to those in Figure 17 are recorded for six primary components. Three of the components have a total of 13 subcomponents (Table 5). Descriptive rating criteria and some photographs are provided for four condition levels for all of the subcomponents and for the components without subcomponents. Table 6 shows an example for the roof, a subcomponent of buildings. Note that the CI criteria provide neither inspection guidance nor specific details of the roof distresses. The condition of roofing and other subcomponents is not recorded in RecBEST. The rater must consider all subcomponents and evaluate building condition. In the Happy Trails Lake example in the RecBEST simulation at http://corpslakes.usace.army.mil/employees/recbest/, the project is subdivided into nine recreation areas. In this example, most areas have three or four buildings, and the rating is for that group of buildings, not an individual building. The example shows similar numbers of roads, boat ramps, and sites for each recreation area.

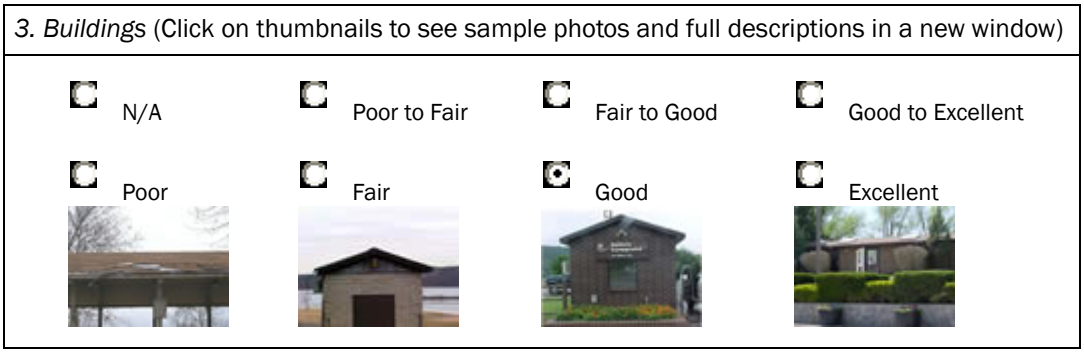


Figure 17. Building condition rating.

Table 5. RecBest facility components and subcomponents.

Component	Subcomponent
Roads	Gravel Roads and Parking Paved Roads and Parking
Boat Ramps	
Buildings	Landscaping Roof Paint Doors and Windows Interior Surfaces and Fixtures
Sites	Impact Zones Tables Canopies Cookers/Fire Rings/Utility Tables/Lantern Holders Utilities Camping Pads/Pullouts
Signs	
Environment	Addressed in Environmental Stewardship Budget Evaluation System (E-SBEST)

Table 6. Condition rating for roofing.

Roof
a. Roof in excellent condition: no damage to or deterioration of roof covering, fascia or soffits
b. Roof in good condition: minor damage to or deterioration of roof covering, i.e., small dents, faded paint, aged shingles
c. Roof in fair condition: some damage to or deterioration of roof covering, i.e., dents, creases, cracked and peeling paint, loose, damaged or curling shingles
d. Roof in poor condition: significant damage to or deterioration of roof support and covering, i.e., warped or bowed, missing paint, missing shingles, leaks; fascia and soffits exhibiting dry rot or mildew

LRD 5-year development perspective

In 2006 the Corps of Engineers Lakes and Rivers Division (LRD) drafted separate reports summarizing a 5-year perspective on the status, needs, and expectations for their Ohio River Basin and Great Lakes navigation. The draft report for the Ohio River system appears to be more comprehensive, was read more thoroughly, and is described in further detail.

As a summary the LRD Ohio River system 5-year plan compiles and presents numerous pieces of useful information, but it should not be mistaken for an information collection tool. The process does not define how to collect the information for the performance ratings. Although specific sources are not cited within the report, most of the information is pulled from other processes and presented without most of the details. Most of this information is at the project level. The following is a partial list of what is included:

- Lock statistics
- Philosophical discussions of navigation benefits, funding needs, and network level planning efforts
- Ten-year actual and optimal out year funding by fiscal year (FY) for LRD and by project (FY01 – FY11). See Table 7. The method for calculating the budget is not described.
- General and specific performance level ratings and minimum acceptable levels for each project (Table 8 – 11).
- Brief review of existing and needed tools for Risk and reliability and for Performance and valuation.

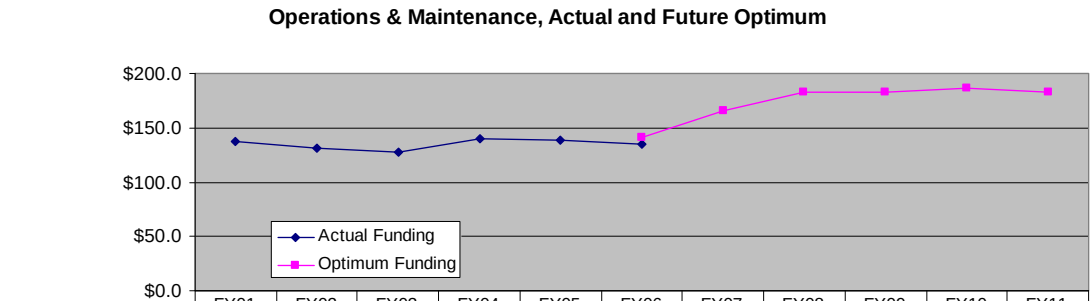
General performance standards

For navigation systems, each major feature category (e.g., locks, dams to maintain navigation pool, channels, and breakwaters) requires a definition for allowable tolerances. For navigation systems categories, five alternative performance standard levels prescribe and define the allowable tolerances (compromise, allowable deviation) generally as shown below. See Table 8.

Specific performance standards descriptions

Achieving acceptable levels of risk for these general categories requires first that performance standards definitions be established. Examples of these standards are shown for navigation locks and dams (Table 9), with more specific criteria for dams (Table 10). Criteria for navigation channels are in Table 11.

Table 7. Ten-year O&M funding.



	FY01	FY02	FY03	FY04	FY05	FY06	FY07	FY08	FY09	FY10	FY11
Actual Funding	$137.8	$130.9	$128.1	$139.8	$138.2	$134.9					
Optimum Funding						$141.5	$165.1	$182.8	$183.0	$185.9	$183.2

Table 8. Generic performance level definitions.

A	Virtually no compromise to authorized Federal project features accepted.
B	Minimal compromise to authorized Federal project features accepted. There is a small probability that degraded conditions may result in inefficient operations, i.e., slower and/or more costly navigation operations.
C	Moderate compromise to authorized Federal project features accepted. There is a high probability that degraded conditions may result in inefficient operations, i.e., slower and/or more costly navigation operations.
D	Significant compromise to authorized Federal project features accepted. Closures of seven or more days are scheduled annually.
F	Extreme compromise to authorized Federal project features accepted. Closures of at least two weeks are scheduled annually.

Table 9. Lock and dam specific performance levels.

US Army Corps of Engineers Great Lakes & Ohio River Division

Performance Standards-Specific Criteria

Navigation Locks & Dams

Level	A	B	C	D	F
Subjective Maintenance & Condition	Well maintained and have minimal deterioration.	Routinely maintained, and have minimal deterioration.	Minimally maintained as required and have moderate deterioration.	Only key items maintained, and have substantial deterioration.	No preventive maintenance, fix as fails, and have significant deterioration.
Unscheduled Closures: X days annually main chamber	4	15	25	35	50
Unscheduled Closures: X days annually auxiliary chamber	YES	----	----	----	NO
Navigation Dams: Condition to retain pool	See Criteria	See Criteria	See Criteria	See Criteria	See Criteria

Table 10. Navigation dam specific performance levels.

US Army Corps of Engineers Great Lakes & Ohio River Division

Performance Standards-Navigation Dams Criteria

A	No major deficiencies with operating machinery, gates, or structure.
B	1 Gate non-operational with no impact on pool control. Operational machinery requires infrequent , minor maintenance. No structural problems.
C	2 Gates non-operational with no impact on pool control. Operational machinery requires regular, moderate maintenance and repair. No emergency bulkhead capability. Minor structural issues, e.g. minor downstream scour, trunnion anchorages.
D	3 Gates non-operational with no impact on pool control. Operational machinery requires frequent maintenance and repair. No emergency bulkhead capability. Major structural issues and/or has potential to affect dam stability.
F	More than 3 gates non-operational and may impact pool control. Operational machinery unreliable. No emergency bulkhead capability. Imminent danger of structural failures or high probability of failure due to dam stability.

Project performance ratings

Based on the Uniform Performance Standards, the projects were rated for their performance. Of the 68 projects, 50 were rated below their acceptable level (Table 12). The report does not explain the basis for determining

the acceptable performance level for individual projects. The primary measure is tonnage, but specifics are not provided.

Table 11. Shallow draft navigation channel specific performance levels.

US Army Corps of Engineers
Great Lakes & Ohio River Division

Performance Standards-Specific Criteria

Navigation Channels Shallow Draft

Level	A	B	C	D	F
Subjective Maintenance & Condition	Optimum availability of channels	Limited availability of channels	Moderate availability of channels	Reduced availability of channels	Minimal availability of channels
Percent Availability of Authorized Project width dimensions in 9' system	100%	90%	80% 1-way traffic	70% 1-way traffic light loading	50% Traffic ceases

Table 12. LRD project performance level summary.

	Current Level of Performance Reliability					
Acceptable Level of Performance Reliability	A	B	C	D	F	# Projects Currently Below Acceptable
A	3	14	14	4	5	37
B		5	7	3	0	10
C			6	3	0	3
D				3	0	0
F					1	0
Totals						50

The LRD 5-year perspective is informative regarding the status of each project. The performance standards provide clear metrics for communicating information to management. The basis for the individual ratings is less clear. Obviously, engineering studies and cost estimates form the basis for the report, but the process for converting that information into ratings is primarily based on expert judgment. This judgment is not provided at the detailed inspection and condition level but instead at a rolled up level for a group of components or a structure. Individual component inspection and condition rating could strengthen the basis for the report findings.

Coastal structures asset management

FY06 funded work at the the U.S. Army Engineer Research and Development Center – Coastal and Hydraulics Laboratory is in the early stages of development. Multiple decision tools are being considered with varying strengths and weaknesses. The tools discussed within this section are for prioritization of repairs based on failure consequences, not physical condition. It is not known whether the developers also plan to use the REMR CI procedures, and it is not clear how well these additional metrics would work together if they were all developed. Figure 18 shows the four indices envisioned for prioritizing repairs. "General Intrinsic Nature" refers to direct impacts of the structure deficiency on Corps activities, e.g., repair cost, loss of life, release of contaminated sediment, increased dredging, morphology change, and impact to adjacent shorelines. "Operational Intrinsic Nature" refers to the impact of loss of project functionality on the general public and commerce, e.g., unsafe navigation, increased port down-time, decreased community economic growth, decreased tourism, loss of infrastructure, and forced relocation. Each of these aspects is then broken down into an economic index and an index for social and environmental repercussions.

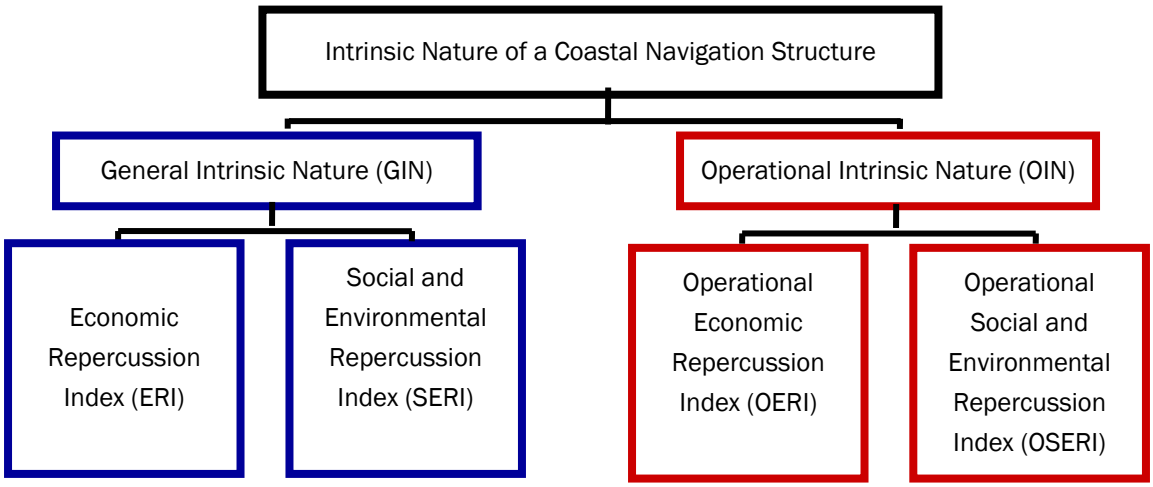


Figure 18. Coastal structures asset management decision tools.

The four indices are defined as follows:

ERI. This index is based on the sum of repair costs and costs incurred due to the degraded state divided by a normalizing factor such as the total budget.

$$ERI = \frac{C_{SG} + C_{PG}\ (N \text{ years})}{C_{OM}}$$

SERI. This index has three components related to the structure: (1) loss of human life, (2) social disruption, and (3) environmental/historical significance/cultural heritage. Each of the three components is given a value (see Figure 19) that is used to determine the index according to the equation that follows:

$$SERI = \frac{SERI_1 + SERI_2 + SERI_3}{50}$$

$SERI_1$	Value	$SERI_2$	Value	$SERI_3$	Value
Remote	0	Remote	0	Low	0
Low	3	Low	2	Moderate	5
High	10	Moderate	4	High	10
Catastrophic	20	High	8	Very high	15
		Very high	15		

Figure 19. SERI values.

OERI. This index includes the impacts of decreased project functionality on the economy. It includes estimates of losses for existing commerce and costs related to delay of planned development. The index is normalized by the structure repair cost.

OSERI. This index has three components related to the resulting functionality: (1) loss of human life, (2) social disruption, and (3) environmental/historical significance/cultural heritage. Each of the three components is given a value that is used to determine the index according to the same equation as for SERI.

The four indices are each multiplied by weighting factors and summed to determine the Total Damage Repercussion Index (Figure 20). The weighting factors have not yet been determined. Since each index is currently on a different scale, the weighting factors would need to consider this. It is likely that they would also be further weighted to include the relative importance of each index on a basis that is not yet determined.

$$DRI = \underbrace{W_E\,(ERI) + W_{OE}\,(OERI)}_{\text{tangible costs}} + \underbrace{W_S\,(SERI) + W_{OS}\,(OSERI)}_{\text{intangible repercussions}}$$

where W_E, W_{OE}, W_S, and W_{OS} are weighting factors

Figure 20. Total Damage Repercussion Index.

The biggest benefit of a tool like this is that it walks the decision maker through a formalized process of checking the factors that should be considered when prioritizing repairs of coastal protection structures. Although moderate to significant effort can be expended to determine some of the base information such as repair cost, benefits lost, etc., those calculations should be made even if this tool is not used. The tool itself adds very little additional effort. That is the significant advantage of this tool compared to a risk-based cost-benefit analysis. The advantage must be weighed against the disadvantages. One disadvantage is the inaccuracies in cost-benefit quantification introduced by the index calculations. For example, ERI includes repair cost in the numerator and OERI use it in the denominator. Strictly speaking, this does not lead to an accurate assessment of the cost-benefit, but this is not necessarily a fatal flaw. It depends very much on how the tool will be used. For example, tools to measure the scale of problems and tools to prioritize individual repairs should not have the same level of detail.

While it may be unfair to judge the negative aspects of this tool until it is more complete, it does offer a useful illustration of the trade-off that must be made between accuracy and effort. It is not always cost effective to use the most accurate methods. If cost were not an issue, a complete cost - benefit analysis might be a better approach.

Federal Highway Administration (FHWA) bridge inspection

The Surface Transportation Assistance Act of 1978 provided badly needed funding for rehabilitation and new construction. It required that all public bridges over 20 ft (6.1 m) in length be inspected and inventoried in accordance with the National Bridge Inspections Standards (NBIS) by 31 December 1980.

In 1978 the American Association of State Highway and Transportation Officials (AASHTO) revised their Manual for Maintenance Inspection of Bridges (AASHTO *Manual*). In 1979 the NBIS and the Federal Highway

Administration (FHWA) *Coding Guide* were also revised. These publications, along with the *Bridge Inspector's Training Manual 70*, provided state agencies with definite guidelines for compliance with the NBIS.

In order for states to receive federal highway funding, they are required to inspect their bridges every 2 years according to a well-defined process. In addition, the bridge inspectors must be certified. The certification process includes mandatory training. The condition assessment procedures were developed based on a generic National bridge Inventory (NBI) condition rating scale (Table 13) similar to the REMR scale.

Table 13. NBI condition rating scale (FHWA).

NBI	Description	Repair Action
9	Excellent Condition	None
8	Very Good Condition	None
7	Good Condition	Minor Maintenance
6	Satisfactory Condition	Major Maintenance
5	Fair Condition	Minor Repair
4	Poor Condition	Major Repair
3	Serious Condition	Rehabilitate
2	Critical Condition	Replace
1	Imminent Failure	Close Bridge and Evacuate
0	Failed	Beyond Corrective Action

The system also includes more specific condition tables for 146 elements, including asphalt overlay, painted steel girders, column or pile extension, pedestrian railings, pin and hangar assembly, elastomeric bearings, filled joint, non-expansion, and the approach slab.

Figure 21 shows an example rating checklist from the Pontis Bridge Management System (BMS). This condition rating system has been in use for 35 years on more than 500,000 bridges inspected every 2 years. These inspections have resulted in an immense database of condition records. Many things can be investigated and learned based on this data record. If the condition data are compared to M&R expenditures, for example, it provides great insight into the relationship between M&R and condition. The Pontis system was first computerized in the early 1990s. In addition to electronically storing and managing the data, the software uses collected cost data and condition data of bridge elements to arrive at least cost (optimal) long-term preservation and improvement policies for a network of bridges.

CS	Description	Rust Code
1	No evidence of active corrosion	-
2	Slight peeling of the paint, pitting or surface rust	Light R1
3	Peeling of the paint, pitting, surface rust	R1
4	Flaking, minor section loss (<10%)	R2
4	Flaking, swelling, moderate section loss (>10% but <30%). Structural analysis not warranted	R3
5	Flaking, swelling, moderate section loss (>10% but <30%). Structural analysis warranted	R3
5	Heavy section loss (>30% of original thickness), may have holes through the base metal	R4

Figure 21. The Pontis BMS open steel girders condition rating checklist.

PAVER

PAVER is a Sustainment Management System (SMS)* for assessing and inspecting pavements. The system includes a microcomputer implementation called MicroPAVER. It was developed by the U.S. Army Engineer Research and Development Center – Construction Engineering Research Laboratory (ERDC-CERL) to help civil engineers, technicians, and managers decide when, where, and how to best maintain airfield and ground vehicle roadway infrastructure. PAVER for airfields was the first inspection method based on quantitative ratings using a 100-point CI scale. PAVER includes more functionality than any other CI-based management system. Longevity may be the primary cause, but the engineering properties of pavements, including relative uniformity, also seem to contribute to this higher level of functionality. PAVER is arguably the most widely used CI system, having gained acceptance within the Air Force and numerous states and local jurisdictions. A Unified Facilities Criteria (UFC) standard, UFC 3-270-05, and an ASTM standard, D 5340-93 both describe the PAVER SMS.

Inventory

The first step in building a pavement inventory is to create a network. A hierarchical relationship exists between pavement inventory items in MicroPAVER. Networks are the parents of branches, and in turn branches are the parents of sections. Sections are the smallest evaluation unit for work done on pavements. When inspecting a pavement network, it can be difficult for surveyors to find individual sections and sample units directly

* SMSs were formerly known as Engineered Management Systems, or EMSs.

from a map. The MicroPAVER program has a tool that allows storage of pictures of individual sections and sample units, as well as images of example distresses, to expedite the inspection process.

Field inspection

Collection and recording of field inspection information are probably the most frequently repeated tasks in MicroPAVER. Recognizing the numerous alternatives for reducing effort and expense, field inspection procedures have been dramatically revised and expanded. Inspection information can now be imported from various independent field data collection programs, entered conveniently from paper forms filled out in the field, or simultaneously entered directly into PAVER using a tablet computer. Using a tablet computer is highly recommended. Currently, the single most common method for collecting and recording MicroPAVER inspection data is to record field information on paper forms, and then enter the data into the computer at a later time.

Condition analysis

The condition analysis feature allows you to view the condition of the entire pavement network or any specified subset of the network. The analysis is based on prior inspection data, interpolated values between previous inspections and projected conditions based on family assignment.

Prediction modeling

The essence of the condition prediction ("family" modeling) process is to identify and group pavements of similar construction that are expected to be subjected to similar maintenance practices, traffic, weather, and other factors that affect pavement performance. The historical data on pavement condition can be used to build a model that can accurately predict the future performance of a group of pavements that possess similar attributes. This model of pavement life is assigned a name, and in the MicroPAVER vocabulary it is referred to as a "family." If the user has not assigned a family model to a section, MicroPAVER will use its default family to predict future pavement performance. A generic guess, like the default family, is unlikely to be as accurate as a model that takes these factors into consideration. The condition prediction model is designed to allow users to blend unique knowledge about their pavements, measured

local condition information, and a powerful modeling tool together to produce highly accurate estimates of future pavement life.

Work planning (M&R)

MicroPAVER Work Plan is a tool for planning, scheduling, budgeting, and analyzing alternative pavement M&R activities. The M&R Work Plan used basic inventory data combined with inspection information, maintenance policies, maintenance costs, and predictions about future pavement condition. Work Plan results are specific to a site. All factors used in determining the M&R or construction activity to apply or the costs to use can be configured to reflect individual pavement management practices and costs.

Reports

The reports section is designed to provide basic pavement information in a variety of formats including summary charts, standard reports, linked geographic information system (GIS), and flexible formats that allow users to define the report matrix.

BUILDER

BUILDER™ is an ERDC-CERL-developed SMS and software application developed to help civil engineers, technicians, and managers decide when, where, and how to best maintain building infrastructure. BUILDER technologies and methods include a comprehensive inventory of building major components, such as:

- photo imaging
- checklist-style, pen-based inspections
- CIs
- functionality ratings
- condition prediction capabilities
- revised remaining service lives based on condition
- seismic and other building compliance ratings
- budget planning procedures
- prioritized long-range work-planning procedures
- presentation graphics, and linkages to AutoCAD, Microstation, and other building drawing formats
- built-in GIS viewing capability and an ability to interface to an external GIS.

BUILDER™ provides managers responsible for the building assets with a support tool for sustainment, restoration, and modernization (SRM) decisions. The system gives functional managers and decision makers instant access to data about their building inventory, the current condition of individual buildings, a fact-based prediction of future condition, a parametric repair cost estimate based on the CI rating, and current and potential regulatory compliance issues. BUILDER™ integrates information about condition, functionality, and remaining service life to develop short and long-range (multi-year) M&R work plans based on sound investment strategies, prioritization criteria, and budget constraints. The SMS consolidates a variety of building-related management issues into a single, proactive decision-support package that helps manage assets and allocate resources, lowers the cost of re-inspections, and provides meaningful SRM decision-support metrics. The BUILDER™ program also includes IMPACT, a simulation engine to model the effects that funding, standards, and prioritization decisions have on facility condition.

Inventory

Similar to PAVER, the entire process starts with inventory. BUILDER breaks a building down hierarchically into systems, components (of systems), and sections (of components). This hierarchy can be organized into either the native BUILDER hierarchy, or use the UNIFORMAT II standard. Since the complexity of facilities is great, several tools have been created to facilitate a more rapid inventory process. Parametric models that use the Department of Defense (DoD) facility degradation models can estimate the building's inventory based upon category code, age, size, and number of floors. Approximately 95% of the department's inventory can be covered using this method. Additionally, a building template library can be created so that common, standardized designs that have been constructed in multiple locations can be used to complete inventory wherever that design has been constructed.

Field inspection

Collection and recording of field inspection information is also probably the most frequently repeated task in BUILDER™. To facilitate efficiency in gathering the information while in the field, a tablet-based application, BUILDER RED (Remote Entry Database) as been created. Designed to work with the main BUILDER application, inspectors can take subsets of inventory into the field to gather updated information. The user interface

has been optimized for the data collection task and for mechanics of the tablet interface (dropdown selections, radio buttons, minimize text entry requirements). In addition, to further minimize the amount of inspection required, a knowledge-based inspection module utilizes the user's risk tolerances, expected points of action, and predicted condition levels to generate an inspection schedule with varying degrees of inspection intensity and frequency to only gather as much information as needed for anticipated work requirements. These "knowledge-based" inspections focus attention on the most critical components at the most appropriate time (to take action). The system tailors inspection schedules to unique asset management requirements, drastically reduces inspection costs, and ensures asset performance to meet mission needs.

Condition analysis

Similar to PAVER, BUILDER™ uses a standard list of 23 distresses for inspection and condition rating of building components. The distress survey can be used to compute the component section CI (CSCI). The direct condition ratings and/or the CSCI can be used to compute the component, system or building CIs. In addition, BUILDER™ also offers direct ratings as a more rapid inspection rating method. Sampling is also permitted for all of the approaches and desired if the component section is large, complex, and/or discontinuous.

Functionality analysis

In addition to condition-based distresses, which reflect the sustainment costs for a facility, ERDC-CERL has developed the patent-pending functionality index and assessment process to identify modernization requirements for a facility. ERDC/CERL Technical Note TN-06-2 describes functionality and its relation to physical condition in the following overview:

> "ASTM International defines building performance as the in-service functioning of a building for a specified use (ASTM E1480-92). The term refers to how effectively, safely, and efficiently a building performs its mission at any time during its life cycle. A building's performance state, which changes during time in service, is reflected by two different indicators: the physical condition state and the functionality state. The physical condition state relates to a facility's general 'physical fitness,' independent of its mission, as it deteriorates due to routine aging, excessive or abusive use, or poor maintenance. The functionality state relates to the facility's suitability to function as intended and required for the mission. The functionality state is distinct

from, and determined independently from, the physical condition state. Condition-based metrics such as the CI have been used by the Army for decades, but a companion index of functionality was not developed at the same time. However, in order to fully describe a building's fitness for changing missions over its entire life cycle, a quantitative and objective functionality index (FI) is needed.

Each of the 14 functionality categories have subordinate input topics. The 14 top level categories are listed and briefly described in Table 14.

Table 14. BUILDER functionality categories.

Category	Description
Location	Suitability of building location to mission performance
Building Size/Configuration	Suitability of building size and layout for the mission
Structural Adequacy	Capability of structure to support seismic, wind, snow, and mission-related loads
Access	Capability of building to support entry, navigation, and egress as required by mission
ADA	Level of compliance with the American with Disabilities Act
AT/FP	Compliance with DoD antiterrorism/force protection requirements
Building Services	Suitability of power, plumbing, telecom, security, and fuel distribution systems
Comfort	Suitability of temperature, humidity, noise, and lighting for facility occupants
Efficiency/Obsolescence	Addresses energy efficiency, water conservation, and HVAC zoning issues
Environmental/Life Safety	Addresses issues such as asbestos abatement, lead paint, air quality, fire protection
Missing/Improper Components	Availability and suitability of components necessary to support the mission
Aesthetics	Suitability of interior and exterior building appearance for the mission
Maintainability	Ease of maintenance for operational equipment
Cultural Resources	Historic significance and integrity issues that impact utilization and modernization

Prediction modeling

BUILDER™ has a patent-pending model for predicting condition. Unlike PAVER, BUILDER™ cannot assume to have multiple assets with the same model behavior from which to create "family curves." BUILDER™ models each section's condition trend independently based upon inspection data for that section. This method is designed to support all the types of inspections used (distress survey, direct rating, etc).

Work planning (M&R)

Based on index triggers, or thresholds, the system will automatically create both sustainment and modernization work recommendations. These index triggers are specified by the user based on their level of risk tolerance and economic efficiencies. Once the work items have been created, BUILDER™ uses cost models to provide cost estimates. The user also can provide a prioritization scheme that uses multiple user-specified metrics and properties (of the asset) to rank the work items for funding. The prioritization module uses the Analytic Hierarchy Process to arrive at the scores and weighting for the scheme. In this way the need to do work (based upon condition trigger) and the consequences of not doing the work (using prioritization scheme) are separated. Additionally, BUILDER includes a simulation engine called IMPACT (Integrated Multi-year Priorities and Consequences Tool) that allows the user to study the effects of various decisions upon the performance of the facilities. Condition, triggers, prioritization, funding, and inventory changes can all be altered to determine how much resources are required to meet facility targets; or how proposed funding changes will affect the facilities condition.

The BUILDER™ decision support tool allows users to manage buildings individually or in groups, enabling effective management of historic, housing, health/environment, and safety/code issues. Projects can be BUILDER™-generated or initiated externally from customer requests.

Expected cost to implement

Implementation cost is estimated at $0.05-0.12/sq ft. Subsequent costs are estimated at $0.02-0.04/sq ft.

NASA deferred maintenance parametric estimating

The National Aeronautics and Space Administration (NASA) has developed a system for estimating M&R needs at a system level. Generally, the information collected is not sufficient to make decisions for a single building or even a small group of buildings. The minimum number of facilities for a good estimate of cost is considered to be 15–25. NASA reports that, for larger groups of buildings, the system accurately estimates how much money will be needed to maintain their buildings for their planning years.

NASA divides the building into nine systems as follows:

- structure
- roof
- exterior
- interior finishes
- heating/ventilating/air conditioning (HVAC)
- electrical systems
- plumbing systems
- conveyance systems
- program support equipment.

Each of the systems is rated on a scale of one to five based on their condition. The score is given for a total system. The system documentation does not discuss the impact of the various system components nor how to incorporate localized deterioration within the total score. These issues would need to be covered in training for the inspectors to avoid significant inconsistency. Inconsistency in the results could occur if the rating of groups of components is based on criteria not addressing each component. Inspector training, use of a single or small number of inspection teams, and using the same inspectors for subsequent inspection can all increase the consistency and validity of the results.

The objective of the NASA process is not specifically to assess condition. That is only an interim step. Their primary intent is to determine repair costs at a network level. For each building type in their inventory, the current replacement value (CRV) has been estimated using a separate tool called PACES (Parametric Cost Estimating System). The percentage of the CRV attributable to each of the nine building systems has also been estimated. Finally, based on the condition rating, the cost to repair a system is estimated as a percentage of the system CRV. The result is that the cost of

repairs can be calculated based on current condition, repair cost as a percentage of CRV, and the CRV.

It is important to understand the capabilities and the limits of this method. The NASA system does not include nearly as much detail as available in BUILDER™. It cannot be used for many of the purposes BUILDER™ serves. However, it is much simpler and less costly to implement. If its capabilities match the user needs, it appears to be a capable tool. While NASA may have successfully implemented this system, it is expected that the Corps would have more difficulties due to its decentralization and the size of its inventory. That does not make it impossible to effectively implement a system such as this for buildings or other infrastructure (e.g., roads) that have relatively uniform unit costs. Note that this system is most capable for buildings because extensive unit cost models have been developed. No such cost models exist for most Civil Works infrastructure and unit costs would be difficult, if not impossible, to determine for most types of Civil Works components.

DOE condition assessment system

The U.S. Department of Energy (DOE) has developed condition assessment reference reports (Table 15) for the building systems that describe common deficiencies and inspection methods for components and materials. These reports are extensive and very detailed. DOE has implemented this inspection method in a computerized system that records basic building information, as well as inspection data including distresses, severities, and quantities. Inspection frequency varies from 1 to 5 years depending on the component type. Condition can be derived either by the Condition Assessment Information System (CAIS) algorithm based on raw deficiency data or by the inspector's subjective judgment. Repair needs can also be defined based on the raw deficiency data and by the inspector's subjective judgment. The Condition Assessment System (CAS) defines three major repair codes: condition, purpose, and urgency (Table 16). Using these repair codes to prioritize repairs has no standardized process.

Table 15. DOE CAS Inspection methods reports.

Publication	File Name
V01: Foundations & Footing	Vol-01.Pdf
V02: Substructure	Vol-02.Pdf
V03: Superstructure	Vol-03.Pdf
V04: Exterior Closure	Vol-04.Pdf
V05: Roofing	Vol-05.Pdf
V06: Interior Finishes & Construction	Vol-06.Pdf
V07: Conveying Systems	Vol-07.Pdf
V08: Mechanical Systems (Book 1)	Vol-08-1.Pdf
V08: Mechanical Systems (Book 2)	Vol-08-2.Pdf
V09: Electrical Systems (Book 1)	Vol-09-1.Pdf
V09: Electrical Systems (Book 2)	Vol-09-2.Pdf
V10: Prod/Lab/Other Equip (future volume)	N/A
V11: Specialty Systems	Vol-11.Pdf
V12: Sitework	Vol-12.Pdf

Table 16. CAS repair codes (DOE).

CONDITION CODE	DEFINITION
A	**Excellent:** Performs to original specifications as measured using non-standard tests; easily restorable to "like new" condition; only minimal routine maintenance required at cost <2% of reolacement value.
B	**Good:** Performs to original specifications as measured using historical data and non-standard tests; routine maintenance or minor repair required at cost <5% of replacement value.
C	**Adequate:** Performance meets requirements; some corrective repair and/or preventive maintenance required at cost <10% of replacement value.
D	**Fair:** Performance fails to meet code or functional requirement in some cases; failure(s) are inconvenient; extensive corrective maintenance and repair required at cost <25% of reolacement value.
E	**Poor:** Consistent substandard performance; failures are disruptive and costly; fails most code and functional requirements; requires constant attention, renovation, or replacement. Major corrective repair or overhaul required at cost <60% of replacement value.
F	**Fail:** Non-operational or significantly substandard performance. Replacement required because repair cost is >60% of replacement cost.

PURPOSE CODE*	DEFINITION
P2	PRG: Capacity
H2	H&S: industrial Safety
E2	ENV: Solid Waste Management
S4	S&S: Security
*	Partial list based on CAMP Order DOE 4330.4A dated 1 O-I7-90.

URGENCY CODE	DEFINITION
1	Repair Immediately: Asset condition critical; initiate corrective action immediately.
2	Repair within 1 Year: Asset condition serious; initiate corrective action within 1 year.
3	Reoair in 1 to 2 Years: Asset condition dearaded: initiate reoair in 1- 2 vears.
4	Repair in 3 to 5 Years: Asset stable for period; integrate repairs into appropriate schedules.
5	No Repairs Necessary: Continue life cycle maintenance actions.

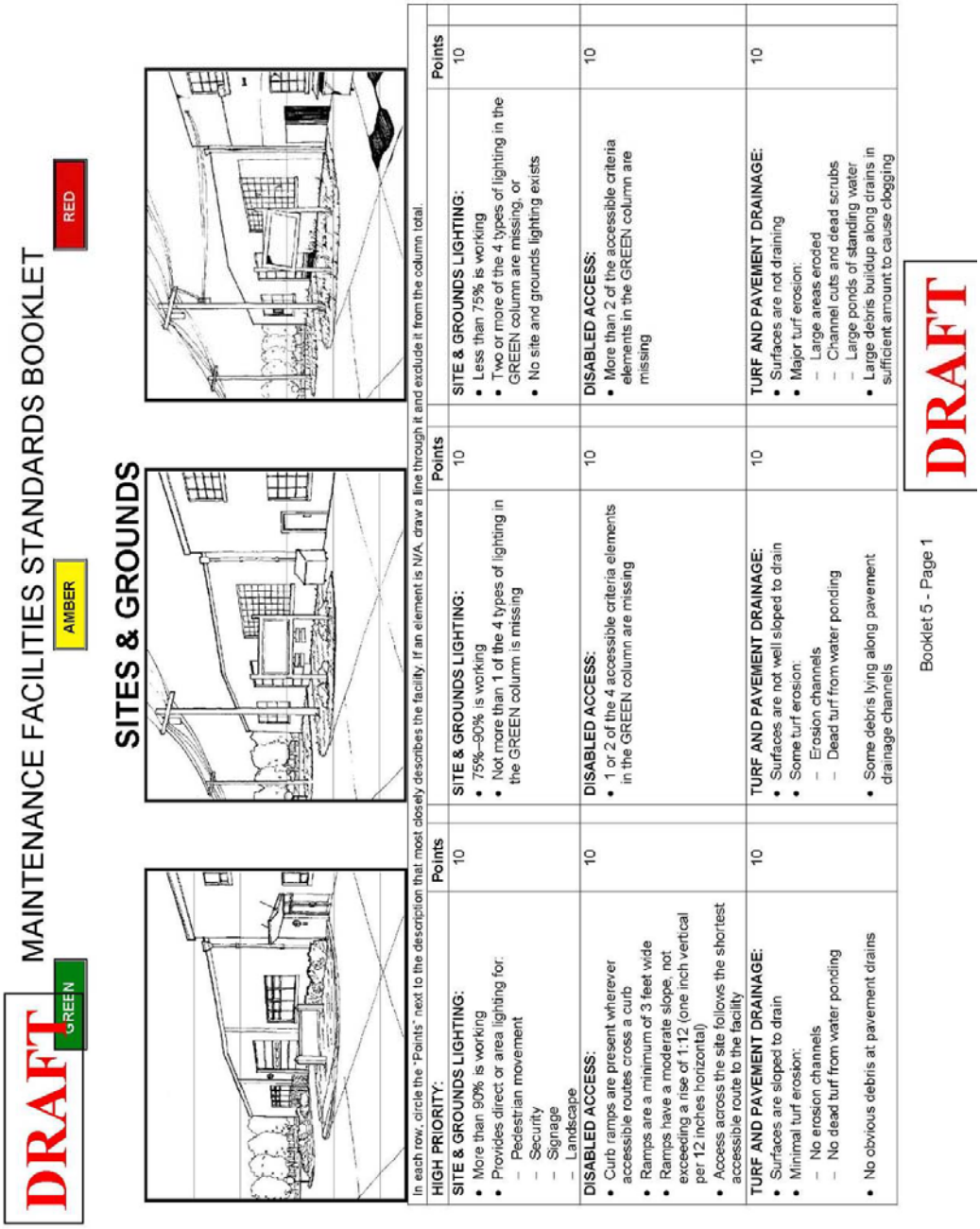
Army installation status reporting

The Installation Status Report (ISR) was initially developed in 1994 by the U.S. Military Academy (USMA) for assessment of facilities. It has been expanded by the Office of the Assistant Chief of Staff for Installation Management (OACSIM) to include more than the assessment of facilities. An ISR module is being developed to replace ISR Environment, but has yet to be implemented system wide. There is also a module that assesses the quality of base operations support (BOS) services provided on an installation.

The condition rating criteria within ISR-infrastructure varies based on facility type. Each facility type is evaluated by component. Most rating criteria are developed for inspectors that have little or no engineering background and are typically the tenant of the facility. Numerous exceptions include utilities, railroad tracks, bridges, vehicle maintenance facilities, central wash facilities, and roads that are evaluated by technically qualified personnel, and Army-owned housing that is rated by the base housing office, not the tenants. Roads and rails are rated using CIs. The facility condition ratings are determined at the "component" level (similar to a major building system) and communicated by green, yellow, and red ratings. The facility assessment standards illustrate and describe aspects of deterioration, function, construction quality, and aesthetics that might be present aggregated by green, amber, and red. ISR-I supporting documents can be accessed on the ISR homepage (http://isr.hqda.pentagon.mil/).

The Army implementing instructions indicate that the facility tenant is responsible for inspecting the facility. While this may be efficient and cost effective, the method has a number of potential drawbacks. First, many of these raters have little or no knowledge of building construction and operation and no engineering background. No possibility exists for providing more than rudimentary training to all of these raters, so consistency is also a concern. However, all facility inspectors are required to receive training based on the ISR guidelines provided to each reporting location. User training has been developed that provides an actual on-site inspection and DVD/video that helps the inspectors to better understand how to conduct an inspection and what to look for. Note that an alternative implementation plan could reduce or eliminate these inspector-specific potential drawbacks, but at a significant additional cost. When the 2005 Infrastruc-

ture update was run, alternative approaches were evaluated and cost estimates for each approach were identified. It was decided that any approach other than that currently used would be cost-prohibitive. Because the ISR condition ratings are based on a combination of construction quality, aesthetics, deterioration, and function, it can be difficult to interpret the results. The ISR-I standards and methodology changed in 2005. Examples are shown in Figure 22. The facility component inspection criteria were made more objective by rating each element of a building component and adding those element scores to rate the component, but the rating criteria remains a mix of condition and function. The skill level required of the rater may be slightly lower than for the NASA system, but due to the mix of function and condition, the results are more ambiguous and difficult to interpret. Separate ratings for condition and function could provide more meaningful results. Cost estimates are developed at the facility component level, and the calculated component improvement costs are aggregated at the facility level to produce a facility number/Facility Category Group improvement cost. Component improvement costs are established based on an objective spread of construction component costs across related ISR rating components. These are based on industry-standard references, such as RS Means, Whitestone, and the like.



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MAINTENANCE FACILITIES STANDARDS BOOKLET

GREEN AMBER RED

SITES & GROUNDS

In each row, circle the "Points" next to the description that most closely describes the facility. If an element is N/A, draw a line through it and exclude it from the column total.

HIGH PRIORITY:	Points		Points		Points
SITE & GROUNDS LIGHTING: • More than 90% is working • Provides direct or area lighting for: – Pedestrian movement – Security – Signage – Landscape	10	SITE & GROUNDS LIGHTING: • 75%–90% is working • Not more than 1 of the 4 types of lighting in the GREEN column is missing	10	SITE & GROUNDS LIGHTING: • Less than 75% is working • Two or more of the 4 types of lighting in the GREEN column are missing, or • No site and grounds lighting exists	10
DISABLED ACCESS: • Curb ramps are present wherever accessible routes cross a curb • Ramps are a minimum of 3 feet wide • Ramps have a moderate slope, not exceeding a rise of 1:12 (one inch vertical per 12 inches horizontal) • Access across the site follows the shortest accessible route to the facility	10	DISABLED ACCESS: • 1 or 2 of the 4 accessible criteria elements in the GREEN column are missing	10	DISABLED ACCESS: • More than 2 of the accessible criteria elements in the GREEN column are missing	10
TURF AND PAVEMENT DRAINAGE: • Surfaces are sloped to drain • Minimal turf erosion: – No erosion channels – No dead turf from water ponding • No obvious debris at pavement drains	10	TURF AND PAVEMENT DRAINAGE: • Surfaces are not well sloped to drain • Some turf erosion: – Erosion channels – Dead turf from water ponding • Some debris lying along pavement drainage channels	10	TURF AND PAVEMENT DRAINAGE: • Surfaces are not draining • Major turf erosion: – Large areas eroded – Channel cuts and dead scrubs – Large ponds of standing water • Large debris buildup along drains in sufficient amount to cause clogging	10

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Figure 22. ISR literature facsimile.

DRAFT

GREEN

MAINTENANCE FACILITIES STANDARDS BOOKLET

AMBER

RED

SITES & GROUNDS (CONT)

In each row, circle the "Points" next to the description that most closely describes the facility. If an element is N/A, draw a line through it and exclude it from the column total.

MEDIUM PRIORITY:	Points		Points		Points
PAVED SIDEWALKS: • Installed from parking to facility • Installed from adjacent streets to facility • Less than 10% of slabs are cracked or broken • At least 4 feet wide	6	PAVED SIDEWALKS: • Not installed from parking to facility, or • Not installed from streets to facility • 10–25% of slabs are cracked or broken • Less that 4 feet wide	6	PAVED SIDEWALKS: • Not installed at all, or • More than 25% of slabs are cracked or broken; sidewalk poses a tripping hazard	6
LOW PRIORITY:	**Points**		**Points**		**Points**
LANDSCAPING: • Displays a mixture of colorful plants and greenery appropriate to the area • Well maintained • Turf areas are green, mowed to proper cut height with less than 25% weed build-up	6	LANDSCAPING: • Displays few color plantings or greenery • Not well maintained • 25%–75% of turf area has brown-out or weeds	6	LANDSCAPING: • No plantings • Turf areas are in total disrepair; brown-out and weeds cover more than 75% of lawn	6
DUMPSTER: • Fully enclosed from view and incorporated into building design • Screened by walls or landscaping high enough (6-8 feet) to restrict view from: – Building occupants – Entrances – Streets – Parking lots • 33 feet or more away from other occupied facilities • 82 feet or more away from billeting and housing	4	DUMPSTER: • Not fully enclosed or covered, but inconspicuously located • Not screened by walls or landscaping sufficiently high to obscure view • More than 20 feet away, but less than 33 feet away from other occupied facilities • More than 50 feet away, but less than 82 feet away, from billeting and housing	4	DUMPSTER: • Not enclosed or screened from view • Less than 20 feet away from other facilities • Less than 50 feet away from billeting and housing	4
UTILITY SERVICES: • All utility lines are underground • Utility equipment is screened by landscaping or fencing	4	UTILITY SERVICES: • Utility lines are not underground, but are concealed by landscaping or fencing • Utility equipment is screened by landscaping or fencing	4	UTILITY SERVICES: • Utility lines and equipment are exposed and disorderly.	4

SUBTOTAL OF POINTS CIRCLED IN THIS COLUMN ON PAGES NO. 1 & 2 _____ GREEN

SUBTOTAL OF POINTS CIRCLED IN THIS COLUMN ON PAGES NO. 1 & 2 _____ AMBER

SUBTOTAL OF POINTS CIRCLED IN THIS COLUMN ON PAGES NO. 1 & 2 _____ RED

TOTAL EACH COLOR COLUMN, AND THEN CIRCLE THE COLOR WITH THE MOST POINTS. NUMERIC COLUMN TIES GO TO THE "WORSE" COLOR. MARK THIS COLOR ON THE FACILITY WORKSHEET.

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Figure 22 concluded.

Like the NASA process, parametric cost estimating is applied to the ISR ratings. The ISR parametric costs have distinct advantages and disadvantages compared to the NASA process. By formally including function in the rating, ISR captures valuable information, but quality of these data is questionable due to the mix of function and condition previously mentioned. As with the NASA process, there should be no expectation that the cost estimates are accurate for a component, a building or even a small

group of buildings. The goal is to have adequate accuracy for assessing an installation or a similarly large group of facilities. Before 2005 there were many "essential elements" that could force the ratings to be lower and distort the cost estimates. OACSIM agreed, as did the Army Audit Agency, and they were removed.

The ISR-I software computes a quality rating (Q-rating) for each facility using the DoD ratio of "cost to fix" divided by Plant Replacement Value (PRV). The DoD Q-rating break points are: Q-1 is a PRV of 10% or less; Q-2 is >10 and <20% PRV; Q-3 is >20 and <40% PRV; Q-4 is greater than 40% PRV. All military services must report Q-ratings using the same DoD methodology. The Army Q-ratings are determined using the ISR-I process.

Two new ratings were added to ISR-I in 2005 for mission support and readiness. The following descriptions are quoted from ISR literature:

> A Mission Support rating was developed to identify how well a facility meets the mission of the assigned organization. It is calculated by weighting the Red, Amber, and Green component ratings using an importance factor (1 to 5 scale). The component weightings were developed by the HQDA proponents for each facility type. Each facility receives a C-1 to C-4 rating based on percent of total points.
>
> The Commander's Readiness Rating is a commander's judgment of how well each facility class contributes to or detracts from the ability of assigned units, organizations and tenants to accomplish their wartime/primary missions. To determine this rating, the installation commander can first consider the quality, quantity and mission support ratings. A C-1 readiness rating would indicate facilities fully support the wartime/primary missions of the organizations, and that the condition, configuration and quantity of facilities present no limitations to unit readiness. A C-4 readiness rating would indicate facilities present significant challenges to organizations, and that the condition, configuration and quantity of facilities require assigned units to expend considerable effort to compensate for shortcomings.

Navy condition assessment

The Navy has a method called Long Range Maintenance Plan (LRMP) that includes a field inspection completed on a 3-year cycle. The field inspection is based on a detailed checklist of components to ensure coverage, but does not have a standard list of distresses, severities, nor a method for quantifying the condition. Inspectors develop repair lists in conjunction with the inspection and, upon return to the office, develop cost estimates

for all repairs. Since only a small percentage of the repairs get funded in each 3-year cycle, much of the cost estimating work has little or no benefit. Also, the deterioration continues while awaiting repair, so even scheduled repairs usually need new cost estimates.

The Navy estimates they spent $0.16/sq ft for LRMP doing many tasks that were not necessary. As a result, the Navy contracted in 2005 with a vendor named Vertex to provide an asset management system for assessment and maintenance of their buildings. The process draft presented by Vertex is based on the condition rating procedures developed by ERDC-CERL for BUILDER™. The content of this system is not finalized for release.

The Navy also has an Annual Inspection Summary (AIS). Criteria for facility inspection are located in "Inspection of Shore Facilities" (Volumes 1, 2, 3). Volume 2 includes inspection criteria for a long list of facility components, but does not include either standardized condition assessment process or condition rating. AIS is focused on two reports. One lists the deficiencies as "what is wrong," along with the cost of correction and urgency. A summary report focuses on labor and cost by craft to restore the facility to acceptable condition.

VA facility condition assessment

The U.S. Department of Veterans Affairs (VA) evaluates their facilities and develops repair needs based on a process they call Facility Condition Assessment (FCA). FCA uses A through F condition ratings of building components. The generic rating criteria are in Figure 23. Criteria specific to components have been developed only for the highest (A) and lowest (D or F) grades and most are not more descriptive than the general descriptions. The ratings are primarily condition-based but include aspects of function. For example, single pane windows in a hospital would be rated lower than the same windows in a residence.

A = Like new condition/Approximately 90% of useful lifespan remains
B = Above average condition/Over half of useful lifespan remains
C = Average condition/Less than half of useful lifespan remains
D = Poor condition/Less than 10% of useful lifespan remains/Failure is not critical
F = Critical condition/Requires immediate attention.

Figure 23. VA facility condition assessment grades.

The initial FCA inspections of 2,340 VA buildings at approximately 170 sites in 8 regional networks were done by independent assessment teams of 8 representing different trades and estimating. Experienced, knowledgeable personnel are a requirement. Correction costs were estimated for all components receiving grades of D or F. These repair actions were then used within a subjective budget prioritization process. The chief engineers for a network can chose to address items rated F first or take an alternative approach of their choosing. Repair costs are also compared to system replacement costs to arrive at a cost ratio similar to the FCI prescribed by FRPC. Buildings are re-inspected every 3 years by teams of four, which also include an estimator.

The American Hospital Association (AHA) has developed a master list of component useful life estimates. FCA uses this master list of useful life estimates, with some adjustments, in the inspection process. When a component is inspected, its remaining life may be adjusted up or down depending on its condition. Criteria for making this adjustment are not preset. It is based on the inspector's experience. It was not determined how these life estimates are used in FCA. They are not used to project long range repair costs.

Department of Interior assessment program

The Department of the Interior Inventory and Condition Assessment Program (ICAP) provides information on the condition of assets as well as data identifying major deficiencies. The ICAP Reference Manual was not available and further details were not obtained.

Other related tools

A significant number of universities have developed and/or implemented asset management plans. Referenced plans include Stanford University, Vanderbilt University, Brigham Young University, University of North Carolina, and the State of North Carolina. The third party references did not indicate whether these asset management plans included standardized condition assessment procedures, nor even if the systems were based on inspection information.

Limited information was located on a number of other asset management tools with diverse capabilities and benefits. The initial conclusion is that

none of these tools include an inspection process or condition assessment based on physical condition.

- DoD Facility Sustainment Model (FSM)
- Air Force Commander's Assessment Program (CAS)
- Navy Shore Based Readiness Reporting system (BASEREP)
- Army Installation Support Modules (ISMs)

These tools all date back to the 1990s. It is not clear if they are all still in use. Preliminary investigation did not locate any documentation for these tools, only references elsewhere. Although the preliminary conclusion was that these tools are not within the scope of this report, it is possible that further investigation would prove otherwise. CAS and BASEREP are both based on C-ratings for readiness, not condition, similar to those included in ISR.

5 CIs Currently in Use

hydroAMP

hydroAMP has been implemented by the Bonneville Power Administration, Portland, OR, primarily for the Columbia River. USACE, BPA, and USBR are using it to program their maintenance funding. The hydroAMP tool is also in the initial stages of implementation in the southeast region of USACE.

Hydro Quebec

USACE's primary collaborator in the development of the embankment and spillway CIs was Hydro Quebec. Hydro Quebec later collaborated with other partners to develop a similar CI for concrete dams. Hydro Quebec has implemented all three of these CIs and uses them to prioritize their dam safety repairs. Other partners are in varying stages of implementation and usage of these CIs. Manitoba Hydro has also implemented all three CIs. Cemagref, the French dam safety agency, is implementing them as well.

USACE CI usage

In 1997 ERDC-CERL researchers performed a telephone survey of USACE Districts, talking to Chiefs of Operations as well as the engineers responsible for inspection of various types of structures for which ERDC-CERL had developed CIs. The Operations chiefs were asked whether they were aware of CIs and if their District used them. Of those surveyed, 41% were unaware of CIs and 56% reported their District did not use them. CIs were discussed in more detail with their engineers and some Districts were found to have used CIs despite a negative report from the Operations Chief. Discussions with the engineers included details about the CIs they had used, including their likes and dislikes. Results are summarized in Figure 24.

District Survey of REMR CI Usage - Summary Page (3/97)

Districts Surveyed	Chief of Op/ConOp Aware That:		CI Systems In Use (or Have Tried)		Likes	Dislikes	If Some or All CI's Not Now Used, Why Not
	CI's Exist	District Use of Them	Type	As Designed			
34	Y:12 (35%)	Y: 8 (24%)	-Coastal: 13	4	See Below	See Below	See Below
			-Lock Gates 13	6			
	N:14 (41%)	N:19 (56%)	-Lock Walls 10	5			
			-Hydropower 5	3			
	?: 8 (24%)	?: 7 (20%)	-Valves 4	2			
			-Dike/Revet. 2	1			
			-Tainter Gate 2	--			

(cwperf/dist-srv.sum)

Districts that use or have tried at least one system: 23 (68%)

Districts that use or tried a system according to the specified procedures: 13 (38%)

Major Likes
1. Provides systematic approach for assessing structures.
2. Establishes a baseline for comparison of structural condition.
3. Guides imspectors to take a more detailed and thoughtful look at structures.
4. Helps in prioritizing repair projects.
5. Helps in documenting defects and repair needs.
6. Provides some improved methods over what was used previously.

Major Dislikes
1. Takes too much time, $, and people to do (nearly universal response).
2. Procedures don't provide information that couldn't be obtained otherwise.

Why Systems are Not Used
1. Takes too much time, $, and people to do (nearly universal response).
2. Lack of organizational awareness that REMR assessment procedures exist.
3. Lack of trained people who know the procedures.
4. Didn't think they were useful.

Figure 24. CI usage summary page.

REMR CI usage

Some Districts (roughly 5–10) have made some use of CIs in their work during the past 5 years. Calls with questions are infrequent but sometimes concern maximum allowed displacements or come when an engineer has been assigned the job of implementing one or more CIs. This engineer is

frequently working with very little support, and no plan exists for incorporating the CI information into the District business process, whether it is annual and periodic inspections or M&R planning for the budget process. Even when these efforts are successful, the benefits are likely marginal because the effort is not fully integrated within the District business process. The weak integration also makes the effort susceptible to termination by intent or oversight, and many of the expected benefits are based on long-term data collection.

6 Current and Potential Benefits of CIs

After discussions with Headquarters, U.S. Army Corps of Engineers, field personnel, and other researchers, the CI research team believes that, in addition to using CIs to aid in work package prioritization, a number of other current and potential benefits can be realized with the use of CIs. Some of these additional benefits are common to all CIs, but others are specific to a smaller group of indexes.

Quantification of condition

The CI scale is a standard language for describing the general condition of a facility, which is the simple underlying intent of CIs. It was desirable to make the quantification as objective as realistically possible. Subjectivity varies between CIs. The use of numerical condition indicators allows for convenient data storage and handling by computer, and the condition indicators can be included in mathematical expressions. The quantification of condition makes most other benefits possible.

Identification of specific problems

With any inspection process, the possibility exists of finding unknown problems. As a standardized procedure with established items to look for, however, the CI inspection assists the engineer in inspecting and becoming more familiar with the structures. The gate CIs discussed in Chapter 3 implement inspection procedures not previously used within the Corps. The CI inspection procedures can also be used by project and area or District office personnel in identifying problems. Local personnel sometimes miss items that they walk by every day. At other times they understand that something is not right but cannot identify the cause. The CI inspection is intended to catch these items, as illustrated in Foltz et al. (2001), Anecdotal Case Histories (p 26). Specific problems can often be solved locally by minor adjustments or small fixes. Fixing items at this stage is, of course, very important so that small problems do not evolve into major ones.

Investigation of concerns

An obvious objective of CIs is to increase understanding (directly or as a communication tool) of a structure based on quantification of its condition. Additionally, most CIs provide some increased level of understanding

of specific problems. The gate CIs do the most to collect information that increases knowledge about the distresses. This source of information can be particularly important between dewaterings when much of the structure cannot be visually observed. (Diving may offer a method for limited visual inspection that is adequate for many specific concerns.)

The geotechnical area within the Corps has had limited application of risk analysis methods. The embankment dam CI may be a useful tool within this area for both small and large repairs. The evaluation process provides a framework for intense, focused discussion of areas of concern by geotechnical engineers. Although currently available information on performance parameters (being developed by Geotechnical and Materials Branch, Engineering Division, Directorate of Civil Works, Headquarters, USACE) is limited to one published manual (USACE EM 1110-2-2300), it appears that the embankment dam CI and performance parameters should be highly complementary. Together they could prove to be more valuable than when used as separate tools.

Creation of a condition history

Based on a set of CI condition histories, the rate of deterioration can be estimated, which has many potential uses in the budgeting process. CI historical information is useful in determining trends and planning out-year expenditures. It complements the periodic inspection process (see Foltz et al. (2001), Chapter 5, "CI Relation to Other Project Inspections"). CI information is often more concise and can be easier to use than contract documents or periodic inspection reports. Although it may not explain the entire situation, the quantified information is usually less ambiguous than descriptive narratives. Repetitive problems may be exposed by the review of CI information.

CI inspection information provides a systematic way to store data for future reference and comparison. Comparisons can be done with previous inspections at the same site and with inspections and performance at other sites with similar conditions (e.g., the same operating equipment, a similar anchorage design, similar gates). The consistent organization of the data seems essential for historical and diagnostic purposes. At the very least, it allows collection of data in a more systematic manner over the Corps domain as opposed to collecting data in a format that varies from site to site. With 30 years of data collected on every bridge in the National Bridge Inventory, the FHWA can more effectively manage its infrastructure. The da-

tabase has been available to researchers who have used it to predict bridge deterioration rates, study life-cycle performance, and even conduct reliability studies on networks of bridges.

Supporting documentation for presentation of decisions and prioritization of work

CI inspections and ratings provide reassuring information to managers for decisions that are often largely subjective in nature. It can increase the confidence of all parties in the decision process, including the engineers. Anecdotal experience indicates CI information has the greatest effect on budgetary and planning managers with limited engineering experience. These are often the people with whom engineers have the most difficulty communicating. CI information helps engineers clearly assert their position and reasoning.

CIs provide information that can assist in determining operational funding levels between Divisions and Districts, which are essentially independent operations with centralized funding distribution. CIs can be helpful in prioritizing work packages and could be used within a more comprehensive prioritization process.

Although it does not always present the whole picture, quantified inspection information can be used to assist in prioritizing more detailed risk analysis studies. Districts need better tools for determining whether to spend large amounts of money on the research and reports necessary to obtain rehabilitation funding. Additional tools based on CIs could be developed to better assist in these highly subjective prioritization decisions. This potential benefit is discussed further in Foltz et al. (2001), Chapter 4, "Reliability and Risk Analysis."

The embankment dam CI includes more analysis of repair priorities. This CI does a good job of quantifying the known geotechnical concerns and priorities for a project. It can be helpful in prioritizing geotechnical dam safety concerns and as a screening tool for piping and seepage problems. It also includes a process for evaluating monitoring and instrumentation priorities and provides a framework for the geotechnical engineers to determine and prioritize their concerns regardless of the current level of knowledge or analysis for specific concerns.

Information source for contracting scopes of work

This benefit is most clear for the coastal CIs. The CI database includes information on location and size of areas needing repair.

Quantification of condition for a project or a system

Project level "summary" CIs based on the component CIs have not been created as there has been some disagreement on the need for these summary indexes. Those opposed to summary indexes have looked primarily at the use of condition quantification information for reliability assessments. Others would like to have summary indexes for additional reasons that may be less important. These reasons include developing a system-wide condition history and developing a CI-performance relationship.

A system-wide condition record serves multiple purposes. If Congress continues to reduce budgets, it is important to know if this reduced funding is causing deterioration in projects and, if so, to have a measure of the severity of deterioration. Funding levels can be adjusted based on the trend in CIs or a target CI. CIs can also help in system management. This is particularly true for structures such as riverine dikes where the system may include thousands of dikes. CIs not only provide a means to communicate infrastructure needs within an organization to make more informed engineering and budgeting decisions, they also enhance communication to the Congress and the American people in a way that a non-technical person can understand. Since all CIs are based on a common 0-100 index, it could be shown, for example, that "in the past decade, the condition of miter gates has decreased from 65 to 55." Cost estimates can be made for restoring a previous condition, and future condition degradation can be estimated if no repairs are accomplished.

Investigations of M&R work packages submitted in the ABS system (discussed in Chapter 3) indicate that work within a single work package often cannot be appropriately reflected by a single CI rating. A method for combining multiple component CIs of single or multiple component types may be needed.

Use as a training tool

All CIs provide some guidance to technicians and new engineers who lack the experience to know what to look for when assessing condition and per-

formance of project structures. Some CIs (e.g., gates) go further and show engineers how to investigate the structures at a level of detail not covered by other inspection guidance. This is true for a gate in a dewatered state, but even more so under normal conditions when much of the gate is hidden under water. As previously stated, various CI procedures direct people to look at things they may not have checked before and to take measurements not previously done. Even experienced engineers can learn new skills based on a general CI approach and specific CI procedures.

The embankment dam approach to obtaining CIs is clearly a good training method. The process clearly illustrates the reasoning process used by engineers in their decision making by providing a framework that focuses on specific concerns. Both new and experienced engineers can learn what others observe about the dam.

Data source for detailed risk analysis

Risk analysis is data intensive. Often the desired data is unavailable. CIs can help when alternative methods must be used. This potential benefit is discussed further in Foltz et al. (2001), Chapter 4, "Reliability and Risk Analysis."

Provides simplified estimate of reliability

Detailed risk analysis is time intensive and expensive. Simplification of detailed procedures for initial review and prioritization of issues can be of limited value and misleading. Depending on the component CI, they can assist or be a substitute process for estimating reliability. This potential benefit is discussed further in Foltz et al. (2001), Chapter 4, "Reliability and Risk Analysis." Estes (2005) proposes a method for using CI ratings to estimate failure probabilities. The Institute for Water Resources (USACE) has also investigated the use of CI data for estimating reliability of hydropower components (Ayyub et al. 1996). They used actual data in their study, but it was at the component level not the distress level, which led to ambiguous results.

7 LRD and SWD Procedures for O&M Budget Prioritization

In 1999 Southwestern Division (SWD) initiated an effort to develop criteria for prioritizing O&M budget items. A similar effort by LRD and South Atlantic Division (SAD) soon followed. Northwestern Division (NWD) developed a method for prioritizing dam safety repairs during a similar time period. While the SWD and LRD tools were the most alike, they all shared similarities in approach if not the details. LRD and SWD collaborated on development of their tools, which merged together and then diverged only slightly in the end. They were based on the summation of five to seven parameters weighted according to importance. LRD's parameters were:

- Mission accomplishment (25%)
- Customer impact (25%)
- Economic benefits (20%)
- Non-Corps compliance issues (15%)
- Safety (15%)

Each parameter was scored according to descriptive criteria for the probability of adverse impact and the consequences of that impact. Each of these parameters was given a relative importance. An example chart for one of the LRD criteria is provided in Figure 25.

LRD and SWD had numerous difficulties developing criteria resulting in budget item priorities that matched their professional judgment. One such difficulty was solved by separately considering the probability of occurrence and the consequences. While the metrics for probabilities and consequences may prove to be too crude, the approach effectively separates the two issues. The working group also had difficulty arriving at a set of parameters. This difficulty resulted in LRD and SWD adopting differing sets of parameters and weighting the importance of these parameters differently. Neither Division seemed wholly satisfied with their solution. The remaining concerns included applicability and comparability across business lines and the more difficult question of how to rank items with indirect impact including inspections, studies, and many compliance-related budget items. Also, because the priority was based on scores for all five parameters, budget items based on one parameter did not score well. Profes-

sional judgment often determined that some of these items were very important, but some thought the rankings did not reflect this. The participants generally believed it was a very useful exercise for understanding ranking priorities in general and differences across Districts and business areas. The work made it clear that it is very difficult to develop objective ranking criteria, and the end result did not have the precision or detail to accurately rank all budget packages.

Risk Assessment Matrix MISSION ACCOMPLISHMENT		Severity of Consequences if work NOT performed		
		HIGH	MEDIUM	LOW
Probability of adverse impact if work NOT performed	HIGH	100	80	60
	MED	80	60	40
	LOW	60	40	20
Negligible / not applicable		0	0	0

Probability / likelihood of adverse impact to mission if work NOT performed during the Budget Year	Severity of Consequences if work NOT performed during the Budget Year
Level: High Description: System/component expected to lose its ability to perform a portion(s) of the project purpose(s) in end of BY.	Category: High Description: Catastrophic Definition: Loss or significant damage to system, equipment, facilities, item, public property, navigation reach, etc. Severely or totally restricts operations for Business Function / Mission.
Level: Medium Description: System/component could lose its ability to perform a portion(s) of the project purpose(s) in the BY.	Category: Medium Description: Critical Definition: Moderate damage to system, equipment, facilities, item, public property, navigation reach, etc. Moderate restrictions to operations for Business Function / Mission.
Level: Low Description: System/component not expected to lose its ability to perform a portion(s) of the project purpose(s) in the BY.	Category: Low Description: Marginal Definition: Minimal, if any, damage to system, equipment, facilities, item, public property, navigation reach, etc. Minimal, if any, restrictions to operations for Business Function / C3Mission.

Weight Factor = 0.25 Category: No Impact = 0 points

Figure 25. LRD prioritization criteria.

8 Federal Asset Management Mandates

Governmental Accounting Standards Board (GASB)

The mission of the GASB is "to establish and improve standards of state and local governmental accounting and financial reporting that will result in useful information for users of financial reports and guide and educate the public, including issuers, auditors, and users of those financial reports" (http://www.gasb.org/).

While GASB is intended to standardize financial information, GASB Statement No. 34 (GASB 34), *Basic Financial Statements and Management's Discussion and Analysis for State and Local Governments*, requires that infrastructure be included in financial accounting. Specifically, an asset valuation is required. While financial data by itself is insufficient for asset management, when available it provides a resource for assessing economics and possibly also understanding priorities. Note that an asset valuation is also required for completing the data submission for FRPC.

GASB34 includes two methods for asset valuation: (1) a depreciated historical value with depreciation and (2) a modified approach without depreciation and expensing preservation costs. In order to verify the preservation cost estimates, GASB34 requires condition assessment inspections every 3 years and comparison of estimated and actual maintenance and preservation costs for at least five reporting periods. GASB does not specify the condition assessment and rating methods to be used, only that they be replicable using a measurement scale. Valuing the assets in this way may seem like a lot of work, but the effort should be done in conjunction with an asset management plan; it provides useful information.

Program Assessment Rating Tool (PART)

PART is based on standardized worksheets containing a series of questions to evaluate the effectiveness of each government program. The Corps of Engineers evaluated nine programs using PART:

1. Coastal Ports and Harbors
2. Coastal Storm Damage Reduction

3. Corps Hydropower
4. Emergency Management
5. Flood Damage Reduction
6. Inland Waterways Navigation
7. Non-regulatory Wetlands Activities
8. Recreation Management
9. USACE Regulatory Program.

Most PART questions are directed toward performance measures, and PART does not specifically require an asset management program. Some questions address issues most easily accomplished within a sound asset management system. The PART evaluation for Corps hydropower specifically mentions hydroAMP in response to two different questions. Corps Hydropower is the only Corps programs to receive an "Adequate" rating.

Federal Real Property Council (FRPC)

Executive Order 13327, *Federal Real Property Asset Management*, directs all major agencies to develop asset management plans. It also created FRPC to establish guidance and best practices. The FRPC has identified and defined 23 mandatory property inventory data elements and performance measures that will be captured and reported by all agencies. The data elements required do not form the basis for an asset management plan, they are only inventory. An asset management plan requires additional data and the methodology for using the information to manage the assets. The 23 inventory data elements have been standardized across the government, but the accompanying asset management system has not been standardized. The 23 data elements are:

1. Real Property Type
2. Real Property Use
3. Legal Interest
4. Status
5. Historical Status
6. Reporting Agency
7. Using Organization
8. Size
9. Utilization (Performance Measure #1)
10. Value
11. Condition Index (Performance Measure #2)
12. Mission Dependency (Performance Measure #3)

13. Annual Operating and Maintenance Costs (Performance Measure #4)
14. Main Location
15. Real Property Unique Identifier
16. City
17. State
18. Country
19. County
20. Congressional District
21. ZIP Code
22. Installation and Sub-Installation Identifier
23. Restrictions.

Comparing FRPC and REMR condition indexes

One of the data requirements required by FRPC is called "condition index." It is unclear why they chose this term and whether they were aware of its use as an engineering condition rating. FRPC chose to use the label for a financial measure of asset condition. The FRPC CI is:

- CI = (repair cost) / (asset value)
- Life cycle cost analysis
- Periodic evaluation of all assets.

The FRPC documents provide no guidance on how to arrive at the repair cost and the asset value. The GASB organization has outlined two methods for determining asset value. Their guidance for determining repair cost, or "preservation cost" according to GASB, is by intent more loosely defined to give each organization the latitude to develop their own methods. Without guidance on determining repair cost from FRPC, GASB, or the specific organization, the repair cost can be highly subjective. This reduces the effectiveness of this metric (comparing apples to oranges).

From an engineering standpoint, the FRPC CI may be judged to have limited value. Since it is a required data point, however, it may be more beneficial to focus on how the information is collected and to what level detail and accuracy is determined. ERDC-CERL BUILDER, Navy LRMP, NASA, VA FCA, Army ISR, and other systems all include varying methods of determining repair needs and costs, and methods within those systems can be used in determining the FRPC CI.

9 Alternatives to REMR-Style Inspections

Introduction

REMR-style inspections are labor-intensive. Depending on the size and number of components, a trained team may need days to inspect every infrastructure component at a given Civil Works project. The original REMR documentation does not include guidance on inspection frequency or other application issues. Recommendations for frequency of REMR inspections were subsequently published in McKay and Foltz (2005), but they apply to only a few CIs. In the meantime, many project managers had assumed it was necessary to perform intensive CI inspections frequently, such as on an annual basis. That perception caused many to question the benefits of the REMR CIs as compared with the investment necessary to implement them. In any asset management program, consistent quantitative knowledge of past, present, and expected future condition and performance of infrastructure is essential to evaluate and prioritize project work packages. However, it typically should be possible to develop that kind of information without completing full REMR-style inspections annually. Less frequent intensive inspections coupled with less intensive and/or issue-focused assessments should provide acceptable benefits at a lower cost.

Multi-level condition assessment

The REMR-style inspections provide an in-depth and detailed understanding of the condition and performance of selected infrastructure components. But it is often the case that O&M managers may require only a very specific piece of information or perhaps only a general assessment of overall condition. A multi-level condition assessment (MLCA) matches the complexity of the required output to a corresponding level of resource investment. For example, why perform a full REMR-style inspection if one is only interested in existing leaks or corrosion levels?

An MLCA is where well-defined levels of inspections of varying complexity, requiring corresponding levels of resource investment, are standardized and matched according to the type of data needed. A lower level MLCA may be performed at a desk by simply opening a file containing the most recent inspection information. A higher level may require a field visit

to the project, but subjective observations such as the spillway component rating checklists may suffice. If an engineered measurement is required, then a more sophisticated inspection such as traditional REMR CI is done. When adopting an MLCA approach, keep a fundamental objective for asset management in mind: condition assessments still need to be consistent, with repeatable results, open, and meaningful to all involved stakeholders.

Simplified inspection processes

While some interim results for simplifying existing REMR inspections to fit into an MLCA approach were a success, funding did not allow full development. Simplified traditional REMR inspection processes developed for tainter gate, miter gate, and lockwall CIs focused on eliminating time consuming parts of the REMR inspection process that had relatively small impact on the overall picture. The idea was to reduce the level of required effort while preserving the integrity of the resulting CIs. Another effort was the development of simplified checklists that could be filled out individually or by group consensus. The checklists for embankments and spillways were set up so that a consistent result could be obtained; although this requires that the person or group checking items is very familiar with the infrastructure component in question.

Other aspects of MLCA and simplified processes address the type and frequency of inspections. In some cases, only a statistically significant sample was recommended for inspection. For a structure with over 20 tainter gates, perhaps only those with known deficiencies need be inspected with the result extrapolated in a formal manner to the remaining gates.

Risk applications for CIs in asset management

One of the known advantages of doing REMR-style inspections is that the systematic inspection process itself demonstrates much about how the structure behaves and how it is likely to behave. The process of obtaining the CIs can often tell you more than the CIs themselves do. Practically speaking, not everyone is going to personally perform REMR-style inspections but, if they did, the experience and data would provide insight for any given component on the probability of failure, an estimate of future performance, and they would be forced to at least consider the risk or consequences involved by delaying execution of certain work packages. These conclusions are drawn from observations in the field and a long history of feedback from personnel who have participated in REMR-style inspec-

tions. Therefore, much work must be done to ensure that these conclusions can be reached deterministically.

The primary advantages of CIs within risk management are (1) the knowledge of the structures gained by using the CI process and (2) the benefits of having quantified condition ratings that can be used when considering current condition and changes in condition over time. Additionally, the embankment dam and spillway CIs are based on relative risk determinations. This is an alternative with clear advantages and disadvantages relative to traditional risk analysis. Circumstances will dictate the relative merits of this approach for the organization.

Observations on condition index policy

REMR-MSs were developed with the expectation that consistent application would help project managers more effectively identify and prioritize M&R and justify requests for limited O&M dollars. By tracking infrastructure condition over time with REMR CIs, trends could be documented and visualized to help users better understand the impact of funding level on the "health" of the infrastructure. USACE might therefore be in a better position to defend its budget requests. In general, however, that did not happen, and two reasons for that are worth noting:

1. CIs are only a small part of an asset management program; too much focus and unrealistic expectations were placed solely on CIs in a manner that they were incapable of meeting. The knowledge from the CI inspection process must constitute only a piece of a larger picture that supports professional judgment – not supersede or replace it. One cannot and should not consider or prioritize work packages on CI information alone, but this data should become a fundamental part of a systematic process.
2. The funding for a CI program must be accomplished corporately. Division or District budgets must contain a line item for a CI program. In the past, Districts had to find the funding on their own. This program needs support and permanency at all levels of command to succeed. Unfunded mandates nearly always get a disappointing reception.

A CI program, as a part of an overarching asset management policy or other condition assessment procedure, must be an open process, available for all to see, accepted and enforced by all stakeholders but especially by a headquarters proponent. The program must provide a convincing metric

that is used in a manner that all concerned can understand. At one point in CI history, CIs became a required part of the budget submissions as outlined in the annual O&M budget Engineer Circular. Reportedly, Districts submitted the required information, but it was not used to make budget decisions.

10 Conclusions

The terms “condition assessment” and “condition index” mean different things to different people. Even with agreement that they are based on an engineering evaluation that includes some sort of standardized inspection of the infrastructure components, the assessment methods and basis for condition assessment and rating can vary significantly. This report discussed some of these differences within the REMR CIs and even bigger differences in non-REMR condition assessment methods. The goals of the assessment and the type of infrastructure being inspected can have large impacts on the suitable methodology. Condition assessments for the NASA model and BUILDER™ may result in similar ratings, but the detail of the data (and thus its utility) is significantly different. The costs and benefits of these two approaches also vary significantly. Gates and levees differ in what can be observed and measured. This may lead to significantly different inspection methods, measurement techniques, targeted accuracy, and other variations. One difficulty created by these differences in objectives and in the infrastructure components themselves is that it becomes very difficult to use the resulting information in a holistic asset management approach. There are no easy answers for addressing these problems, but the limitations that currently exist should not be used as an excuse to ignore condition assessment and inspection.

Condition assessment information is only one aspect of the understanding needed to maintain infrastructure. Repairs may be based on any one of many combinations of condition, function, risk, economics, and priorities. It is important to consider all of these factors when prioritizing budgets, but some work package benefits cannot easily be quantified according to even these five broad factors. For example, inspections such as annual and periodic are needed regardless of their benefits relative to other work packages. The FRPC has mandated that certain steps be taken to improve asset management. While the benefits of these actions vary based on the specifics of what is implemented, such an asset management plan offers yet another example of budget items that are not easy to prioritize against other funding needs.

This report discussed the condition assessment capabilities of REMR CIs and numerous non-REMR CIs and condition assessment tools. These tools

vary greatly in methods, level of detail, and results. While some have more advantages than others, it is important to realize that the asset management goals must be understood to select the most appropriate condition assessment approach. It is hoped that this summary of condition assessment tools will help match the condition assessment goals to example approaches.

One condition assessment goal is to develop a quantitative measure or "report card" of the status of an inventory of infrastructure. The report card might be compared to the ASCE report card on the health of the nation's highways, bridges, waterways, etc. If this report card were based on condition index style ratings, it would have the advantage of being more objective and defendable than the ASCE report card. The report card should rate infrastructure for all of the routine Civil Works business functions. The product will represent current condition and operability states, and these ratings could be compared with future ratings to improve understanding of the changes in infrastructure condition and how that is affecting the operational environment.

Within the USACE community, condition assessment and particularly CIs have been maligned for what they do not do. From the budgeting viewpoint, it is true that CIs are not a measure of repair priority. Condition is only one of many factors that should be considered in the budget prioritization process. Other factors include infrastructure performance, risk, economics, policies, and priorities. Condition indexing also draws complaints as a relative rather than absolute measure of risk. This also is absolutely correct, but recent work by Estes et al. (2005) begins to bridge this gap. Regardless of how risk is determined, the reality is that, until the Corps has a substantial database of performance data on which to base failure rates, all risk methods used within USACE will have limitations. In that environment, CIs and condition assessment in general provide complementary data that can help improve risk methods. The FHWA has 30 years of data collected on every bridge in the National Bridge Inventory. The database has been used to predict bridge deterioration rates, study life-cycle performance, and even conduct reliability studies on networks of bridges. FHWA's use of this database can be looked at this as an example of how condition assessment data can enhance infrastructure management.

REMR-style CIs have many alternatives for performing condition assessment. All such methods have distinct advantages and disadvantages. It is most important that the user's objectives be explicitly determined prior to judging the merits of a condition assessment methodology.

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Appendix: REMR Technical Reports

Copies of these reports are available from the National Technical Information Service, 5285 Port Royal Road, Springfield, VA USA 22161. Hyperlinks to downloadable PDF versions are included below. In the case of multiple reports on the same subject, the most recent report is hyperlinked.

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14. ABSTRACT

Central to a comprehensive asset management program is the ability to evaluate and know the condition and performance characteristics of all inventoried assets in the real property inventory (Federal Real Property Council [FRPC] Guidance, Section 4 "Operations of Real Property Assets"). In the case of the U.S. Army Corps of Engineers (USACE) Civil Works business area, this inventory includes an enormous array of multi-purpose dams, locks, levees, and hydropower generation facilities (as well as buildings, roads, and bridges).

This report is a digest of condition assessment methodologies for Civil Works infrastructure. Included in the digest are insights and observations collected by the research team over the duration of the Repair, Evaluation, Maintenance, and Rehabilitation (REMR) Program that are pertinent to any organization interested in developing an asset management program. This digest is intended to be used in creating a USACE asset management program that also follows FRPC guidance.

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