Repair, Evaluation, Maintenance, and Rehabilitation Research Program

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REMR Management Systems— Navigation and Reservoir Structures Condition Rating Procedures for Concrete in Gravity Dams, Retaining Walls, and Spillways

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Preface

The study reported herein was authorized by Headquarters, US Army Corps of Engineers (HQUSACE), as part of the Operations Management Problem Area of the Repair, Evaluation, Maintenance, and Rehabilitation (REMR) Research Program. The work was performed under Civil Works Research Work Unit 32672, "Development of Uniform Evaluation Procedures/Condition Index for Deteriorated Structures and Equipment," for which Stuart D. Foltz is Principal Investigator. Mr. James E. Crews (CECW-O) is the REMR Technical Monitor for this study.

Mr. David B. Mathis (CERD-C) is the REMR Coordinator at the Directorate of Research and Development, HQUSACE. Mr. Crews and Dr. Tony C. Liu (CECW-EG) serve as the REMR Overview Committee. Dr. Anthony M. Kao was the Problem Area Leader for the Operations Management problem area during this study. Mr. David T. McKay is the current Problem Area Leader for the Operations Management problem area.

This study was performed under the general supervision of Dr. Paul Howdyshell, Chief of the Engineering and Materials Division (FM), Infrastructure Laboratory (FL), US Army Construction Engineering Research Laboratories (USACERL); and under the direct supervision of Dr. Anthony M. Kao. The Program Manager for REMR is Mr. William F. McCleese, US Army Engineer Waterways Experiment Station (CEWES). The USACERL technical editor was Linda L. Wheatley, Technical Resources Center.

Permission to use the copyrighted material from *Guide for Making a Condition Survey on Concrete in Service* was obtained from the American Concrete Institute.

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COL James T. Scott is Commander and Acting Director, USACERL, and Dr. Michael J. O'Connor is Technical Director.

Conversion Factors, Non-SI to SI Units of Measurement

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
degrees (angle)	0.01745329	radians
feet	0.3048	meters
gallons (US liquid)	3.785412	liters
inches	25.4	millimeters

1 Introduction

Background

The US Army Corps of Engineers operates approximately 270 navigation dams, usually with accompanying attachments and appurtenances, constructed of plain or reinforced concrete. The Corps of Engineers also operates more than 350 reservoir dams, most of which are either concrete gravity structures or embankment structures with accompanying attachments and appurtenances constructed of plain or reinforced concrete. Many of these structures require or will require significant repairs to ensure safe and efficient operations. A quantitative rating system for the condition of concrete in gravity dams and attachments and appurtenances provides objective information to aid in making the subjective decision of which dam, which structural unit within a dam, and which deficiency within a structural unit most merit repair. Successive ratings with time would provide a measure of the rate of deterioration. The methodology for such a system was originally developed for pavement (Shahin, Darter, and Kohn, 1976-1977) and has been used previously for navigation locks (Bullock, 1989).

Purpose

The purpose of this report is to describe a proposed system for determining a condition index (CI) value that numerically rates the condition of concrete in a gravity dam, retaining wall, or spillway structural unit on a scale of 0 to 100 (Table 1) by evaluating each concrete deficiency. The deduct values for individual structurally related distresses were developed based on expected performance under extreme loading conditions. Most serviceability related distresses have only nominal deduct values.

Table 2 groups the condition index values into three zones that are related to engineering and management actions. The zone into which a structure's condition rating falls cannot be used as an absolute determination of the required action. Final determination of maintenance and repair needs will require engineering judgment or a more detailed engineering investigation. For example, a structure with only deck distresses would have a condition rating in zone 1 that calls for no further action; however, the deck may require substantial repairs. Likewise, multiple wide cracks through the structure would result in a zone 3 rating requiring further investigation.

Table 1. Condition index scale.

Value	Condition	Description
85 to 100	EXCELLENT	No noticeable defects. Some aging or wear may be visible.
70 to 84	VERY GOOD	Only minor deterioration or defects are evident.
55 to 69	FAIR	Some deterioration or defects are evident, but function is not significantly affected.
40 to 54	MARGINAL	Moderate deterioration. Function should be adequate under expected maximum loading.
25 to 39	POOR	Serious deterioration in at least some portions of structure. Function may be inadequate under maximum load.
10 to 24	VERY POOR	Extensive deterioration. Function inadequate.
0 to 9	FAILED	No longer functions. General failure or failure of a major component is likely under maximum probable load.

Table 2. General interpretation of the condition.

Zone	CI Range	Action
1	70 to 100	Immediate action is not required.
2	40 to 69	Economic analysis of repair alternatives is recommended to determine appropriate maintenance action.
3	0 to 39	Detailed evaluation is required to determine the need for repair, rehabilitation, or reconstruction.

This investigation may or may not result in a determination that maintenance and repair is necessary.

Scope

The CI prescribed herein applies only to the concrete in gravity dams and attachments or appurtenances such as retaining walls, spillways, and bridge piers. Other factors that are not rated, such as foundation deterioration, also can affect the safety of a dam or appurtenance. These unrated problems should be noted and a more detailed investigation can be recommended. Other elements such as spillway gates and machinery require a separate rating system. Under no circumstances should the CI of the concrete be taken as the overall CI of the structural unit or entire structure.

The rating system described herein allows the CI to be determined by visual investigation using limited equipment. The rating is related primarily to structural integrity and secondarily to serviceability. An expanded investigation including engineering evaluations should be made when the CI is 40 or below. A CI greater than 40 does not indicate that an expanded investigation is unnecessary.

Mode of Technology Transfer

It is recommended that the inspection procedures developed in this study of concrete in gravity dam monoliths, retaining walls, and spillways be incorporated into Engineer Regulation (ER) 1110-2-100, "Periodic Inspection and Continuing Evaluation of Completed Civil Works Structures."

Approach

The concepts and ideas presented in this report for the maintenance management of concrete in gravity dams, spillways, and retaining walls rely heavily on work in a similar project for concrete in lockwalls (Bullock, 1989). During that earlier work, basic ideas such as structural considerations, condition indexes, safety and serviceability, quantification of distresses by field measurements, repair and maintenance alternatives, and others began to evolve. As these concepts were applied, several enhancements and some new ideas have been used.

Using a tentative inspection procedure and a set of inspection rules, a panel of Corps of Engineers experts were assembled to field test the system. The panel conducted site visits and field investigations at diverse dams and met with Corps personnel associated with these structures. At each site, improvements to the inspection and rating procedures were made by the experts.

The goal of the inspection is to objectively determine deficiencies and calculate a condition index with this data. A CI is a numerical measure of the current state of a structure. One of the goals of this project is to define a CI that uniformly and consistently describes and ranks the condition of the concrete in a gravity dam, retaining wall, or spillway structural unit. The index should focus management attention on those structures most likely to warrant immediate repair or further evaluation. Second, the CI values can be used to monitor change in general condition over time and can serve as an approximate comparison of the condition of different structures. The CI, a numbered scale from 0 to 100, indicates the relative need to perform REMR work because of deterioration of the general operating and structural characteristics of the structure (Table 1).

2 Development

General

The CI procedure was developed by assigning specific deduct values to concrete defects defined in Appendix A, "Guide for Making a Condition Survey of Concrete in Service," American Concrete Institute (ACI) 201.1R-92. Other distresses related to concrete in dams were added. Primary deduct values were determined with the intent of obtaining a CI of 40 when the severity of an individual distress caused the safety of that monolith to become questionable. Nominal deduct values were assigned for most defects in serviceability. The deduct values are, in part, subtracted from 100 to establish the CI. The exact method of calculating the CI from the deduct values was determined by collecting subjective expert ratings based on the condition descriptions in Table 1. The system is designed to be independent of the inspector; however, field experience with different trained inspectors rating the same structural units has shown that a variation of ±10 in the CI for a structural unit can be expected. The variation can be greater if the inspectors have not received formal training in the use of this system.

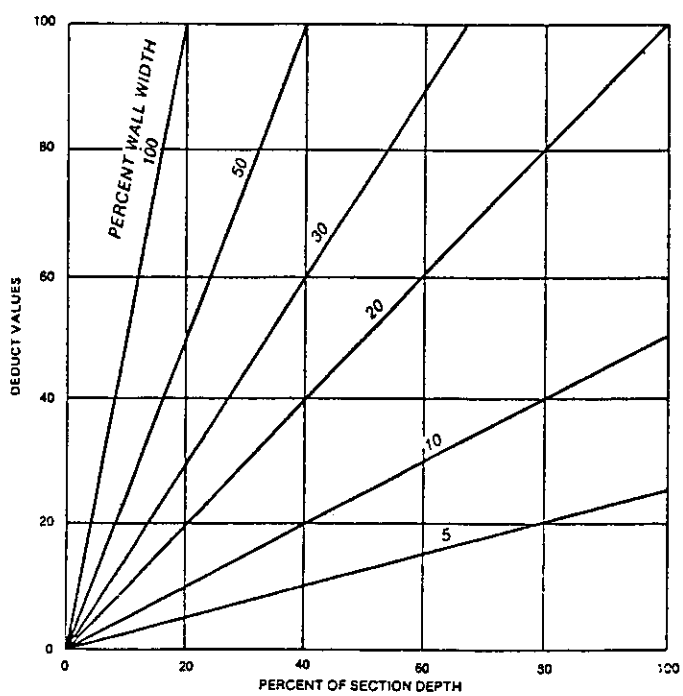
Cracking

Since calculation of shear transfer across cracks in a structural unit subjected to bending is impractical in the present state of the art, all deduct values for cracks were set by judgment, recognizing that shear transfer would decrease as cracks widen.

Volume Loss

Deduct values for distress categories that tend to result in loss of effective concrete were determined both for units subject to lateral load and for units subjected primarily to axial load. For units subject to lateral load and distresses that tend to result in loss of concrete from the structure (volume), and thus loss of effective weight and cross section, deduct values were assigned by making approximations concerning safety, assuming (1) all sections were cracked so that no tension or cohesion existed at the section and, (2) the total force tending to produce sliding or total moment tending to produce overturning was constant. Although the first assumption is conservative, the second may not be. Changes in ground-water level, uplift pressures, or active pressure of backfill may result in some increase in force or moment. However, as previously stated, a detailed investigation of such factors and an engineering evaluation should be made when the CI is determined to be 40 or below. This practice will prevent excessive reduction in safety factors before remedial action is taken.

Safety against both sliding and overturning was considered. The percentage of cross section in compression was determined to be the critical consideration. If a criterion of maintaining 75 percent of the undeteriorated cross section in compression is used, and it is assumed that the section was originally designed with the resultant force at the kern boundary, then losses greater than a 12-percent reduction in cross-section depth and weight on 100 percent of the wall width on that cross section as a result of deterioration exceeds this criterion. A deduct value of 60 was set for a depth reduction of 12 percent on 100 percent of wall width, and all other deduct values were determined linearly (Figure 1). It may be more convenient to use the equation below the figure to calculate the deduct value. For units subject primarily to axial loads, such as pier stem columns supporting bridges, the deduct value was set as 1.1 times the percentage of deteriorated cross-sectional area to account for the possible development of eccentricities.



$$\text{DEDUCT VALUE} = \left(\frac{\text{\% of wall width effected}}{20} \right) \left(\text{\% of depth reduced} \right)$$

Figure 2. Volume loss deduct values for vertical and near-vertical surfaces.

3 Methodology

Procedure

The CI is determined by visual inspection and recording the needed information on the field inspection form (Figure 2) for computer input. Examples of completed inspection forms are in Appendix B. The field inspection form provides space for inspection details and accumulates data for input to a PC-based REMR Management System currently being developed at USACERL. A REMR Management System typically consists of four modules: inventory and data management, condition inspection and assessment, maintenance and repair alternatives, and life cycle cost analyses. The condition assessment module will calculate the CI using the algorithm developed in this report. The accumulation of such data using the management system affords managers a quantitative means of comparing the condition of concrete in one structure to the concrete in others. In time this accumulation of data also will provide curves yielding rates of concrete deterioration in structural units. More details of the REMR Management System will be described in a separate report.

For the purpose of data management, identification numbers are needed for each unit being inspected. The structural unit or section numbers such as those in construction drawings can and should be used. Construction or as-built drawings of the structure also are necessary to determine such factors as physical dimensions, reinforcing details, and so forth, which are needed for the inspection. If repairs have been made, drawings of the repairs are necessary to determine the extent of the repair and to provide other information such as the location of post-tension tendons. During inspection, equipment to clean areas and remove debris from cracks and equipment to estimate crack widths is required. Although all structural units should be visually inspected if possible, it may not be advantageous to determine the CI of all structural units. The CI should be determined on one of each type of unit and on the more distressed structural units. It is recommended that a minimum of 20 percent of all monoliths and at least three of the structural units be rated.

DAM MONOLITH FIELD INSPECTION FORM

Dam: Monolith#:

Date: Inspector:

Are there any indications of misalignment? Yes / No

Location Codes: UF-Upstream Face DF-Downstream Face P-Pier D-Deck S-Spillway RW-Retaining Wall F-Floor G-Gallery T-Tunnel C-Conduit
Structural Loading: L-Lateral Loads A-Axial Loads

Distress Codes: 21-CH-Checking 22-DC-D-Cracking 23-PA-Pattern 24-HZ-Horizontal 24A-HZA-One Side Gallery 25-VT-Vertical&Transverse 26-VL-Vertical & Longitudinal 26A-VLA-One Side Gallery 27-DG-Diagonal 28-RN-Random 29-LF-Longitudinal Floor 31-AB-Abrasion 32-CV-Cavitation 33-HC-Honeycomb 34-PO-Popouts 35-SC-Scaling 36-SP-Spalling 37-DS-Disintegration

CRACKING DISTRESSES

1	Category:	Width:	(in.)	L A	UF	DF	P	D	S	RW	F	G	T	C

Remarks: ____

2	Category:	Width:	(in.)	L A	UF	DF	P	D	S	RW	F	G	T	C

Remarks: ____

3	Category:	Width:	(in.)	L A	UF	DF	P	D	S	RW	F	G	T	C

Remarks: ____

4	Category:	Width:	(in.)	L A	UF	DF	P	D	S	RW	F	G	T	C

Remarks: ____

5	Category:	Width:	(in.)	L A	UF	DF	P	D	S	RW	F	G	T	C

Remarks: ____

VOLUME LOSS TYPE CRACKING / DETERIORATION

1	Distress Category:	L A	UF	DF	P	D	S	RW	F	G	T	C	

Distress: width ____ depth ____ height ____ elevs. ____
Section: width ____ depth ____ (at elevation of distress)
Remarks: ____

2	Distress Category:	L A	UF	DF	P	D	S	RW	F	G	T	C	

Distress: width ____ depth ____ height ____ elevs. ____
Section: width ____ depth ____ (at elevation of distress)
Remarks: ____

Monolith#:

LOCATION CODES: UF-Upstream Face DF-Downstream Face P-Pier D-Deck S-Spillway RW-Retaining Wall F-Floor G-Gallery T-Tunnel C-Conduit

STEEL

42-Reinforcing (percentage of bars exposed at X-section)
43-Prestress (any exposure or indicated corrosion)

42 43	UF DF P D S RW F G T C	____ %	Remarks: ____
42 43	UF DF P D S RW F G T C	____ %	____
42 43	UF DF P D S RW F G T C	____ %	____

OTHER

36-Spalled Joint 41-Corrosion Stain 44-Damaged Armor 51-Leakage
52-Deposits (Moderate Leakage <10 gpm, Moderate Deposit <1/2" thick)

36 41 44 51 52	UF DF P S RW G T C	LIT MOD HVY CRIT	Remarks:
36 41 44 51 52	UF DF P S RW G T C	LIT MOD HVY CRIT	
36 41 44 51 52	UF DF P S RW G T C	LIT MOD HVY CRIT	
36 41 44 51 52	UF DF P S RW G T C	LIT MOD HVY CRIT	
36 41 44 51 52	UF DF P S RW G T C	LIT MOD HVY CRIT	

Sketches or Comments (Include any indications of foundation or alignment problems) -

* REMARKS: In all instances describe distress locations as completely as possible. Use the monolith's deck, faces or joints as datums. When applicable, as in volume loss, distress width and depth may be expressed as percentages of section width or depth at given elevation. For volume loss in decks, indicate the percentage of the deck area that is affected.

Figure 2. Field inspection form.

The inspection and condition assessment procedure for determining the CI described in this report is based on simple visual inspection techniques. If the condition of the structure being inspected has deteriorated severely, e.g., the CIs determined by the visual inspection are below 40, more detailed inspections are warranted. More detailed inspections could include a number of actions, such as (1) using divers, (2) drilling cores and using borehole cameras, (3) installing instruments to monitor crack width variation, (4) using soniscope surveys, and (5) making dye tests. Additional details are given by Stowe and Thornton (1984).

Distress Categories and Deduct Values

Distress categories discussed in this section are listed in Table 3. Each category discussion includes guidance on how to determine deduct values. Appendix A reproduces ACI 201.1R-92 and contains photographs illustrating types of concrete defects. An inspector should be familiar with this guide before performing an inspection to determine the CI.

Table 3. Distress categories.

Alignment
Cracking
21 CH Checking 22 DC D-cracking 23 PN Pattern 24 HZ Horizontal 25 VT Vertical and transverse 26 VL Vertical and longitudinal 27 DG Diagonal 28 RN Random 29 LF Longitudinal floor
Volume loss
31 AB Abrasion 32 CV Cavitation 33 HC Honeycomb 34 PO Popouts 35 SC Scaling 36 SP Spalling 37 DS Disintegration
Steel deterioration
41 CS Corrosion stains 42 RE Reinforcing 43 PS Prestressing 44 AR Armor
Leakage and deposits
51 LK Leakage 52 DP Deposits

Alignment

Alignment problems - misalignment or distortion - may result from such factors as construction procedures, load deflection, foundation movement, and concrete growth. Alignment problems do not have deduct values herein, although if present, alignment problems limit the CI to a maximum of 40. Other effects that result from the same causes as misalignment may have deducts, and any misalignment should be examined for a pattern that would indicate a cause. Is there a deflection pattern that would result from normal or abnormal loads? Is a structural unit(s) displaced uniformly, horizontally, or vertically, or does the displacement indicate a rotation? Is there a variation in joint or crack openings? If possible, a deduct value from one of the distresses herein should be assigned. If a foundation problem is indicated, a foundation investigation should be initiated. Unexplained alignment problems should be noted on the inspection form and brought to the attention of the proper official.

Cracking

For cracking distresses on decks no deduction is made unless cracks are raveling, 5 points are deducted for a small amount of raveling, and 10 points are deducted if disintegration or ponding is present. All surface defects on decks (categories 21 to 23, 34 to 37, and raveling of other cracks) are to be considered together so as to have only one deduct value for the deck. For volume loss distresses, 5 points are deducted for no more than 25 percent of the deck area affected and 10 points for more than 25 percent. If volume-loss surface defects on decks (categories 34-37) occur in combination with raveling cracks, only 5 points are deducted unless more than 25 percent of the deck area is affected by distresses 34 to 37 or unless ponding is occurring. The maximum deduct for decks is 10 points.

A number of crack categories are provided. The first three, checking (21), D-cracking (22), and pattern cracking (23), are generally shallow surface effects that tend to result in loss of concrete. Deduct values are selected based on estimates of depth and extent, similar to volume loss deterioration (31 to 37), rather than on crack width. For these three cracking distresses (21-23), use the same methods of calculating deduct values as for the volume loss distresses.

The other categories of cracking - horizontal (24), vertical and transverse (25), vertical and longitudinal (26), diagonal (27), random (28), and longitudinal floor (29) - have deduct values dependent on crack width. A table of deduct values based on crack width is included with the description of the crack type. In addition, Appendix D graphically shows the deduct values versus crack width. A crack's width should be determined or estimated where it is widest, and measurement should be to the nearest one-hundredth inch. Although measurement to the nearest five-thousandth inch, especially for narrow cracks, may be beneficial for historical comparison, it will have negligible effect on the deduct values or condition index. Representative crack illustrations are shown in Figures 3 and 4. Two or more cracks from base restraint generally join to form one wide crack at some distance above the base. Some cracks do not easily fit into a specific category. For example, a crack that is generally horizontal may slope upward to intersect a sloping face at an approximate right angle. Such a crack would be evaluated as a horizontal crack. Although a crack may be observed on more than one surface, it should be deducted only once. If a crack has raveled at a surface, width should be estimated where raveling has not enlarged the crack. Repairs to these types of cracks are generally made by grouting and stitching and are effective as long as the grout does not crack or debond or otherwise show distress. If a crack is stitched without grouting, it will probably be necessary to do continuous monitoring of the crack width to determine whether the repair is fully effective. Any relative shear displacement along a crack of one part with respect to the part on the other side of the crack indicates a misalignment, and calculation of the condition index is limited to values no greater than 40. This concern is considered appropriate even though redistribution of loads may have prevented collapse. Deduct values listed with each category allow for no relative displacement along the crack. If a crack produces a spall with a deduct value less than that of the crack, then the deduct for the spall should be used. This should not be confused with spalling that occurs along a crack. Cracks in otherwise sound, unbonded floor toppings do not have deduct values unless they are raveling.

Checking (category 21). Checking cracks are relatively shallow surface cracks at closely spaced but irregular intervals.

D-cracking (category 22). D-cracks form progressively on a concrete surface as a series of fine cracks at close intervals; they form randomly but parallel with edges, joints, and major cracks. Exudations frequently form along the cracks. It is usually advisable to core concrete exhibiting severe D-cracking to determine the depth of deterioration and for examination by a petrographer to determine cause.

Pattern cracking (category 23). Pattern cracking results from a relative volume change of interior and exterior concrete. Pattern cracking together with distortion generally indicates a volume increase such as occurs from alkali-aggregate reaction. The effect is generally shallow, less than 1 ft. Extensive pattern cracking makes coring advisable to determine depth and cause. Pattern cracking may progress to disintegration. The effect of cycles of freezing and thawing also contributes to further deterioration of concrete with pattern cracking.

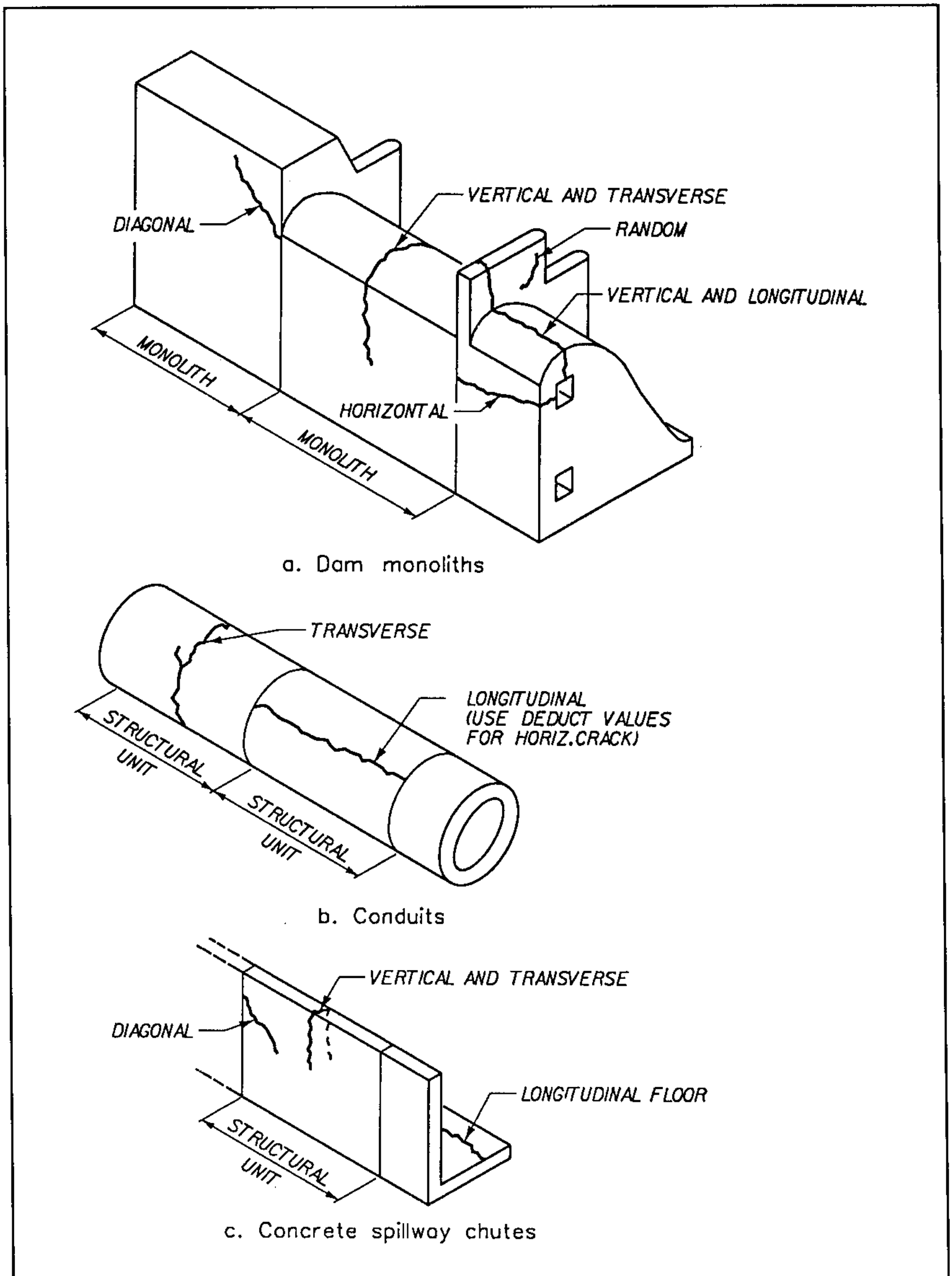
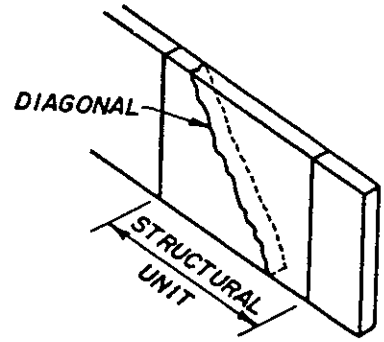
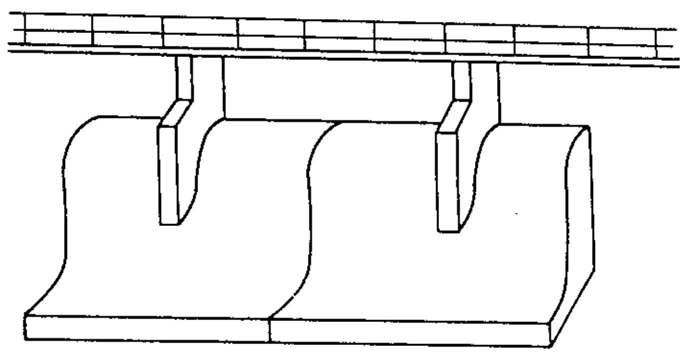


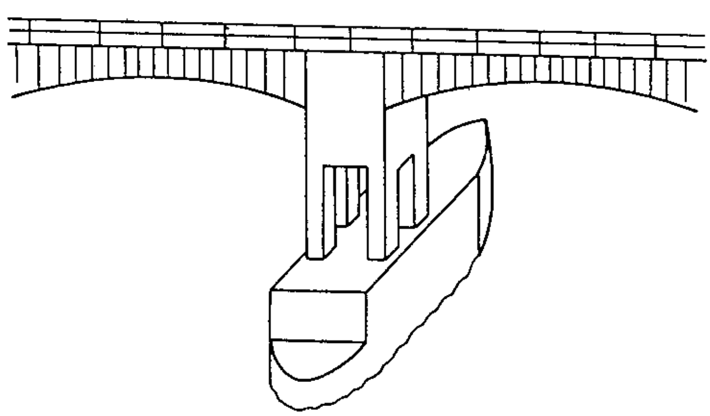
Figure 3. Simplified crack representations.



d. Retaining Wall



or



e. Piers

Figure 4. Simplified crack representations.

Horizontal cracking (category 24). Horizontal cracks may be created by thermal or other volume changes, and they may be at lift joints or may go to culvert or gallery openings. Deduct values are assigned as follows for concrete under lateral or axial loading:

Crack widths, in.		Deduct values
Very fine	≤0.01	5
Fine	>0.01, ≤0.04	width X 500
Medium	>0.04, ≤0.08	20 + (width -.04) X 375
Wide	>0.08	35

For cracks on only one side of a gallery in lateral loaded elements, deduct values are one-half the above.

Vertical and transverse cracking (category 25). Vertical and transverse cracks may initially be caused by thermal or other volume changes and may go to machinery openings or anchorages. Deduct values are assigned as follows for concrete under lateral or axial loading:

Crack widths, in.		Deduct values
Very fine	≤0.01	5
Fine	>0.01, ≤0.04	width X 500
Medium	>0.04, ≤0.08	20 + (width - .04) X 375
Wide	>0.08	35

For cracks on only one side of a gallery in lateral loaded elements, deduct values are one-half of the above.

Vertical and longitudinal cracking (category 26). Vertical and longitudinal cracks may be initiated by thermal or other volume changes, go through machinery openings or anchorages, or go to galleries or culverts.

Crack widths, in.		Deduct values
Very fine	≤0.01	10
Fine	>0.01, ≤0.04	2.5 + width X 750
Medium	>0.04, ≤0.08	32.5 + (width - .04) X 687.5
Wide	>0.08	60

All vertical cracks in axially loaded members are to be considered transverse. For cracks on only the top side of an upper gallery or duct bank in a laterally loaded element or in axially loaded concrete, deduct values are one-half of the above. The longitudinal direction in a pier is to be considered the same as the longitudinal direction in the body of a dam. For longitudinal cracks in closed conduits, use deduct values for horizontal cracking regardless of orientation.

Diagonal cracking (category 27). Diagonal cracking usually results from an overload, which may result from structural distortion. Such cracks may be through an entire structural unit, a partial structural unit adjacent to shear keys between structural units, a culvert wall or wall segment, or an anchorage. A crack bounding a spall created by compressive forces at a contraction joint should be evaluated as a spall. Deduct values are assigned as follows for concrete under lateral or axial loading:

Crack widths, in.		Deduct values
Very fine	≤0.01	15
Fine	>0.01, ≤0.04	6.67 + width X 833
Medium	>0.04, ≤0.08	40 + (width - .04) X 625
Wide	>0.08	65

Random cracking (category 28). Random cracks may form in plastic or hardened concrete. It is advisable to thoroughly investigate such cracks to ensure that they are really random and not associated with embedded metal or trapped water freezing. In such cases, deduct values for a spall (category 36) are to be used. Deduct values are assigned as follows for concrete under lateral or axial loading:

Crack widths, in.		Deduct values
Very fine	≤0.01	10
Fine	>0.01, ≤0.04	5 + width X 500
Medium	>0.04, ≤0.08	25 + (width - .04) X 625
Wide	>0.08	50

Longitudinal floor cracking (category 29). Longitudinal floor cracks are evaluated only in reinforced U-Frame spillway chutes.

Crack widths, in.		Deduct values
Very fine	≤0.01	10
Fine	>0.01, ≤0.04	5 + width X 500
Medium	>0.04, ≤0.08	25 + (width - .04) X 375
Wide	>0.08	40

Volume Loss

A number of concrete volume-loss categories are listed in Table 3. Deduct values depend on estimated depth, extent, and location of volume loss. For vertical or sloping surfaces of laterally loaded elements, deduct values may be taken from

Figure 1 or calculated using the equation with that figure. The PC-based management system currently under development will accept entry of the percentage volume loss and it will calculate the value. For volume losses on opposite sides of a structural unit at the same elevation, add the deduct values for each volume loss to get one deduct value for volume loss at that elevation. For volume loss that occurs in a culvert or conduit wall, the percentage of depth is to be based on the thickness of the wall except for abrasion and cavitation. Deducts for volume loss in conduits and culverts apply not only to vertical surfaces but also to horizontal surfaces. Volume-loss deterioration generally does not develop to a significant depth on backfilled or always-submerged faces.

Repairs generally require removal of additional concrete before replacement. Repairs are effective as long as they do not debond or otherwise deteriorate. When repairs have debonded, a deduction should be calculated based on the volume loss of the debonded repair.

Abrasion (category 31). Abrasion generally occurs when solid particles are moved by water flow, and usually it can be limited by removal of debris. For abrasion within conduits, deduct values in Table 4 should be used. Measurement should be at the point of deepest abrasion.

Cavitation (category 32). Cavitation results from the collapse of vapor bubbles in flowing water and is generally caused by high-velocity flow over abrupt changes in surface alignment. Cavitation causes additional changes in alignment. To prevent further damage, repairs should be made promptly and the cause of the damage should be eliminated. Deduct values from Table 4 are used. Measurement should be at the point of deepest cavitation.

Honeycomb (category 33). Honeycomb generally results from poor concrete-placing practices and most frequently occurs at lift joints. If honeycomb was poorly repaired, the repair may have subsequently been easily removed by erosion.

Popouts (category 34). Popouts generally are caused by freezing of saturated porous aggregate particles but may also result from alkali-aggregate reaction. They are more aesthetically offensive than structurally serious.

Table 5. Conduit erosion deduct values.

Depth, in.	Abrasion	Cavitation
0 to 2	10	20
2 to 6	Depth X 5	Depth X 10
>6	30	60

Scaling (category 35). Scaling is the flaking or sloughing away of the near-surface portion of concrete. It is usually caused by the development of osmotic and hydraulic pressures during freezing.

Spalling (category 36). Spalling is the breaking away of a fragment, usually wedge or conical shaped, by the action of pressure or a blow. Structural distortion may apply sufficient pressure at contraction joints to cause spalls. Corrosion of reinforcing steel or other embedded metal may spall the concrete cover. Also, trapped water in voids may result in a spall. No deduction is made for a joint spall less than 3 in. deep. A spall of less than 9 in. along a joint in a vertical surface is considered light. If a spall on a vertical surface has a calculated volume-loss deduct value that is larger than the applicable 5- or 10-point deduct value, use that value instead.

Disintegration (category 37). Disintegration may result from cycles of freezing and thawing, chemical attack, alkali-aggregate reaction, or other actions. It usually proceeds from D-cracking, pattern cracking, or scaling. Core sampling is essential for determining the actual depth of deterioration beyond the exposed surfaces and to determine cause.

Steel deterioration (categories 41 to 44). Corrosion and overloading are the two main causes of steel deterioration. Corrosion may be indicated initially by rust stains on concrete surfaces (category 41); however, except for high-strength steels, corrosion cannot be significant without the concrete cover delaminating or spalling. Exposed steel (category 42) may have corroded sufficiently to have significantly reduced cross section. Reinforcing bars with exposed or partially exposed ends may not develop load. High-strength steel is susceptible to stress corrosion and may lose load capacity with little corrosion. For delamination or exposure of any area of reinforcing steel (category 42) serving a structural purpose, 30 points are deducted. If over 50 percent of the steel at a cross section is exposed, or for any exposure or indicated corrosion of prestressing steel (category 43), 60 points are deducted. For compression faces of retaining wall surfaces, deduct 10 points for any exposure or indicated corrosion and 20 points for exposure or indicated corrosion greater than 50 percent. For exposure or indicated corrosion between one reinforcing bar and 50 percent, the deduct value can be increased linearly from 30 to 60 points or from 10 to 20 points (see Appendix D). Five points are deducted for slight corrosion stains and 10 points for more general corrosion stains from reinforcing steel. For a slight amount of damaged armor (category 44), 5 points are deducted, and 10 points are deducted for more general damage to armor. One or two missing or displaced pieces that are not a hazard should be considered as slight damage. For more than two pieces or any hazardous projections, the larger deduct is used.

Leakage and deposits (categories 51 and 52). Leakage (category 51) through cracks, joints, voids, and pores may affect the durability and function of a structure. Seeping water may increase concrete saturation, thus accelerating damage from cycles of freezing and thawing or producing mechanical failure during freezing. Deposits (category 52) left by evaporating water are formed by ions that have diffused out of the paste and weakened the concrete. Moving water may also erode backfill or foundation material, requiring a foundation investigation. For seepage, 5 points are deducted. For leakage of up to approximately 10 gal/min, 10 points are deducted, and for larger quantities a deduct of 20 points should be used. Leakage at all locations throughout the monolith should be combined and the deduct should be based on this total sum. Leakage sufficient to affect the operation of the dam has a deduct of 40 points. It may be desirable to evaluate leakage at maximum head and minimum temperature. When leakage is from a crack, there is a deduct value both for the crack and the leakage; however, when leakage is from a joint, there is only a deduct for the leakage. For deposits of less than approximately 0.1 in., 2 points are deducted. For deposits up to approximately 0.5 in. thick, 5 points are deducted. Larger quantities should use a deduct of 10 points.

Calculating the Condition Index

Once the distresses in each monolith to be rated are determined, the CI for monoliths can be calculated. By inputting the distresses into the PC-based management system software, hand calculation of deduct values and the CI can be avoided. The CI is based on the five largest deduct values (DV), with DV1 the largest value and other values in descending order to the fifth largest, DV5. The calculation is based on the following equation:

$$CI = 100 - [DV1 + 0.4(DV2) + 0.2(DV3) + 0.15(DV4) + 0.1(DV5)]$$

However, a deduct value sum above 100 is not to be used. Table 5 is an example manual calculation of the CI. Manual calculation of the index can be avoided by using the software developed to automate the storage of inspection-related information. Appendix C (trip reports) includes discussion of how this equation was chosen (C24-C26 and also C10, 15, 16, 19-21).

It is suggested that the overall condition of the dam be represented by the lowest monolith CI and the average for the monoliths rated. Further investigation of preferable methods of presenting overall structure condition rating information will be made at a later date.

Table 5. Example of manual calculation of the CI.

Step 1. Inspect monolith to determine distresses and quantities.
Step 2. Calculate deduct values for each distress.
Step 3. Rank the deduct values from largest to smallest. Only the five largest are used in the CI calculation.

DISTRESS and QUANTITY (STEP 1)	DEDUCT VALUE (STEP 2)	RANK (STEP 3)
1. Horizontal crack, 0.09 in.	35	DV1
2. Deposits, 0.4 in. thick	5	DV4
3. Leakage, 6 gal/min	10	DV3
4. Vol. loss, 100% width, 0.5% depth	(100)(0.5)/20 = 2.5	-
5. Diagonal crack, 0.03 in.	6.67 + (0.03)(833) = 31.66	DV2
6. Corrosion stains, light	5	DV5

Step 4. Calculate the CI based on the ranked deduct values:

CI = 100 - [DV1 + (0.4)DV2 + (0.2)DV3 + (0.15)DV4 + (0.1)DV5]

CI = 100 - [35 + (0.4)31.66 + (0.2)10 + (0.15)5 + (0.1)5] = 49.01

The monolith CI is 49, which is "fair."

4 Summary and Recommendations

The inspection and rating procedures described in this report have intentionally been kept as simple as possible. The inspections require only simple tools such as a crack comparator, wire brush, binoculars, tape measure, and ruler. An inspection form has been developed to document distress information (distresses, measurements, locations, and so on).

While the tools and inspection procedures are relatively simple, preparation for an inspection is not always as simple. For example, an inspection of a conduit may require planning to avoid conflicts with operations. Some volume loss distresses may require coring to accurately determine the depth affected if that information is needed.

Once the data is obtained, software has been developed to compute the CI directly from the inspection records. The CI is a numbered scale from 0 to 100 that indicates the current state of the structure. It is primarily a planning tool that indicates the relative need to perform REMR work. CIs below 40 indicate that a more detailed inspection and analysis is required.

Distresses reduce the CI according to rules based on the opinion of Corps experts. They involve at least two considerations: (1) structural integrity, or how, in the judgment of expert engineers, the safety of the structure has been degraded by various distresses, and (2) serviceability, or how the structure performs its function on a day-to-day basis. A CI for each monolith is calculated by a weighted addition of the five largest distresses.

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Appendix A
Guide for Making a Condition Survey of Concrete in Service

(Reported by ACI Committee 201)

ACI 201.1R-92

Guide for Making a Condition Survey of Concrete in Service

Reported by ACI Committee 201

Members of Committee 201 who voted on the 1992 revisions:

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This guide provides a system for reporting on the condition of concrete in service. It includes a check list of the many details that may be considered in making a report, and repeats the ACI 116 standard definitions of terms associated with the durability of concrete. Its purpose is to establish a uniform system for evaluating the condition of concrete.

The guide was revised by a task group chaired by K.R. Lauer. The other task group members are indicated by an asterisk.

Keywords: bridges (structures); buildings; concrete construction; concrete durability; concrete pavements; concretes; corrosion; cracking (fracturing); deterioration; environments; freeze thaw durability; inspection; joints (junctions); popouts; quality control; scaling; serviceability; spalling; strength; surveys.

CONTENTS

CHAPTER 1—INTRODUCTION

This guide presents a system for making a condition survey of concrete in service. A condition survey is an examination of concrete for the purpose of identifying and defining areas of distress. The system is designed to be used in recording the history of a project from inception through construction and subsequent life of the structure.

While it probably will be used most often in connection with the survey of concrete that is showing some degree of distress, its application is recommended for all concrete structures. In any case, records of the materials and construction practices used should be maintained because they are difficult to obtain at a later date.

The committee has attempted to include pertinent items that might have a bearing on the performance of the concrete. Those making the survey should, however, not limit their investigation to the items listed, thereby possibly overlooking other contributing factors. Following the guide does not eliminate the need for intelligent observations and the use of sound judgement.

Those performing the survey should be experienced and competent in this field. In addition to verbal descriptions, numerical data obtained by laboratory tests and field tests and measurements should be obtained wherever possible. Photographs, including a scale to indicate dimensions, are of great value in showing the condition of concrete.

This report was approved by letter ballot of the committee and reported to ACI headquarters July, 1990.

The check list is provided to facilitate a thorough survey. The definition of terms and associated photographs are an attempt to standardize the reporting of the condition of the concrete in a structure.

This guide should be used in conjunction with the following:

1. ACI Committee 116 "Cement and Concrete Terminology" (ACI 116R).
2. ACI Committee 311 "Recommended Practice for Concrete Inspection" (ACI 311.1R).
3. ACI Committee 201, "Guide to Durable Concrete" (ACI 201.2R).

CHAPTER 2—CHECK LIST

Personnel conducting the condition survey must select those items important to the specific concerns relating to the reasons for the survey. Other factors may be involved and should not be overlooked during the survey.

CHECK LIST

1. Description of structure or pavement
   - 1.1 Name, location, type, and size
   - 1.2 Owner, project engineer, contractor, when built
   - 1.3 Design
     - 1.3.1 Architect and/or engineer
     - 1.3.2 Intended use and history of use
     - 1.3.3 Special features
   - 1.4 Construction
     - 1.4.1 Contractor—general
     - 1.4.2 Subcontractors—concrete placement
     - 1.4.3 Concrete supplier
     - 1.4.4 Agency responsible for testing
     - 1.4.5 Other subcontractors
   - 1.5 Photographs
     - 1.5.1 General view
     - 1.5.2 Detailed close up of condition of area
   - 1.6 Sketch map—orientation showing sunny and shady and well and poorly drained regions

2. Present condition of structure
   - 2.1 Overall alignment of structure
     - 2.1.1 Settlement
     - 2.1.2 Deflection
     - 2.1.3 Expansion
     - 2.1.4 Contraction
   - 2.2 Portions showing distress (beams, columns, pavement, walls, etc., subjected to strains and pressures)
   - 2.3 Surface condition of concrete
     - 2.3.1 General (good, satisfactory, poor, dusting, chalking, blisters)
     - 2.3.2 Cracks
       - 2.3.2.1 Location and frequency
       - 2.3.2.2 Type and size (see definitions)
       - 2.3.2.3 Leaching, stalactites
     - 2.3.3 Scaling
       - 2.3.3.1 Area, depth
       - 2.3.3.2 Type (see definitions)
     - 2.3.4 Spalls and popouts
       - 2.3.4.1 Number, size, and depth
       - 2.3.4.2 Type (see definitions)
     - 2.3.5 Extent of corrosion or chemical attack, abrasion, impact, cavitation
     - 2.3.6 Stains, efflorescence
     - 2.3.7 Exposed reinforcement
     - 2.3.8 Curling and warping
     - 2.3.9 Previous patching or other repair
     - 2.3.10 Surface coatings
       - 2.3.10.1 Type and thickness
       - 2.3.10.2 Bond to concrete
       - 2.3.10.3 Condition
     - 2.3.11 Abrasion
     - 2.3.12 Penetrating sealers
       - 2.3.12.1 Type
       - 2.3.12.2 Effectiveness
       - 2.3.12.3 Discoloration
   - 2.4 Interior condition of concrete (in situ and samples)
     - 2.4.1 Strength of cores
     - 2.4.2 Density of cores
     - 2.4.3 Moisture content
     - 2.4.4 Evidence of alkali-aggregate or other reaction
     - 2.4.5 Bond to aggregate, reinforcing steel, joints
     - 2.4.6 Pulse velocity
     - 2.4.7 Volume change
     - 2.4.8 Air content and distribution
     - 2.4.9 Chloride-ion content
     - 2.4.10 Cover over reinforcing steel
     - 2.4.11 Half-cell potential to reinforcing steel
     - 2.4.12 Evidence of reinforcement corrosion
     - 2.4.13 Evidence of corrosion of dissimilar metals
     - 2.4.14 Delaminations
     - 2.4.15 Depth of carbonation
     - 2.4.16 Freezing and thawing distress (frost damage)
     - 2.4.17 Extent of deterioration
     - 2.4.18 Aggregate proportioning and distribution

3. Nature of loading and detrimental elements
   - 3.1 Exposure
     - 3.1.1 Environment—arid, subtropical, marine, freshwater, industrial, etc.
     - 3.1.2 Weather—(July and January mean temperatures, mean annual rainfall and months in which 60 percent of it occurs
     - 3.1.3 Freezing and thawing
     - 3.1.4 Wetting and drying

3.1.5 Drying under dry atmosphere
3.1.6 Chemical attack—sulfates, acids, chloride
3.1.7 Abrasion, erosion, cavitation, impact
3.1.8 Electric currents
3.1.9 Deicing chemicals which contain chloride ions
3.1.10 Heat from adjacent sources

3.2 Drainage
3.2.1 Flashing
3.2.2 Weepholes
3.2.3 Contour
3.2.4 Elevation of drains

3.3 Loading
3.3.1 Dead
3.3.2 Live
3.3.3 Impact
3.3.4 Vibration
3.3.5 Traffic index
3.3.6 Other

3.4 Soils (foundation conditions)
3.4.1 Compressibility
3.4.2 Expansive soil
3.4.3 Settlement
3.4.4 Resistivity
3.4.5 Evidence of pumping
3.4.6 Water table (level and fluctuations)

4. Original condition of structure
4.1 Condition of formed and finished surfaces
4.1.1 Smoothness
4.1.2 Air pockets ("bugholes")
4.1.3 Sand streaks
4.1.4 Honeycomb
4.1.5 Soft areas (retarded hydration)
4.1.6 Cold joints
4.1.7 Staining

4.2 Defects
4.2.1 Cracking
4.2.1.1 Plastic shrinkage
4.2.1.2 Thermal shrinkage
4.2.1.3 Drying shrinkage
4.2.2 Curling

5. Materials of construction
5.1 Hydraulic cement
5.1.1 Class or classes—(portland, blended, high alumina, ground granulated blast furnace slag)
5.1.2 Type or types, and source
5.1.3 Chemical analysis (obtain certified test data if available)
5.1.4 Physical properties

5.2 Aggregates
5.2.1 Coarse
5.2.1.1 Type, source and mineral composition (representative sample available)
5.2.1.2 Quality characteristics
5.2.1.2.1 Percentage of deleterious material
5.2.1.2.2 Percentage of potentially reactive materials
5.2.1.2.3 Coatings, texture, and particle shape
5.2.1.2.4 Grading, soundness, hardness
5.2.1.2.5 Other properties as specified in ASTM Designation C 33 (C 330 for lightweight aggregate)
5.2.1.2.6 Service record on other projects
5.2.2 Fine
5.2.2.1 Type, source, and mineral composition (representative sample available)
5.2.2.2 Quality characteristics
5.2.2.2.1 Percentage of deleterious material
5.2.2.2.2 Percentage of potentially reactive materials
5.2.2.2.3 Coatings, texture, and particle shape
5.2.2.2.4 Grading, soundness, and hardness
5.2.2.2.5 Other properties as specified in ASTM Designation C33 (C 330 for lightweight aggregate)
5.2.2.2.6 Service record on other projects

5.3 Mixing water
5.3.1 Source and quality

5.4 Admixtures
5.4.1 Air entraining admixtures
5.4.1.1 Type and source
5.4.1.2 Composition
5.4.1.3 Dosage
5.4.1.4 Manner of introduction
5.4.2 Mineral admixtures
5.4.2.1 Class and source
5.4.2.2 Physical properties
5.4.2.3 Chemical properties
5.4.3 Chemical admixtures
5.4.3.1 Type and source
5.4.3.2 Composition
5.4.3.3 Dosage
5.4.3.4 Manner and time of introduction

5.5 Concrete
5.5.1 Mixture proportions
5.5.1.1 Cement content

5.5.1.2 Proportions of each size aggregate
5.5.1.3 Water-cementitious materials ratio
5.5.1.4 Water content
5.5.1.5 Chemical admixture(s)
5.5.1.6 Mineral admixture(s)
5.5.1.7 Air entraining admixture
5.5.2 Properties of fresh concrete
5.5.2.1 Slump or other workability measure
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5.5.2.4 Unit weight
5.5.2.5 Temperature
5.5.3 Type
5.5.3.1 Cast-in-place
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5.5.3.3 Prestressed (pre-tensioned or post-tensioned)
5.5.4 Reinforcement
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5.5.5 Initial physical properties of hardened concrete
5.5.5.1 Strength—compressive, flexural
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5.5.5.5 Volume change potential
5.5.5.5.1 Shrinkage or contraction
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5.5.6.1 Description of tests and frequency
5.5.6.2 Actual results for full project
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5.5.6.4 Evaluation of strength results per ACI 214

6. Construction practices
6.1 Storage and processing of materials
6.1.1 Aggregates
6.1.1.1 Grading
6.1.1.2 Washing
6.1.1.3 Storage
6.1.1.3.1 Stockpiling
6.1.1.3.2 Bins
6.1.1.3.3 Moisture control/prewetting
6.1.1.3.4 Cooling
6.1.1.3.5 Heating
6.1.2 Cement and admixtures
6.1.2.1 Storage
6.1.2.2 Handling
6.1.3 Reinforcing steel and inserts
6.1.3.1 Storage
6.1.3.2 Placement
6.2 Forming
6.2.1 Type
6.2.2 Bracing
6.2.3 Coating-type and time of application
6.2.4 Insulation
6.3 Concreting operation
6.3.1 Batching plant
6.3.1.1 Type—automatic, manual, etc.
6.3.1.2 Condition of equipment
6.3.1.3 Batching sequence
6.3.1.4 Availability of computer printouts
6.3.2 Mixing
6.3.2.1 Type—central mix, truck mix, job mix, shrink mix, etc.
6.3.2.2 Condition of equipment
6.3.2.3 Mixing time
6.3.3 Transporting—trucks, buckets, chutes, pumps, etc.
6.3.4 Placing
6.3.4.1 Methods—conventional, underwater, slipform, etc.
6.3.4.2 Equipment—buckets, elephant trunks, vibrators, etc.
6.3.4.3 Weather conditions—time of year, rain, snow, dry wind, temperature, humidity, etc.
6.3.4.4 Site conditions—cut, fill, presence of water, etc.
6.3.4.5 Construction joints
6.3.4.6 Contraction and isolation joints
6.3.5 Finishing
6.3.5.1 Type—slabs, floors, pavements, appurtenances
6.3.5.2 Method—manual or machine
6.3.5.3 Equipment—screeds, floats, trowels, straightedge, belt, etc.
6.3.5.4 Hardeners, water, dust coat, coloring, etc.
6.3.6 Curing

6.3.6.1 Type (water, covering, curing membrane, forms in place)
6.3.6.2 Application
6.3.6.3 Duration
6.3.6.4 Efficiency
6.3.7 Form removal (time of removal)
6.3.7.1 Vertical
6.3.7.2 Shoring

CHAPTER 3—DEFINITIONS AND ASSOCIATED PHOTOGRAPHS

Distress manifestations have been categorized and illustrated by photographs. Their severity and extent of occurrence have been quantified where possible. Their purpose is to attempt to standardize the reporting of the condition of the concrete in a structure. Those performing the survey should be thoroughly familiar with the various types of distress and the rating scheme before starting the survey.

A.1 *Crack*—A complete or incomplete separation, of either concrete or masonry, into two or more parts produced by breaking or fracturing.

A.1.1 *Checking*—Development of shallow cracks at closely spaced but irregular intervals on the surface of plaster, cement paste, mortar, or concrete.

A.1.2 *Craze cracks*—Fine random cracks or fissures in a surface of plaster, cement paste, mortar, or concrete.

Crazing—The development of craze cracks; the pattern of craze cracks existing in a surface.

A.1.3 *D-cracking*—A series of cracks in concrete near and roughly parallel to joints, edges, and structural cracks.

A.1.4 *Diagonal crack*—In a flexural member, an inclined crack caused by shear stress, usually at about 45 deg to the axis; or a crack in a slab, not parallel to either the lateral or longitudinal directions.

A.1.5 *Hairline cracks*—Cracks in an exposed concrete surface having widths so small as to be barely perceptible.

A.1.6 *Pattern cracking*—Fine openings on concrete surfaces in the form of a pattern; resulting from a decrease in volume of the material near the surface, or increase in volume of the material below the surface, or both.

A.1.7 *Plastic cracking*—Cracking that occurs in the surface of fresh concrete soon after it is placed and while it is still plastic.

A.1.8 *Shrinkage cracking*—Cracking of a structure or member due to failure in tension caused by external or internal restraints as reduction in moisture content develops, or as carbonation occurs, or both.

A.1.9 *Temperature cracking*—Cracking due to tensile failure, caused by temperature gradient in members subjected to external restraints or by temperature differential in members subjected to internal restraints.

A.1.10 *Transverse cracks*—Cracks that develop at right angles to the long direction of the member.

A.2 *Deterioration*— 1) Physical manifestation of failure of a material (e.g., cracking, delamination, flaking, pitting, scaling, spalling, straining) caused by environmental or internal autogenous influences on hardened concrete as well as other materials; 2) Decomposition of material during either testing or exposure to service.

Disintegration—Reduction into small fragments and subsequently into particles.

A.2.1 *Abrasion damage*—Wearing away of a surface by rubbing and friction.

A.2.2 *Blistering*—The irregular raising of a thin layer, frequently 25 to 300 mm in diameter, at the surface of placed mortar or concrete during or soon after completion of the finishing operation; blistering is usually attributed to early closing of the surface and may be aggravated by cool temperatures. Blisters also occur in pipe after spinning or in a finish plastic coat in plastering as it separates and draws away from the base coat.

A.2.3 *Cavitation damage*—Pitting of concrete caused by implosion, i.e., the collapse of vapor bubbles in flowing water which form in areas of low pressure and collapse as they enter areas of higher pressure.

A.2.4 *Chalking*—Formation of a loose powder resulting from the disintegration of the surface of concrete or of applied coating, such as cement paint.

A.2.5 *Corrosion*— destruction of metal by chemical, electrochemical, or electrolytic reaction with its environment.

A.2.6 *Curling*—The distortion of an originally essentially linear or planar member into a curved shape such as the warping of a slab due to creep or to differences in temperature or moisture content in the zones adjacent to its opposite faces.

A.2.7 *Deflection*—Movement of a point on a structure or structural element, usually measured as a linear displacement transverse to a reference line or axis.

A.2.8 *Deformation*—A change in dimension or shape.

A.2.9 *Delamination*—A separation along a plane parallel to a surface as in the separation of a coating from a substrate or the layers of a coating from each other, or in the case of a concrete slab, a horizontal splitting, cracking or separation of a slab in a plane roughly parallel to, and generally near, the upper surface; found frequently in bridge decks and other types of elevated reinforced-concrete slabs and may be caused by the corrosion of reinforcing steel; also found in slabs on grade caused by development, during the finishing operation, of a plane of weakness below the densified surface; or caused by freezing and thawing, similar to spalling, scaling, or peeling except that delamination affects large areas and can often be detected by tapping.

A.2.10 *Distortion*—See *Deformation*.

A.2.11 *Dusting*—The development of a powdered material at the surface of hardened concrete.

A.2.12 *Efflorescence*—A deposit of salts, usually white, formed on a surface, the substance having emerged in solution from within either concrete or masonry and subsequently been precipitated by evaporation.

A.2.13 *Erosion*—Progressive disintegration of a solid by the abrasive or cavitation action of gases, fluids, or solids in motion.

A.2.14 *Exfoliation*—Disintegration occurring by peeling off in successive layers; swelling up and opening into leaves or plates like a partly opened book.

A.2.15 *Exudation*—A liquid or viscous gel-like material discharged through a pore, crack, or opening in the surface of concrete.

A.2.16 *Joint spall*—A spall adjacent to a joint.

A.2.17 *Pitting*—Development of relatively small cavities in a surface; in concrete, localized disintegration, such as a popout; in steel, localized corrosion evident as minute cavities on the surface.

A.2.18 *Peeling*—A process in which thin flakes of mortar are broken away from a concrete surface, such as by deterioration or by adherence of surface mortar to forms as forms are removed.

A.2.19 *Popout*—The breaking away of small portions of a concrete surface due to localized internal pressure which leaves a shallow, typical conical, depression.

A.2.19.1 *Popouts, small*—Popouts leaving holes up to 10 mm in diameter, or the equivalent.

A.2.19.2 *Popouts, medium*—Popouts leaving holes between 10 and 50 mm in diameter, or the equivalent.

A.2.19.3 *Popouts, large*—Popouts leaving holes greater than 50 mm in diameter, or the equivalent.

A.2.20 *Scaling*—Local flaking or peeling away of the near-surface portion of hardened concrete or mortar; also of a layer from metal.

A.2.20.1 *Scaling, light*—Loss of surface mortar without exposure of coarse aggregate.

A.2.20.2 *Scaling, medium*—Loss of surface mortar 5 to 10 mm in depth and exposure of coarse aggregate.

A.2.20.3 *Scaling, severe*—Loss of surface mortar 5 to 10 mm in depth with some loss of mortar surrounding aggregate particles 10 to 20 mm in depth.

A.2.20.4 *Scaling, very severe*—Loss of coarse aggregate particles as well as mortar, generally to a depth greater than 20 mm.

A.2.21 *Spall*—A fragment, usually in the shape of a flake, detached from a larger mass by a blow, by the action of weather, by pressure, or by expansion within the large mass.

A.2.21.1 *Small spall*—A roughly circular depression not greater than 20 mm in depth nor 50 mm in any dimension.

A.2.21.2 *Large spall*—May be roughly circular or oval or in some cases elongated, more than 20 mm in depth and 150 mm in greatest dimension.

A.2.22 *Warping*—A deviation of a slab or wall surface from its original shape, usually caused by either temperature or moisture differentials or both within the slab or wall.

A.3 *Textural features and phenomena relative to their development.*

A.3.1 *Air void*—A space in cement paste, mortar, or concrete filled with air; an entrapped air void is characteristically 1 mm or more in size and irregular in shape; an entrained air void is typically between 10 μm and 1 mm in diameter and spherical or nearly so.

A.3.2 *Bleeding*—The autogenous flow of mixing water within, or its emergence from, newly placed concrete or mortar; caused by the settlement of the solid materials within the mass; also called water gain.

A.3.3 *Bugholes*—Small regular or irregular cavities, usually not exceeding 25 mm in diameter, resulting from entrapment of air bubbles in the surface of formed concrete during placement and consolidation.

A.3.4 *Cold joint*—A joint or discontinuity resulting from a delay in placement of sufficient time to preclude a union of the material in two successive lifts.

A.3.5 *Cold-joint lines*—Visible lines on the surfaces of formed concrete indicating the presence of joints where one layer of concrete had hardened before subsequent concrete was placed.

A.3.6 *Discoloration*—departure of color from that which is normal or desired.

A.3.7 *Honeycomb*—Voids left in concrete due to failure of the mortar to effectively fill the spaces among coarse aggregate particles.

A.3.8 *Incrustation*—A crust or coating, generally hard, formed on the surface of concrete or masonry construction or on aggregate particles.

A.3.9 *Joint*—A physical separation in concrete, whether precast or cast-in-place, including cracks if intentionally made to occur at specified locations; also the region where structural members intersect such as a beam-column joint.

A.3.10 *Laitance*—A layer of weak and nondurable material containing cement and fines from aggregates, brought by bleeding water to the top of overwet concrete; the amount is generally increased by overworking or over-manipulating concrete at the surface by improper finishing or by job traffic.

A.3.11 *Sand pocket*—A zone in concrete or mortar containing fine aggregate with little or no cement.

A.3.12 *Sand streak*—A streak of exposed fine aggregate in the surface of formed concrete, caused by bleeding.

A.3.13 *Segregation*—The differential concentration of the components of mixed concrete, aggregate, or the like, resulting in nonuniform proportions in the mass.

A.3.14 *Stalactite*—A downward-pointing deposit formed as an accretion of mineral matter produced by evaporation of dripping water from the surface of concrete, commonly shaped like an icicle.

A.3.15 *Stalagmite*—An upward-pointing deposit formed as an accretion of mineral matter produced by evaporation of dripping water, projecting from the surface of concrete, commonly conical in shape.

A.3.16 *Stratification*—The separation of overwet or overvibrated concrete into horizontal layers with increasingly lighter material toward the top; water, laitance, mortar, and coarse aggregate tend to occupy successively lower positions in that order; a layered structure in concrete resulting from placing of successive batches that differ in appearance; occurrence in aggregate stockpiles of layers of differing grading or composition; a layered structure in a rock foundation.

A.3.17 *Water void*—Void along the underside of an aggregate particle or reinforcing steel which formed during the bleeding period; initially filled with bleed water.

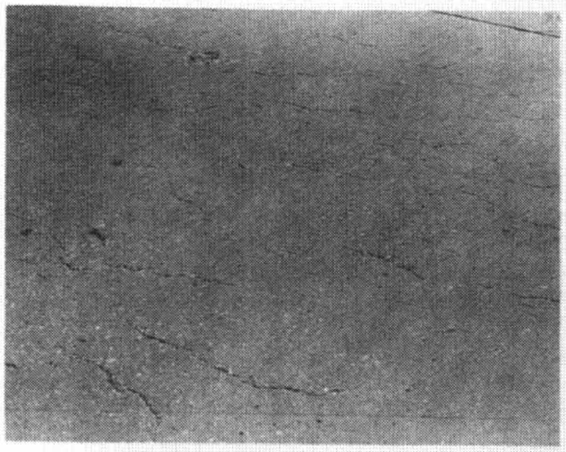


Fig. A.1.1—Checking

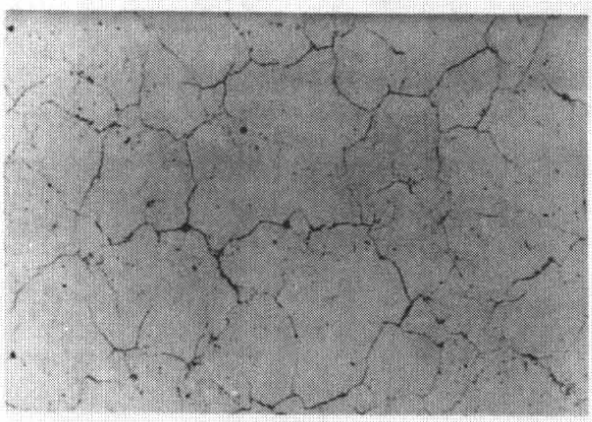


Fig. A.1.2—Craze cracks

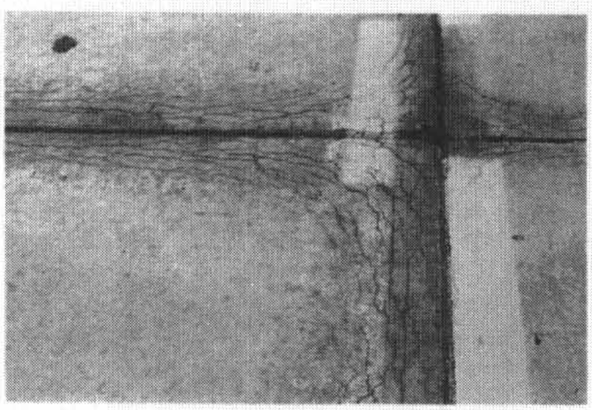


Fig. A.1.3—D-cracking (fine)

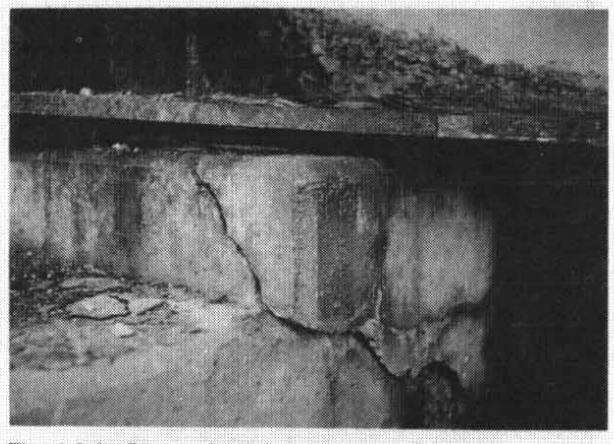


Fig. A.1.4—Diagonal cracks

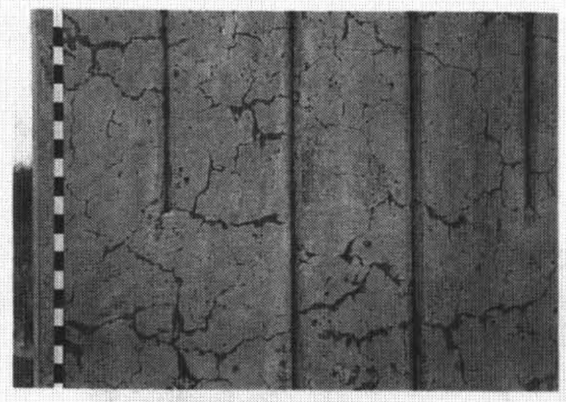


Fig. A.1.6a—Pattern cracking (fine)

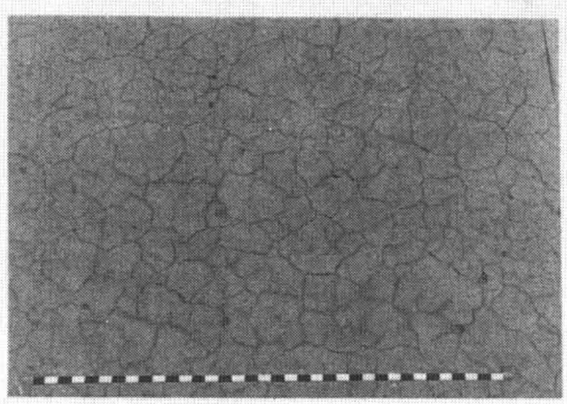


Fig. A.1.6b—Pattern cracking (medium)

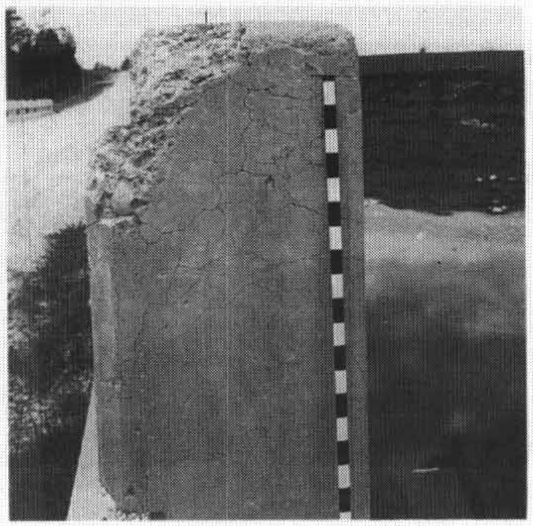


Fig. A.1.6c—Pattern cracking (wide)

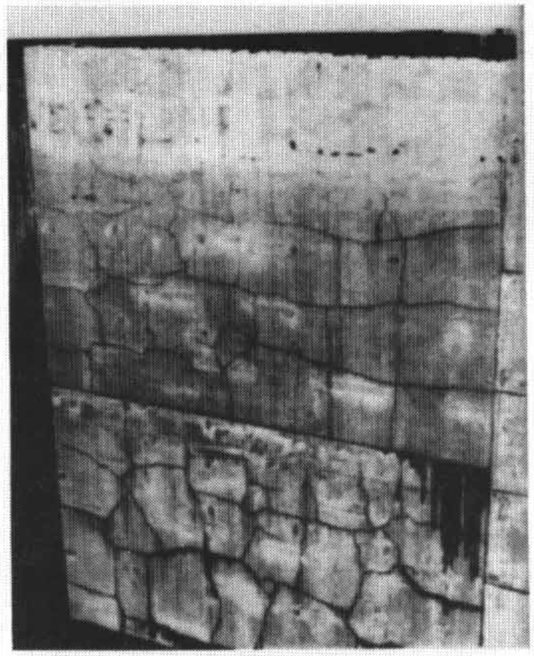


Fig. A.1.6e—Pattern cracking (restraint of volume change)

Fig. A.1.6d—Pattern cracking (alkali-silica reaction)

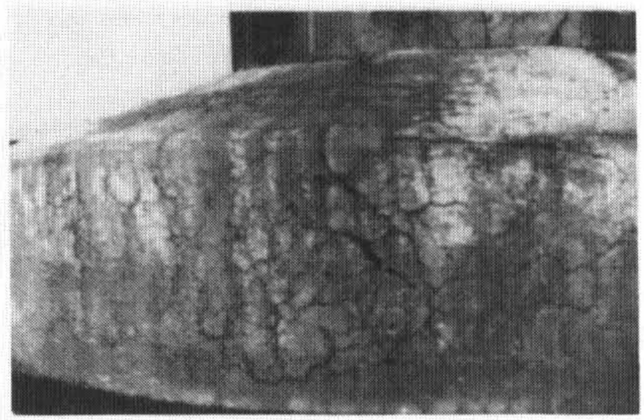


Fig. A.1.6f—Pattern cracking (alkali-carbonate reaction)

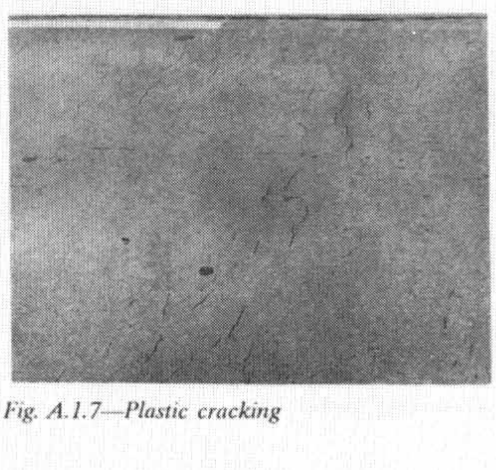


Fig. A.1.7—Plastic cracking

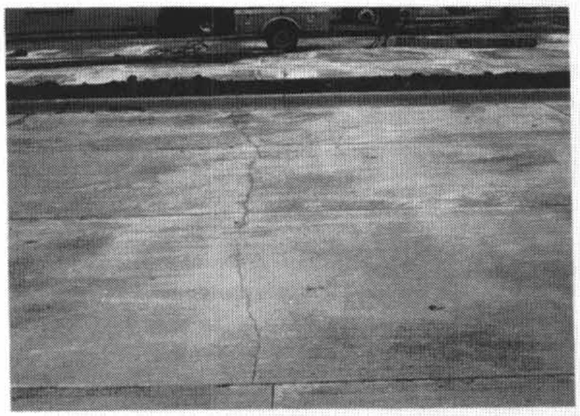


Fig. A.1.8—Shrinkage cracking

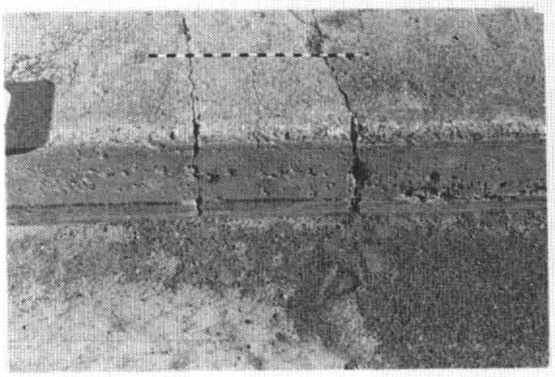


Fig. A.1.10—Transverse cracking (wide)

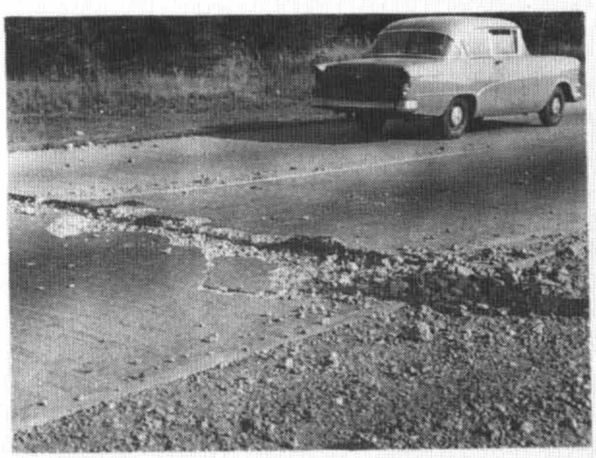


Fig. A.2—Disintegration

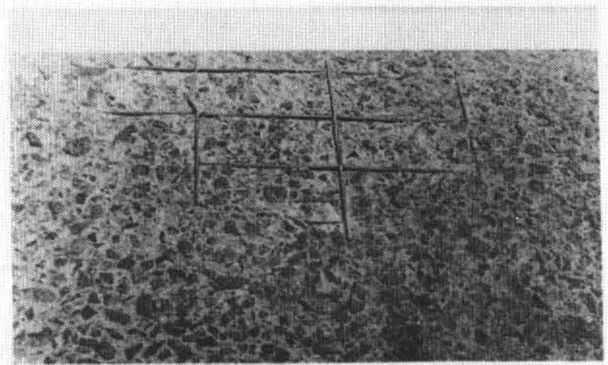


Fig. A.2.1—Abrasion damage

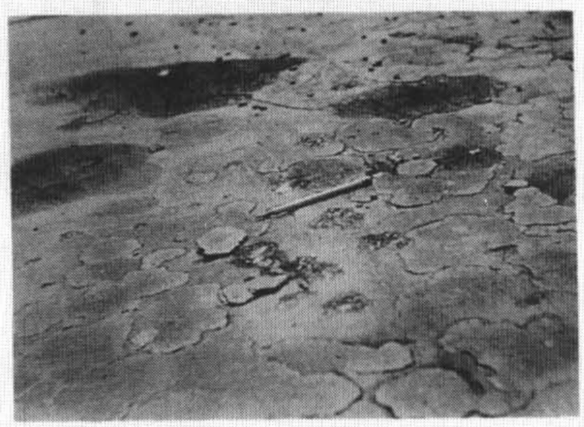


Fig. A.2.2—Blistering

Fig. A.2.3—Cavitation damage

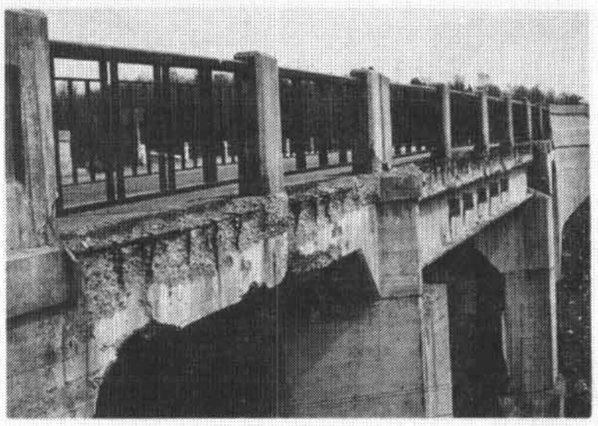


Fig. A.2.5—Corrosion damage

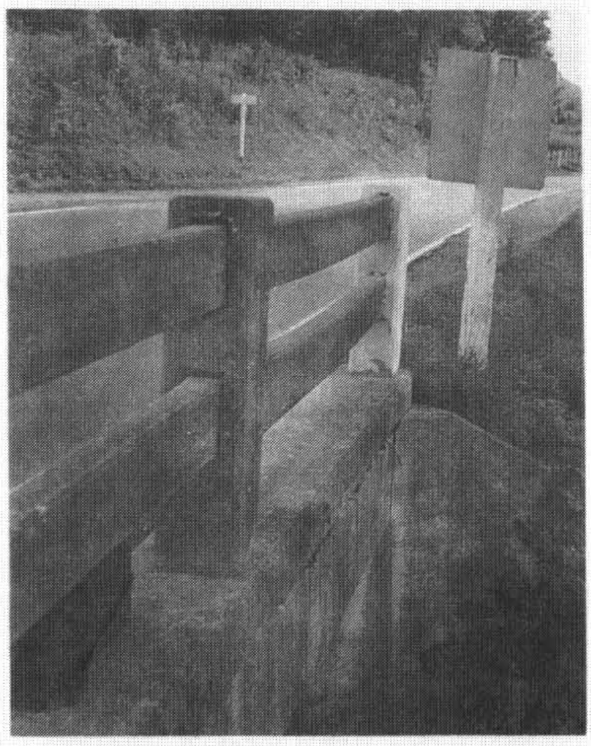


Fig. A.2.10—Distortion

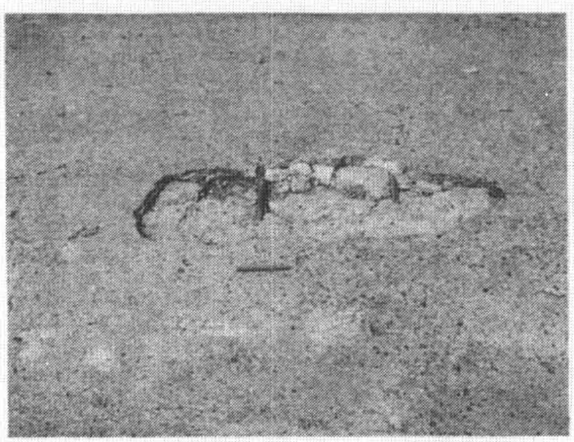


Fig. A.2.9—Delaminations

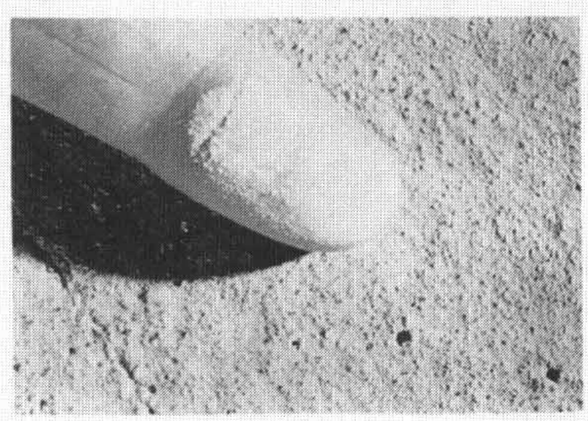


Fig. A.2.11—Dusting

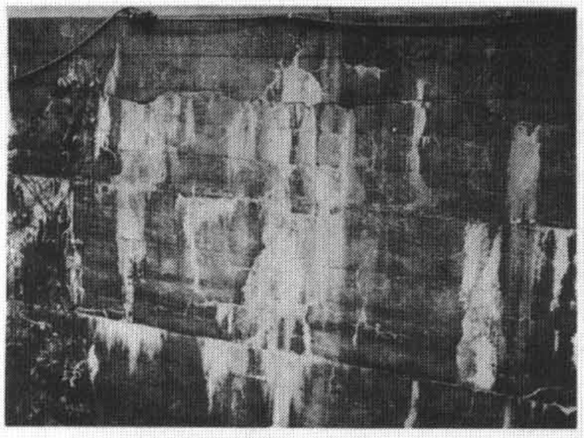


Fig. A.2.12—Efflorescence

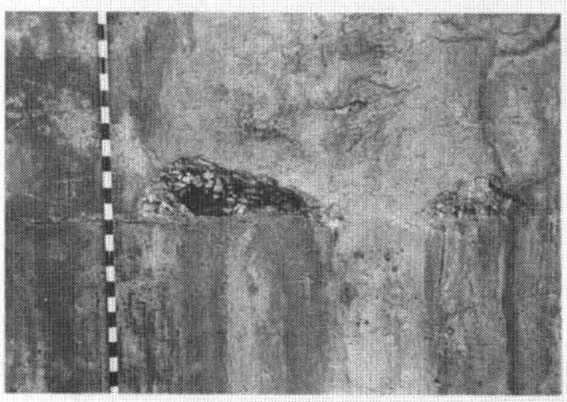


Fig. A.2.13—Erosion

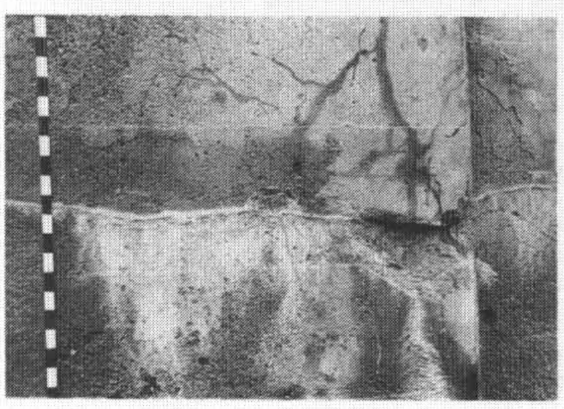


Fig. A.2.15—Exudation

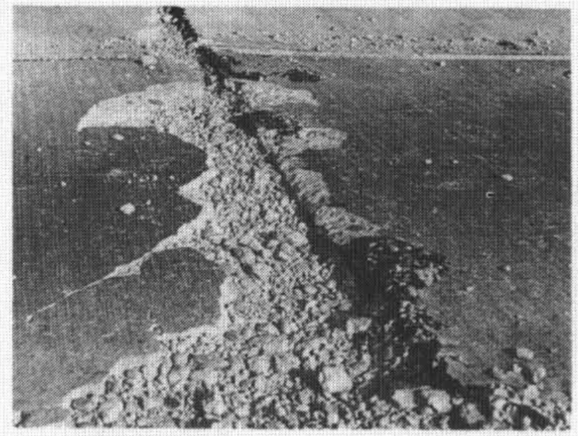


Fig. A.2.16a—Joint spall

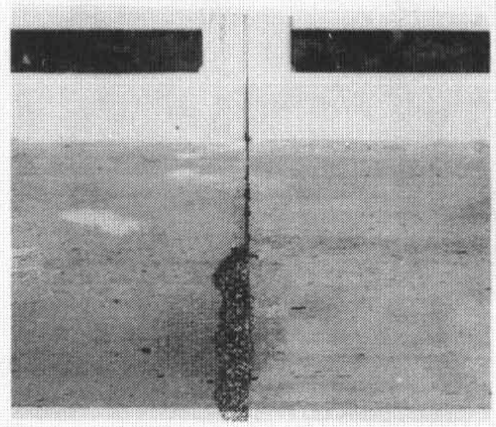


Fig. A.2.16b—Joint spall

Fig. A.2.17—Pitting

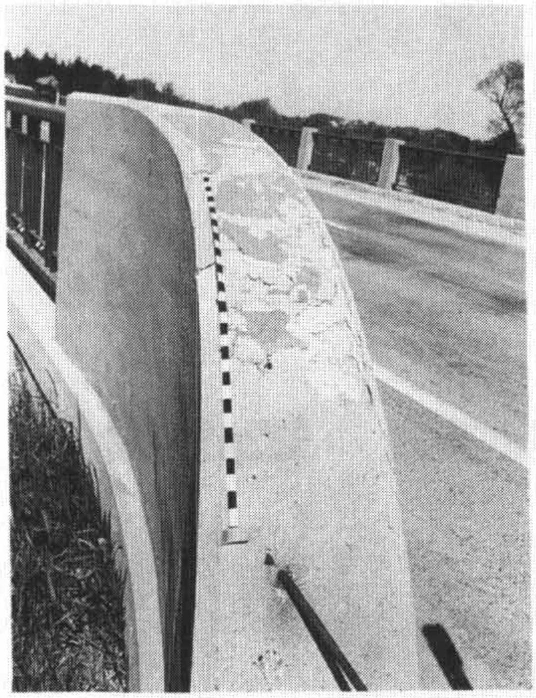


Fig. A.2.18a—Peeling

Fig. A.2.19—Popout

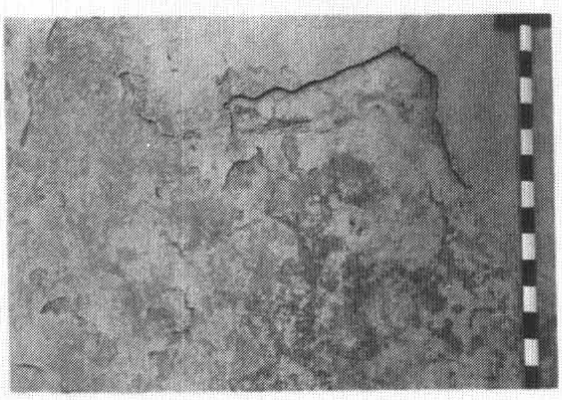


Fig. A.2.18b—Peeling (close-up)

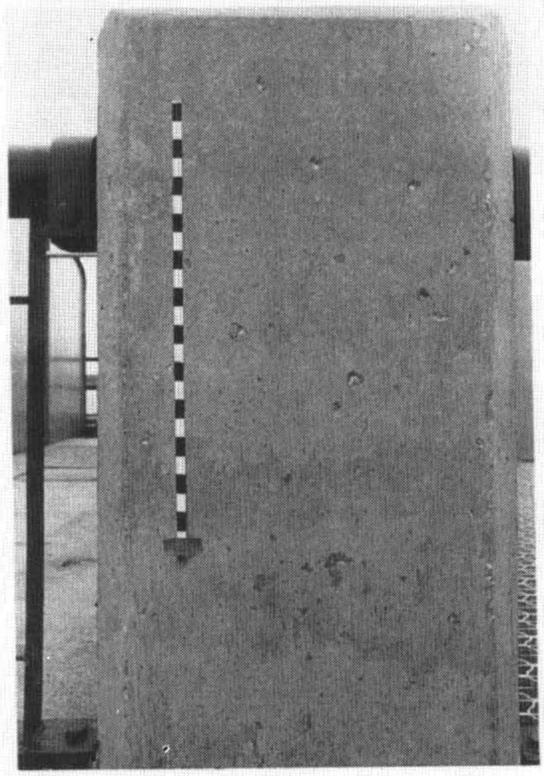


Fig. A.2.19.1—Popout (small)

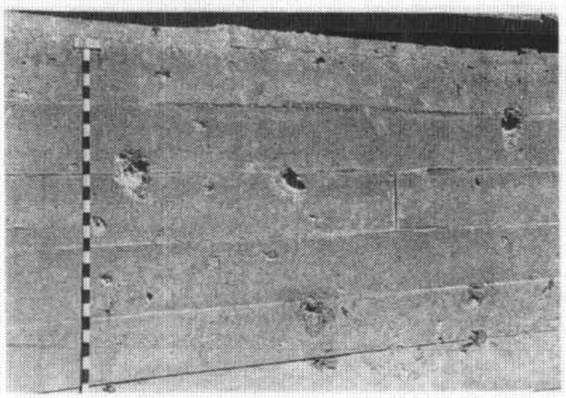


Fig. A.2.19.2—Popout (medium)

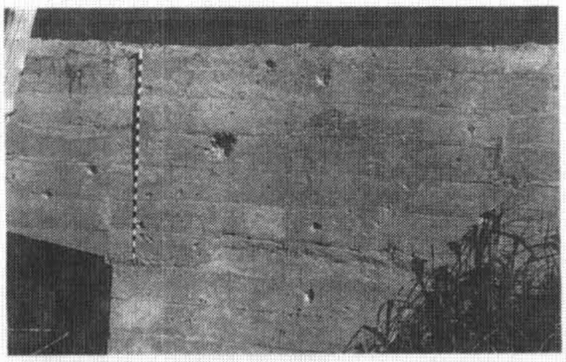


Fig. A.2.19.3—Popout (large)

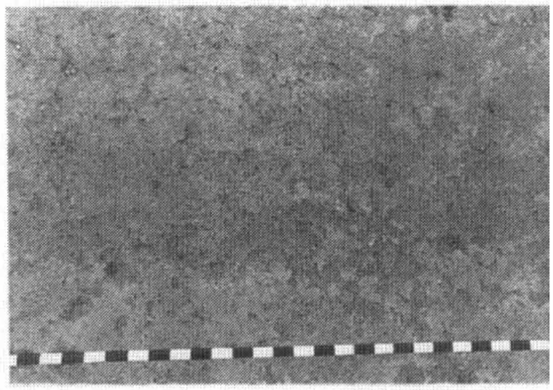


Fig. A.2.20.1b—Close-up scaling (light)

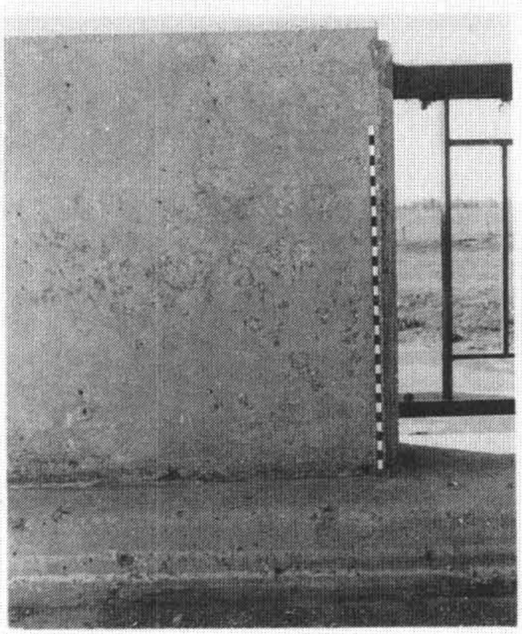


Fig. A.2.20.1a—Scaling (light)

Fig. A.2.20.2a—Scaling (medium)

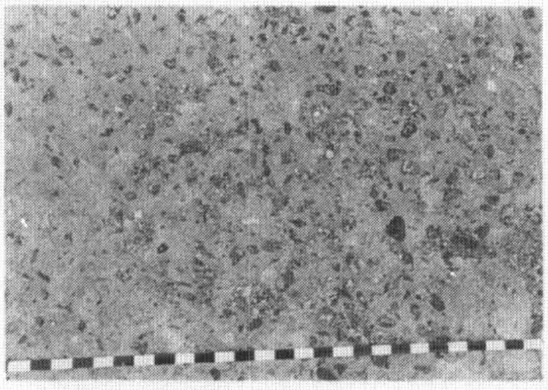


Fig. A.2.20.2b—Close-up scaling (medium)

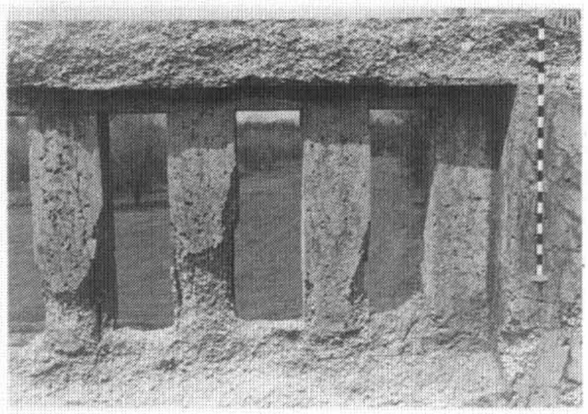


Fig. A.2.20.4a—Scaling (very severe)

Fig. A.2.20.3a—Scaling (severe)

Fig. A.2.20.4b—Close-up scaling (very severe)

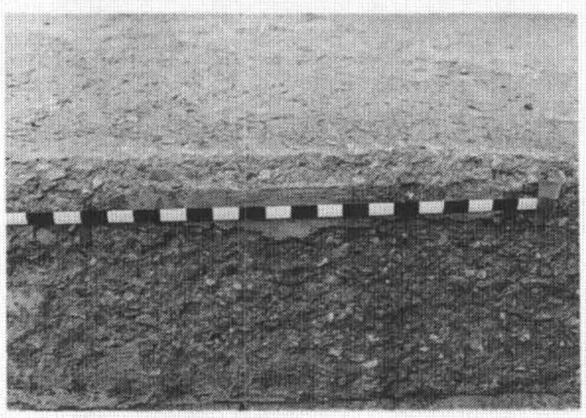


Fig. A.2.20.3b—Close-up scaling (severe)

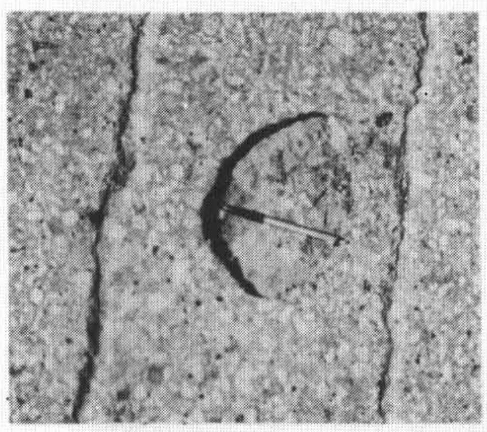


Fig. A.2.21.1—Small spall

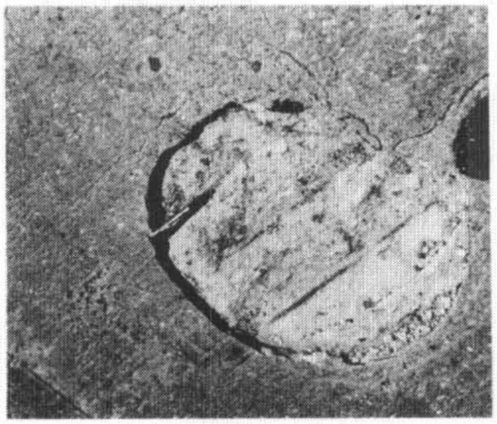


Fig. A.2.21.2—Large spall

Fig. A.3.5—Cold joint

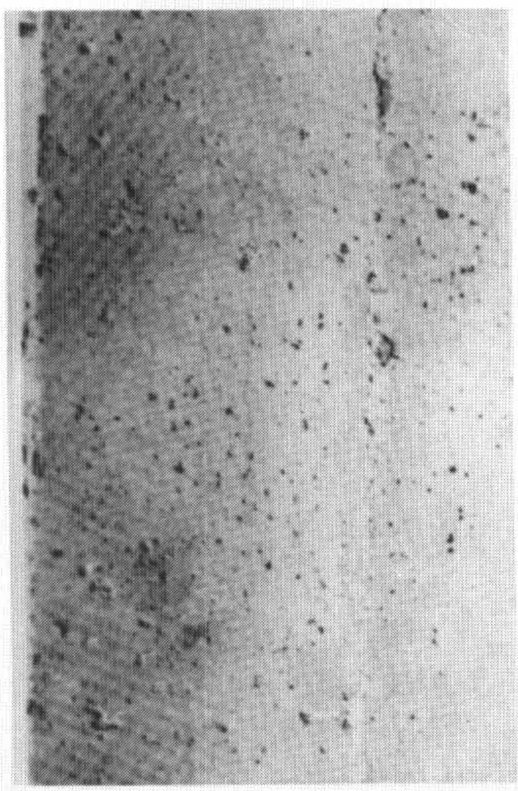


Fig. A.3.3—Bugholes

Fig. A.3.6—Discoloration

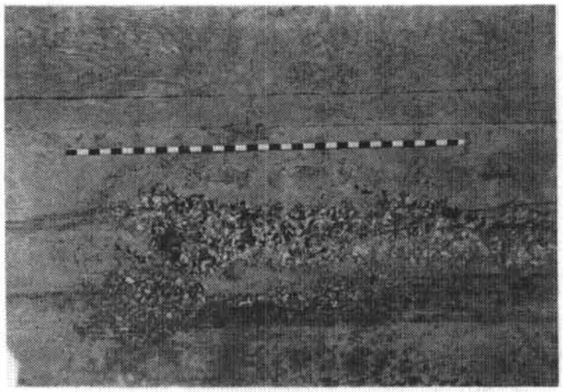


Fig. A.3.7—Honeycomb

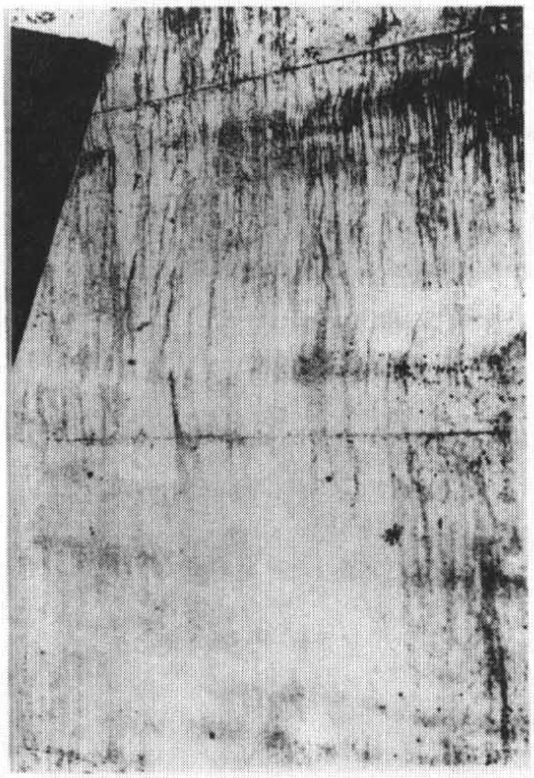


Fig. A.3.12—Sand streak

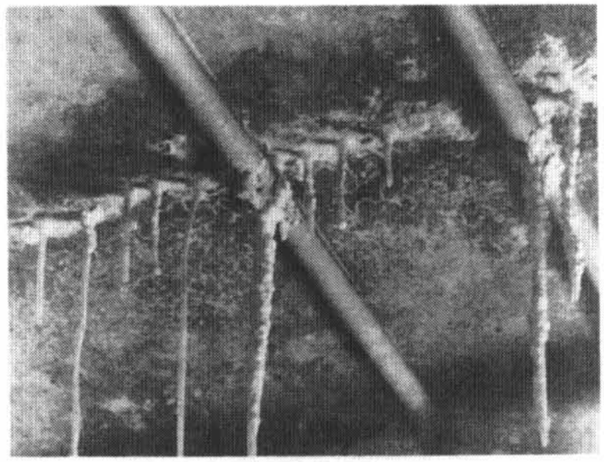


Fig. A.3.14—Stalactite

Appendix B
Sample Monolith Inspection Forms

DAM MONOLITH FIELD INSPECTION FORM

Dam: L & D "A" Monolith#: 12

Date: 8/26/94 Inspector: REB

Are there any indications of misalignment? Yes / (No)

Location Codes: UF-Upstream Face DF-Downstream Face P-Pier D-Deck S-Spillway RW-Retaining Wall F-Floor G-Gallery T-Tunnel C-Conduit
Structural Loading: L-Lateral Loads A-Axial Loads

Distress Codes: 21-CH-Checking 22-DC-D-Cracking 23-PA-Pattern 24-HZ-Horizontal 24A-HZA-One Side Gallery 25-VT-Vertical&Transverse 26-VL-Vertical & Longitudinal 26A-VLA-One Side Gallery 27-DG-Diagonal 28-RN-Random 29-LF-Longitudinal Floor 31-AB-Abrasion 32-CV-Cavitation 33-HC-Honeycomb 34-PO-Popouts 35-SC-Scaling 36-SP-Spalling 37-DS-Disintegration

CRACKING DISTRESSES

1	Category: 24 Width: .04 (in.)	L (A)	UF DF (P) D S RW F G T C
	Remarks: EL 482'		
2	Category: Width: (in.)	L A	UF DF P D S RW F G T C
	Remarks:		
3	Category: Width: (in.)	L A	UF DF P D S RW F G T C
	Remarks:		
4	Category: Width: (in.)	L A	UF DF P D S RW F G T C
	Remarks:		
5	Category: Width: (in.)	L A	UF DF P D S RW F G T C
	Remarks:		

VOLUME LOSS TYPE CRACKING / DETERIORATION

1	Distress Category:	L A	UF DF P D S RW F G T C

Distress: width ______ depth ______ height ______ elevs. ______
Section: width ______ depth ______ (at elevation of distress)
Remarks: ______

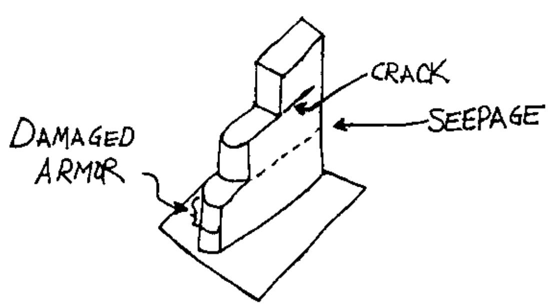
2	Distress Category:	L A	UF DF P D S RW F G T C

Distress: width ______ depth ______ height ______ elevs. ______
Section: width ______ depth ______ (at elevation of distress)
Remarks: ______

Monolith#: 12

LOCATION CODES: UF-Upstream Face DF-Downstream Face P-Pier D-Deck S-Spillway RW-Retaining Wall F-Floor G-Gallery T-Tunnel C-Conduit			
STEEL			
42-Reinforcing (percentage of bars exposed at X-section) 43-Prestress (any exposure or indicated corrosion)			
42 43	UF DF P D S RW F G T C	____ %	Remarks: ________
42 43	UF DF P D S RW F G T C	____ %	________
42 43	UF DF P D S RW F G T C	____ %	________
OTHER			
36-Spalled Joint 41-Corrosion Stain 44-Damaged Armor 51-Leakage 52-Deposits (Moderate Leakage <10 gpm, Moderate Deposit <1/2" thick)			
36 41 (44) 51 52	UF DF (P) S RW G T C	(LIT) MOD HVY CRIT	Remarks:
36 41 44 (51) 52	UF DF (P) S RW G T C	(LIT) MOD HVY CRIT	
36 41 44 51 52	UF DF P S RW G T C	LIT MOD HVY CRIT	
36 41 44 51 52	UF DF P S RW G T C	LIT MOD HVY CRIT	
36 41 44 51 52	UF DF P S RW G T C	LIT MOD HVY CRIT	

Sketches or Comments (Include any indications of foundation or alignment problems) -



* REMARKS: In all instances describe distress locations as completely as possible. Use the monolith's deck, faces or joints as datums. When applicable, as in volume loss, distress width and depth may be expressed as percentages of section width or depth at given elevation. For volume loss in decks, indicate the percentage of the deck area that is affected.

DAM MONOLITH FIELD INSPECTION FORM

Dam: L&D "A" Monolith#: 13

Date: 8/26/94 Inspector: SF

Are there any indications of misalignment? Yes / (No)

Location Codes: UF-Upstream Face DF-Downstream Face P-Pier D-Deck S-Spillway RW-Retaining Wall F-Floor G-Gallery T-Tunnel C-Conduit Structural Loading: L-Lateral Loads A-Axial Loads
Distress Codes: 21-CH-Checking 22-DC-D-Cracking 23-PA-Pattern 24-HZ-Horizontal 24A-HZA-One Side Gallery 25-VT-Vertical&Transverse 26-VL-Vertical & Longitudinal 26A-VLA-One Side Gallery 27-DG-Diagonal 28-RN-Random 29-LF-Longitudinal Floor 31-AB-Abrasion 32-CV-Cavitation 33-HC-Honeycomb 34-PO-Popouts 35-SC-Scaling 36-SP-Spalling 37-DS-Disintegration

CRACKING DISTRESSES

#	Category / Width (in.)	L A	UF DF P D S RW F G T C
1	Category: PA Width: (in.)	L A	UF DF P D S RW F G T C
	Remarks: Pattern cracks have raveled.		
2	Category: Width: (in.)	L A	UF DF P D S RW F G T C
	Remarks:		
3	Category: Width: (in.)	L A	UF DF P D S RW F G T C
	Remarks:		
4	Category: Width: (in.)	L A	UF DF P D S RW F G T C
	Remarks:		
5	Category: Width: (in.)	L A	UF DF P D S RW F G T C
	Remarks:		

VOLUME LOSS TYPE CRACKING / DETERIORATION

#	Distress Category	L A	UF DF P D S RW F G T C
1	Distress Category:	L A	UF DF P D S RW F G T C
	Distress: width ___ depth ___ height ___ elevs. ___ Section: width ___ depth ___ (at elevation of distress) Remarks:		
2	Distress Category:	L A	UF DF P D S RW F G T C
	Distress: width ___ depth ___ height ___ elevs. ___ Section: width ___ depth ___ (at elevation of distress) Remarks:		

Monolith#:

LOCATION CODES: UF-Upstream Face DF-Downstream Face P-Pier D-Deck S-Spillway RW-Retaining Wall F-Floor G-Gallery T-Tunnel C-Conduit

STEEL

42-Reinforcing (percentage of bars exposed at X-section)
43-Prestress (any exposure or indicated corrosion)

42 43	UF DF P D S RW F G T C	60 %	Remarks: rebar corrosion has spalled cover. Remaining concrete is sound.
42 43	UF DF P D S RW F G T C	___ %	
42 43	UF DF P D S RW F G T C	___ %	

OTHER

36-Spalled Joint 41-Corrosion Stain 44-Damaged Armor 51-Leakage
52-Deposits (Moderate Leakage <10 gpm, Moderate Deposit <1/2" thick)

36 41 44 51 52	UF DF P S RW G T C	LIT MOD HVY CRIT	Remarks: Interferes with operations in gate mechanical room.
36 41 44 51 52	UF DF P S RW G T C	LIT MOD HVY CRIT	
36 41 44 51 52	UF DF P S RW G T C	LIT MOD HVY CRIT	
36 41 44 51 52	UF DF P S RW G T C	LIT MOD HVY CRIT	
36 41 44 51 52	UF DF P S RW G T C	LIT MOD HVY CRIT	

Sketches or Comments (Include any indications of foundation or alignment problems) -

EL 485'

many locations

* REMARKS: In all instances describe distress locations as completely as possible. Use the monolith's deck, faces or joints as datums. When applicable, as in volume loss, distress width and depth may be expressed as percentages of section width or depth at given elevation. For volume loss in decks, indicate the percentage of the deck area that is affected.

Appendix C
Field Test Trip Reports and Comments

Memorandum to Files
Subject: Trip Report to Mississippi River Dam No. 24
Date: September 1992

Background

1. A concrete dam condition index system has been developed as a modification of a concrete lockwall system. The purpose of this trip was to test the dam condition index system at an old concrete dam to determine what adjustments or modifications to the system were desirable.

Objective

2. The objective was to evaluate the system for rating the concrete in the dam and appurtenances and to obtain field input on the system. Factors to be considered were:

a. Does the system produce consistent results that are independent of the inspector?
b. Does the system consider all types of deficiencies in all the different elements?
c. Are the deficiencies properly weighted?

Evaluation

3. The evaluation took place September 15-17, 1992. (A list of participants is provided as enclosure 1.) An orientation meeting took place at the St. Louis District office on the afternoon of September 15. Participants had previously been provided a copy of the report. This meeting was to provide a brief overview and answer questions.

4. The dam was visited on September 16. Participants traveled from St. Louis to the dam, inspected the dam, compared results, and returned to St. Louis. Each of the selected monoliths was inspected and each inspector was requested to calculate a condition index for the monoliths. Table 1 (attached) lists the condition index numbers reported. Two numbers are listed for monoliths 2 and 9. The first number omits the pier stem columns subject primarily to axial load; these columns were severely deteriorated. The second number includes the columns even though the system did not provide guidance for doing so. Monoliths 15 and 16 had the same condition index with or without the columns. The lower condition index numbers by some raters for ratings without piers were obtained by considering incipient spalls on downstream noses of the monoliths as wide cracks.

5. A meeting was held at the St. Louis District office on the morning of September 17 to discuss the results of the dam visit and to recommend items for further consideration.

Conclusions

6. The system needs to be expanded to include elements that are subject primarily to axial load.

7. Clarification needs to be added so that cracks tending to produce spalls are evaluated as spalls if that will produce a smaller deduct.

Rupert E. Bullock
Consultant

2 Encls

Evaluation Team

Mississippi River Dam No. 24

NAME	ORGANIZATION	PHONE
1. Rupert Bullock	Consultant	615-458-1152
2. Ed Demsky	CELMS-ED-GE	314-331-8426
3. Stuart Foltz	CECER-FMM	217-398-5499
4. Jerry Hawkins	CELMS-ED-GI	314-331-8412
5. Thomas L. Hugenberg	ORD-PE-G	513-684-3038
6. Tony Kao	CECER-FMM	217-398-5486
7. Michael G. Kruckeberg	CELMS-OD-NL	314-331-8588
8. Lee Lenzner	CELMS-ED-GE	314-331-8425
9. Bill McCleese	WES	601-634-2512
10. Jim McDonald	WES	601-634-3230
11. Jim Mills	CELMS-ED-DA	314-331-8233
12. Jerry Wickersham	CENCR-ED-G	309-788-6361

Table 1

Mississippi River Dam No. 24
Condition Index of Dam Monoliths

	Monolith No.					
	2		9		15	16
Inspector						
Bullock	80	40	85	70	90	90
Kao	70	65	70	65	-	-
Foltz	70	0	80	70	-	70
McCleese	80	40	80	55	80	70
McDonald	70	0	75	69	70	70
Hugenberg	70	0	75	69	70	70
Wickersham	70	55	70	55	70	70
Lenzner	40	0	-	70	50	30
Hawkins	50	0	50	50	50	-
Mills	35	0	0	45	65	45

Comments on Trip to Mississippi River Dam No. 24, by Stuart Foltz

The condition index numbers which the panel members were asked to calculate have little significance as a set of data. There is only one concern that can be directly addressed by these numbers. "Are the raters coming up with similar ratings through application of these procedures?" On this trip the answer was no, but that is in part due to the axially loaded columns that are not yet addressed in the procedures. Another reason is the spalls that were recorded as cracks by some raters; this also will be clarified in the documentation. Estimating crack width results in variations that are difficult to eliminate, especially for raveled cracks. Variance can be minimized by ensuring that raters do not include raveling in the width estimation. Measuring the ravel width might be why the participants from the St. Louis District had larger crack width estimates. Finally, modification of the procedure by raters who disagree with some part of the method, an individual deduct, or the final rating is a managerial problem that is beyond the scope of this work.

Memorandum to Files
Subject: Trip Report to Center Hill Dam
Date: December 17, 1992

Background

1. A concrete dam condition index system has been developed as a modification of a concrete lockwall system. The purpose of this trip was to test the dam condition index system at another concrete dam to determine what adjustments or modifications to the system were desirable.

Objective

2. The objective was to evaluate the system for rating the concrete in the dam and appurtenances and to obtain field input on the system. Factors to be considered were:

a. Does the system produce consistent results that are independent of the inspector?
b. Does the system consider all types of deficiencies in all the elements, including the powerhouse and the pylon?
c. Are the deficiencies properly weighted?

Evaluation

3. The evaluation took place December 9-10, 1992. (The list of participants is provided as enclosure 1.) Monoliths to be inspected were selected in an overview meeting.

4. First, the downstream faces of some of the monoliths were inspected from the powerhouse roof, then upstream faces were inspected from a boat. Crack widths could be only roughly estimated. The top of the dam and the grouting and operating galleries were then walked as were the pylon stairs. Each inspector was requested to calculate a condition index for the selected monoliths and the pylon. Table 1 lists the condition index numbers reported. The following day a walkthrough inspection of the powerhouse was conducted.

5. A meeting was held to discuss results and to recommend further actions. Tony Kao objected to the zero ratings on monolith 6 and pointed out that such a rating did not fit the condition descriptions in Figure 1 of the proposed report. Tom Hugenberg objected to the deduct values for deposits on the basis that the concrete

was not damaged to the extent indicated. There was discussion of the adequacy of the post-tensioning repair to the horizontal lift joint in monolith 11 since the joint was still leaking under a low head and there was no method for inspecting the tendons. Also, there was discussion of the deck deduct values as to whether they represented damage to a monolith or they were to indicate only a possible repair requirement for serviceability. Discussion of the powerhouse noted that other, more distressed powerhouses may require separation into divisions smaller than those between expansion joints to properly represent the condition indices. Also, it was pointed out that it may be difficult to distinguish abrasion and cavitation. Requirements for a future inspection trial also were discussed.

Conclusions

6. Stuart Foltz is to circulate information about a condition index calculation method developed in the ROOFER Engineered Management System.

7. The deduct values for deposits are to be decreased.

8. There will be an attempt to locate a dam with an intake tower for inspection.

Evaluation Team

Center Hill Dam

NAME	ORGANIZATION	PHONE
1. Rupert Bullock	Consultant	615-458-1152
2. Stuart Foltz	CECER-FMM	217-398-5499
3. Bill Heyenbruch	Sacramento Dist.	916-557-6610
4. Tom Hugenberg	CEORD-PE-G	513-684-3038
5. Ken Hull	CEORN-EP-D	615-736-5617
6. Tony Kao	CECER-FMM	217-398-5486
7. Bill McCleese	CEWES	601-634-2512
8. Jerry Wickersham	CENCR-ED-G	309-788-6361

Table 1

Center Hill Dam
Condition Index of Dam Monoliths and Pylon

	Monolith No.					
Inspector	6	7	11	16	19	Pylon
Bullock	0	40	60	60	65	50
Foltz	0	40	70	85	75	10
Heyenbruch	13	53	50	70	95	25
Hugenberg	15	55	88	80	95	20
Kao	55	40	70	80	70	-
McCleese	10	40	70	60	60	20
Wickersham	0	45	70	60	85	20

Comments on Trip to Center Hill Dam, by Stuart Foltz

It became apparent to me during this trip that straight addition of the deducts to determine the condition rating was inaccurate. The reason for this follows: On a unit with little distress, the small distresses should have a significant effect on the rating. As the unit deteriorates over time, these smaller distresses may become larger, or new distresses with large deduct values may develop. In either case, any small distresses approach insignificance in the presence of larger distresses. As an example, the presence of deposits may reduce the condition of a unit from Excellent to Very Good, but in the presence of major cracking or some other large distress, the deposits do not make a Poor structure a Very Poor structure. I proposed a nomographic method (ASTM D5340-93; Shahin, Bailey, and Brotherson, 1987; and Shahin and Walther, 1990) of calculating the rating as one possible method to achieve the expected result and illustrated the effect to the panel members. The method finally used to calculate the index should be based on subjective ratings by the panel members. I also thought the distress deduct values should be based on subjective ratings by the panel members.

Memorandum to Files
Subject: Trip Report to Chief Joseph and Grand Coulee Dams
Date: May 19, 1993

Background

1. A concrete dam condition index system has been developed as a modification of a concrete lockwall system. The purpose of this trip was to further test the dam condition index system to determine what adjustments or modifications were desirable.

Objective

2. The objective was to evaluate the system for rating the concrete in the dams and to obtain field input on the system. Factors to be considered were:

   a. Does the system produce consistent results that are independent of the inspector?
   b. Does the system consider all types of deficiencies in all the elements selected?
   c. Are the deficiencies properly weighted?

Evaluation

3. Elements in Chief Joseph Dam were inspected on May 4. Elements of the dam and two powerhouses at Grand Coulee were inspected on May 5. (A list of participants is provided in enclosure 1.)

4. Table 1 lists the condition index numbers reported for Chief Joseph Dam. The numbers for monoliths S1, S2, and 12 reported by R. Bullock and B. Heyenbruch include 10 points deducted for pattern cracking over 100 percent of the deck that the other inspectors did not deduct since serviceability was not affected. Other variations resulted from judgments concerning deposits and cracks in the concrete encasing the penstocks.

5. Table 2 lists the condition index numbers reported for Grand Coulee Dam and a section each from two powerhouses. The numbers for monoliths 81 and 82 reported by B. McCleese include 5 points deducted for slight raveling of some pattern cracking on the deck that was ignored by others. The numbers reported for monolith 118 by R. Bullock and B. Heyenbruch include 5 points for a downstream face construction joint spall ignored by others.

6. Discussion indicated that decks were of less importance to dams than to locks and that it would be appropriate to delete division C and make cracking on decks deductable only if cracks were raveling or causing ponding. It was decided that no deduction should be made for a joint spall less than 3 in. deep. It was decided to add a category for leakage sufficient to affect the operation of the dam.

Conclusions

7. R. Bullock is to revise the report so that it can be distributed for comments.

Evaluation Team

Chief Joseph Dam and Grand Coulee Dam

NAME	ORGANIZATION
1. Rupert Bullock	Consultant
2. Stuart Foltz	CECER-FMM
3. Bill Heyenbruch	CESPK-ED
4. Tony Kao	CECER-FMM
5. Bill McCleese	CEWES-SC
6. Jan Shrader	Bureau of Reclamation
7. Ken Sondergard	CENPS-EN-GT-GI
8. Jerry Wickersham	CENCR-ED-G

Table 1

Chief Joseph Dam

Inspector	Unit Number			
	S1	S2	12	15
Bullock	68	55	60	78
Heyenbruch	60	70	65(13)	60
Kao	75	65	73	80
McCleese	75	73	83	68
Wickersham	78	73	68	78

Table 2

Grand Coulee Dam

Inspector	Unit Number					
	63	81	82	118	OPHse	NPHse
Bullock	80	83	78	68	-	75
Heyenbruch	83	78	63	68	68	73
Kao	93	73	65	78	-	-
McCleese	88	68	65	78	83	73
Wickersham	88	75	73	78	88	75

Comments on Trip to Chief Joseph and Grand Coulee Dams, by Stuart Foltz

In my notes after the last trip I mentioned getting subjective ratings from the panel members on the individual distresses and the unit rating. The idea of collecting subjective ratings to compare to the objective rating method did not have much support by the panel. Because there were so few distresses present at Chief Joseph and Grand Coulee (and almost all of those were minor), I did not consider it worthwhile to pursue the idea further during the trip.

Memorandum to Files
Subject: Trip Report to Friant Dam, et al.
Date: July 29, 1993

Background

1. A concrete dam condition index system has been developed as a modification of a concrete lock wall system. The purpose of this trip was to test the dam condition index system at additional concrete dams to determine what adjustments or modifications were desirable.

Objective

2. The objective was to evaluate the system for rating the concrete in the dam and appurtenances and to obtain field input on the system. Factors to be considered were:

a. Does the system produce consistent results that are independent of the inspector?
b. Does the system consider all types of deficiencies in all the elements?
c. Are the deficiencies properly weighted?

Evaluation

3. The evaluation took place from June 29 to July 1, 1993. (The list of participants is provided in enclosure 1.) Four monoliths in Friant Dam were inspected on June 29. The control towers and outlet conduits on Hidden Dam and Buchanan Dam were inspected on June 30. An outlet conduit on Pine Flat Dam was inspected on July 1.

4. Table 1 lists the condition index numbers reported for Friant Dam. The numbers in parentheses are subjective numbers based on the descriptions in Figure 1 of the report. Inspection results from other trips have shown that procedures were not being followed and it is especially apparent here. Blocks 36 and 42 were being distorted into the spillways by alkali-aggregate expansion. This has interfered with gate operation and has initiated cracking. A wide diagonal crack has formed in block 36, but this is not apparent in some condition index numbers.

5. Condition index numbers were not collected on the other structures. The outlet conduit at Hidden Dam appeared to have a slight chemical attack that had exposed the aggregate. A wall at the outlet had pattern cracking in the top, probably from

alkali aggregate expansion. The pattern joined together such that some inspectors judged it a vertical and longitudinal crack. The outlet conduit at Buchanan Dam had a number of narrow cracks. The outlet conduit at Pine Flat Dam had small amounts of both abrasion and cavitation.

6. A meeting was held to discuss results. It was pointed out that the condition index numbers are generally too low to fit the descriptions in Figure 1 of the report. McDonald suggested that Division B be reduced as Division A gets larger. I stated that Division A deduct values for cracks could be reduced by approximately 20 percent. Foltz suggested a nomograph to combine a number of defects. Kao stated that a deduct value of 60 was being used for any misalignment in navigation locks. Liu suggested

a. Reinforced concrete be separated from plain concrete.
b. That a crack not have a deduct if it does not leak or have relative movement along the crack, or that deduct values be multiplied by a number less than 1 if there is no leakage or relative movement along the crack.
c. That deduct values be reduced and multipliers greater than 1 be used for related effects such as leaking or relative movements.
d. That the extent of a crack affect the deduct value.
e. That the area of abrasion or cavitation affect the deduct value.

When I pointed out that relative movement along a crack in an element constituted a failure of the element, Liu asserted that this was not true.

Conclusions

7. Foltz will prepare a nomograph for the next inspection.

8. I will prepare a new calculation form reducing deducts for cracks and reducing Division B as Division A increases.

Rupert E. Bullock
Consultant

Evaluation Team
Friant Dam

NAME	ORGANIZATION	PHONE
1. Rupert Bullock	Consultant	615-458-1152
2. Stuart Foltz	CECER-FMM	217-398-5499
3. Bill Heyenbruch	CESPK-ED	916-557-6610
4. Tom Hugenberg	CEORD-PE-G	513-684-3038
5. George Hunter	USBR Friant	209-822-2211
6. Tony Kao	CECER-FMM	217-398-5486
7. Tony Liu	CECW-EG	202-272-0222
8. Jim McDonald	CEWES-SC	601-634-3230
9. Glenn Smoak	D-3731, USBR	303-236-6103

Table 1

Friant Dam

Condition Index of Dam Monoliths

	Monolith No.			
	35	36	38	42
Inspector				
Bullock	55 (60)	0 (20)	40 (50)	25 (40)
Foltz	45	0	40	20
Heyenbruch	10 (45)	10 (30)	45 (50)	25 (35)
Hugenberg	40 (85)	10 (50)	20 (95)	40 (75)
Kao	40 (40)	20 (30)	40 (30)	40 (40)
Liu	40 (40)	40 (40)	40 (50)	40 (50)
McDonald	55 (55)	0 (40)	45 (60)	45 (60)
Smoak	40 (45)	45 (40)	45 (50)	50 (55)

Comments on Trip to Friant Dam, et al., by Stuart Foltz

Friant Dam had some major cracks in a few monoliths and I thought useful information could be generated by collecting subjective ratings. At the time, this met some resistance but the information was collected. When meeting after the inspection there was a definite change in attitude of nearly all group members, and that is when it was agreed that I should again address the nomographic calculation method. It was agreed that on the next trip we should calculate condition indices by both methods (nomographic and straight addition with an upper limit on serviceability deducts) and compare each to subjective ratings. I'm not sure if this change was due to the lack of correlation between the subjective and calculated ratings or if it was due to the influence of Tony Liu, who had a large effect on discussions. We decided to return to Center Hill Dam, if possible, because we knew there were numerous distresses that would provide a good test of the two calculation methods.

Memorandum to Files
Subject: Trip Report to Center Hill Dam
September 27, 1993

Background

1. A concrete dam condition index system has been developed and modified after a number of inspection trips. The purpose of this trip was to test the system at a previously inspected dam.

Objective

2. The objective was to evaluate the system for rating the concrete in the dam and to obtain field input. Specifically, it was to be determined if the modified deduct values produced CIs more consistent with the descriptions in Figure 1 of the report.

Evaluation

3. The evaluation took place September 14-15, 1993. (The list of participants is provided in enclosure 1.)

4. The upstream faces of the selected monoliths were first inspected from a boat. Since crack widths could only be estimated, the diagonal crack in block 6 was assigned a width of 0.06". The top of the dam and operating and grouting galleries were then walked. Each inspector was requested to calculate a condition index number for the selected monoliths and to make a subjective judgment for each monolith in accordance with the descriptions in Figure 1 of the report. Table 1 lists the calculated CIs and Table 2 lists the subjective CIs reported.

5. A discussion was then held of the calculated versus the subjective CIs. It was noted that the subjective CIs were smaller than the calculated for blocks 6 & 7. The calculated CIs from the December 1992 inspection were referred to and it was noted that the widths for the diagonal cracks in block 6 were probably estimated to be greater than .08" at that time. I questioned the validity of the subjective ratings since there were such large disparities. Hugenberg stated that the district had post-tensioning tendon repairs designed for block 6 (and some other blocks) because it would fail under design probable maximum flood (PMF), but that the district was not restricting pool elevation until the tendons were installed. I stated that in my judgment the new deduct values produce CIs that are too large because they should have indicated a more serious condition for blocks 6 & 7.

6. A discussion was then held on Figure 1 of the report. It was stated that the condition descriptions should indicate they applied to the probable condition after application of the maximum probable load.

7. Foltz made a presentation on a nomograph solution to reduce CIs for more than one defect. I stated that secondary defects did not make a failure more probable; however, they may modify the extent of a failure. Kao objected to the nomograph solution on the basis that it did not continuously reduce a CI as the number of defects increased.

8. It was noted that any type of crack in a deck that was raveling should have a "deck deduct" and that provision should be made for combining raveling cracks with popouts or other defects for an overall deck deduct.

Conclusions

9. I am to prepare a final report for distribution.

Evaluation Team

Center Hill Dam

NAME	ORGANIZATION	PHONE
1. Rupert Bullock	Consultant	615-458-1152
2. Stuart Foltz	CECER-FMM	217-398-5499
3. Tom Hugenberg	CEORD-PE-G	513-684-3038
4. Tony Kao	CECER-FMM	217-398-5486
5. Bill McCleese	WES	601-634-2512
6. Jerry Wickersham	CENCR-ED-G	309-794-5713

Center Hill Dam

Table 1
Condition Index of Dam Monoliths

	Monolith No.								
Inspector	5	6	7	8	11	14	15	16	19
Bullock	90	40	60	95	60	65	60	80	85
Foltz	85	50	65	100	64	64	74	69	85
Hugenberg	40	40	45	85	60	70	40	60	70
Kao	90	45	70	100	70	70	80	75	70
McCleese	80	45	45	100	65	70	60	75	75
Wickersham	70	45	55	95	60	80	60	75	90
AVERAGE	76	44	57	96	63	70	62	72	79

Table 2
Subjective Condition Index of Dam Monoliths

	Monolith No.								
Inspector	5	6	7	8	11	14	15	16	19
Bullock	80	20	40	80	60	70	50	80	80
Hugenberg	95	50	50	100	95	100	95	100	99
Kao	80	50	55	100	80	75	75	75	80
McCleese	80	35	35	100	80	80	75	80	80
Wickersham	84	39	39	84	84	84	54	84	80
AVERAGE	84	39	44	93	80	82	70	84	84

Comments on Second Trip to Center Hill Dam, by Stuart Foltz

We collected subjective ratings for the monoliths reported. Overnight, I calculated everyone's ratings using the nomographic procedure and using deducts for all cracks, not just the largest single crack deduct. The nomographic ratings closely tracked the subjective ratings for monoliths with both high and low indices. The originally proposed method of simple addition with a limit on serviceability deducts did not track the subjective ratings as well. When subjective ratings were high, simple addition tended to calculate lower ratings than subjective opinion. As the subjective ratings went down, the calculated ratings did not decrease as fast and tended to be higher than low subjective ratings. The table that follows includes statistical information that confirms the supposition, based on the limited data. The correlation coefficient is much closer to 1 and the standard deviation is much smaller for the nomographic and implemented calculation methods. Rupert Bullock was the only panel member who strongly objected to the nomographic calculation results or the inclusion of all crack deducts instead of just the largest. He stated that secondary cracks did not matter because the unit would fail by the major distress. Other members had smaller objections. Tony Kao disliked the fact that the rating did not continuously decrease as distresses were added. Tom Hugenberg did not think the accuracy improvement was worth the added complication of the calculation process.

After the trip the nomographic calculation method was replaced with the current method, which is a slight modification of a method proposed by Tom Hugenberg. This was done to remove Tony Kao's objection. (The nomographic method did not result in the rating sometimes improving with the addition of distresses because the lowest value is always used; however, sometimes these distresses had no effect on the rating.) Ratings calculated by this method differ by a statistically insignificant amount from those calculated using the nomographs, considering the limited data.

Table 1 provides a comparison of the three methods considered for calculating the CI. Method 1 is proposed by Rupert Bullock and he discusses this method in the trip reports. Method 2 is a nomograhic method of determining the CI. Method 3 is based on the equation on page 28 of this report. The CIs shown are the average of the five raters for the identified monolith and calculation method or subjective ratings. Below the monolith ratings are the average CIs of all monoliths for each calculation method and the subjective rating. Methods 2 and 3 were purposely made conservative relative to the subjective rating average. The standard deviations and correlation coefficients (correlation to subjective ratings) both indicate that methods 2 and 3 are substantial improvements over method 1. The correlation coefficients for each rater were also better for methods 2 and 3 than for method 1.

Subjective ratings for individual distresses were not recorded. This was for two reasons: First, any resultant changes would be unlikely to impact the monolith rating. Second, it would be difficult to collect enough data to base the deducts on subjective ratings. Although we had changed the deducts for cracking distresses after the last trip, there was little disagreement on the proposed deducts on the field trips and no change in cracking distresses relative to each other. Further, cracking distresses largely determine the final rating, so our subjective monolith ratings basically determine how the cracking distresses and deducts are transformed into the condition rating. Noncracking distresses are all relatively small with the exception of critical leakage, and subjective ratings are difficult to make when the distresses are always in the Excellent or the top of the Very Good categories.

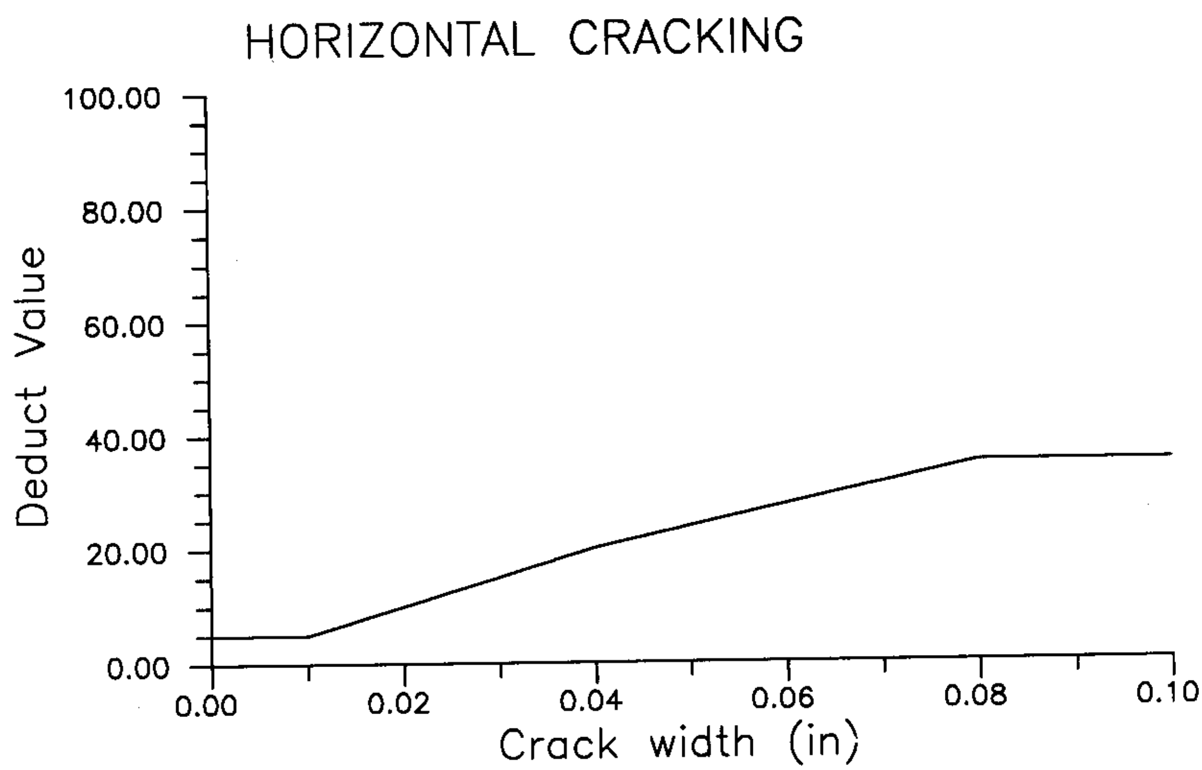
Throughout development and field testing of the condition index, cracking deducts were based on ranges of crack widths, similar to the method used for lockwalls (Bullock, 1989). The deduct value was the same over the entire range. This was a necessary simplification in order for the index to be easily hand calculated. With the switch to a more complex calculation method, the deduct values should change in proportion to any change in crack width and the step function should be removed. Using the step function could result in large differences in deduct value between raters. If the crack width is near the step, one rater could determine the deduct value to be at a different step from another rater. Without the step, a small deviation between raters can only have a small impact on the deduct value.

Table 1
Condition Index Ratings for Center Hill Dam

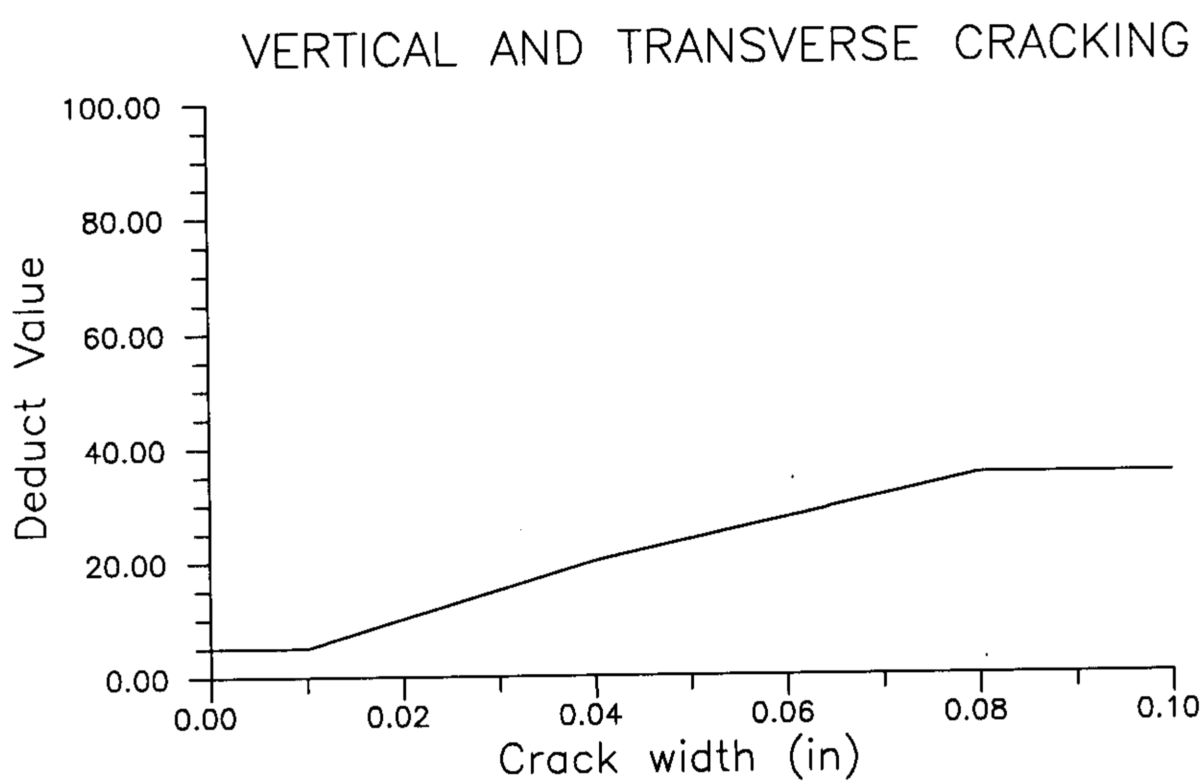
	Method 1*	Method 2*	Method 3*	Subjective
Monolith 5	82	87	85	84
Monolith 6	43	43	37	39
Monolith 7	55	48	47	44
Monolith 11	63	75	73	80
Monolith 14	71	76	74	82
Monolith 15	60	65	61	70
Monolith 16	73	80	80	84
Monolith 19	78	82	80	84
AVG.	66	69	67	71
Std. Dev.	6.16	3.48	4.11	-
Corr. Coeff.	0.897	0.980	0.975	-

*Method 1 - Simple addition of deducts with limit on serviceability deducts.
*Method 2 - Calculation of ratings based on nomographs.
*Method 3 - Implemented method, using smaller percentage of each additional smaller deduct.

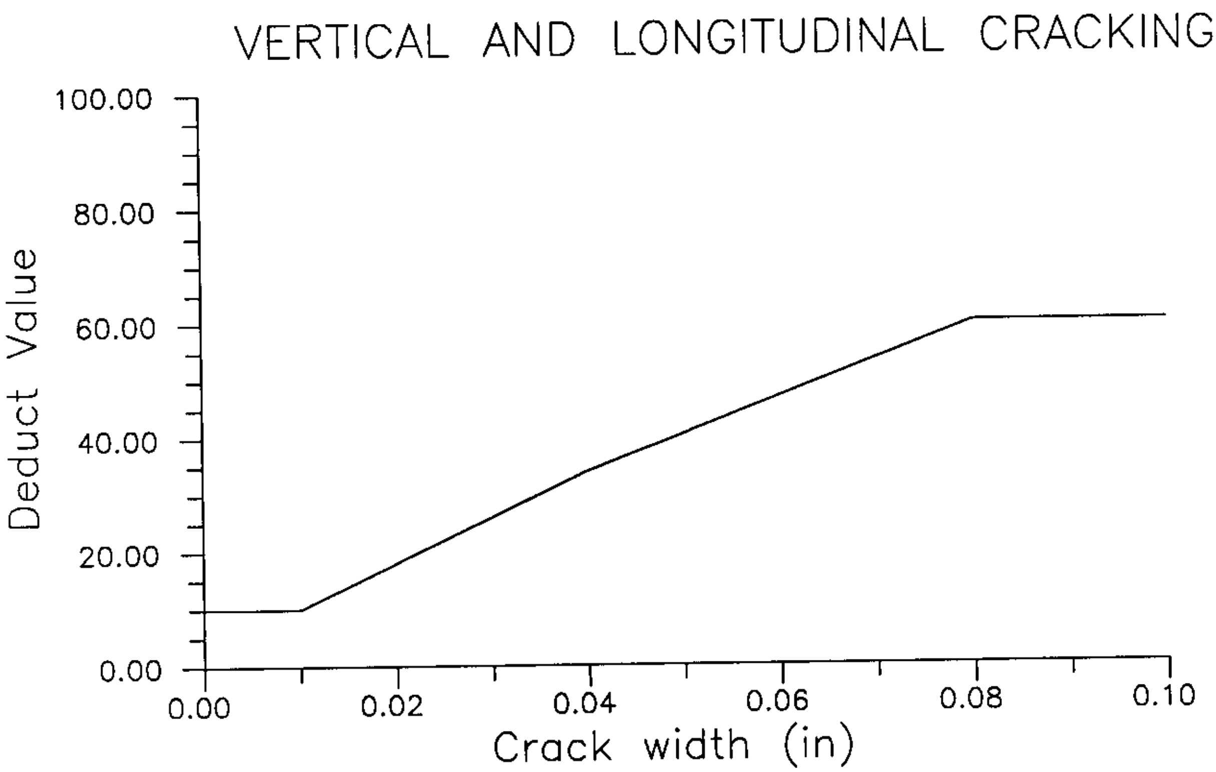
Appendix D
Deduct Value Curves

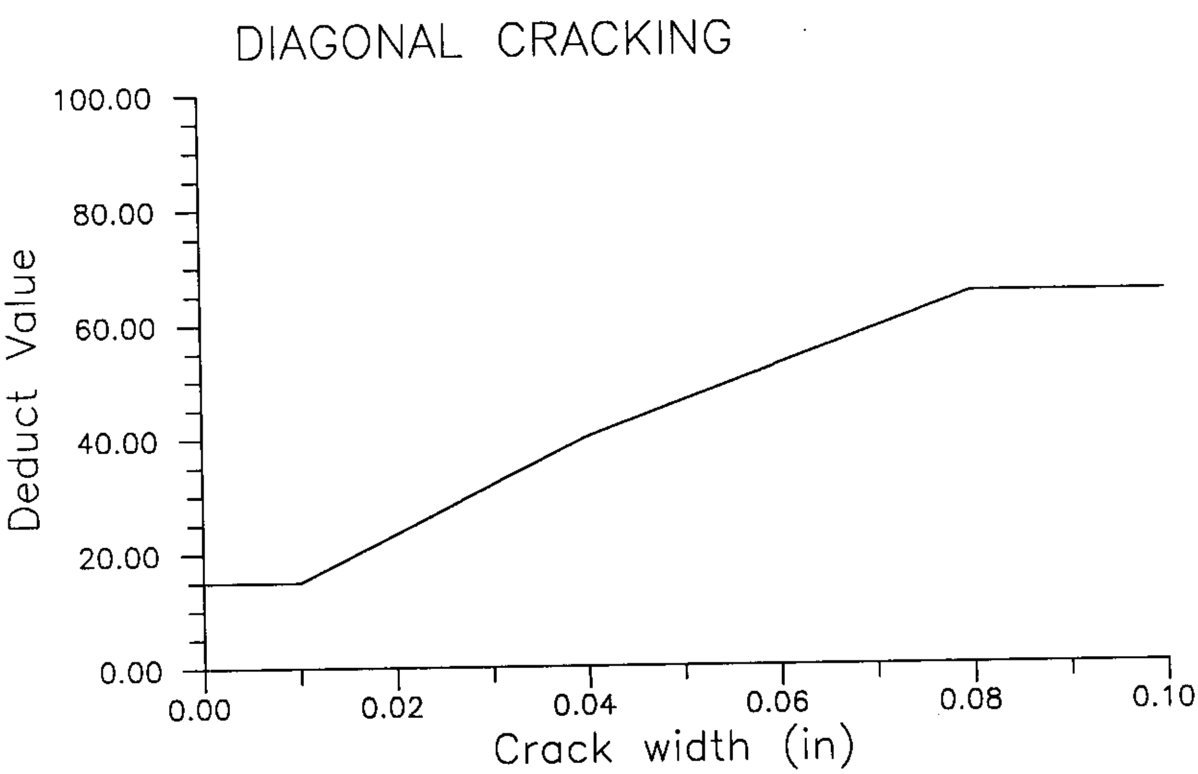


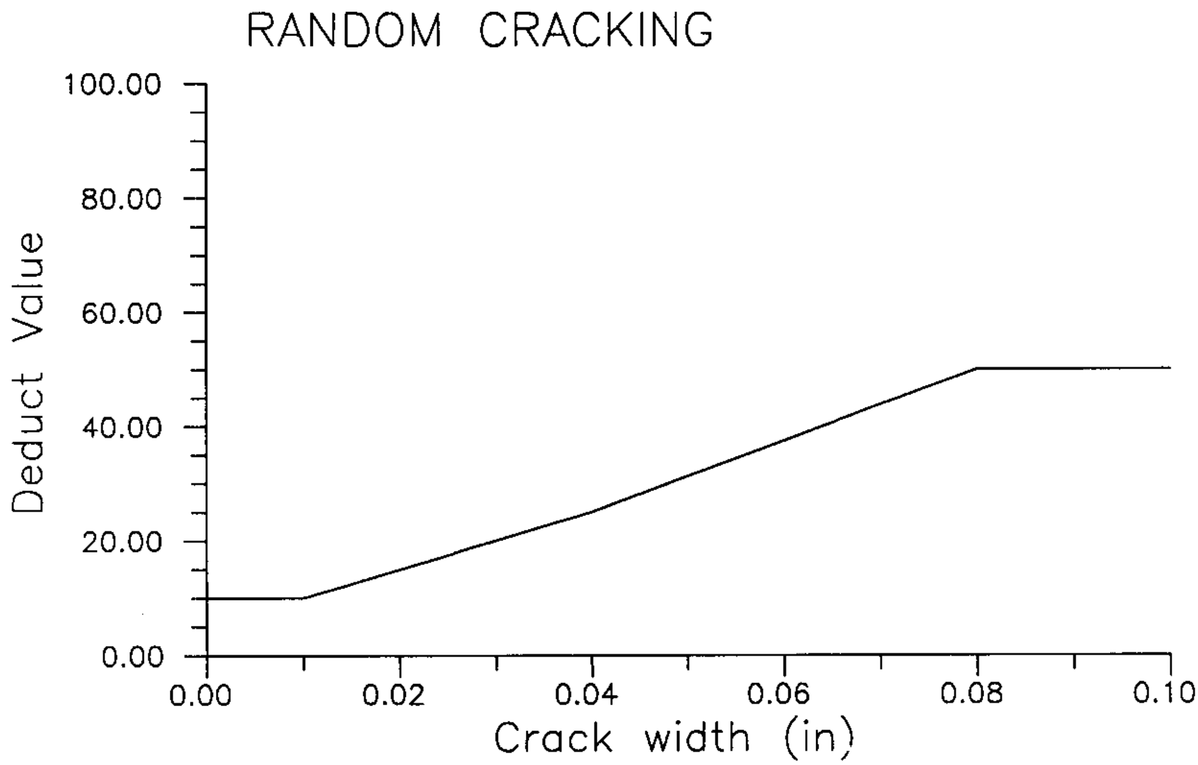
HORIZONTAL CRACKING
Deduct Value
100.00
80.00
60.00
40.00
20.00
0.00
0.00
0.02
0.04
0.06
0.08
0.10
Crack width (in)

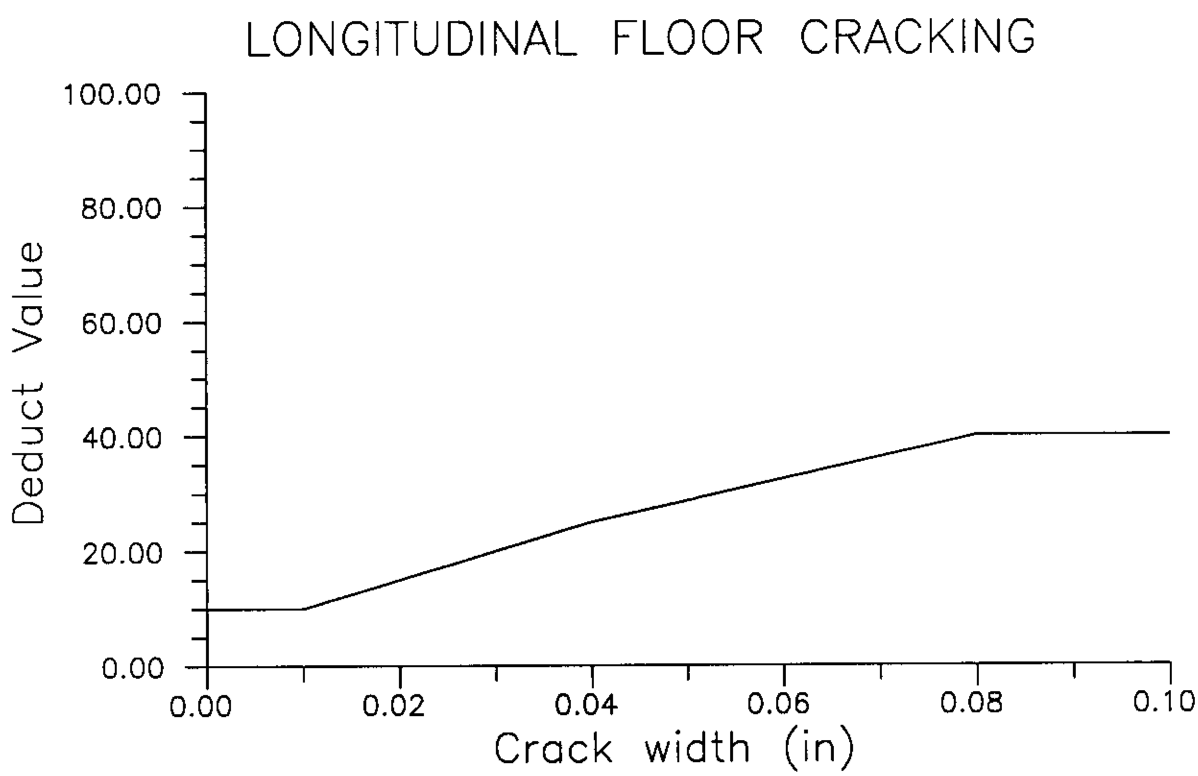


VERTICAL AND TRANSVERSE CRACKING
Deduct Value
100.00
80.00
60.00
40.00
20.00
0.00
0.00
0.02
0.04
0.06
0.08
0.10
Crack width (in)

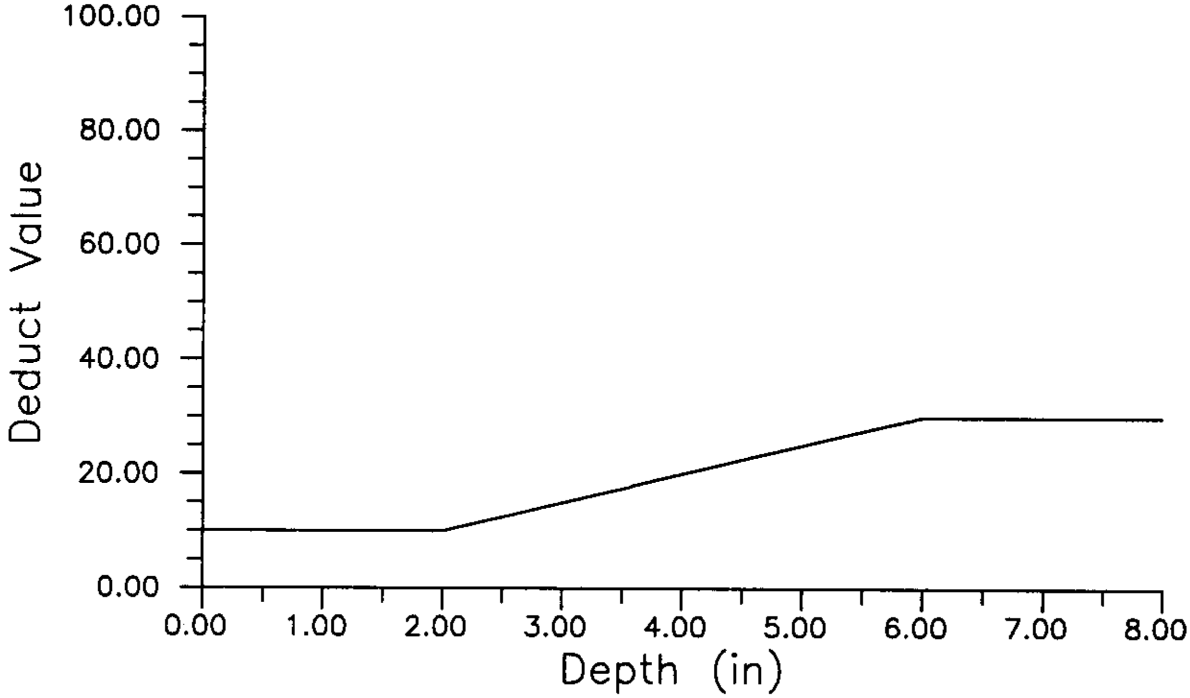

VERTICAL AND LONGITUDINAL CRACKING
100.00
80.00
60.00
40.00
20.00
0.00
Deduct Value
0.00
0.02
0.04
0.06
0.08
0.10
Crack width (in)


DIAGONAL CRACKING
100.00
80.00
60.00
40.00
20.00
0.00
Deduct Value
0.00
0.02
0.04
0.06
0.08
0.10
Crack width (in)

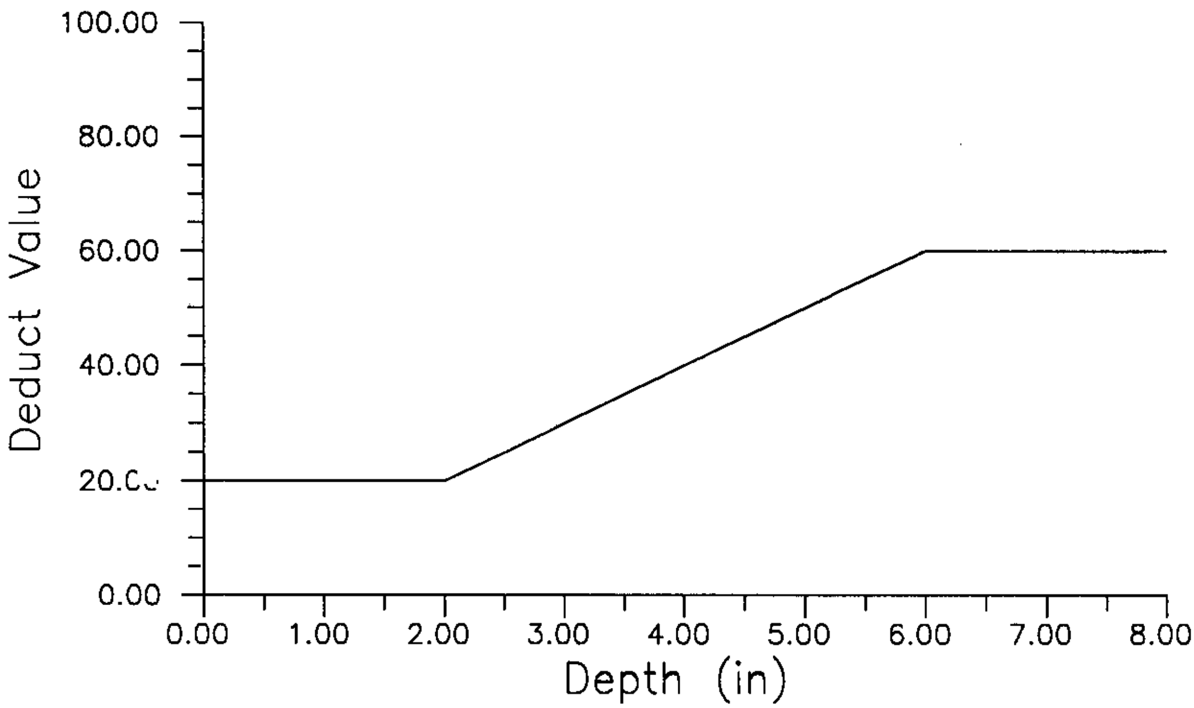

RANDOM CRACKING
Deduct Value
100.00
80.00
60.00
40.00
20.00
0.00
0.00
0.02
0.04
0.06
0.08
0.10
Crack width (in)

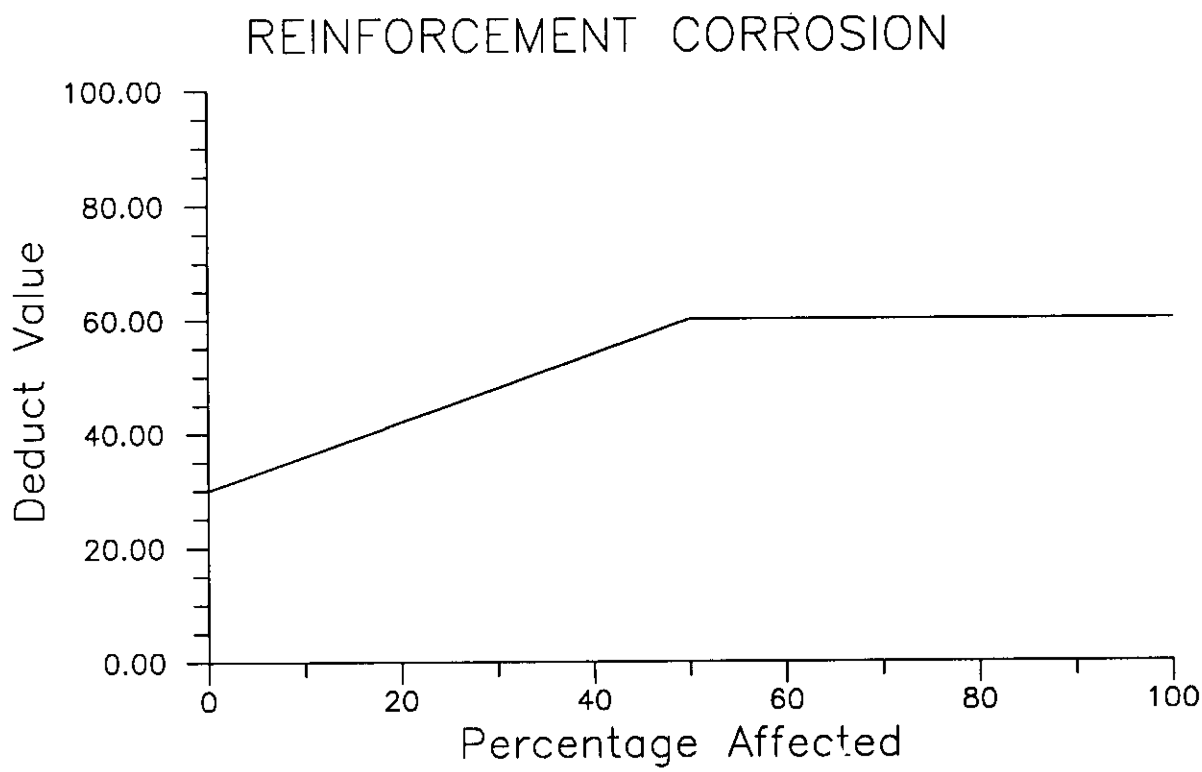

LONGITUDINAL FLOOR CRACKING
Deduct Value
100.00
80.00
60.00
40.00
20.00
0.00
0.00
0.02
0.04
0.06
0.08
0.10
Crack width (in)

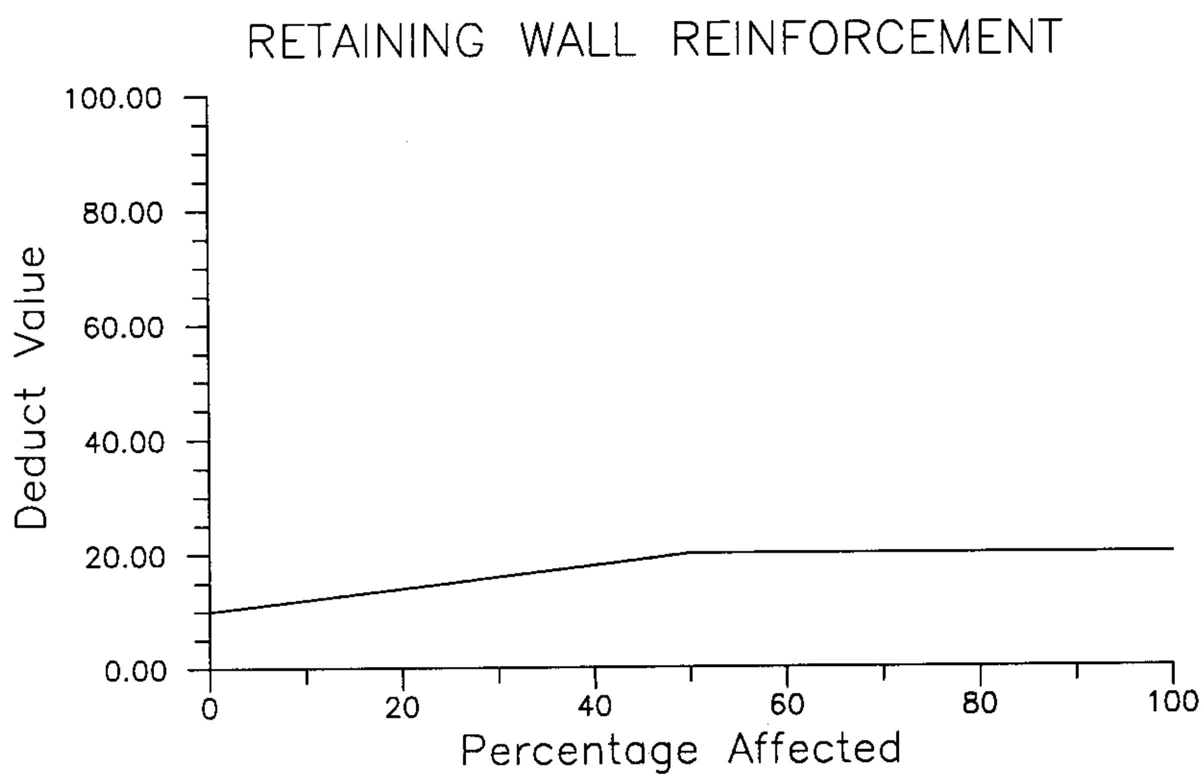
ABRASION FOR CONDUITS



CAVITATION FOR CONDUITS




REINFORCEMENT CORROSION
Deduct Value
100.00
80.00
60.00
40.00
20.00
0.00
0
20
40
60
80
100
Percentage Affected


RETAINING WALL REINFORCEMENT
Deduct Value
100.00
80.00
60.00
40.00
20.00
0.00
0
20
40
60
80
100
Percentage Affected

REPORT DOCUMENTATION PAGE

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13. ABSTRACT (Maximum 200 words)

The purpose of this report is to describe a proposed system for determining a condition index (CI) that numerically rates the condition of the concrete in a gravity dam monolith, retaining wall, or spillway on a scale of 1 to 100 by evaluating each concrete distress objectively. The rating system described herein allows the CI to be determined by the use of a visual investigation with limited equipment. The rating is related primarily to structural integrity and secondarily to serviceability.

The CI procedure was developed by assigning deduct values to defects which include the following distress categories: alignment, cracking (checking, D-cracking, pattern, horizontal, vertical and transverse, vertical and horizontal, diagonal, random, and longitudinal floor), deposits, leakage, steel deterioration (corrosion stains, reinforcing, prestressing, and armor), and volume loss (abrasion, honeycomb, pop-outs, scaling, spalling, and disintegration). The deduct values are, in part, subtracted from 100 to establish the CI. Primary deduct values were determined with the intent of obtaining a CI of 40 when deterioration of a concrete monolith caused the safety of that monolith to become questionable. Nominal deduct values were assigned for defects in serviceability. The CI should be determined on at least one of each type of monolith and the more distressed monoliths. At least 20 percent of the monoliths should be rated.

14. SUBJECT TERMS
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condition indexes
navigation structures
maintenance and repair
REMR Management System

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