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13. ABSTRACT (Maximum 200 words)

For much of its early history, the US Army Corps of Engineers concentrated on designing and constructing new facilities. But now the mission of the Corps is shifting from construction to maintenance of existing facilities. As part of the Repair, Evaluation, Maintenance, and Rehabilitation (REMR) program, this research focuses on the evaluation and repair of the steel sheet pile structures within the Corps' Civil Works projects.

The objectives of this work were to (1) develop an inspection and rating system that uniformly and consistently describes the current condition of steel sheet pile structures, and (2) develop guidelines for the maintenance and repair of these structures.

This report discusses the current inspection and rating system and provides the definition of a condition index and a brief description of sheet pile distresses. A detailed description of the inspection process is included.

Inspection data are entered onto a computer disk through a PC program that summarizes the safety and serviceability problems associated with the structure. By supplying the initial costs, expected life, downtime costs, interest rates, and inflation rates, an experienced engineer can make a preliminary maintenance and repair plan for the structure.

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PREFACE

This study was authorized by Headquarters, US Army Corps of Engineers (HQUSACE), under Civil Works Research Work Unit 32280, "Development of Uniform Evaluation for Procedures/Condition Index for Deteriorated Structures and Equipment," for which Dr. Anthony M. Kao is Principal Investigator. This work unit is part of the Operations Management Problem Area of the Repair, Evaluation, Maintenance, and Rehabilitation (REMR) Research Program sponsored by HQUSACE. Mr. James E. Crews (CECW-OM) is the REMR Technical Monitor for this work.

Mr. Jesse A. Pfeiffer, Jr. (CERD-C) is the REMR Coordinator at the Directorate of Research and Development, HQUSACE; Mr. Crews and Dr. Tony C. Liu (CEMP-ED) serve as the REMR Overview Committee; Mr. William F. McCleese (CEWES-SC-A), US Army Engineer Waterways Experiment Station, is the REMR Program Manager; Dr. Kao is also the Problem Area Leader for the Operations Management problem area.

The study was performed by the College of Engineering, Iowa State University, under contract to the US Army Construction Engineering Research Laboratory (USACERL). Principal Investigators for Iowa State University were Professors Lowell Greimann and James Stecker.

The study was conducted under the general supervision of Dr. Paul A. Howdyshell, Acting Chief of Engineering and Materials Division (EM), USACERL, and under the direct supervision of Dr. Anthony M. Kao who was the Contracting Officer's Representative. The technical editor was Gloria J. Wienke, USACERL Information Management Office.

COL Everett R. Thomas is the Commander and Director of USACERL, and Dr. L. R. Shaffer is Technical Director.

CONTENTS

(CONTENTS cont'd)

LIST OF FIGURES

CONVERSION FACTORS, NON-SI TO SI (METRIC) 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	0.0174533	radians
cubic ft (ft^3)	0.0283	cubic metres
feet	0.3048	meters
inches	25.4	millimetres
pounds (force)	4.448222	newtons
pounds (force) per square foot	47.88026	pascals
pounds (force) per square inch	0.006894757	megapascals
pounds (mass) per cubic foot	16.01846	kilograms per cubic metre

MAINTENANCE AND REPAIR OF SHEET PILE STRUCTURES

PART I: INTRODUCTION

Background

1. The US Army Corps of Engineers has acquired a large inventory of Civil Works projects over the past 100 years. For much of this time the Corps concentrated on the design and construction of new facilities, such as locks and dams on the navigable inland waterways and coastal systems, as well as power generation. Recently, the mission of the Corps has been shifting from the construction of new facilities to the maintenance of existing facilities. Several factors have prompted this shift: many existing structures are nearing the end of their design life and fewer opportunities for expansion of Corps projects are available. The Corps has addressed its changing role by instituting a Repair, Evaluation, Maintenance, and Rehabilitation (REMR) program. As the name implies, there are several aspects to the general topic of maintenance. To some extent, each aspect requires the development of a new technology and methodology.

2. As a part of this program, the project team at Iowa State University has undertaken a research effort focusing on the evaluation and repair of the steel sheet pile structures within the Corps' Civil Works projects. Steel sheet pile structures are certainly not the most critical items in a lock and dam facility. These structures, which have a long design life and are not a part of the operating machinery of the lock and dam facility, do not require a great deal of maintenance. On the other hand, failure of a steel sheet pile wall can significantly affect operations--especially as a part of a lock and dam facility. As such, these structures provide an excellent vehicle around which a maintenance program can be developed. The methodology developed for this relatively simple type of structure can be extended to more complex and critical structural systems.

Objectives and Scope

3. The objectives of this work were to (1) develop a uniform procedure to describe the current condition of steel sheet pile structures and (2) develop guidelines for the maintenance and repair of these structures.

4. The scope of this project has been specifically limited to steel sheet pile structures associated with lock and dam facilities. A previous report (Greimann and Stecker 1987) summarized the work associated with the first objective. For completeness, much of that work has been rearranged and repeated here. In addition, work on the second objective is also described.

Mode of Technology Transfer

5. The inspection procedures developed in this study for steel sheet piles will be incorporated into ER 1110-2-100, "Periodic Inspection and Continuing Evaluation of Completed Civil Works Structures." Software will be available from U.S. Army Engineer Waterways Experiment Station's Engineering Computer Program Library (ECPL). Address requests to: Commander and Director, U.S. Army Engineer Waterways Experiment Station, ATTN: CEWES-IM-DS, 3909 Halls Ferry Road, Vicksburg, MS 39180-6199 or call (601) 634-2581. All other inquiries should be directed to Commander and Director, U.S. Army Construction Engineering Research Laboratory, P.O. Box 4005, Champaign, IL 61824-4005, telephone (217) 373-7011.

PART II: OVERVIEW

6. During the past 3 years, Corps personnel, Iowa State University (ISU) personnel, and others have met several times to develop and refine a steel sheet pile evaluation process. The project team at ISU has conducted several site visits and field investigations, including a field trip to the Chicago area in July, 1987. Experts from the Corps of Engineers were asked to rate nine walls. Their ratings were compared to a preliminary version of the rating system, and modifications were made to reflect the experts' opinions more accurately. During meetings with these experts, a number of maintenance and repair alternatives were also identified. This information has been assembled and the entire rating procedure and maintenance and repair analysis process has been implemented into a personal computer program.

Field Inspection

7. The maintenance and repair procedure is illustrated schematically in Figure 1. The entire process is based on a thorough field inspection of the steel sheet pile structure. During this inspection, current physical attributes of the systems are obtained. Data, such as the location of the wall, inspection history, historical water level, and maintenance history, are recorded on the first two pages of the inspection sheet developed specifically for this purpose. Another page is used to describe some of the structural details, such as cross section type, soil information, and anchor configuration. Alternate pages exist for anchored or cantilevered walls, single cells and multiple cells. On the next page, the loading data behind the wall and the dredge depth adjacent to the structure are recorded. The last page is used to describe distresses that have occurred to the wall during its lifetime (e.g., misalignment, corrosion, cracks, and dents).

8. The information collected on the inspection form is entered into a data file through a program on a personal computer. The program permits editing of the file and handles the data for all of the succeeding steps.

Condition Index

9. The rating process is the next step. Information from the inspection data is used in the program to calculate a condition index for the structure. A condition index is a numerical measure of the current state of a structure. It is part of the objective of this project to define a condition index that uniformly and consistently describes and ranks the condition of steel sheet pile structures. The condition index is primarily a planning tool, with the index values serving as an indicator of the general condition level of the structure. The index is meant to focus management attention on

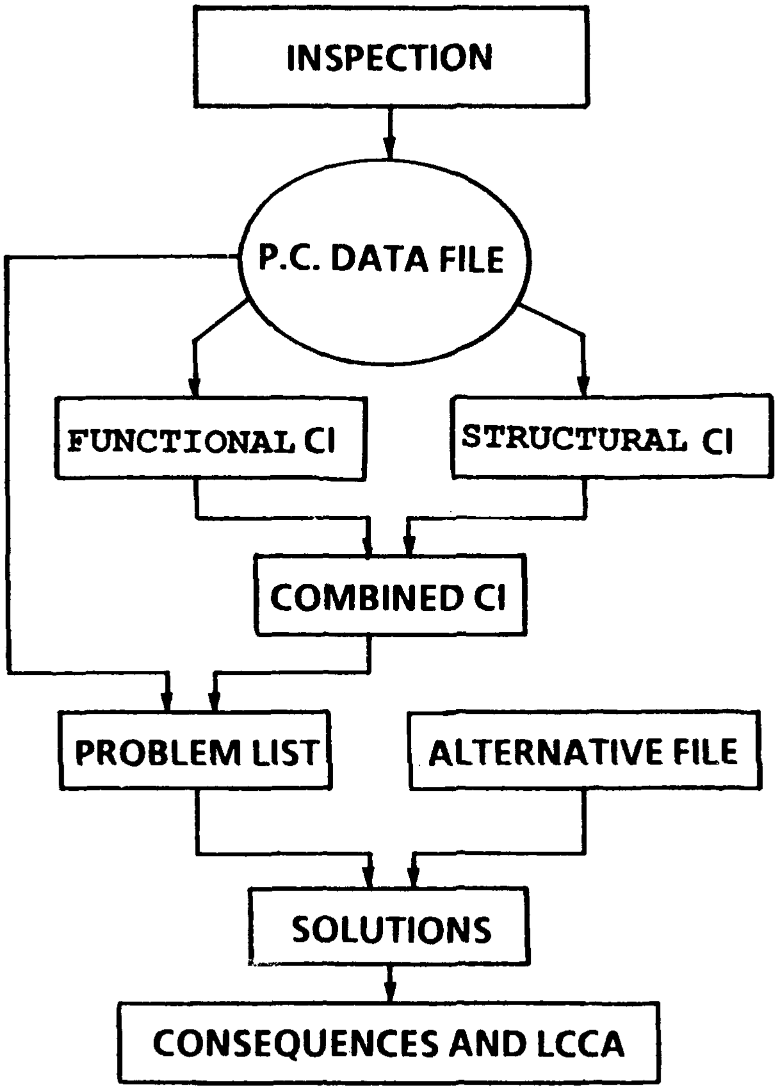


Figure 1. Maintenance and repair analysis of steel sheet pile

those structures most likely to warrant immediate repair or further evaluation. In addition, 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.

10. During the meetings that have been held on this subject, a common definition of condition index for the REMR work has evolved. The REMR Condition Index (CI) is a numbered scale, from a low of 0 to a high of 100. The numbers indicate the relative need to perform REMR work because of deterioration of the functional and safety characteristics of the structure. The

condition index scale in Table 1 has been adopted. For management purposes, the condition index scale is calibrated to group structures into three basic categories or zones, as listed in Table 2.

11. Two general structural criteria for evaluating the condition index are available: safety and serviceability. Safety relates to the performance of a structure beyond normal service conditions, for example, under abnormal conditions such as excessive load or unexpectedly poor soil conditions. Serviceability relates to the performance of a structure under normal service conditions, for example, excessive misalignment. Two condition indexes were formulated to describe the structure relative to these criteria. The first, the structural condition index, is based upon a structural analysis of the sheet pile structure. It includes primarily safety aspects. The second, the functional condition index, is based upon field measurements of the distresses and the subjective opinion of experts. It includes both safety and serviceability aspects.

12. As the condition index zones in Table 2 indicate, one purpose of the condition index is to draw attention to a particular problem that may require further investigation (Zone 3). In this regard, the combined condition index or, simply, the condition index will be defined as

Condition Index = Minimum of:
Structural Condition Index
Functional Condition Index

Hence, if the structure has a poor condition index, a flag is raised and the engineer can trace back to determine whether the cause is a low safety or functional condition index. Indeed, the engineer would presumably trace back through the entire rating process and possibly conduct a more detailed field inspection or structural analysis to establish the basic cause.

Maintenance and Repair Analysis

13. After an evaluation of the current condition of the structure, the user of the computer program has an option to investigate and compare several maintenance and repair possibilities. After the program has displayed a list of problems associated with this structure, the user can select from a list of maintenance and repair alternatives that would provide various levels of remedial action for each of the distresses. Some alternatives may fix only one distress; others may fix several. A set of alternatives is collected together to form one maintenance and repair solution.

14. Several different solutions can be formulated, and the program can be used to compare and evaluate each of them. The consequences of each solution are obtained by calculating a new condition index that reflects the as-repaired structure. If the user provides cost and lifetime information about each solution, the program will calculate an annualized cost by a life

cycle cost analysis. With this maintenance and repair analysis option within the program, the user can make a preliminary evaluation of a maintenance plan.

15. Realistically, the program has limitations of which the user should be aware. The entire process is intended to be a preliminary assessment. The inspection is not sufficiently detailed to isolate the cause of all distresses. For example, wall misalignment is a symptom of several possible causes (anchor failure, toe failure, impact, or overload). Before selecting a maintenance or repair alternative, the user may need to conduct a more thorough investigation. Some alternatives may not fix the cause. Also, the cost analysis is intended to be indicative only and is based upon preliminary estimates. Detailed cost estimates and analyses may be required to differentiate between two competing solutions.

Steel Sheet Pile Component Identification

16. To inspect and rate steel sheet pile structures, the user must clearly identify their functions and components.

Functions

17. Lock Chamberwall--One of two long parallel walls that form the lock chamber. The lock chamberwalls will generally extend just beyond the recesses for the lock gates (Figure 2).

18. Lock Guidewall--A wall used to guide barge traffic into and out of the lock; this wall begins at the end of the lock chamberwall. The guidewall may be upstream or downstream from the lock and on the land side or river side of the lock approach (Figure 2).

19. Transition Wall--A retaining wall used in the transition from the lock guide walls to the natural bank or levee (Figure 2).

20. Cutoff Wall--A wall used to retard the flow of water under a lock dam or other structure. The wall is usually completely buried and has no anchorage system.

21. Mooring Cell Structure--A structure to which a barge is tied. The most common type is a steel sheet pile cell filled with concrete or coarse aggregate (Figure 3).

22. Protection Structure--A structure used to prevent damage from barge collisions to bridge piers, lock facilities, and the like. The most common type is a steel sheet pile cell filled with aggregate and covered with a concrete cap.

Components (Figure 4)

23. Steel Sheet Pile--Hot-rolled and cold-formed steel sections that may have a variety of shapes (Z, arch, straight) and methods of interlock (thumb and finger, ball and socket). The sections are driven vertically into the soil. Each sheet is interlocked continuously from top to bottom with adjacent sheets. (See Appendix A.)

24. Wale--Rolled-steel section running horizontally along a steel sheet pile wall and used to transfer loads from the steel sheet pile wall to a tie-rod and anchor system. The wale generally consists of two channels back to back with 2 in. or 3 in. spacers. The sheets are often bolted to the wale.

25. Tie-Rod--Steel rod used to transfer loads from the wale to an anchor system. The rod is threaded at each end in order to bolt it to the wale and anchor it with a turnbuckle in between. The tie-rod is usually a 2- to 3-in. diameter rod. A steel cable may also be used.

26. Anchor--A structure that transmits the tie-rod loads to the soil. It may consist of a sheet pile wall and wale, a concrete block, some battered pile and cap arrangement, or a soil anchor. A battered pile bolted directly to the wale may also be used for an anchor.

27. Cap--A wood, steel, or concrete structure placed on top of the sheet piles. A railing may be attached to the cap.

28. Fenders--Structures used to prevent damage to the piles from barges. These may be wood or steel and are usually bolted horizontally to the sheets above the water level.

29. Armor Plating--A curved steel section welded between flanges of Z piles to help protect the wall from barge collisions. The void is usually filled with concrete.

Structural Form

30. Cantilevered Wall--Wall that resists the active earth pressure, or water and ice force as a vertical cantilever. The horizontal force and moment resistance are provided by the passive soil pressure on the embedded portion.

31. Anchored Wall--Wall that resists active earth pressure as a beam spanning between the passive soil pressure on the embedded portion and the anchor tie-rods near the top. (Figure 4).

32. Single Cells--A series of interconnected, straight-web steel sheet piles usually arranged in a circular shape. The interior is filled with soil and concrete and/or stone. The structure resists the applied forces (e.g., mooring and impact as well as wave and ice loads), principally by gravity and sliding forces.

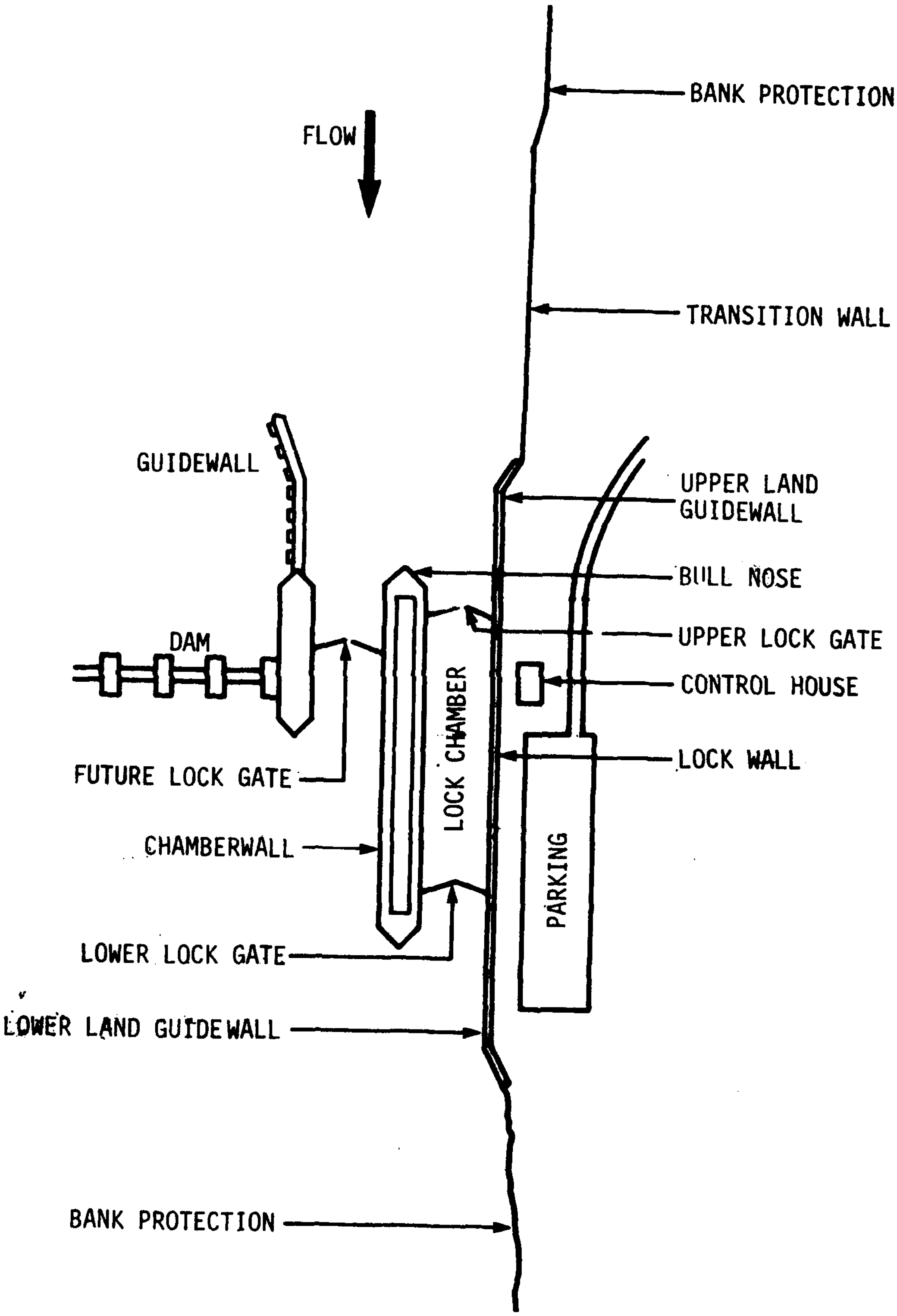


Figure 2. Lock and dam facility

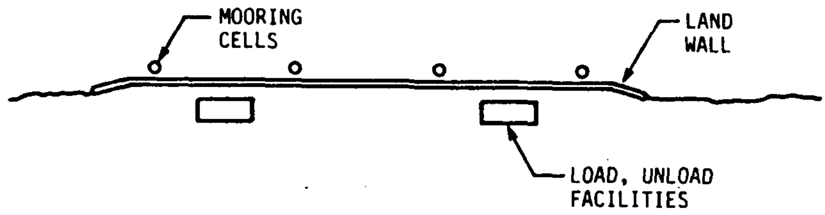


Figure 3. Terminal facility

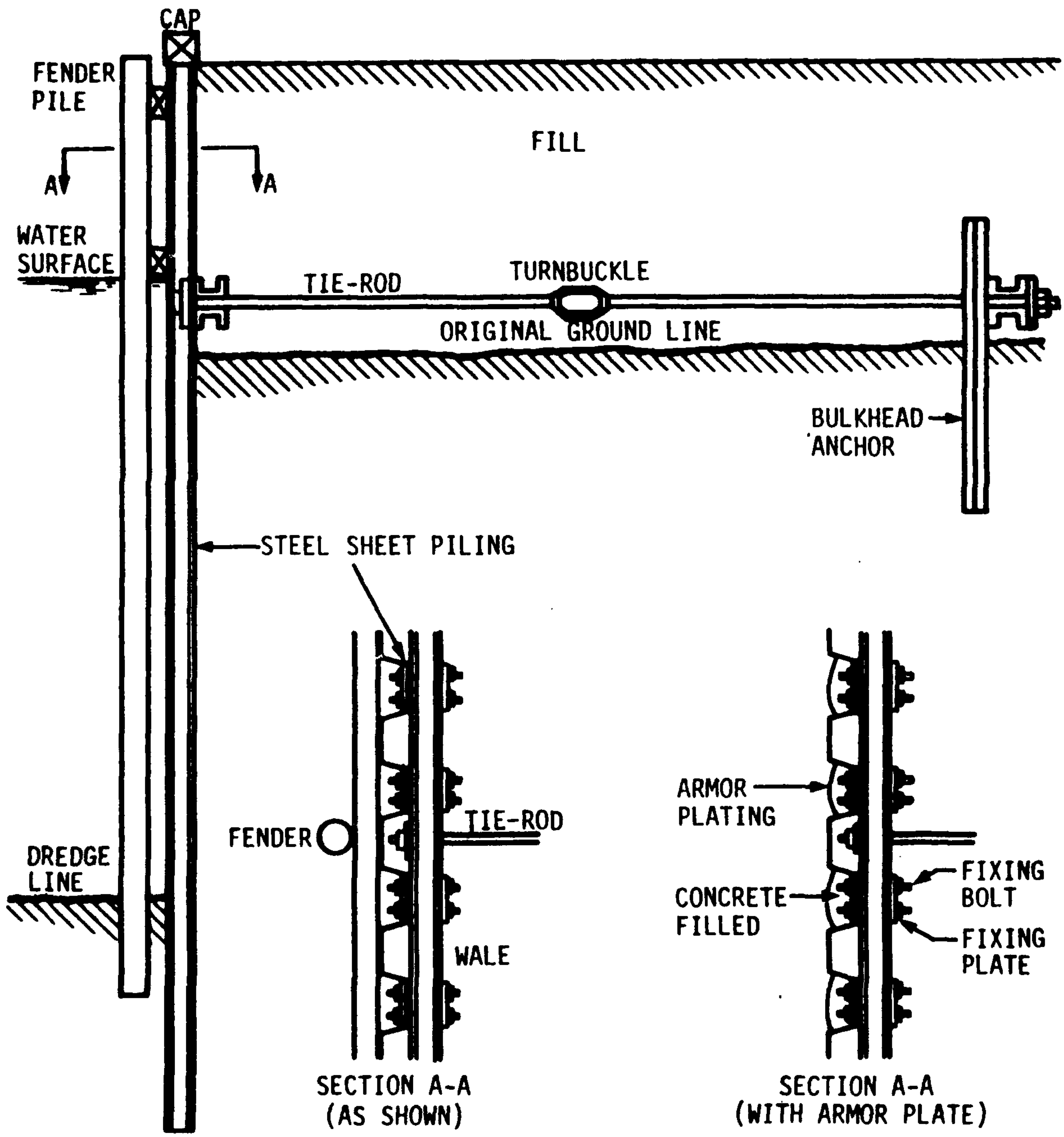
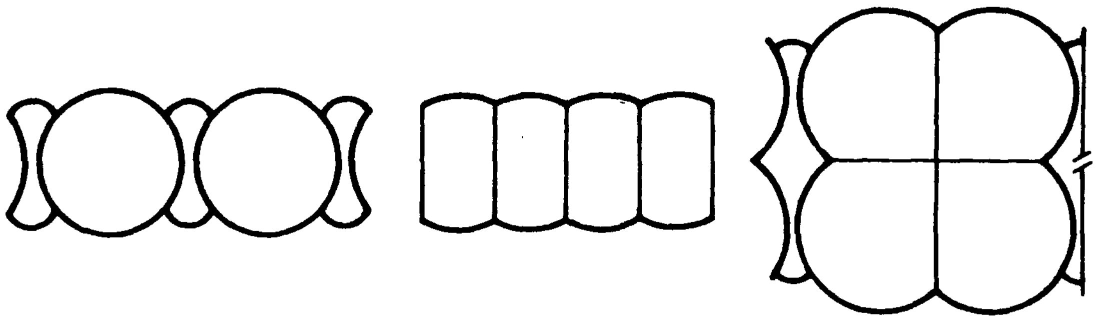


Figure 4. Typical components of steel sheet pile structures

33. Cellular Wall--A wall formed by interconnected cells. Figure 5 illustrates some of the possible plan views. A cellular wall resists forces in a manner similar to single cells.



(a) CIRCULAR CELLS (b) DIAPHRAGM CELLS (c) CLOVERLEAF TYPE CELL

Figure 5. Cellular walls

PART III: FIELD INSPECTION

Inspection Concepts

34. A basic idea behind the inspection procedure is simplicity. As meetings and field tests with Corps personnel progressed, it became increasingly clear that any steel sheet pile inspection program must be simple to learn and not time consuming. Two factors force this conclusion: (a) steel sheet pile structures are not the most critical item in a lock and dam facility and (b) Corps personnel who work with lock and dam facilities generally feel they will have little time to devote to this work. Current inspection procedures ranged significantly between the various districts. No district that was involved in this pilot project now spends much time inspecting steel sheet pile structures. In districts where steel sheet pile is used for floodwalls or dams, the situation may be different.

35. With these restrictions, the field inspection had to be based upon easily obtainable data. In this case, easily obtainable data were taken to be those that could be obtained by walking along the land side of the wall and boating along the water side. The normal inspection would involve no excavation or diving. No ultrasonic or other "sophisticated" devices could be used. All data would be measured by subjective observation (poor, average, good, excellent, etc.), a tape measure, a level, a string line, a camera, and similar devices. As a goal, the data would be recorded by technicians with a minimum of specific engineering training or experience in the design or construction of steel sheet pile structures. Certain components such as the wale, anchor rod, and anchor system are not visible and, hence, cannot be a part of this inspection.

36. The inspection process generally follows this pattern:

- a. Historical information, such as drawings and previous inspections, is reviewed and recorded before a site visit.
- b. A site inspection is conducted and specific visual data are recorded.
- c. The inspection data are entered into a personal computer program.

The time between inspection periods has not been established but will probably be between 3 and 5 years.

37. The results of the inspection (e.g., the condition index and a problem list) are intended to be indicative only of the existing condition and must be viewed as such. For some cases, it may be necessary to return and conduct a more detailed inspection, such as by excavation, diving, or surveying. This will clearly be the case if a dangerous condition is indicated by the initial inspection. It is beyond the scope of this portion of the project to describe a detailed inspection and evaluation.

Overview of the Inspection Sheet

38. The inspection sheet in Figure 6 has been designed to provide flexibility in documenting a variety of field conditions within one uniform sheet. Though there are seven pages in the inspection form, not all pages are used for every structure nor will every question have an answer. The following section illustrates the use of the inspection form. The following paragraphs briefly outline the inspection form.

Historical Information

39. Historical information related to the steel sheet pile structure is recorded on pages 1 and 2. Information requested includes project reference data to identify and to locate the specific structure. Further data categorize the structure into a particular type and function. This information helps the inspector determine which of the structural component forms (Page 3A, 3B, or 3C) is to be completed. The information is also used to sort through the base of expert rules in the evaluation model. The recent history of maintenance, modifications, and inspections is recorded. Finally, a section to record current physical conditions of nonessential steel sheet pile accessories is also provided.

Structural Components

40. Information relative to the structural components of specific steel sheet pile structures is recorded on page 3A, 3B, or 3C of the inspection form. Page 3A is used for anchored (tied-back) or cantilevered wall types, page 3B for single cells, and page 3C for multiple-cell walls or bulkheads. The appropriate page is determined by the structure type or wall system type selected on page 1. The information compiled on these pages provides the basis for an elementary review of the structural adequacy of the structure. Most of the structural data will be recorded on the sheet before the site visit and verified during field inspection. The prior information may be taken from original design drawings, as-built construction drawings, or drawings of field modifications to the structure. The structural data sheets are set up to record multiple subsections of wall types or cellular structures. Whenever there is a change in steel pile components or construction conditions along a wall length, the subsection changes. It is not unusual in a steel sheet pile project for a wall section to be composed of two or three subsections of wall with variable sized components or different construction conditions. For example, the first 500 feet of wall might be a PZ27 steel sheet pile cross-section and the second 500 feet a PZ32. Or the overall length of the steel sheet pile might become shorter over the length of the wall because the pile steps up with the rising grade of the river bottom. A separate structural data sheet is filled out for each subsection; complete as many copies of page 3A as required. The use of station-to-station references for

distance location of subsection changes further identifies the wall characteristics.

Loading and Dredge Line

41. Page 4 of the inspection sheet provides additional information required to review the structural adequacy of the steel sheet pile structure. The format of the sheet allows one section for specific information regarding load magnitudes (surcharges) and location by station reference along the structure length. The second section, for dredge depths, records the existing grade levels of the dredge line or river bottom. This information is correlated with the structural component data from pages 3A, 3B, or 3C to give a structural condition evaluation along all points of the structure length.

Distress Profile

42. The distress profile (page 6 of the inspection sheet), is a record of distresses in the structure. Refer to Part V for more complete descriptions of the distresses and their limits.

General Notes

43. The layout of the inspection sheet in Figure 6 has been designed to facilitate both the data collection process and also the computer input and evaluation model. After the initial inspection and computer modeling of a structure, the data on pages 1 through 3C will become relatively permanent and will require only nominal editing of computer data files to keep them current. Pages 4, 5, and 6, however, are data pages that in general must be filled out in the field during the inspection because the information is subject to change. The following pages of this report duplicate the actual inspection sheet with entries from an actual test inspection. The side-by-side arrangement of the pages displays specific explanations adjacent to the entry on the inspection form. Pages 4, 5, and 6 also have notes on how to measure and record critical data.

44. For all pages on the inspection sheet, station coordinates are used to locate structure characteristics or distresses. This reference is the familiar civil engineering standard of 0+00 equals a starting point and 1+50 is 150 feet away from the starting point. Every effort should be made to have the stationing be the same as for an existing system, such as when the structure was constructed. It is important that the station references on all pages of the inspection form be consistent. This should be discussed and agreed on before the field inspection. The sketch requested on page 2 of the inspection sheet is used to identify the beginning station reference location. Station locations should be entered as whole numbers, that is, 250 in lieu of 2+50.

U.S. ARMY CORPS OF ENGINEERS
STEEL SHEET PILE STRUCTURE INSPECTION

NAME OF CIVIL WORKS PROJECT:

(1): LAGRANGE LOCK & DAM

(2): UPPER GUIDE WALL

LOCATION OF CIVIL WORKS PROJECT: (1. Indicate body of water, and 2. nearest town)

(1): ILLINOIS WATERWAY

(2): BEARDSTOWN, IL

DATE OF INSPECTION: 8-5-86 INSPECTED BY: L GREEMANN, J. STECKER

PLEASE INDICATE THE TYPE OF STEEL PILE STRUCTURE INSPECTED
(NOTE: Use one inspection form per structure. Later data collected on this form is specific to only one structure type.)

1. Lock Chamber Wall
2. Lock Guide Wall
3. Transition or Retaining Wall
4. Guard Wall
5. Single Cell

STRUCTURE TYPE: (No.) 2

TYPE OF WALL SYSTEM: (Ignore if single cell structure)

1. Anchored (tie-back) or Cantilever
2. Cellular:

WALL SYSTEM: (No.) 1

LENGTH OF WALL OR CIRCUMFERENCE OF CELL STRUCTURE (ft): (NO.) 565

LOCATION OF STRUCTURE:
FACING DOWNSTREAM, WHICH SIDE IS THE STRUCTURE? (1.Right 2.Left): (No.) 2
IN RELATION TO THE LOCK, IS IT? (1. Upstream 2. Downstream): (No.) 1
PROXIMITY TO LOCK PROJECT SITE? (1. Near Lock 2. Remote): (No.) 1

LENGTH OF LOCK CHAMBER (ft): (NO.) 600

CONSTRUCTION DATE: 1939

ARE DRAWINGS AVAILABLE FOR REFERENCE?: (YES/NO) YES
ARE THE DRAWINGS INCLUDED WITH THIS FILE?: (YES/NO) NO

PRESENT WATER LEVEL: 429.0 (Reference to mean sea level elevation)
RECORD LOW WATER LEVEL: ?
RECORD HIGH WATER LEVEL: 447.25

Figure 6. Inspection sheet and comments (Sheet 1 of 26)

Page 1 Comments: Historical or Recordkeeping Data

Completed prior to the site inspection and verified or changed during the site inspection.

Data blanks on page 1 prefaced by (No.) ____ must be recorded as numbers.

Enter in (1) the CORPS OF ENGINEER PROJECT TITLE (55 characters). Line (2) is for additional title description.

Indicate the BODY OF WATER (1). This may be a river, canal or improved channel, lake, or coastline.

Indicate SSP STRUCTURE TYPE and WALL SYSTEM TYPE by entering the appropriate number in the blank following each name. Refer to the section called "Steel Sheet Pile Component Identification" for descriptions and illustrative figures if additional information is required to identify structure or wall types.

NOTE: Only one structure type is allowed per inspection form. Page 3A, 3B, or 3C (of this inspection form) is selected for further data collection based on the selections made in these two questions.

Actual length of SSP STRUCTURE to nearest whole foot. For SINGLE CELL STRUCTURES, the circumference of the cell is recorded.

Enter nominal LENGTH OF LOCK CHAMBER (e.g., 600 ft or 1200 ft).

Information from the design or as-built drawings is necessary to complete structural data sections on Page 3A, 4, or 5 later in this form. The drawings may be useful for review in the field during an inspection.

Water level gauge readings referenced to mean sea level. PRESENT and RECORD LOW and HIGH WATER LEVELS are important for reference at a later date. Low and high water levels are used in some safety calculations. Include the data if known.

Figure 6. (Sheet 2 of 26)

GENERAL INFORMATION - Use the back of this page to list additional information that will not fit in spaces provided.

PAST 10 YEAR HISTORY OF:

MAJOR MAINTENANCE, REPAIRS, OR OTHER MODIFICATIONS

	DATE	DESCRIPTION
(1):	?	CURVED SECTION @ END EXTENSIVELY REPAIRED
(2):		AFTER IMPACT DAMAGE
(3):		

CHANGES IN BACKFILL, BUILDING STRUCTURES, ROADS, EQUIPMENT, STOCK PILES, ETC. ADJACENT TO STRUCTURE, OR BEHIND STRUCTURE UP TO A DISTANCE OF 1/2 THE SSP STRUCTURE HEIGHT

	DATE	DESCRIPTION
(1):		NONE
(2):		
(3):		

PREVIOUS INSPECTIONS OR STRUCTURAL REVIEWS (Attach copies if available)

	DATE	DESCRIPTION
(1):		UNKNOWN
(2):		
(3):		

PRESENT DAY: - Use this section of the Inspection Form to describe the location and physical condition of SSP accessories such as Cap, Railing, Armor Protection, Fender, Mooring Posts, Rings, etc.

	STATIONS FROM	STATIONS TO	DESCRIPTION (Materials, type connections, etc.)
Ex.1	0	600	Fenders, 3 Rows 8 x 8 Oak Timbers
Ex.2	250	300	Steel Channel Cap is missing
(1):	0	565	TIMBER FENDERS, 3 ROWS 8x8 OAK
(2):	0	565	STEEL PLATE CAP
(3):	0	565	CABLE HAND RAIL
(4):	0	565	MOORING POSTS @ 50' INTERVALS
(5):			
(6):			
(7):			
(8):			
(9):			
(10):			

Attach a general site plan of the civil works project. Use ATTACHMENT FORM A or other available plan and include with the Inspection Form.
Attach a sketch of the particular SSP section covered by this inspection. Use ATTACHMENT FORM B or other plan and include with the Inspection Form.

Figure 6. (Sheet 3 of 26)

Page 2 Comments: Historical or General Data

Completed prior to the site inspection and verified or changed during the site inspection.

The first three sections are expanding records and can record up to five lines of data. Dates and descriptions are entered on one line as one record. Each record is limited to 70 characters.

Enter SSP component MODIFICATIONS or REPAIR operations performed on the structure within the last 10 years.

Examples: 1977 Sandblast and epoxy paint all exposed steel
1979 Replace SSP Sta. 100 to 120 from tow collisions
in 1978

Enter CHANGES IN BACKFILL from original construction; record additions or removal of building structures, roads, heavy equipment, material stockpiles, and the like from the area immediately behind the SSP or within the area of SSP cells.

Example: 1981 Store concrete rubble Sta. 350 to 550 to load barges
for transfer to dam site
Note: two records were used for one note.

Enter brief description of any PREVIOUS INSPECTIONS OR STRUCTURAL REVIEWS of the specific structure inspected. General inspections of the civilian project should be cited when the structure is specifically noted.

Example: 1981 Structural review of anchor rating for surcharges.

Enter PRESENT DAY status of miscellaneous SSP accessories observed during the inspection of the structure. The items noted in this section are for information only and do not affect the condition index rating of the structure. They are recorded in the inspection file so that future observations can note changes that have occurred in the accessories. See Ex. 1 and 2 on form at left. This section can be expanded up to 20 records. Stations and description are entered on one line and are one record. As in the example above, it is acceptable to use two records to define one condition.

Sketch a general layout drawing as ATTACHMENT A or attach a copy of the project site plan. Note locations of SSP structures.

Sketch a general layout of the SSP structure or attach a detail design drawing laying out the structure as ATTACHMENT B. Note the beginning station reference must coincide with rest of inspection pages.

Figure 6. (Sheet 4 of 26)

U.S. ARMY CORPS OF ENGINEERS
STEEL SHEET PILE STRUCTURE INSPECTION   PAGE 3A

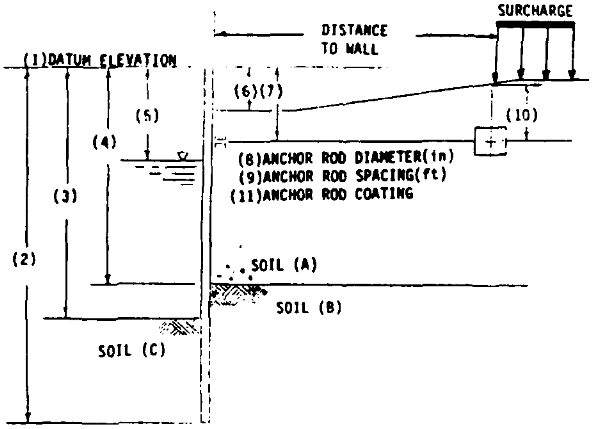
ANCHORED OR CANTILEVER WALL CROSS-SECTION

NOTES FOR USE OF THIS DATA PAGE:

1. Use this Data Page for recording dimensions if the wall system selected on Page 1 is an anchored or cantilevered wall.
2. Use more than one sheet for recording da'a on multiple subsections of the wall components or measurements for the cross-section change.

FROM STATION: 0
TO STATION: 565

FIGURE 1: WALL CROSS-SECTION



WALL TYPE:
1. Anchored
2. Cantilever
(No.) 1

ANCHOR SYSTEM DRAWINGS ATTACHED?
(YES/NO) NO

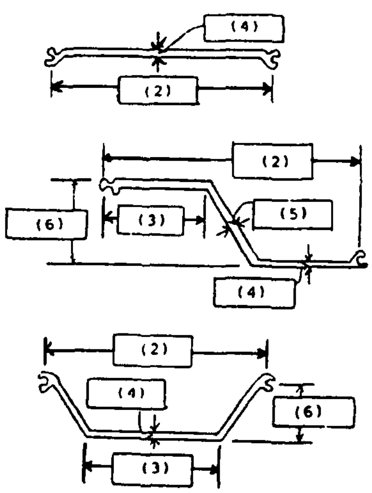
SOIL COMPOSITION:

1. Sand	5. Medium Clay
2. Gravel	6. Stiff Clay
3. Rock	7. Unknown
4. Soft Clay	8. Not Applicable

SOIL(A): (No.) 2
SOIL(B): (No.) 5
SOIL(C): (No.) 5

WALL CROSS-SECTION: (Refer to Figure 1)
(1) DATUM ELEVATION: 434.0
(2) PILE LENGTH (ft): 38
(3) TOP-TO-DREDGE (ft): 23
(4) TOP-TO-SOIL(B) (ft.): 23
(5) TOP-TO-WATER (ft): 5.5
(6) TOP-TO-SOIL(A) (ft): 0
(7) TOP-TO-ANCHOR ROD (ft): 7-0
(8) ANCHOR ROD DIAMETER (in): 2.25
(9) ANCHOR ROD SPACING (ft): 8-0
(10) ANCHOR DEPTH (ft): 7-0
(11) ANCHOR ROD COATING: ?

FIGURE 2: PILE CROSS-SECTION



PILE CROSS-SECTION: Provide the Design SSP SECTION SHAPE DESIGNATION (Ex. PZ32 or PSA28) in (1.) or dimension the appropriate section as shown at the right in Fig. 2 in blanks (2) thru (6).

(1) SECTION DESIGNATION: MZ 38
(2) DRIVING WIDTH(in): ______
(3) FLANGE WIDTH(in): ______
(4) FLANGE THICKNESS(in): ______
(5) WEB THICKNESS(in): ______
(6) CROSS-SECTION DEPTH(in): ______
(7) YIELD STRENTH: ______
(If left blank, 36,000 is assumed)

Figure 6. (Sheet 5 of 26)

Page 3A Comments: Structural Components Data

Complete data entry on Page 3A if:

- o Structure type noted on page 1 is Type 1, 2, 3, or 4 and
- o Wall type note on page 1 is No. 1 (anchored or cantilevered).

Complete prior to the site inspection and verify or change data during the site inspection. Data blanks on Page 3A prefaced by (No.)______ must be recorded as numbers.

It is possible to have more than one configuration (or cross-section detail) of an SSP structure. When the configuration changes, use additional sheets of this form to record the separate subsections of the wall.

Examples: Use two forms for the following condition

Sta.	0 to 250	Design pile length is 28 ft
Sta.	250 to 600	Design pile length is 34 ft

NOTE: The beginning station reference for the first subsection must be the same as the beginning station on the other inspection form pages.

WALL TYPE: Select anchored or cantilevered. If unsure of condition, review design drawings. This selection is used in the safety analysis. When a wall changes from an anchored wall to a cantilevered wall, then a new inspection form for a new SSP structure must be used, not just a new subsection page.

SOIL COMPOSITION: Select the appropriate soil type from information usually found on the as-built construction drawings. If Type 7 (unknown) is selected, the soil is assumed to be soft clay.

WALL CROSS-SECTION: Provide the information requested based on dimensions available on the design drawings. The dimensions must be entered in the order noted and in the units noted.

PILE CROSS-SECTION: Figure 2 on the opposite page illustrates the several SSP shapes that have been and are currently available. The section designation (1) must be entered into the computer program. If it is not

available on the drawings, record the field dimensions for the actual SSP sheet, i.e., (2) through (6), and see Appendix A for several tables of SSP sheet sections. Select the section that matches most closely the dimensions (2) through (6) and enter this section designation in (1).

YIELD STRENGTH: Several yield strength steels are used in SSP sheets. If a yield strength is known, e.g., 55,000 psi, enter the value in this entry. The default is 36,000 psi.

Figure 6. (Sheet 6 of 26)

U.S. ARMY CORPS OF ENGINEERS

STEEL SHEET PILE STRUCTURE INSPECTION — PAGE 3B

NOT APPLICABLE TO LAGRANGE UPPER GUIDEWALL

SINGLE CELL CROSS-SECTION

NOTES FOR USE OF THIS DATA PAGE:

1. Use this Data Page for recording dimensions if a single cell is the structure type selected on Page 1.
2. Only one cell can be recorded on this Data Page. Use a separate inspection form, Pages 1, 3B, etc., to record each individual cell.

CELL CROSS-SECTION: (Refer to Figure 1 or 2)

(1) DATUM ELEVATION: (ft.) ________
(2) TOP-TO-WATER: (ft.) ________
(3) TOP-TO-DREDGE: (ft.) ________
(4) PILE LENGTH: (ft.) ________
(5) CELL DIAMETER: (ft.) ________

LOADING ON CELL: (Refer to Figure 1 or 2)

P = HORIZONTAL: (lbs) ________
(Concentrated pull or impact load)
Q2= SURCHARGE: (Uniform psf)________

INTERIOR BACKFILL AND FOUNDATION MATERIAL:

1. Sand 5. Medium Clay
2. Gravel 6. Stiff Clay
3. Rock 7. Unknown
4. Soft Clay 8. Not Applicable

SOIL (A):(No.)____ Interior backfill
SOIL (B):(NO.)____ Foundation soil or rock
SOIL (C):(No.)____ Soil layer over rock

PILE CROSS-SECTION: (Refer to Figure 3)
Provide the Design SSP SECTION SHAPE DESIGNATION (1) (Ex. PSA28); or dimension the DRIVING WIDTH (2) & FLANGE THICKNESS (3).

(1) SECTION DESIGNATION: ________
(2) DRIVING WIDTH: (IN.) ________
(3) APPROX. THICKNESS: (IN.) ________

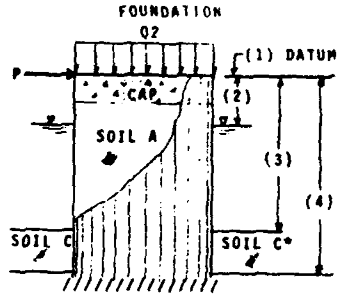
CELL CAP:

TYPE (None, Concrete, Asphalt): ______
THICKNESS OF CELL CAP: (ft.)______
ACCESS MANHOLE/PORT EXIST?:(Y or N)______

CELL PURPOSE:

(1.Protection, or 2.Mooring):(No.)______

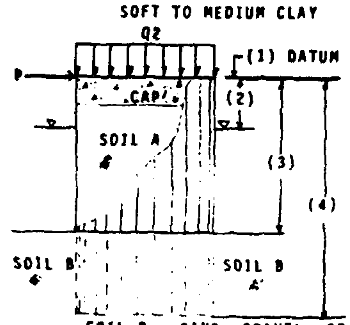
FIGURE 1: ROCK OR STIFF CLAY FOUNDATION



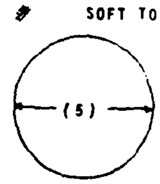
SOIL B = ROCK OR STIFF CLAY

NOTE:*SOIL C MAY BE ABSENT WITH ROCK OR COULD BE ANY OTHER SOIL TYPE

FIGURE 2: SAND, GRAVEL, OR SOFT TO MEDIUM CLAY



SOIL B = SAND, GRAVEL, OR SOFT TO MEDIUM CLAY



PLAN - BOTH FIG.

FIGURE 3: PILE CROSS-SECTION

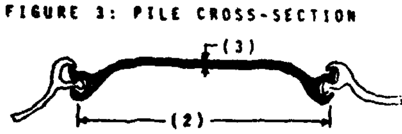


Figure 6. (Sheet 7 of 26)

Page 3B Comments: Structural Components Data

Complete data entry on page 3B if structure type noted on page 1 is Type 5.

Complete prior to the site inspection and verify or change data during the site inspection.

Data blanks on page 3B prefaced by (No.)______ must be recorded as numbers.

More than one configuration of steel sheet pile within one cellular SSP structure is not likely. However, if the configuration changes, use additional sheets of this form to record the separate subsections of the cell.

CELL CROSS-SECTION: Provide the information requested based on dimensions available on the design drawings. The dimensions must be entered in the order noted and in the units noted. These data are used in analysis

of factors of safety for the SSP components. Occasionally the pile lengths will vary around the circumference of the cell. When that occurs, enter the shortest pile length (4).

LOADING ON CELL: The force P represents a concentrated force applied to the cell, for example, by a barge. It may include impact. Q2 is a uniform surcharge applied to the top at the cell.

INTERIOR BACKFILL MATERIAL: Select the appropriate soil type from information usually found on the as-built construction drawings. If Type 7 (unknown) is selected, the soil is assumed to be soft clay. Figure 1 opposite is used if the foundation is rock or soft clay; otherwise, Fig. 2 opposite is used.

PILE CROSS-SECTION: Figure 3 on the opposite page illustrates the typical SSP shape that has been used for cells and is currently available. The SSP section designation (1) must be entered into the computer program. If it is not available on the drawings, record the field dimensions for the actual SSP sheet (2) and (3) and see Appendix A for several tables of SSP sheet sections. Select the section that most closely matches the dimensions (2) and (3) and then enter this section designation in (1) and the computer program.

CELL PURPOSE: The purpose of the single cell is significant in the evaluation of the condition index for the cell structure.

Figure 6. (Sheet 8 of 26)

U.S. ARMY CORPS OF ENGINEERS
STEEL SHEET PILE STRUCTURE INSPECTION *Not Applicable to* PAGE 3C

MULTIPLE CELL CROSS-SECTION PROFILE *Lagrange Upper Guide Wall*

NOTES FOR USE OF THIS DATA PAGE:

1. Use this Data Page for recording dimensions if the wall system selected on Page 1 is a cellular wall.
2. Use more than one sheet for recording data on multiple subsections of the wall components or measurements for the cross-section change.

FROM STATION: __________
TO STATION: __________

CROSS-SECTION TYPE: (Case No.) __________
Refer to Figure 1 on the back of this page to select the Case Type No. 1 to 4 appropriate to this subsection of wall.

CELL TYPE: (Refer to Figure 2)
(1.DIAPHRAGM, 2. CIRCULAR): (No.) __________

CELL CROSS-SECTION (Refer to Figure 1 for 1 - 6, and Figure 2 for 7 - 9)
(1) DATUM ELEVATION: __________
(2) TOP-TO-HIGH SIDE WATER(ft): (ft.) __________ (Cases 1 & 3 only)
(3) TOP-TO-SOIL(C) in Cases 1 & 2 (ft.) __________ (Soil(B) in Cases 3 & 4)
(4) PILE LENGTH: (ft.) __________
(5) TOP-TO-LOW SIDE WATER: (ft.) __________
(6) TOP-TO-DREDGE: (ft.) __________ (Low water side)
(7) MAXIMUM CELL WIDTH: (ft.) __________
(8) CELL SPACING: (ft.) __________
(9) ARCS ANGLE: (Deg) __________ (Circular Cell type only)

LOADING ON CELLULAR WALL: (Refer to Figure 1)
Q2= SURCHARGE: (Uniform PSF) __________
Note: When a loading occurs on the soil behind the wall, e.g. as Q1 is shown in Cases 2 & 3, this loading must be entered in the Loading Table in Page 4 of the Inspection Form.

INTERIOR BACKFILL AND FOUNDATION MATERIAL: (Refer to Figure 1)
1. Sand 2. Gravel 3. Rock 4. Soft Clay
5. Medium Clay 6. Stiff Clay 7. Unknown 8. Not Applicable
SOIL (A): (No.) ______ Interior backfill
SOIL (B): (NO.) ______ Foundation soil or rock
SOIL (C): (No.) ______ Soil layer over rock
SOIL (D): (No.) ______ Backfill behind wall

PILE CROSS-SECTION: (Refer to Figure 3)
Provide the Design SSP SECTION SHAPE DESIGNATION (1) (Ex. PSA28);
or dimension the DRIVING WIDTH (2) & FLANGE THICKNESS (3).

(1) SECTION DESIGNATION: __________
(2) DRIVING WIDTH: (IN.) __________
(3) APPROX. THICKNESS: (IN.) __________

CELL CAP:
TYPE (None, Concrete, Asphalt, etc.): __________
THICKNESS OF CELL CAP: (ft.) __________
ACCESS MANHOLE/PORT EXIST?: (YES or NO) __________

Figure 6. (Sheet 9 of 26)

Page 3C Comments: Structural Components Data

Complete data entry on page 3C if:
- o Structure type noted on page 1 is Type 1, 2, 3, or 4 and
- o Wall type noted on page 1 is No. 2 (cellular).

Complete prior to the site inspection and verify or change data during the site inspection.

Data blanks on page 3C prefaced by (No.)______ must be recorded as numbers.

Multiple cell structures are similar to walls in that they have a linear configuration and function similar to a wall and thus can be identified readily with station references.

It is possible to have more than one configuration (or cross-section detail) of a SSP structure. When the configuration changes, use additional sheets of this form to record the separate subsections of the wall.

NOTE: The beginning station reference for the first subsection must be the same as the beginning station references on the other inspection form pages.

CROSS-SECTION TYPE: See next page for description.

CELL TYPE: Select diaphragm or circular. If unsure, review design drawings. This selection is used in the safety analysis (see Fig. 2 on next page).

CELL CROSS-SECTION: Provide the information requested based on dimensions available on the design drawings. The dimensions must be entered in the order noted and in the units noted. These data are used in analysis of factors of safety for the SSP components.

LOADING ON CELLULAR WALL: Q2 is the surcharge on the top of the cell. Loadings behind the wall, e.g., Q1 in Case 2 and 3 are entered on Page 4.

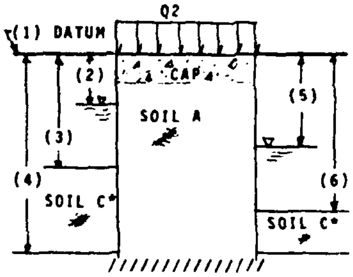
BACKFILL MATERIAL: Select the appropriate soil type from information usually found on the as-built construction drawings. If Type 7 (unknown) is selected, the soil is assumed to be soft clay.

PILE CROSS-SECTION: Figure 3 on the next page illustrates the typical SSP shape that has been used for cells and is currently available. The SSP section designation (1) must be entered into the computer program. Also, see Page 3B of Inspection Forms.

Figure 6. (Sheet 10 of 26)

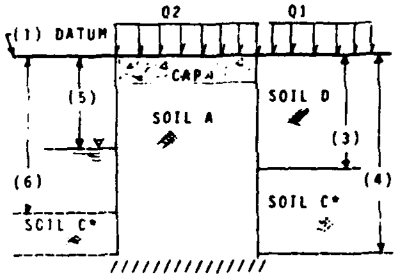
FIGURE 1: WALL CROSS-SECTION CONDITIONS by CASE TYPES

CASE 1: ROCK OR STIFF CLAY FOUNDATION WITH DIFFERENT WATER LEVELS ON EITHER SIDE OF CELLULAR WALL



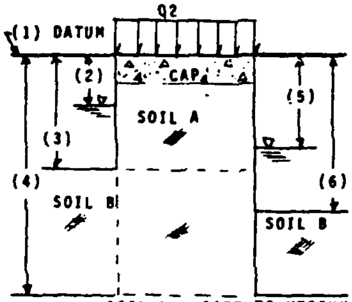
SOIL B = ROCK OR STIFF CLAY
*NOTE: SOIL C MAY BE ABSENT WITH ROCK OR COULD BE ANY OTHER SOIL TYPE

CASE 2: ROCK OR STIFF CLAY FOUNDATION WITH WATER ON ONE SIDE AND EARTH FILL ON THE BACK SIDE OF THE WALL



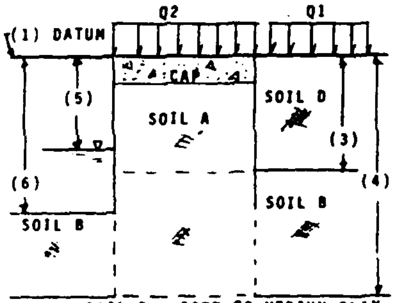
SOIL B = ROCK OR STIFF CLAY
*NOTE: SOIL C MAY BE ABSENT WITH ROCK OR COULD BE ANY OTHER SOIL TYPE

CASE 3: SAND, GRAVEL, OR SOFT TO MEDIUM CLAY FOUNDATION WITH DIFFERENT WATER LEVELS ON EITHER SIDE OF THE CELLULAR WALL



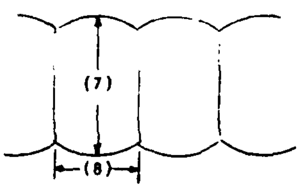
SOIL B = SOFT TO MEDIUM CLAY

CASE 4: SAND, GRAVEL, OR SOFT TO MEDIUM CLAY FOUNDATION WITH WATER ON ONE SIDE AND EARTH FILL ON THE BACK SIDE OF THE WALL

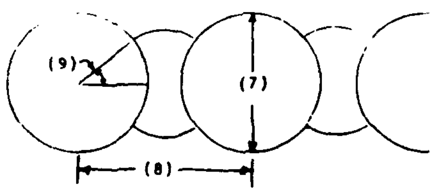


SOIL B = SOFT TO MEDIUM CLAY

FIGURE 2: CELL TYPES



DIAPHRAGM TYPE WITH STRAIGHT OR CURVED CROSS WALLS



CIRCULAR TYPE

FIGURE 3: PILE CROSS-SECTION

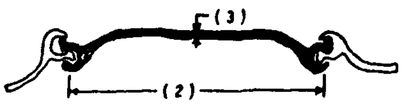


Figure 6. (Sheet 11 of 26)

CROSS-SECTION TYPE: Figure 1 opposite is used to identify various cross-section cases that are utilized in the structural analysis. Different assumptions and calculations are associated with each case. Generally, the cases differ by foundation type and loading condition on the back (right) side of the wall:

Case	Foundation	Right Side
1	Rock or Stiff Clay	Water
2	Rock or Stiff Clay	Soil
3	Other	Water
4	Other	Soil

Figure 6. (Sheet 12 of 26)

U.S. ARMY CORPS OF ENGINEERS
STEEL SHEET PILE STRUCTURE INSPECTION

LOADING DATA PROFILE SHEET

GENERAL INFORMATION - Use the back of this page or another data sheet to list additional information that will not fit in spaces provided.

LOADING TABLE: Use this section to describe the location, loading weight (psf) and a brief description of the type of loads applied to the SSP structure.

	STATIONS FROM	STATIONS TO	LOADING (psf)	DISTANCE TO WALL (ft)	DESCRIPTION OF LOADING
Ex.	135	215	300	12	Rock Stockpile
(1):	0	350	0		
(2):	350	450	300	6	STORAGE AREA ON CONC. PEDESTAL SLAB
(3):					
(4):					
(5):					
(6):					
(7):					
(8):					
(9):					
(10):					

DREDGE DEPTH ALONG STRUCTURE:

Measurement (or soundings) for Dredge Depth should be recorded at 50' intervals for walls along the entire length of the wall or at quarter points of the circumference of single cells. Specific station notation of greater depth holes, such as Ex. 2 should be noted at other than 50' intervals.

	STATION	DEPTH
Ex.1	50	23
Ex.2	87	25.8
(1):	100	23
(2):	150	23
(3):	200	24
(4):	230	25
(5):	250	28
(6):	300	28.5
(7):	350	29.5
(8):	400	30
(9):	450	29.5
(10):	500	30
(11):	550	28.5
(12):	565	28
(13):		
(14):		
(15):		
(16):		
(17):		
(18):		
(19):		
(20):		

Figure 6. (Sheet 13 of 26)

Page 4 Comments: Loading Data

The LOADING TABLE: An expanding record field for up to 20 different combinations of locations and surcharge loads. These data do not need to be entered in order of stations; the computer will sort the records after all data are entered.

The factor of safety calculations outlined in Chapter 3 correlate SSP load capacities with the location of the loads and the recorded dredge depths from below. The station references must be in agreement with the subsection references on page 3A, 3B, or 3C, because the structural data are selected from the appropriate section of wall.

The LOADING value, or surcharge, is expressed in pounds per square foot (psf). It is an estimate of the actual uniform surcharge applied to the soil behind the SSP structure. Surcharges of less than 150 psf can be ignored and not recorded. (A 1-ft thick section of concrete, or a 3-ft pile of wood materials weighs approximately 150 psf.) The DISTANCE TO WALL column lists the distance from the wall to the point at which the loading begins. The safety calculation assumes that any load is applied directly behind the wall and is a uniform intensity back from the wall. Applying the surcharges in this manner is conservative. The engineer can review and adjust the loading rates according to best judgment. The DESCRIPTION OF LOADING should provide additional information to the engineer to evaluate accurately the loads on the SSP structure. The description record is limited to 44 characters.

Page 5 Comments: Dredge Depth Data

The DREDGE DEPTH PROFILE is a data file of up to 60 records of the depth of the dredge line or river bottom relative to the top of the SSP structure. This dimension is the actual measurement of the exposed height, given as TOP TO DREDGE on the previous structural data pages. This measurement is directly correlated with the loading information above in computing the condition index. When this measurement varies from the design, it is said to have "scoured".

Measurements of the dredge depth can be accomplished in a number of ways. The authors have used a weighted line to get reasonably accurate depth records. Sounding records in navigable waters may be available and provide reliable data, but these should be verified at several points. The authors believe several of the commercially available depth finders could also be used effectively. The authors recommend depth measurements be taken at 50 ft intervals except where sharply rising or falling grades suggest more fre?quent measurements. The depth should be measured adjacent to the wall and at some distance, say 5 ft, out from the wall to account for sloping fills, short berm areas, or walls adjacent to navigation channel lines. The lowest dredge value should be used. It should be noted that at least one depth record must be recorded to provide data for the safety analysis. The computer will sort the records according to station order after all data are entered.

Figure 6. (Sheet 14 of 26)

DISTRESS PROFILE FORM

NOTES FOR USE OF THIS DATA PAGE:
1. Use this DATA PAGE for recording pertinent information relative to the DISTRESS TYPES indicated below. Enter each occurence of a specific distress by recording the DISTRESS TYPE data in the appropriate section below. The appropriate units of measurement are noted in the column boxes.
2. Use additional sheets of this DATA PAGE if more space is needed.
3. Refer to the Instruction References if more information is required.

MISALIGNMENT

STATION FROM	STATION TO	STATION OF MAX. DISPLAC.	DISPLAC. FROM NORMAL	FROM TOP OF WALL
FT	FT	FT	IN	FT
150	200	190	6.5	0
200	250	230	25	0

CORROSION

STATION FROM	STATION TO	SEVERITY LEVEL (1-5)
FT	FT	#
0	565	2

SETTLEMENT

STATION FROM	STATION TO	STATION OF MAX. DISPLAC.	DISPLAC. FROM NORMAL	SURFACE DESCR. TYPE *
FT	FT	FT	IN	#
160	200	190	10"	2
300	350	340	8"	2
390	400	398	14"	2
480	505	500	6"	2

*@WALL 1)STRUCTURE, 2)SURFACED, 3)NOTHING
*@CELL 1)UNIFORM, 2)DIFFERENTIAL SETTLEMENT

INTERLOCK SEPARATION

INTERLOCK STATION	LENGTH	FROM TOP OF WALL
FT	FT	FT

CAVITY FORMATION

CAVITY AT STATION	ESTIMATE CAVITY SIZE LENGTH	WIDTH	HEIGHT	SURFACE TYPE *
FT	FT	FT	FT	#

* 1)STRUCTURE, 2)SURFACED, 3)NOTHING

HOLES

HOLE AT STATION	HOLE SIZE LENGTH	WIDTH	FROM TOP OF WALL
FT	FT	FT	FT

DENTS

DENT AT STATION	DENT SIZE LENGTH	WIDTH	DEPTH	FROM TOP OF WALL
FT	FT	FT	IN	FT
250	3-0	2-0	6"	0

CRACKS

CRACK AT STATION	CRACK SIZE LENGTH	WIDTH	FROM TOP OF WALL
FT	FT	IN	FT
125	2-0	0	0
180	2-0	0	0
220	2-0	0	0

Figure 6. (Sheet 15 of 26)

Page 6 Comments: Distress Profile

Refer to Chapter 4 for more descriptive information about any distress type.

One needs only small hand tools to measure the distress characteristics. It is also necessary to have access to a boat. In the course of a typical inspection, the inspector will walk the top of the structure and get in the boat to observe all visible portions of the SSP structure.

The need for detailed accuracy in recording distress characteristics is limited. It is acceptable to record station references and location of maximum displacements to the nearest whole foot. The other dimensions requested as FT will generally be acceptable if recorded to the nearest whole inch increment, for example, 2 ft, 6 in. This would be entered as 2.5 ft in the computer program. Those dimensions requested as IN. will generally be acceptable if recorded to the 1/2 in. increment.

The DISTRESS PROFILE FORM on the left is filled out with distress data observed at an actual test inspection and matches data on the previous pages of the inspection form.

On the following pages, additional copies of page 6A are used to further illustrate an example entry for each of the distresses. The form will also be used to note other pertinent comments for each distress. The entries on the following pages are not associated with any particular wall.

Figure 6. (Sheet 16 of 26)

U.S. ARMY CORPS OF ENGINEERS
STEEL SHEET PILE STRUCTURE INSPECTION

DISTRESS PROFILE FORM

NOTES FOR USE OF THIS DATA PAGE:

1. Use this DATA PAGE for recording pertinent information relative to the DISTRESS TYPES indicated below. Enter each occurence of a specific distress by recording the DISTRESS TYPE data in the appropriate section below. The appropriate units of measurement are noted in the column boxes.
2. Use additional sheets of this DATA PAGE if more space is needed.
3. Refer to the Instruction References if more information is required.

MISALIGNMENT

STATION FROM	STATION TO	STATION OF MAX. DISPLAC.	DISPLAC. FROM NORMAL	FROM TOP OF WALL
FT	FT	FT	IN	FT
125	165	145	10"	0
FOR A	CELL			
35	40	38	2"	2'-0

CORROSION

STATION FROM	STATION TO	SEVERITY LEVEL (1-5)
FT	FT	#
0	600	2

SETTLEMENT

STATION FROM	STATION TO	STATION OF MAX. DISPLAC.	DISPLAC. FROM NORMAL	SURFACE DESCR. TYPE *
FT	FT	FT	IN	#
400	422	415	7"	2
FOR A	CELL			
0	105	80	5.5"	2

*@WALL 1)STRUCTURE, 2)SURFACED, 3)NOTHING
*@CELL 1)UNIFORM, 2)DIFFERENTIAL SETTLEMENT

INTERLOCK SEPARATION

INTERLOCK STATION	LENGTH	FROM TOP OF WALL
FT	FT	FT
510	3'-0	3'-0

CAVITY FORMATION

CAVITY AT STATION	ESTIMATE CAVITY SIZE LENGTH	WIDTH	HEIGHT	SURFACE TYPE *
FT	FT	FT	FT	#
510	2'-0	2'-6	1-4	2

* 1)STRUCTURE, 2)SURFACED, 3)NOTHING

HOLES

HOLE AT STATION	HOLE SIZE LENGTH	WIDTH	FROM TOP OF WALL
FT	FT	FT	FT
190	0-9"	1'-4"	4'-6"

DENTS

DENT AT STATION	DENT SIZE LENGTH	WIDTH	DEPTH	FROM TOP OF WALL
FT	FT	FT	IN	FT
195	2'-0	2'-0	8"	4'-0

CRACKS

CRACK AT STATION	CRACK SIZE LENGTH	WIDTH	FROM TOP OF WALL
FT	FT	IN	FT
240	2'-3	0	0-8"

Figure 6. (Sheet 17 of 26)

Distress Type 1 - Misalignment

Line 1: MISALIGNMENT of a Wall

The measurement of misalignment can be made with a tape measure, a line, a two foot level, and a straightedge. The typical misalignment of a wall is represented by a bow or curvature in the wall that deviates from its initial alignment for some length. Refer to Chapter 4 for types of misalignment and also illustrations of causes for failure. This line illustrates a bow in the wall that is 40 ft long. The bow is from Station 125 to 165 with a horizontal displacement of 10 in. from the design alignment of the wall. The point where maximum misalignment was measured is Sta. 145 at the top of the wall. For cellular walls, wall misalignment is associated with a line that touches the front edge of each cell.

Minimum misalignment of a wall:

Misalignments in walls 2 in. to 3 in. or less can be ignored. However, if another distress such as settlement, a cavity, or a missing fixing bolt occurs at the same station location, then the misalignment should be recorded for monitoring its change over time.

Line 3: MISALIGNMENT of a Single Cell

The typical misalignment for a cellular structure, particularly a single cell, is out-of-plumbness. Cell misalignment is recorded by measuring the offset from the plumb line at the point of maximum offset. The location of this measurement must correspond with other location criteria relating to the cell configuration. For this example, the station location of the misalignment, or out of-plumbness is from Station 35 to 40 approximately 1/3 of the way around a 35 ft diameter cell. The beginning station location is referenced on the plan view of the cell structure attached to page 2. The reading of the misalignment was 2.0 ft down from the top of the cell and a 2 in. offset (from vertical line) was measured in the length of the 24 in. hand level. Cells will bulge and deform from an exact circle as they are filled. This naturally occurring bulge should not be interpreted as misalignment. In this case four measurements at 90 degree intervals should be taken and the average should be entered.

Minimum Misalignment of a Single Cell:

Construction standards allow up to 1/8 in. per foot variance from plumb or 1/4 in. per two foot. A minimum standard to record vertical misalignment could be 1/2 in. vertical offset per two ft.

Figure 6. (Sheet 18 of 26)

U.S. ARMY CORPS OF ENGINEERS
STEEL SHEET PILE STRUCTURE INSPECTION

DISTRESS PROFILE FORM

NOTES FOR USE OF THIS DATA PAGE:

1. Use this DATA PAGE for recording pertinent information relative to the DISTRESS TYPES indicated below. Enter each occurence of a specific distress by recording the DISTRESS TYPE data in the appropriate section below. The appropriate units of measurement are noted in the column boxes.
2. Use additional sheets of this DATA PAGE if more space is needed.
3. Refer to the Instruction References if more information is required.

MISALIGNMENT

STATION FROM FT	STATION TO FT	STATION OF MAX. DISPLAC. FT	DISPLAC. FROM NORMAL IN	FROM TOP OF WALL FT
125	165	145	10"	0
FOR A CELL				
35	40	38	2"	2-0

CORROSION

STATION FROM FT	STATION TO FT	SEVERITY LEVEL (1-5) #
0	600	2

SETTLEMENT

STATION FROM FT	STATION TO FT	STATION OF MAX. DISPLAC. FT	DISPLAC. FROM NORMAL IN	SURFACE DESCR. TYPE * #
400	422	415	7"	2
FOR A CELL				
0	105	80	5.5"	2

*@WALL 1)STRUCTURE, 2)SURFACED, 3)NOTHING
*@CELL 1)UNIFORM, 2)DIFFERENTIAL SETTLEMENT

INTERLOCK SEPARATION

INTERLOCK STATION FT	LENGTH FT	FROM TOP OF WALL FT
510	3'-0	3'-0

CAVITY FORMATION

CAVITY AT STATION FT	ESTIMATE CAVITY SIZE LENGTH FT	WIDTH FT	HEIGHT FT	SURFACE TYPE * #
510	2'-0	2'-6	1-4	2

* 1)STRUCTURE, 2)SURFACED, 3)NOTHING

HOLES

HOLE AT STATION FT	HOLE SIZE LENGTH FT	WIDTH FT	FROM TOP OF WALL FT
190	0-9"	1'-4"	4'-6"

DENTS

DENT AT STATION FT	DENT SIZE LENGTH FT	WIDTH FT	DEPTH IN	FROM TOP OF WALL FT
195	2'-0	2'-0	8"	4'-0

CRACKS

CRACK AT STATION FT	CRACK SIZE LENGTH FT	WIDTH IN	FROM TOP OF WALL FT
240	2'-3	0	0-8"

Figure 6. (Sheet 19 of 26)

Distress Type 2 - Corrosion

Line 1: CORROSION
The rating of the deterioration of the SSP structure due to corrosion is made in a subjective manner. Refer to Chapter 4 for a more detailed description of the rating system. Selection of the corrosion level observed on a particular section of a structure is made either by comparing the observed condition to standards in Table 6 or by visually comparing it to photographs in Fig. 15. In the field inspection the only comparison that can be made is a visual inspection of the exposed areas of the structure. There are six levels of deterioration within which to rate the structure. The default condition, Group 0, is new or nearly equal to new. This condition requires no entry on the Profile Form. For the remaining five levels, Groups 1 through 5, a selection must be made and assigned to specific locations of the structure. In this example, the entire length of a 600-foot wall, Sta. 0 to Sta. 600, was rated at Level 2. An alternative example would be Sta. 0 to 300 rated at Level 2 and Sta. 300 to 600 rated Level 4, if there had been a major difference in deteriorated condition between the two sections of wall.

Distress Type 3 - Settlement

Line 1: SETTLEMENT Behind an Anchored or Cellular Wall
The measurement of settlement can be made with a tape measure, a line, a 2-ft level, and a straightedge. Measurement of settlement will be made at every location where a depression of soil occurs and where it appears to be inconsistent with the surrounding soil grade conditions. The settlement condition noted in this line suggests a depression approximately 22 ft long and 4 ft wide occurring from Sta. 400 to 422. The maximum depth of the settlement is 7 in. at Sta. 415. For settlement, it is also important to note that the surface condition is met at the location of the settlement. For a wall, the program needs to know whether the backfill is (1) supporting a structure, (2) surfaced with paving or sidewalk, or (3) nothing on the surface. In this example, the number 2 recorded in the last column suggests a pavement or sidewalk was present at the time of the inspection.

In a cellular wall, settlement may occur under a cell cap structure without any visible shifting of the cap. This would reflect a surfacing condition type (2) with settlement under the paving. The only way this condition can be observed is by checking through an access port or manhole in the cap structure. When the condition exists, it approximates a large cavity until the cap settles down on the fill or the fill is replaced. When this type of settlement occurs and is observed, it should be recorded and the void height should be measured as the settlement of the fill.

Figure 6. (Sheet 20 of 26)

U.S. ARMY CORPS OF ENGINEERS

STEEL SHEET PILE STRUCTURE INSPECTION — PAGE 6A

DISTRESS PROFILE FORM

NOTES FOR USE OF THIS DATA PAGE:

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2. Use additional sheets of this DATA PAGE if more space is needed.
3. Refer to the Instruction References if more information is required.

MISALIGNMENT

STATION FROM (FT)	STATION TO (FT)	STATION OF MAX. DISPLAC. (FT)	DISPLAC. FROM NORMAL (IN)	FROM TOP OF WALL (FT)
125	165	145	10"	0
FOR A CELL				
35	40	38	2"	2'-0

CORROSION

STATION FROM (FT)	STATION TO (FT)	SEVERITY LEVEL (1-5) (#)
0	600	2

SETTLEMENT

STATION FROM (FT)	STATION TO (FT)	STATION OF MAX. DISPLAC. (FT)	DISPLAC. FROM NORMAL (IN)	SURFACE DESCR. TYPE * (#)
400	422	415	7"	2
FOR A CELL				
0	105	80	5.5"	2

*@WALL 1)STRUCTURE, 2)SURFACED, 3)NOTHING
*@CELL 1)UNIFORM, 2)DIFFERENTIAL SETTLEMENT

INTERLOCK SEPARATION

INTERLOCK STATION (FT)	LENGTH (FT)	FROM TOP OF WALL (FT)
510	3'-0	3'-0

CAVITY FORMATION

CAVITY AT STATION (FT)	ESTIMATE CAVITY SIZE LENGTH (FT)	WIDTH (FT)	HEIGHT (FT)	SURFACE TYPE * (#)
510	2'-0	2'-6	1-4	2

* 1)STRUCTURE, 2)SURFACED, 3)NOTHING

HOLES

HOLE AT STATION (FT)	HOLE SIZE LENGTH (FT)	WIDTH (FT)	FROM TOP OF WALL (FT)
190	0-9"	1'-4"	4'-6"

DENTS

DENT AT STATION (FT)	DENT SIZE LENGTH (FT)	WIDTH (FT)	DEPTH (IN)	FROM TOP OF WALL (FT)
195	2'-0	2'-0	8"	4'-0

CRACKS

CRACK AT STATION (FT)	CRACK SIZE LENGTH (FT)	WIDTH (IN)	FROM TOP OF WALL (FT)
240	2'-3	0	0-8"

Figure 6. (Sheet 21 of 26)

Minimum Settlement at a Wall

If the settlement occurs at or near the lock chamber, the minimum settlement that should be recorded is a 2 in. depression in less than 10 feet. If the settlement occurs away from a lock site, the minimum settlement that should be recorded is a 4 in. depression in less than 10 feet.

Line 3: SETTLEMENT of a Single Cell Interior Fill

Settlement of interior backfill material can occur and be observed as uniform settlement or as differential settlement. Uniform settlement of the top surface is measured from the original construction level or design level to the current level of the backfill material or cap at its highest point. Differential settlement of the top surface is characterized by a tilted cap structure or uneven slopes that have one point significantly lower than any other point or surface level. Differential settlement is measured from the level of the original construction surface or design level to the current level of the lowest point. The settlement condition noted in this line suggests that at circumference of 105 feet, a differential settlement measuring 5 1/2 in. is located near Sta. 80 (going around the cell). For a cell, the type of settlement is recorded in the last column, "Surface Description Type", as either (1) for uniform settlement, or (2) for differential settlement.

Settlement may also occur under a single cell cap structure without any visible shifting of the cap. The only way this condition can be observed is by checking through an access port or manhole in the cap structure. When the condition exists, it approximates a large cavity until the cap settles down on the fill or the fill is replaced. When this type of settlement occurs and is observed, it should be recorded as uniform settlement and the void height should be recorded as the measured displacement of the fill.

Minimum Settlement of Cell Interior Fill:
If the settlement is uniform the minimum settlement that should be recorded is a 2 in. change or more. If the settlement is differential, any apparent settlement that can be measured should be recorded. This provides a record for future observation.

Figure 6. (Sheet 22 of 26)

U.S. ARMY CORPS OF ENGINEERS
STEEL SHEET PILE STRUCTURE INSPECTION

DISTRESS PROFILE FORM

NOTES FOR USE OF THIS DATA PAGE:

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2. Use additional sheets of this DATA PAGE if more space is needed.
3. Refer to the Instruction References if more information is required.

MISALIGNMENT

STATION FROM (FT)	STATION TO (FT)	STATION OF MAX. DISPLAC. (FT)	DISPLAC. FROM NORMAL (IN)	FROM TOP OF WALL (FT)
125	165	145	10"	0
FOR A CELL				
35	40	38	2"	2-0

CORROSION

STATION FROM (FT)	STATION TO (FT)	SEVERITY LEVEL (1-5) (#)
0	600	2

SETTLEMENT

STATION FROM (FT)	STATION TO (FT)	STATION OF MAX. DISPLAC. (FT)	DISPLAC. FROM NORMAL (IN)	SURFACE DESCR. TYPE * (#)
400	422	415	7"	2
FOR A CELL				
0	105	80	5.5"	2

*@WALL 1)STRUCTURE, 2)SURFACED, 3)NOTHING
*@CELL 1)UNIFORM, 2)DIFFERENTIAL SETTLEMENT

INTERLOCK SEPARATION

INTERLOCK STATION (FT)	LENGTH (FT)	FROM TOP OF WALL (FT)
510	3'-0	3'-0

CAVITY FORMATION

CAVITY AT STATION (FT)	ESTIMATE CAVITY SIZE LENGTH (FT)	WIDTH (FT)	HEIGHT (FT)	SURFACE TYPE * (#)
510	2'-0	2'-6	1-4	2

* 1)STRUCTURE, 2)SURFACED, 3)NOTHING

HOLES

HOLE AT STATION (FT)	HOLE SIZE LENGTH (FT)	WIDTH (FT)	FROM TOP OF WALL (FT)
190	0-9"	1'-4"	4'-6"

DENTS

DENT AT STATION (FT)	DENT SIZE LENGTH (FT)	WIDTH (FT)	DEPTH (IN)	FROM TOP OF WALL (FT)
195	2'-0	2'-0	8"	4'-0

CRACKS

CRACK AT STATION (FT)	CRACK SIZE LENGTH (FT)	WIDTH (IN)	FROM TOP OF WALL (FT)
240	2'-3	0	0-8"

Figure 6. (Sheet 23 of 26)

Distress Type 4 - Cavity Formation

Line 1: CAVITY FORMATION

The measurement of a cavity that is present behind a SSP wall or within a SSP cell is, at times, a difficult or impossible task. The access point to the cavity may prevent an accurate measurement of the length, depth, and height of the cavity. The equipment required to measure a cavity includes a flashlight, tape measure, and a length of wire that can be bent at angles to explore the concealed sections of the cavity. This line of data describes a cavity behind a wall that is 2 ft wide, 2 ft- 6 in. high, and 1 ft- 4 in. deep. The cavity occurs at Sta. 510, which coincides with the interlock separation recorded at Sta. 510. This illustrates the relationship that a cavity will normally have with a hole, crack, or a separated interlock. For cavity formation, it is also important to note what the surface condition is above the cavity. For a wall or cellular structure, the program needs to know whether the backfill is (1) supporting a structure, (2) surfaced with paving or sidewalk, or (3) nothing on the surface. In this example, the number 2 recorded in the last column suggests a pavement or a sidewalk was present at the time of the inspection.

Minimum Cavity Formation

Any cavity formation with a depth exceeding 1 ft. should be recorded. The inspector may record cavities of a smaller size if other conditions suggest increasing size or possible contribution to other problems.

Distress Type 5 - Interlock Separations

Line 1: The measurement of interlock separation is made with a tape measure. The incidence of interlock separation may occur in several different forms but the measurement will always be the same, that is, the length of the interlock connection that is no longer connected. The location of the interlock separation relative to the vertical dimensions of the structure is important, particularly in cellular type structure. This line illustrates an interlock separation that occurs at Sta. 510 that is 3 ft long and begins 3 ft from the top of the wall. Every effort should be made to document accurately the total length of the interlock separation, particularly if the separation extends below the water level. This can be done by feel, by interview of local staff, or by requesting information from local staff when the water level recedes.

Minimum Interlock Separation:

On a wall-type SSP structure, any separation that exceeds 12 in. in length should be recorded. On a cellular type structure, all separations should be recorded.

Distress Type 6 - Holes

Line 1: The measurement of holes is made with a tape measure. The relative height and width of the opening in the SSP section is recorded. The shape

Figure 6. (Sheet 24 of 26)

DISTRESS PROFILE FORM

NOTES FOR USE OF THIS DATA PAGE:

1. Use this DATA PAGE for recording pertinent information relative to the DISTRESS TYPES indicated below. Enter each occurence of a specific distress by recording the DISTRESS TYPE data in the appropriate section below. The appropriate units of measurement are noted in the column boxes.
2. Use additional sheets of this DATA PAGE if more space is needed.
3. Refer to the Instruction References if more information is required.

MISALIGNMENT

STATION FROM	STATION TO	STATION OF MAX. DISPLAC.	DISPLAC. FROM NORMAL	FROM TOP OF WALL
FT	FT	FT	IN	FT
125	165	145	10"	0
FOR A	CELL			
35	40	38	2"	2'-0

CORROSION

STATION FROM	STATION TO	SEVERITY LEVEL (1-5)
FT	FT	#
0	600	2

SETTLEMENT

STATION FROM	STATION TO	STATION OF MAX. DISPLAC.	DISPLAC. FROM NORMAL	SURFACE DESCR. TYPE *
FT	FT	FT	IN	#
400	422	415	7"	2
FOR A	CELL			
0	105	80	5.5"	2

*@WALL 1)STRUCTURE, 2)SURFACED, 3)NOTHING
*@CELL 1)UNIFORM, 2)DIFFERENTIAL SETTLEMENT

INTERLOCK SEPARATION

INTERLOCK STATION	LENGTH	FROM TOP OF WALL
FT	FT	FT
510	3'-0	3'-0

CAVITY FORMATION

CAVITY AT STATION	ESTIMATE CAVITY SIZE LENGTH	WIDTH	HEIGHT	SURFACE TYPE *
FT	FT	FT	FT	#
510	2'-0	2'-6	1-4	2

* 1)STRUCTURE, 2)SURFACED, 3)NOTHING

HOLES

HOLE AT STATION	HOLE SIZE LENGTH	WIDTH	FROM TOP OF WALL
FT	FT	FT	FT
190	0-9"	1'-4"	4'-6"

DENTS

DENT AT STATION	DENT SIZE LENGTH	WIDTH	DEPTH	FROM TOP OF WALL
FT	FT	FT	IN	FT
195	2'-0	2'-0	8"	4'-0

CRACKS

CRACK AT STATION	CRACK SIZE LENGTH	WIDTH	FROM TOP OF WALL
FT	FT	IN	FT
240	2'-3	0	0-8"

Figure 6. (Sheet 25 of 26)

of the opening, circular or oblong, is not as crucial as is the occurrence of an opening that does not have an intended or obvious use. This line illustrates an oblong opening (hole) that occurs at Sta. 190 that begins 4 ft, 6 in. down from the top of the wall. Additional information recorded an opening that is 9 in. long (measured horizontally) by 1 ft 4 in. high or wide. The length of the opening is recorded as the horizontal dimension to indicate if more than one section is affected by the opening.

Minimum Size of Holes:
Any opening in an SSP section where the sum of the two recorded dimensions, length and height, will exceed approximately 8 in. should be recorded. For example, a round hole of 4 in. in diameter or an oblong hole 6 in. long by 2 in. wide should be about the minimum size opening recorded. An exception to this might be a smaller opening that is the apparent cause of another distress, such as settlement or cavity. The other distress should also be recorded for thorough documentation.

<u>Distress Type 7 - Dents</u>
Line 1: Dents are measured with a tape measure. The relative height and width of the deformation is recorded. The shape of the deformation could be important if it is very large and affects several sections. However, in general, the dimensions of the length and height will be adequate. This line illustrates an approximately square deformation that occurs at Sta. 194 and begins 4 ft down from the top of the wall. Additional information describes a deformation that is 2 ft long by 2 ft high or wide and is displaced from the normal plane of the SSP section approximately 8 in. at its maximum displacement. The length of the deformation indicates if more than one section is affected by the deformation.

Minimum Size of Dent:
Any dent in an SSP section where the sum of the two recorded dimensions, length and width, will exceed approximately 18 in. should be recorded. For example, an oblong dent 8 in. by 10 in. or a creased dent 3 in. by 24 in. should be recorded. Dents less than 1 in. deep need not be recorded.

<u>Distress Type 8 - Cracks</u>
Line 1: The measurement of cracks in an SSP section is made with a tape measure. The incidence of a crack and its ramifications are very much like the discussion for interlock separation. Refer to that section, Distress Type 5, Interlock Separations, for specifics about measurement and concerns. This line illustrates a crack occurring at Sta. 240 that begins 8 in. down from the top of the wall and the crack is 2 ft-3 in. long. The dimensions describe a horizontal crack traversing across the sheet.

Minimum Length of Crack:
A crack is not intended to be present, so any crack that exceeds 6 in. in length should be recorded.

Figure 6. (Sheet 26 of 26)

PART IV: STRUCTURAL CONDITION INDEX

45. Safety often refers to potential loss of life or significant property damage. If a structure is unsafe, it is in danger of collapse. Structural safety has traditionally been measured by a factor of safety. Hence, uncertainties in loading and structural strength (i.e., abnormal conditions) are covered by selecting an appropriately high factor of safety to ensure a sufficient margin between the applied loads and the structural resistance. For example, the design criteria for steel sheet pile typically require a factor of safety of two.

46. In this project, a structural condition index is defined as a measure of the safety of the structure or risk of failure of the structure. It is based directly on the factor of safety of the structure. The factor of safety calculation is often perceived as a fairly rational, objective process. This is so, in spite of the many simplifying assumptions that must be made. Presumably, the structural condition index would be reasonably repeatable.

Structural Analysis

47. A basic part of the structural safety evaluation is a structural analysis. As with all structural analyses, several assumptions must be made. In this work, the basic assumption is that steel sheet piles behave in the manner in which they were designed. With this assumption, the US Army Corps of Engineers design manual (1958) and the US Steel Corporation manual (1975) are used for the safety analysis. These sources are supplemented by a US Corps of Engineers computer program (Dawkins 1981) that implements these rules. These documents describe how to calculate the active and passive soil pressures on the steel sheet pile by the Coulomb theory.

Cantilevered and Anchored Walls

48. For anchored walls, the equivalent beam method is used to calculate the bending moments in the sheet pile and the anchor tension. In the equivalent beam method, the sheet is assumed to act as a statically determinate beam from the top to the inflection point below the dredge line (Figure 7). This inflection point is assumed to occur at the point of zero net soil pressure, that is, passive pressure equal to active pressure. In cantilevered wall design, the sheet is embedded to a sufficient depth to behave as a vertical cantilever. As referred to in Figure 8, the pile is assumed to rotate about point 0, mobilizing passive pressure above and below the pivot point 0. Equilibrium is satisfied for horizontal forces and moments about any point.

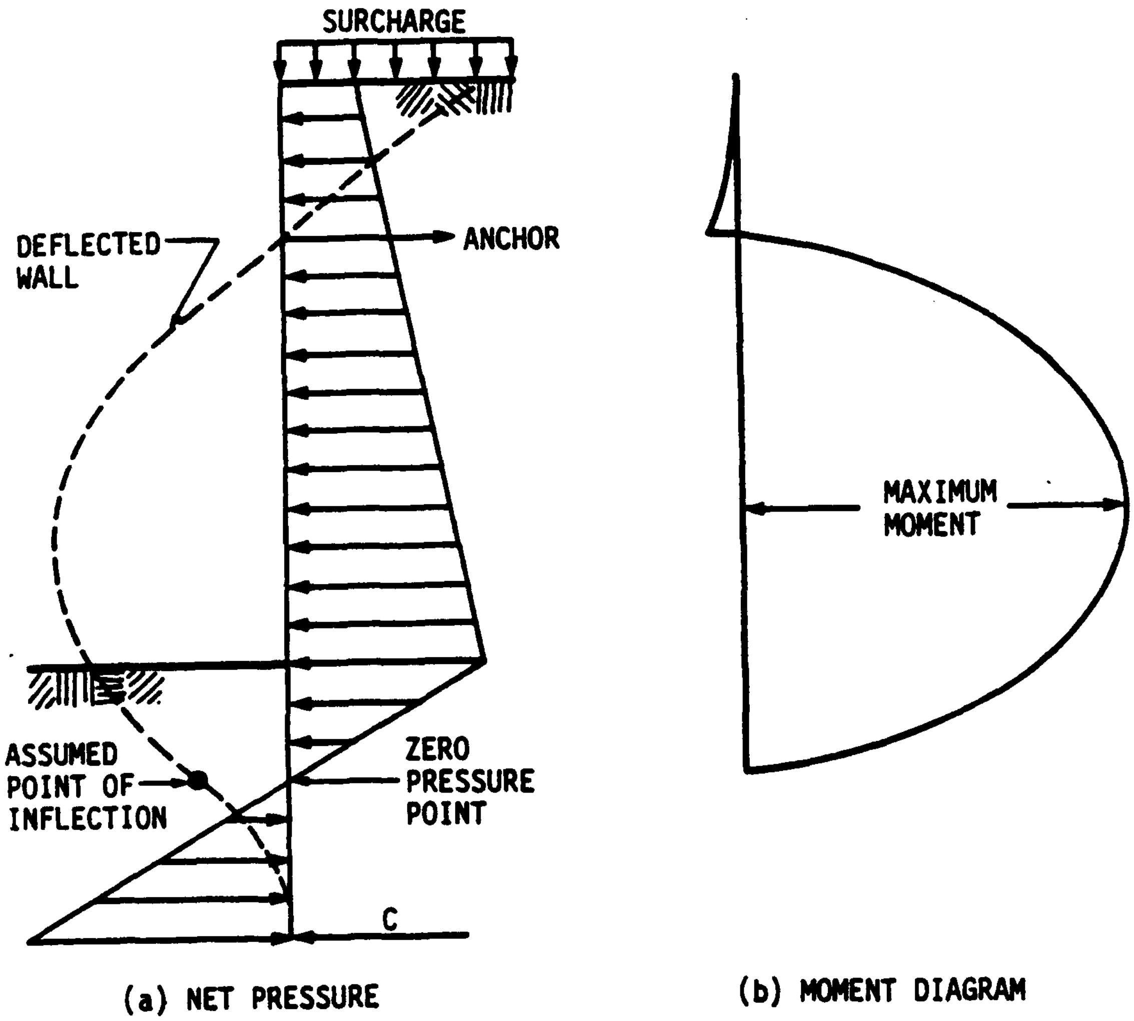

Figure 7. Anchored wall design by equivalent beam method

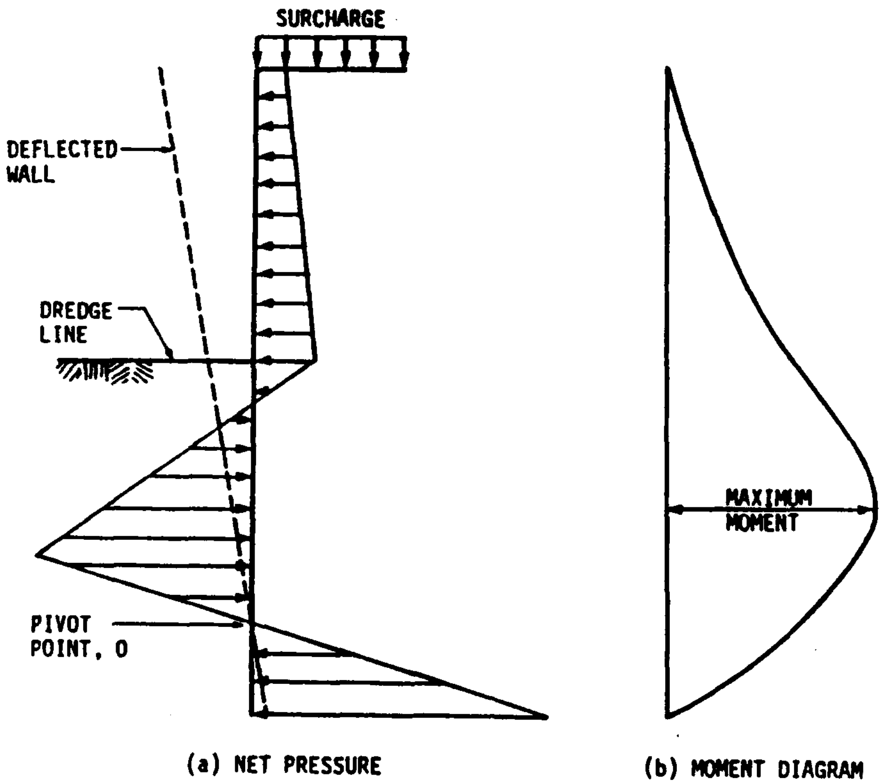

Figure 8. Cantilevered wall

49. Three failure modes are analyzed and three factors of safety (FS) are computed:

a. Pile sheet bending mode

$$FS_1 = F_y/f_b \tag{1}$$

b. Anchor tension mode (anchored wall only)

$$FS_2 = F_y/f_t \tag{2}$$

c. Soil failure at toe

$$FS_3 = s\ (c + \tan d)/t \tag{3}$$

where: F_y = steel yield stress
f_b = maximum pile-bending stress
f_t = tensile stress in anchors or bolts
s = soil normal stress
c = soil cohesive strength
d = soil friction angle
t = soil shear stress.

Some failure modes are not analyzed: fixing bolt, wale bending, and anchor at the far end of the anchor rod. Also, only uniform surcharge loadings are considered.

50. The steel yield strength is requested on the inspection sheet. If it is not available, it is assumed to be 36,000 psi. The inspection sheet lists various broad categories of soil descriptions. Table 3 lists the soil properties that are used within this analysis for each of these descriptions (Lee 1961). These are approximate values selected by the authors as representative. As discussed in the US Steel Corporation manual (1975, p 25), the cohesive strength for clays may approach zero for long-term loading. and an appropriate assumption for such cases is to set the cohesion equal to zero and a frictional angle between 20 and 30 degrees. "However, many sheet pile walls have been built on the usual Ø = 0 basis by using the conventional procedures...and it is thought that it would be unduly conservative to design on the long term Ø′ basis" (Winterkorn 1975). "However, a great diversity of opinion exists as to the proper values to use for Ø under different circumstances" (Terzaghi 1948) "...Such walls are designed on the basis of simple semiempirical rules for estimating the backfill pressure...the design of walls by this procedure leads on rare occasions to failure, but in the great majority of cases the walls are safer than necessary" (Terzaghi 1948). In the judgement of the authors, the use of long term properties for clay is too conservative. Several actual walls which were analyzed using long term properties had factors of safety less than 1. The time variation of the properties is obviously difficult to predict, especially with changing water elevation. Therefore, in this work, the walls will be analyzed using the short term properties in Table 3.) If users wish to use a more conservative assumption, they may enter a weaker soil on the inspection sheet.

51. A computer program has been written to calculate the factors of safety listed above. The program interfaces with the data file prepared from the inspection data. Hence, to calculate the safety of a steel sheet pile structure, one need only respond appropriately to the computer prompts. Within each section, the computer selects the worst case in terms of lowest dredge depth or largest loading (pages 4 and 5 of inspection sheet). The water level is assumed to be the same on both sides of the wall since the water levels usually change slowly enough to permit equalization of the water level on both sides of the steel sheet. (This is not assumed for lock walls.) In addition, the water is conservatively assumed to be at the low water level on page 1 of the inspection sheet. If users wish an analysis at a different water level, they may enter another low water level on page 1 of the inspection sheet. If the structural conditions appear to be marginal based on this analysis, the structural evaluator should use computer programs such as that developed for the U.S. Army Waterways Experiment Station (Dawkin 1981).

Cells and Cellular Walls

52. Single cells are designed to resist impact or mooring forces from vessels, while cellular walls are usually designed to resist water and soil pressures. While the applied forces on a single cell are different from those on a cellular wall, the analysis for stability is the same for both. Cellular structures consist of two different materials, steel and soil, which interact in a complex way to resist forces. A totally rational design approach is difficult. Designers rely heavily on past practice and experience. Generally, the design is performed by first establishing the controlling dimensions: the height of the structure, and the low and high water elevations. The design of cellular structures is generally separated into two categories: cellular structures on rock foundation and cellular structures on deep soil deposits.

53. Three different factors of safety associated with three different failure modes are considered for all cellular structures (see Figure 9) (US Steel Corporation 1975):

a. Vertical shear on centerline of cell

$$FS_1 = S_T/Q \quad (4)$$

b. Sliding on foundation

$$FS_2 = F_R/F_D \quad (5)$$

c. Bursting

$$FS_3 = t_u/t_{max} \quad (6)$$

where: S_T = shearing resistance of the cell fill and the interlocks

Q = shearing force per unit length of cellular structure

F_R = horizontal resisting forces

F_D = horizontal driving forces

t_u = minimum ultimate interlock strength

t_{max} = maximum interlock tension.

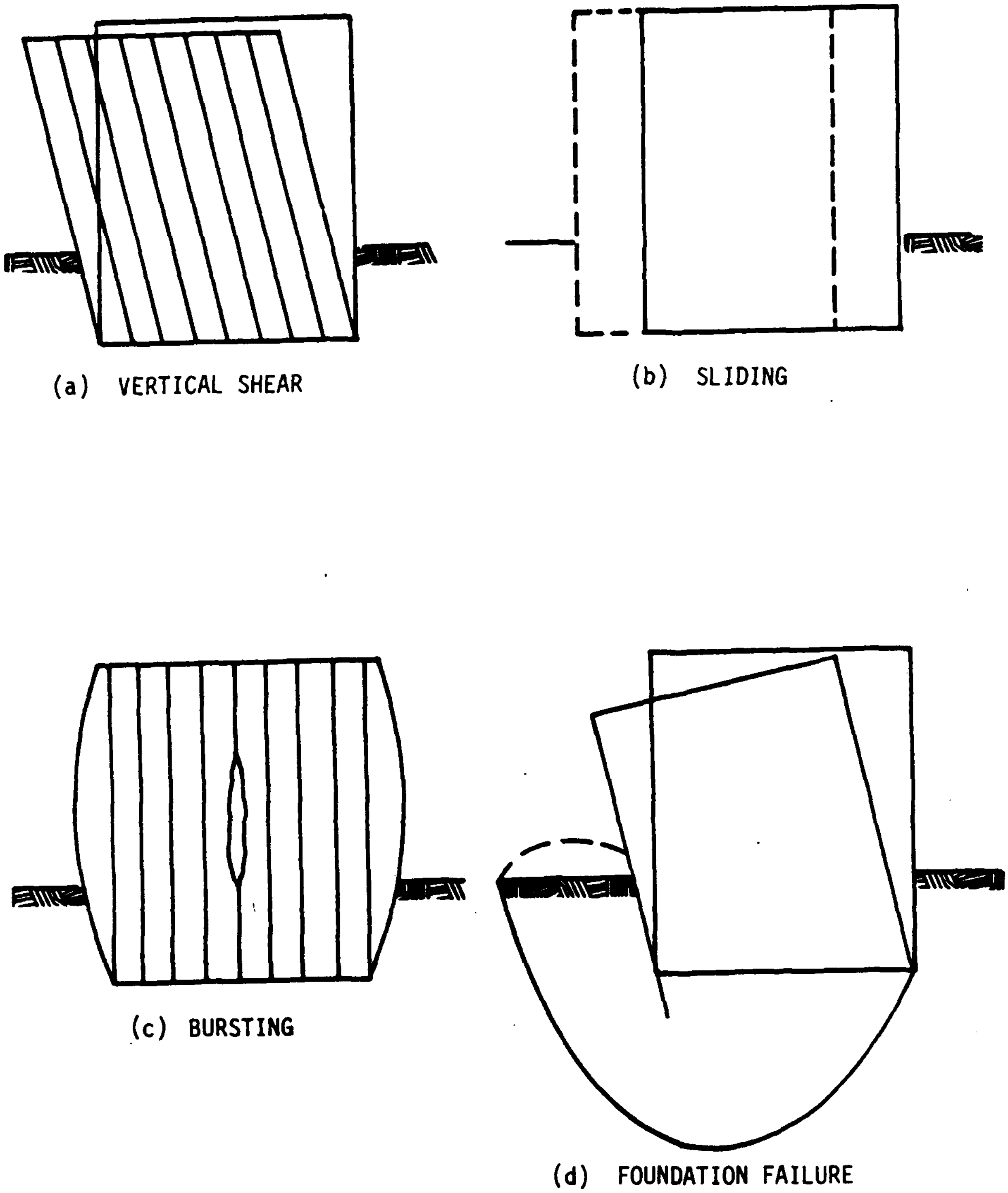

Figure 9. Failure modes for cellular structures

For cellular structures founded on consolidating clay (soft to medium) the foundation failure factor of safety is also considered (US Steel Corp. 1972):

$$FS_4 = 5.7c/\gamma H \quad (7)$$

where: γ = unit weight of fill

H = height of cellular structure above ground surface.

54. To determine the structural condition index of the cellular structure, the high water level and the low water level that give the worst combination are used to give the lowest factor of safety.

55. For cellular walls, the high water level is assumed to be on the right side of the wall, but not higher than the top of the cell (Figure 10a). The low water level is assumed to be on the left side of the wall. In the case of a lock chamber wall, the low water level is assumed to be at the dredge line.

56. For a single cell, the structural condition index is calculated at both the low and the high water level, but not higher than the top of the cell (see Figure 10b) and the minimum of these two values is used.

57. In both cases, if users wish to make the analysis for different water elevations, they may do so by changing the low and high water level on page 1 of the inspection sheet.

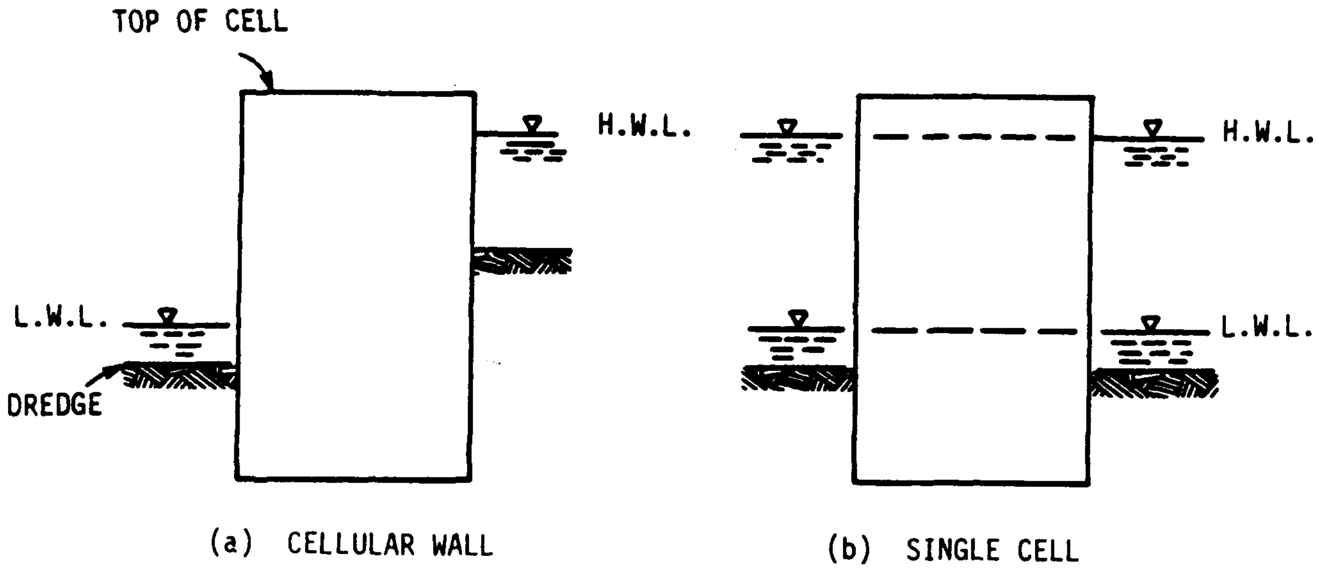

Figure 10. Water level worst case

Factor of Safety Relationship

58. The factor of safety is related directly to the structural condition index using the condition index zones in Table 2. If the factor of safety is equal to the design value, the condition index is 100. If the factor of safety falls below one, a Zone 3 (condition index less than 40) is indicated. Figure 11 illustrates the two straight lines that are used to relate factor of safety and structural condition index:

$$CI = \begin{cases} 40 \times FS & FS < 1 \\ 40 + 60\left(\dfrac{FS - 1}{FS_d - 1}\right) & FS > 1 \end{cases} \tag{8}$$

where: F: = the design factor of safety.

59. As described in the previous section, several factors of safety are calculated, one for each failure mode. The condition index for each mode, CI;₋ᵢ, is calculated using Equation 8. The structural condition index for the wall section is found as

$$Structural = \left(\frac{CI_1}{100}\right)\left(\frac{CI_2}{100}\right)\ldots \tag{9}$$

If a wall has more than one subsection, the minimum value from all of the subsections is used.

60. Only the scour distress is included in the calculated structural condition index. Scour is erosion of soil at the toe of the wall caused by water currents. The effect of scour on safety can be dramatic, since the passive soil resistance at the wall toe can be significantly reduced. Actual dredge line elevations from the inspection sheet are used in the safety calculations. Other distresses discussed in Part V and listed in Table 4 are not included in the structural condition index.

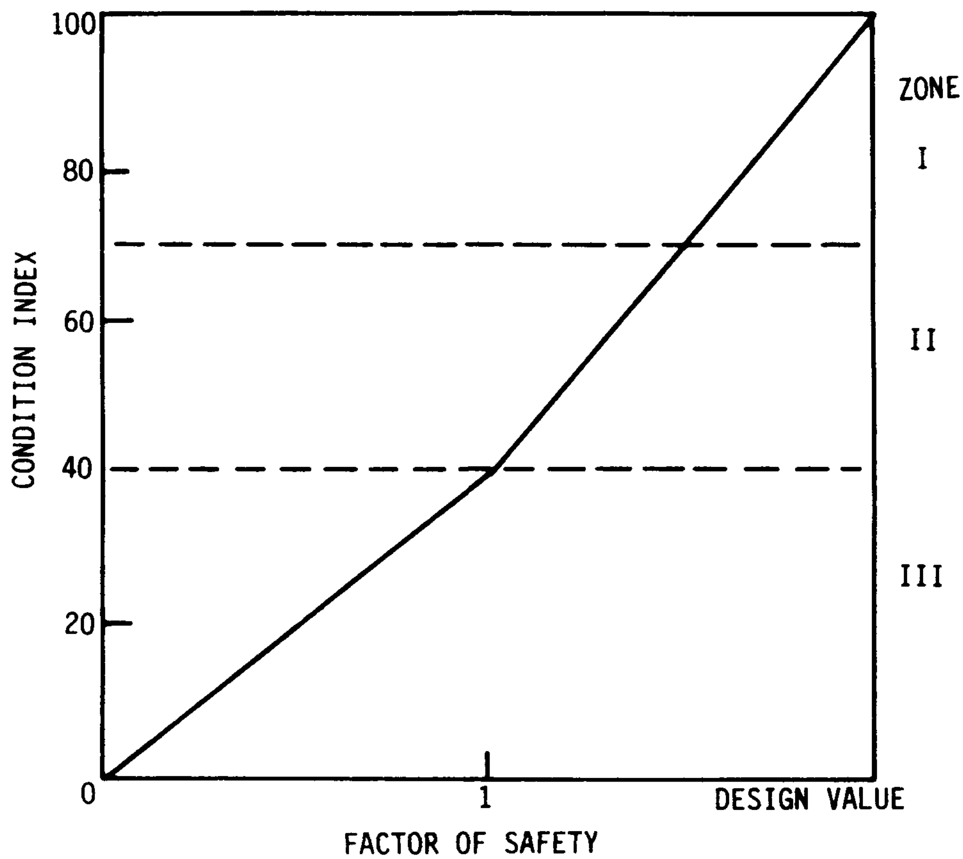

Figure 11. Relationship between factor of safety and structural condition index

PART V: FUNCTIONAL CONDITION INDEX

61. The second set of criteria that evolved during this project was much more subjective than the safety evaluation. This set of criteria involve "engineering judgment" and depends upon the experience of the person making the evaluation. These aspects of the condition index were much more difficult to capture. Experts in this field were interviewed and discussions continued for some time until a consensus began to develop. The "expert opinion" rules embedded in the computer-based evaluation of the functional condition index have been designed to interpret straightforward visual observation data in much the same manner as a seasoned engineer would interpret field observations.

62. The experts took many factors into account as they evaluated the functional condition index. One aspect was the serviceability of the structure, that is, its performance at and below normal service conditions on a day-to-day basis. For example, if a lock wall is significantly out of alignment, the movement of barges through the lock will be affected. Aesthetics is also an aspect of serviceability. The appearance of the wall in its particular location is important.

63. Another factor involved in the functional condition index is, for lack of a better phrase, subjective safety. Functional safety refers to the idea that an engineer, using his or her subjective engineering judgment, may decide that a safety problem is likely. However, with only a visual indication of the problem, the engineer cannot identify the exact problem without detailed information.

64. Using misalignment as an example shows that if misalignment exists, it may not significantly affect serviceability but it may be an indication that structural failure--such as a tie-rod failure, sheet bending failure, or passive soil failure at the toe--has occurred or is in progress. Thus, although the exact cause and effect of the misalignment cannot be pinpointed without further investigation, the condition index of the structure should reflect some increased safety risk. For this example and many others, the increased risk cannot be evaluated by a simple analytical means; thus, it cannot be included in the structural condition index. It is, therefore, appropriate to reduce the functional condition index.

65. A distress such as misalignment could be included in the structural condition index or the functional condition index depending upon the level of investigation (i.e., objective versus subjective information). Since the structural analysis in this investigation is at an elementary level (see PART IV) only one distress (scour) is included in the structural condition index.

66. Typically, each distress (such as misalignment, settlement, or the number of holes) will be measured by some geometric or numerical quantity X that is recorded on the inspection sheet. Hence, in the case of misalignment,

X will be the deviation of the wall from its design condition. Such measurable X must be reasonably repeatable. The functional condition index is given by

$$FunctionalCI = 100\,(0.4)^{x/x_{max}}$$

where X_{max} is some limiting value of X. Referring to the above description of action zones (Table 2), X_{max} is selected as the point at which the functional condition index is 40, that is, the dividing point between Zone 2 and 3. Figure 12 illustrates the equation and zones from Table 2. If X is zero, that is, no distress, the condition index is 100. Note that the functional condition index never quite reaches zero. Following the discussion in the paragraphs above, X_{max} for misalignment has been selected by experts to be the point at which the misalignment requires immediate repair or, at a minimum, a more detailed inspection and condition index evaluation must be made. It is a potentially hazardous situation. The expert makes the judgment for X_{max} based on serviceability or subjective safety considerations. Tables of X_{max} are given in this chapter for several distresses.

67. If there are several occurrences of an individual distress, the condition index is found as

$$CI = 100\left(\frac{CI}{100}\right)\left(\frac{CI}{100}\right)$$

That is, the functional condition index for a distress is equal to the product of the condition indexes for each occurrence of the distress. This equation is used for all distresses except corrosion.

Distress Descriptions and X_{max}

68. A steel sheet pile structure properly designed and constructed would have an initial condition index of 100. As time passes and the structure is exposed to varying environmental and operational situations, its condition will deteriorate. The condition index will degrade as various distresses are incurred. A total of eight distresses have been identified for categorization in this project. Each is described briefly in Table 4. Each of these distresses can detract from the safety and serviceability of the steel sheet pile.

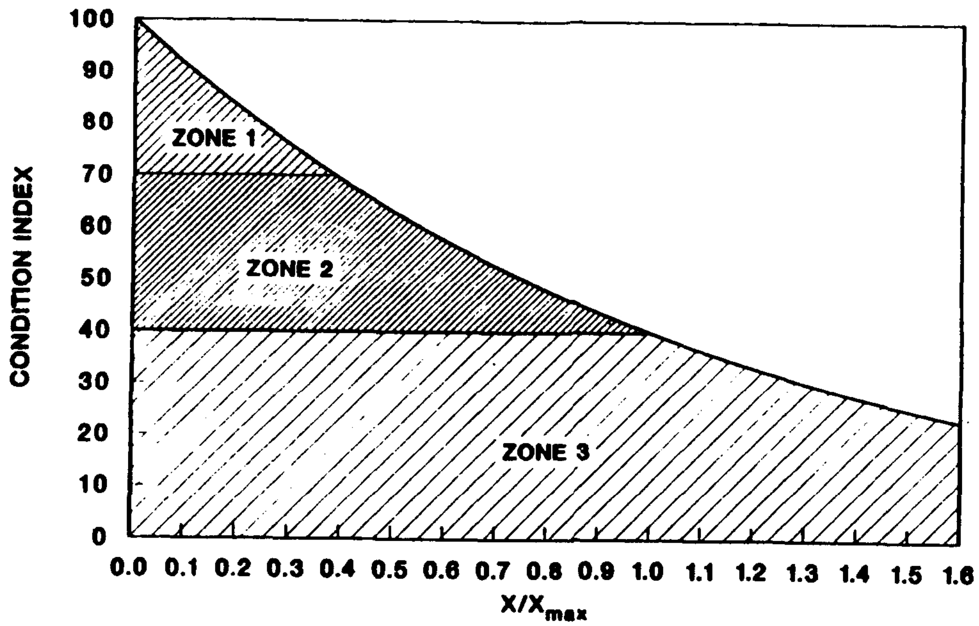

Figure 12. Functional condition index related to X/X_{max}

69. The functional condition index for each distress depends upon the ratio of a field measurement of that distress X to some limit X_{max} as in Equation 10. In the following sections, definition, potential causes, measurement of X, and X_{max} values for each distress will be described. Values are presented here on a trial basis Before a field inspection, all distress types should be discussed, with examples and photographs given to assist the inspectors.

Distress Code 1: Misalignment

Definition and Causes

70. Misalignment is a geometric deviation of the sheet pile from its initial design alignment. It usually has both vertical and horizontal components. Misalignment can be caused by several factors (see Figure 13):

a. Structural failure of the sheet, wale, or anchor
b. Soil failure of the toe or slope
c. Horizontal sliding
d. Seepage.

Since misalignment has many causes, its presence may indicate a significant structural problem. As such, misalignment will reduce the experts' subjective opinion of the safety of the structure.

Measurement and Limits

71. Measurement of the displacement will be made at every location where either horizontal or vertical misalignment occurs and exceeds a minimum dimension. The measured dimension will be documented on the profile sheet of the steel sheet pile structure inspection sheet (PART III). Documentation of misalignment at each inspection will provide a log of the current conditions, as well as a record for future inspections, to determine the rate of deflection. This rate can give information on the severity of the misalignment problem. The X_{max} values fcr misalignment for variojs steel sheet pile structures are listed in Table 5.

Examples

72. A lock guide wall 1500 ft long has a bow from 5+00 to 7+00 with the maximum deflection of 8 in. at 6+00 (or 600 ft from the 1200 ft lock chamber). From the formula in Table 5

$$X_{max} = 6 + 6 \frac{600}{1200} = 9 \text{ in.}$$

and the functional condition index for this case (Equation 10) is

$$CI = 100 \ (0.4)^{8/9} = 44$$

73. An erosion control wall 3000 ft long and 2 miles upriver from a lock has an 18 in. bow that is 600 ft long. Select 40 in. for X_{max} from Table 5. The functional condition index is

$$CI = 100 \ (0.4)^{18/40} = 66$$

74. A cell 40 ft high and 32 ft in diameter is 3 in. out of plumb in 24 in. within the exposed height. It is used for protection in the upper pool. The ratio of cell diameter to height is 32 ft/40 ft or 0.80. Select X_{max} = 4 in. from Table 5. The functional condition index is

$$CI = 100(0.4)^{3/4} = 50$$

Distress Code 2: Corrosion

Definition and Cause

75. Corrosion is the loss of the steel material in the sheet pile due to interaction with its environment. The rate of corrosion is dependent on the oxygen concentration and moisture in contact with the steel. A steel sheet pile structure is exposed to different zones of corrosion (Figure 14). While corrosion is usually very evident and easily noticed in the exposed

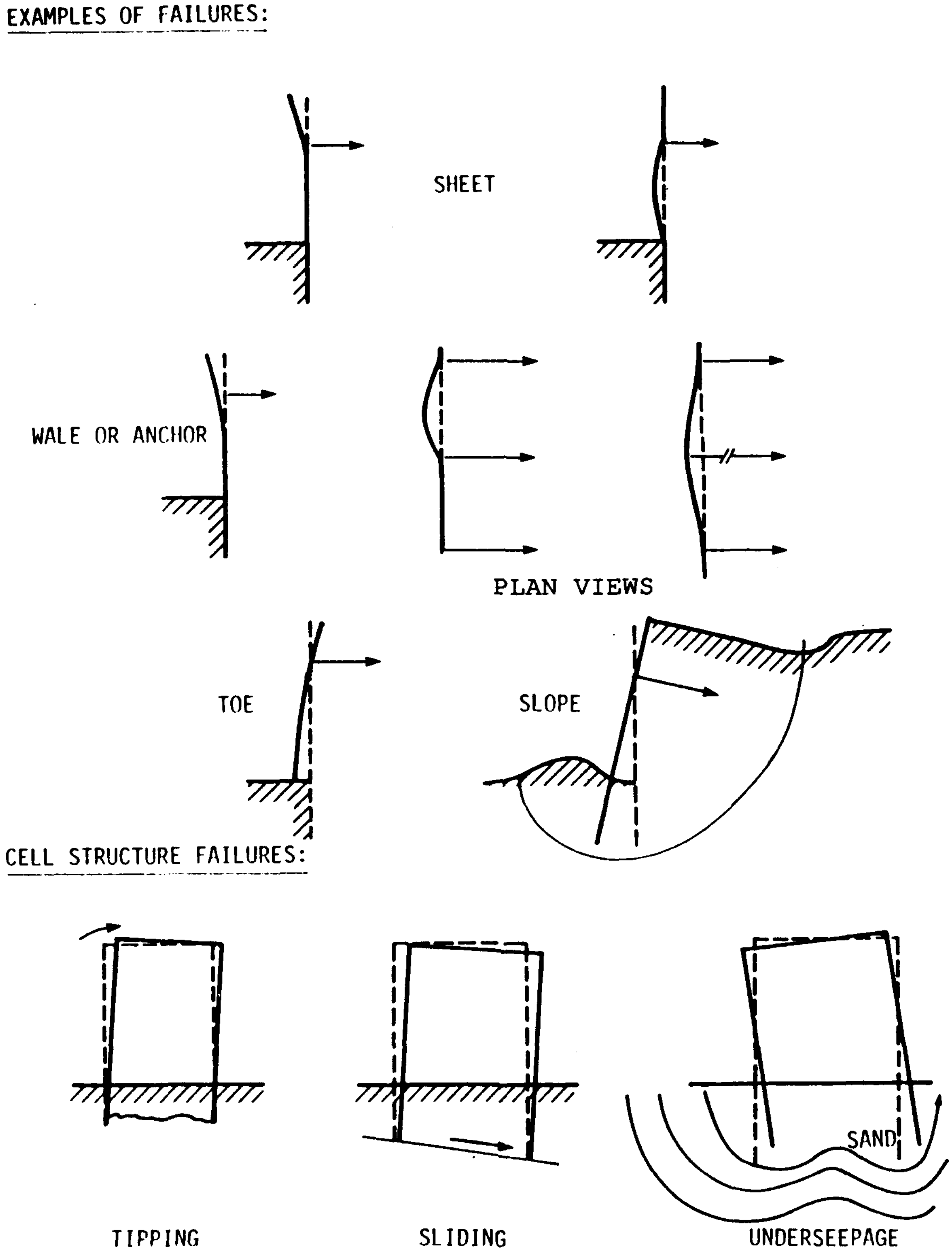

Figure 13. Causes of misalignment

areas, it is the concealed components (those below the water surface) that are of most concern for safety reasons.

Measurement and Limits

76. The effect of corrosion in the atmospheric and splash zones is used to evaluate the functional condition index because it is visible. A distress coefficient for corrosion must take into account that corrosion of a steel sheet pile structure seldom impedes the successful or smooth operation of the structure. However, the condition of a corroded structure of some age is not as good as the condition of new structure. Its safety has been reduced. The effect is a subjective evaluation of safety that is difficult to quantify by measurements or testing. One way to evaluate the corrosion of a structure is to set a series of standards, or levels of corrosion, with corresponding numeric distress coefficients. The base for such an evaluation standard would be new steel sheet pile or clean and painted steel sheet pile with no scale or pitting. Table 6 describes the various levels of corrosion. The photographs in Figure 15 illustrate these levels. The limiting value of corrosion is selected as $X_{max} = 4$. This places a corrosion level of four as the dividing line between fair and poor condition (condition index of 40, see Table 1); corrosion level five is poor. If more than one level of corrosion is recorded for a wall, the corrosion condition index is obtained as the length-weighted average.

77. A 600-ft steel sheet pile wall has a corrosion level of 1 over 500 ft and a corrosion level of 3 over 100 ft. The functional condition index for the 500 ft length is calculated as

$$CI = 100\ (0.4)^{1/4} = 80$$

and for the 100 ft length as

$$CI = 100\ (0.4)^{3/4} = 50$$

so that the final corrosion functional condition index is the length-weighted average

$$CI\ 80\left(\frac{500}{600}\right) + 50\left(\frac{100}{600}\right) = 75$$

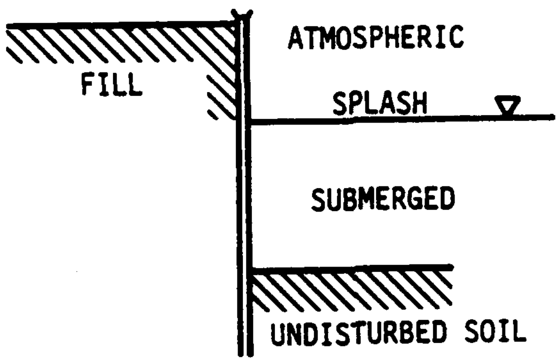

Figure 14. Zones of corrosion

Figure 15a. Corrosion in atmospheric zone, level 1: minor surface scale or widely scattered small pits

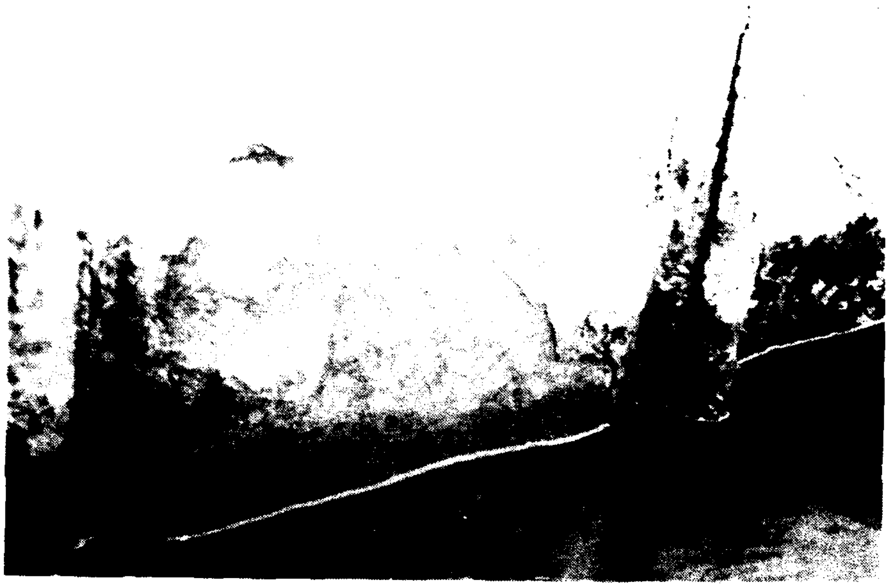

Figure 15b. Corrosion in atmospheric zone, level 2: considerable surface scale and/or moderate pitting

Figure 15c. Corrosion in atmospheric zone, level 3: severe pitting in dense pattern, thickness reduction in local areas

Figure 15d. Corrosion in atmospheric zone, level 4: obvious uniform thickness reduction

Figure 15e. Corrosion in atmospheric zone, level 5: Holes due to thickness reduction and general thickness reduction

Distress Code 3: Settlement

Definition and Cause

78. Settlement is the vertical movement of the soil behind the sheet pile. It can be caused by consolidation of the soil, loss of backfill, or wall movement. Settlement can affect operations behind the wall. In cells it can indicate a partial loss of strength, that is, a subjective reduction in safety.

Measurement and Limits

79. Measurement will be made at every location where settlement occurs and exceeds a minimum dimension. The measurements must note the location of the depression on the profile sheet. The settlement depth is recorded and used to calculate the functional condition index. Additional documentation of the width of the settlement behind the structure is also recorded. The X_{max} limits for settlement are listed in Table 7.

Examples

80. A lock guide wall (cantilevered, anchored, or cellular) is 1500 ft long and has no surfacing behind the wall. A depression 27 in. deep by 35 ft long occurs behind the wall at 800 ft from the lock. From Table 7, select X_{max} = 36 in. and find the functional condition index as

$$CI = 100\ (0.4)^{27/36} = 50$$

81. A single cell has a 42 ft diameter and is 24 ft tall. If a uniform settlement of 5 in. occurs, the functional condition index is

$$CI = 100\ (0.4)^{5/12} = 68$$

If a differential settlement of 5 in. occurs, the functional condition index is

$$CI = 100\ (0.4)^{5/(4.2)(3)} = 70$$

Distress Code 4 : Cavity Formation

Definition and Cause

82. Cavity formation occurs behind the sheet when some of the fill material is lost. Associated settlement may or may not occur, but the potential exists. The material may be lost through a hole in the sheet or beneath the sheets. The loss of fill material could obstruct navigation, damage underground utilities, and reduce strength.

Measurement and Limits

83. A cavity behind a sheet is recorded during the inspection by measuring its size: depth, length, and height. Its location (station) will also be recorded. The volume of the cavity is used as the measure of its effect on the functional condition index. The limiting values are listed in Table 8.

Example

84. A cavity is found under the concrete cap on a single cell. The approximate dimensions of the cavity are 2 ft wide x 18 in. x 10 in. high.

$$X = (2)\ (1.5)\ (0.83) = 2.49 \text{ cu ft}$$

Distress Codes 5-8:
5. Interlock Separation, 6. Holes, 7. Dents, 8. Cracks

Definition and Cause

85. These four distresses represent openings in the steel sheet. They can be caused by several factors but usually are caused by impact or corrosion. Large, major holes due to impact will most likely be fixed very shortly after they occur. Generally, they will not be present at an inspection and therefore are not included.

86. These four distresses are grouped together in terms of their consideration for service loss and safety to the steel sheet pile structure. In general, these distresses cause no significant loss or impedance to operation of the structure. However, as is the situation with corrosion, the occurrence of these distresses does cause the steel sheet pile structure to be in a less than design condition. Subjectively, the safety has been reduced though it is difficult to quantify in an analytical manner. These distresses may contribute directly to the presence of other primary distresses, such as settlement, which have safety and serviceability consequences. In this case, the effect of the opening is also accounted for in the primary distress condition index.

Measurement and Limits

87. The sizes of all significant separations--holes, dents, or cracks--are recorded. Openings below a certain size (e.g., bolt holes or lifting holes) are ignored.

88. For each singular occurrence of any of these distresses, little effect would be noted on serviceability. However, the cumulative effect of five of these distresses would be significant if they occurred in 100 ft of steel sheet pile structure. Therefore, the X_{max} limits for openings are defined in a slightly different manner than other distresses. The size and length limits are not explicitly defined. Rather, notes are made of one occurrence of an interlock separation, a hole, a dent, or a crack. Dimensions for each are recorded on the profile sheet. The density of the holes per

length of structure is defined as X. An X_{max} of 5 holes/100 ft is selected; that is, 5 or more holes per 100 ft is a Zone 3 condition.

Example

89. If 10 holes are recorded in a 700 ft wall, X is equal to 10/7 holes per 100 ft and the functional condition index would be

$$CI = 100\ (0.4)^{(10/7)/5} = 77$$

Multiple Distresses

90. When several types of distress occur, such as both misalignment and settlement, the condition indexes are combined into a single value. Weighting factors are introduced to reflect the importance of the various distresses. Hence, let w_i be the weighting factor for the functional condition index for distress i. The weighting factors assign more value to the more significant distresses. Relative initial weights are listed in Table 9. The table illustrates that misalignment carries twice the weight of settlement, cavities, interlock separation, and cracks.

91. The normalized weighting factors are defined by

$$W_i = w_i / \sum w_i \ (100) \tag{12}$$

Note that

$$W_i = 100 \tag{13}$$

Values are listed in Table 9 (rounded to add up to 100). The combined functional condition index for all distresses is then given by

$$\text{Functional CI} = W_1 CI_1 + W_2 CI_2 + \ldots \tag{14}$$

where the sum is for all eight distresses.

92. During the field testing of a preliminary version of the above rating procedure, it became clear that, as a distress became more severe, its relative importance became larger. To account for this, a variable adjustment factor was introduced to increase the distress weighting factor as its functional condition index approached Zone 3 (Table 2). The adjustment factor, plotted in Figure 16, has a maximum value of eight; that is, if a distress has a condition index less than 40, its importance increases eight times.

93. Suppose that only the following distresses are recorded:

	X	X_{max}	CI (from Eq 10)
Misalignment	6	12	63
Settlement	2	12	86
Misalignment	4	6	54
Corrosion	3	4	50

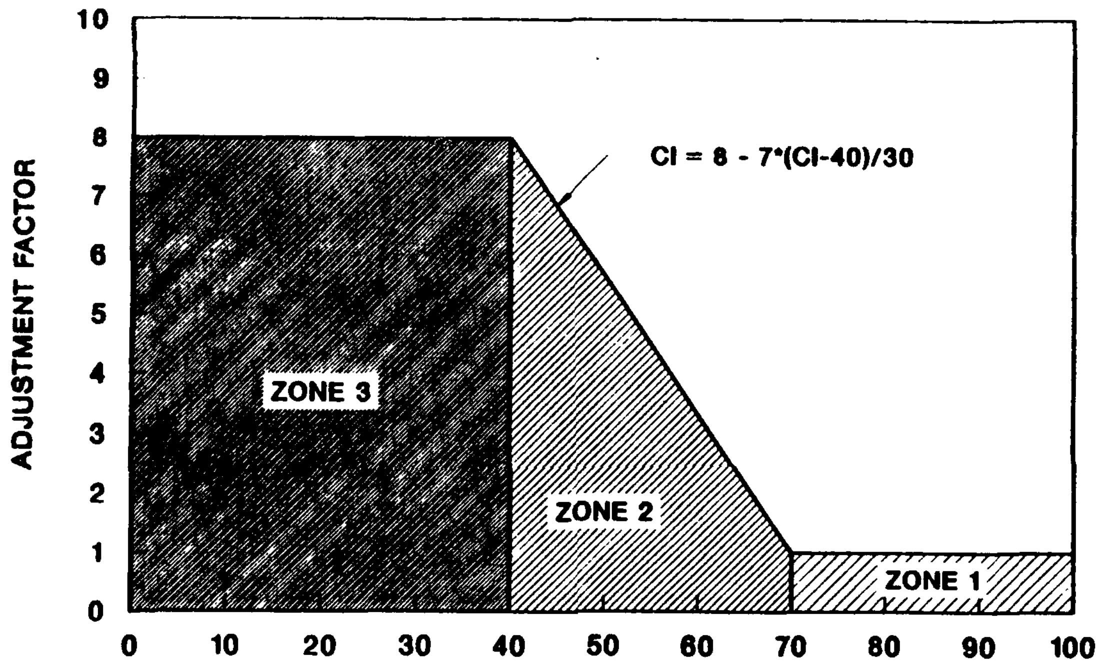

Figure 16. Weight adjustment factor for functional condition index

Following Equation 11, the functional condition index for misalignment is 100(0.63)(0.54) or 34. With the initial weights from Table 9 and the adjustment factor from Figure 16, the revised weights are found as:

	CI	w_i	Adjustment Factor	Revised w_i	Revised W_i%
Misalignment	34	8	8.0	64	56.7
Corrosion	50	5	5.7	28	24.8
Settlement	86	4	1.0	4	3.5
Cavities	100	4	1.0	4	3.5
Interlock Separation	100	4	1.0	4	3.5
Holes	100	3	1.0	3	2.7
Dents	100	2	1.0	2	1.8
Cracks	100	4	1.0	4	3.5
				11	100.0

The final functional condition index is now found as

$$\text{Subjective CI} = 0.567(34) + 0.248(50) + 0.035(86) + 0.035(100) + 0.035(100) + 0.027(100) + 0.018(100) + 0.035(100) = 50$$

Field Testing

94. The inspection and rating procedure described in this report has been applied in two field tests. In July 1986 the procedure was applied to the upper and lower guide wall at Peoria Lock and Dam in Peoria, IL. Three U.S. Army Corps of Engineer experts were involved in this testing: John Sirak (Ohio River Division), Richard Atkinson (Rock Island District), and Raymond Horton (Rock Island District). Dr. Anthony Kao, USACERL project monitor, was an observer. The results of that field test, although primarily qualitative, were used to make several modifications to a previous version of the rating procedure. The results of that test are not specifically addressed here.

95. In July 1987 another field test was conducted in the Chicago area by four Corps engineers: Sirak, Atkinson, Horton, and Joseph Jacobazzi (North Central Division). Kao was also present. Nine dif-ferent wall locations and functions were inspected. Each expert was asked to rate the individual distresses in each wall and rate the overall wall, that is, assign a functional condition index. Many of the comments and suggestions made during that test have been incorporated into the current version of the procedure.

Wall A

96. Wall A is an anchored-type wall approximately 400 ft long that is used as a loading dock retaining wall. The wall height exposed above water was 7 ft and the overall height from top of wall to dredge averaged 24 ft. Anchor rods appeared to be 2.25 in. in diameter at 6 ft spacings. The steel sheet pile appeared to be PZ27. The observed distresses included two instances of misalignment with displacements of 8 in. over 75 ft and 5 in. over 20 ft; seven instances of dents with six being small (1 to 2 ft in diameter) and one being much larger (9 ft by 3 ft and depressed 8 in.); and a general state of corrosion judged to be about Level 2. No other distresses were noted for the computer evaluation, although several of the experts noted that they considered settlement behind the misalignment and also interlock damage and cracks in conjunction with the dents.

Wall B

97. Wall B was, in fact, the same wall as Wall A. However, the experts were asked to rate the wall as if it were a guide wall in a lock and dam facility.

Wall C

98. Wall C is an anchored-type wall approximately 285 ft long that is used as a loading dock retaining wall where salt is unloaded. The exposed

wall height was 9 ft and the overall wall height was approximately 19 ft. The steel sheet pile appeared to be PDA27. The observed distresses were dominated by the severe corrosion. Different levels of corrosion were recorded for sections of the wall and included levels 2, 3, 4, and 5. One instance of misalignment with a displacement of 6 in. over 40 ft and one hole 2 ft long by 6 in. wide were also recorded. No other distresses were noted, although several experts noted they considered the corrosion to be severe enough to have caused interlock damage and left the steel material so thin that holes were imminent.

Wall D

99. Wall D is an anchored-type wall approximately 700 ft long that is used as a retaining wall for a parking lot. The exposed wall height was 17 ft and the overall wall height was approximately 28 ft. The steel sheet pile is PZ32. The original anchorage system was battered H-pile at 4 ft-6 in. centers. When a soil failure occurred at the toe of the wall, a misalignment developed with the bottom of the wall moving out with a displacement of 24 in. over 125 ft. Additional anchor rods were installed at 6 ft centers at a lower elevation to hold this section of wall. The experts were aware of this repair so that it may have affected their judgment on the condition index. The experts were not asked to judge the wall as if the repair had not been made. One hole was present and a general state of corrosion was judged to be about Level 2. The experts commented that settlement behind the misalignment might be a problem.

Wall E

100. Wall E is an anchored-type wall approximately 200 ft long used as a retaining wall. The exposed wall height was 11 ft and the overall wall height was approximately 21 ft. Anchor rods appeared to be 1.5 in. in diameter at 7 ft spacings. No other data could be obtained. The observed distresses included four instances of holes about 1 ft in diameter, one crack that was about 2 ft long and separated 1/2 in., and three small dents. A general state of corrosion was judged to be about Level 4. No particular comments were noted by the experts.

Wall F

101. Wall F is an anchored-type wall approximately 400 ft long used as a loading dock retaining wall. The exposed wall height was 8 ft and the overall wall height was approximately 21 ft. No other data were obtained. The observed distresses included one misalignment with a displacement of 18 in. at the top of the wall over 65 ft of wall, 14 instances of dents that were all in the small category (1 to 2 ft in diameter), and one instance of a crack that was about 2 ft long but not separated. A general state of corrosion was judged to be about Level 2. No other distresses were noted, although the experts noted they considered settlement behind the misalignment and interlock damage and cracks in conjunction with the dents.

Wall G

102. Wall G was in fact the same wall as Wall F above but the experts were asked to evaluate and rate the wall as if it were a lock guide wall at a lock site.

Thomas J. O'Brien Lock Wall

103. The lock walls of the O'Brien Lock and Dam facility on the Little Calumet River in South Chicago are cellular structures. The river wall of the lock chamber is 965 ft long and 23 ft wide, com-posed of diaphragm cells. The land side wall of the lock chamber is similar in construction, but the steel sheet pile is not normally exposed to view so no observation could be made.

104. The exposed sheet pile in the river wall appeared to be in reasonably good condition except for two observed distresses. There was a crack in one cell running from the top down about 5 ft. The concrete cap had settled as much as 4 in. near the center of the cells. Little if any settlement had occurred at the cell diaphragms, producing a slightly uneven surface on top of the wall. Corrosion was at a low level.

Thomas J. O'Brien Lower Guide Wall

105. The lower pool guide wall is an anchored-type wall 1000 ft long used as a retaining wall and for barge alignment with the lock. The exposed wall height was 7 ft and the overall wall height was 24 ft. The anchor rods were 2.5 in. in diameter at 6 ft spacing. The steel sheet pile is PZ27. The only observed distress was a general state of corrosion judged to be about Level 2.

Expert Rating

106. During the field test, each expert was asked to estimate the functional condition index for each of the individual distresses. The experts viewed each wall and observed several distresses summarized earlier in this section. The experts were also asked to assign a weight factor to each distress, considering wall location and function. Finally, an overall functional condition index for the wall was requested. The results from each expert for each wall are presented graphically in Greimann and Stecker (1987).

107. The averages of the experts' ratings for the individual distresses are also presented in Greimann and Stecker (1987). When these averages were compared to the functional condition indexes in a previous version of the rating system, several observations were apparent:

a. The previous version tended tc overrate the wall. This was corrected by introducing Equation 10 for the functional condition index.

b. No expert gave a condition index of 100. Apparently, the experts judged that no wall could be "perfect" if it had been in existence for several years, even though no particular distresses could be documented. No correction was made to the current rating model to reflect this observation.

c. No condition indexes of zero were recorded. Equation 10 reflects this change.

With these modifications to the previous version, the walls were reanalyzed using the current version and the resulting individual distress, functional condition indexes were compared to the expert averages.

108. With regard to the overall wall rating, one observation was very clear--if a wall had a major distress, the overall wall rating was greatly affected. That is, if a distress became severe, its importance was increased. For example, Wall C had a severe corrosion problem. The experts gave the wall a very low overall rating even though they gave corrosion only about a 25 percent weighting factor. This obser-vation was accounted for by introducing the weight adjustment factor described in Figure 16. The adjustment factor increases the importance of a distress as the distress becomes more severe. A comparison of the expert's average and the overall functional condition index from the current version is summarized in Figure 17.

109. The correct version of the rating system now shows an improved reflection of the experts' subjective rating. As one might expect, however, there is still variance between the current and the expert version (and, in fact, between individual experts). The results of any rating must be interpreted in this light (Greimann and Stecker 1987, Appendix E).

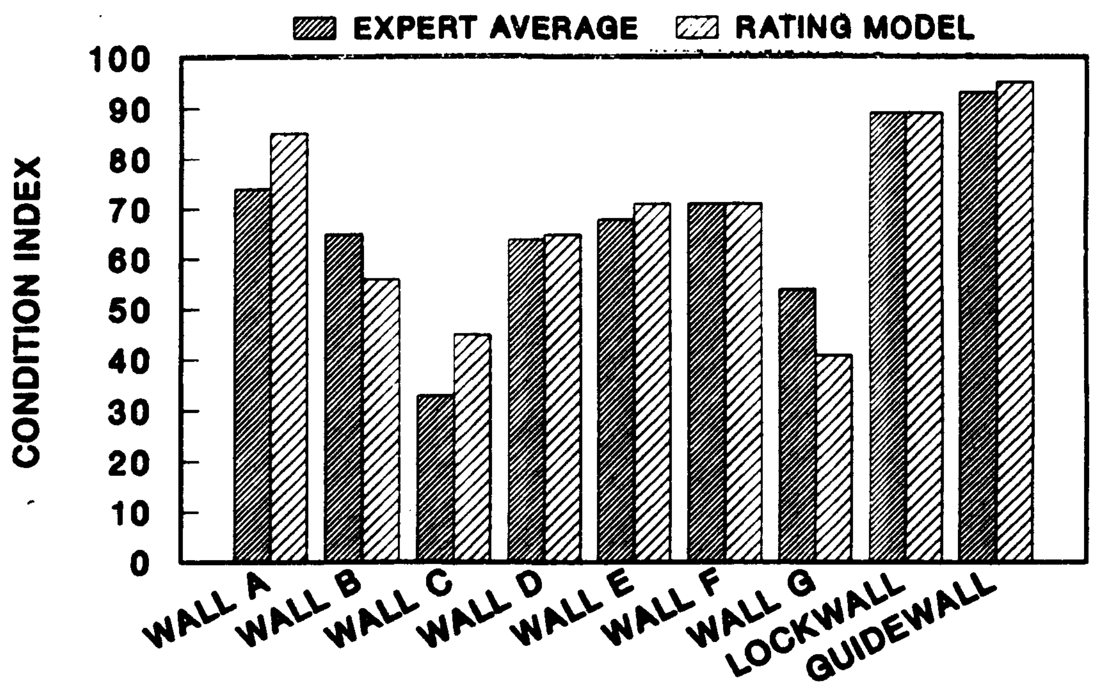

Figure 17. Comparison of functional index rating with experts' rating.

PART VI: MAINTENANCE AND REPAIR ANALYSIS

Problems List

110. The inspection and rating procedure is aimed at assessing the current condition of the structure. Through the safety and functional condition indexes, a number of distresses and safety problems may be identified for each structure. Each problem is quantifiable either by a field measurement or by a safety calculation. The software developed for this project will display a list of problems that were identified during the inspection. The number of occurrences and type of distresses (Table 4) are listed. If the safety calculation produces a factor of safety (see PART IV for various factors of safety) less than 2.0, a safety problem is also identified on the list.

111. Each problem detracts from the performance (safety and/or serviceability) of the structure. As discussed and listed in PARTS IV and V, each problem can have one or more causes. A problem or distress is usually a symptom of a cause. To repair the problem, it is often desireable to know the cause. Frequently, however, the level of inspection does not permit the precise determination of the cause of a problem. For example, misalignment (the problem) can have several causes as mentioned in PART V (sheet bending, anchor failure, toe failure). As another example, a low factor of safety for the soil on an anchored wall could be caused by weak soil at the toe, insufficient pile penetration, eroded dredge line, or high surcharge behind the wall. The software for this project does not diagnose the cause. Each problem is described and possible causes are listed. "Engineering judgment" is required to look at the information and assess the cause. In fact, as mentioned in PART III, an in-depth field inspection with excavation, diving, or ultrasonic inspections may be required to identify the cause.

Maintenance and Repair Alternatives List

112. For each problem identified above, there is a set of possible maintenance and repair alternatives. Hence, to fix the misalignment problem, sections of sheet pile could be replaced, the anchor system repaired, or the dredge line brought back to design levels and protected. Or, for the low soil factor of safety problem, longer pile could be driven, soil at the dredge line could be replaced, or the surcharge could be removed. As discussed in the previous section, the appropriate maintenance and repair alternative will often depend upon the cause of the problem. Using engineering judgement, the user can select preliminary alternatives. Several alternatives may be possible, ranging from inexpensive but short term fixes to complete replacement of the wall. Some alternatives can solve more than one problem. For

example, replacing a section of wall with longer pile can remove several distresses and solve a safety problem.

113. Each alternative is described by a note in the personal computer (PC) software. The list of alternatives and notes can be edited and updated by the user. The user assigns an estimated cost and an effective life to each alternative. Engineering judgement, past experience in the district, and the current market value of repair services enter into the cost and life estimate.

Maintenance and Repair Solutions

114. Up to five separate maintenance and repair solutions can be set up in the current software. Each solution consists of a set of maintenance and repair alternatives. Some of these alternatives can be selected from those mentioned in the previous section. Others not on the list can be added. Each solution can involve varying approaches to fixing the problems. One solution could be a do-nothing alternative with no initial costs but large, long-term user costs. Another solution may replace the entire wall, which fixes all the problems, but at a large initial cost. Other immediate solutions may include maintenance and repair alternatives that completely fix some problems or partially fix several problems.

115. As emphasized above, the engineer must use his or her judgment when developing each solution from the alternatives. The program does not isolate cause. Many alternatives can often be eliminated "by inspection." Again, it may be necessary to collect additional field or analytical data beyond that recorded on the inspection sheets.

116. The time period for the maintenance and repair solution is entered by the user. Some alternatives (e.g., painting) may need to be repeated at a regular frequency throughout the time period for the solution. Since the expected life and cost of each alternative have been determined by the user, the total initial cost and annualized costs can be computed for the solution, as will be described in the discussion of life cycle cost analysis.

Consequence Modeling

117. All of the maintenance and repair alternatives have consequences that affect the condition of the structure. Consequence modeling is the part within the maintenance and repair analysis in which the effect of the various solutions on the safety and functional condition indexes are evaluated and a life cycle cost analysis performed. The software user is asked to assess the effect of the solution on the distresses and the safety attributes recorded during the inspection. Hence, pages 4, 5, and 6 of the inspection sheet are displayed on the PC monitor one portion at a time. The user is asked to modify the entries to reflect the solution that is being evaluated. For

example, if a sheet pile section is being replaced, the user would eliminate the associated crack or hole or dent from the distress profile. Similarly, if safety features such as dredge line or surcharge are altered, the corresponding entries are modified. The user can request a printout of these modifications as a more detailed explanation of the solution.

118. After the changes have been entered, new safety and functional condition indexes are calculated to quantify the consequences.

Life Cycle Cost Analysis

119. A preliminary cost analysis can be performed by the program. The current cost and life of each maintenance and repair alternative, the length of analysis period, and the beginning year of the analysis period have been entered in the solution phase of the analysis process. When a life cycle cost analysis is requested, the user is asked to furnish the interest rate and inflation rate for the analysis period. Length of downtime and out-of-service costs are also requested. With this information the program calculates

$$\text{First Cost} = C_{RM} + C_D \tag{15}$$

and

$$\text{Annual Cost} = (CTRM + CTD)/AP$$

where:

- C_{RM} = initial cost of solution (sum of current cost of individual maintenance and repair alternatives adjusted to year of implementation by inflation rate)
- C_{TRM} = total cost of solution (sum of initial cost of individual maintenance and repair alternatives incremented by interest rate for the length of the analysis period)
- C_D = initial downtime costs (number of days times rate per day)
- C_{TD} = initial downtime costs incremented by the interest rate for the length of the analysis period
- AP = length of the analysis period in years

Final Solution

120. A printed record of all the information developed in the inspection and rating process and the maintenance and repair analysis are available to the user. Using the consequence modeling results (revised condition indexes), the preliminary cost analysis, and individual judgment, the engineer can make a preliminary selection of a maintenance plan for the sheet pile structure. The program and process that have been developed and presented here are useful tools to help an engineer perform an inspection, record the

data from an inspection, evaluate the condition of a structure from the inspection data, and perform a preliminary analysis of various maintenance and repair solutions. However, there are some limitations to the analysis. At this time, one would be naive to use only the results of this analysis (ratings and costs) as a basis for a final decision. One purpose of this report is to publish this analysis process for the Corps community. Exposure to the analysis system is intended to build confidence in its usage and results. This work should be viewed as a step in the process of evolving a more complete maintenance and repair program for steel sheet pile structures.

PART VII: SUMMARY AND RECOMMENDATIONS

Summary

121. As a part of the U.S. Army Corps of Engineers REMR program, the project team at Iowa State University has developed an inspection and rating procedure and a maintenance and repair analysis for steel sheet pile structures. Anchored, cantilevered, and cellular structures of steel sheet pile serve as lock walls, dams, guide walls, protection structures, and mooring structures.

122. The inspection and rating procedure has intentionally been kept as simple as possible. The inspection requires only simple hand tools such as a tape measure, level, weighted rope, and string. An inspection sheet has been developed for recording historical information (location, previous inspections, or repair history, etc.), structural information (wall type, cross section, pile lengths, water depths, dredge line depth, surcharge loadings, etc.) and distress documentation (misalignment, corrosion, settlement, interlock separation, etc.). PC software has been written to record the inspection information on disks. Software will be available from U.S. Army Engineer Waterways Experiment Station's Engineering Computer Program Library (ECPL). Address requests to: Commander and Director, U.S. Army Engineer Waterways Experiment Station, ATTN: CEWES-IM-DS, 3909 Halls Ferry Road, Vicksburg, MS 39180-6199 or call (601) 634-2581.

123. A condition index is computed directly from the inspection records. The condition index is a number scale from zero 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. Condition indexes below 40 indicate that immediate repair is required or, possibly, that a more detailed inspection and reanalysis are required.

124. Two separate condition indexes make up the condition index. The structural condition index is a reasonably objective measure of the structural safety. It is related directly to the factor of safety, which is automatically calculated by the PC software. A functional condition index, based on the opinion of several experts from the Corps of Engineers, is also calculated. It involves at least two considerations: (1) serviceability, or how the structure performs its function on a day-to-day basis and (2) subjective safety, or how, in the judgment of expert engineers, the safety of the structure has been degraded by various distresses.

125. The inspection and rating procedure has been applied in two field tests (July 1986 and July 1987). The results of these tests have been incorporated into the current version of the procedure.

126. A maintenance and repair analysis phase of the program allows the user to make a preliminary assessment of various alternatives for fixing the

structure. A list of problems in the structure is collected from the inspection data. A list of maintenance and repair alternatives within the program can be updated and expanded. The user develops up to five maintenance and repair solutions, each of which consists of a set of maintenance and repair alternatives that solve the associated problems. Initial cost and expected life of each solution are entered. The consequences of each solution are quantified by reevaluating the condition index of the structure. Life cycle costs of each solution are evaluated after the rates of interest and inflation and downtime costs are furnished.

Recommendations

127. The current inspection and rating procedure for steel sheet pile structures has had sufficient development and testing to warrant its distribution on a wider basis. However, it should still be considered in a state of development. Many of the concepts introduced, such as structural condition index, functional condition index, X_{max} values, and weighting factors, should be exposed to a broader range of engineers who work in the area. Modifications to the procedure are certainly expected and welcomed.

128. The maintenance and repair analysis presented here represents a significant tool to be used by experienced engineers to help them arrive at maintenance and repair decisions. It, too, is ready for an initial distribution and evaluation by the Corps community. It should be considered as a preliminary version; a step in an evolutionary process. As with all engineering analyses, numerical results should not be interpreted too literally, but considered in the light of "engineering judgement."

REFERENCES

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3. Lee, D.H., 1961. Deep Foundation and Sheet Piling, London: Concrete Series.
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5. US Army Corps of Engineers, 1958. Design of Pile Structures and Foundations, U.S. Army Corps of Engineers, Washington, DC.
6. US Steel Corporation, 1975. U.S. Steel Sheet Piling Design Manual.
7. Winterkorn, H. F., and Fang, H.-Y., 1975. Foundation Engineering Handbook, Van Nostrand-Reinhold.

Table 1

Condition Index Scale

Value	Condition Description
85-100	Excellent--No noticeable defects, some aging or wear visible
70-84	Very Good--Only minor deterioration or defects evident
55-69	Good--Some deterioration or defects evident, function not impaired
40-54	Fair--Moderate deterioration, function not seriously impaired
25-39	Poor--Serious deterioration in at least some portions of structure, function seriously impaired
10-24	Very Poor--Extensive deterioration, barely functional
0-9	Failed--General failure or failure of a major component, no longer functional

Table 2

Condition Index Zones

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

Table 3

Assumed Properties of Soil

Short-term Soil Properties	Unit Weight (PCF)	Friction Angle (ϕ)	Wall Friction (δ)	Cohesion (C) (PSF)
1. Sand	90	30	10	0
2. Gravel	110	35	11	0
3. Rock	90	45	15	0
4. Soft clay	95	5	0	400
5. Medium clay	105	10	3	800
6. Stiff clay	115	15	5	1500
7. Unknown	95	5	0	400

Table 4

Distresses in Steel Sheet Pile Structures

Distress Code	Distress	Brief Description
1	Misalignment	Horizontal or vertical deviation from the design alignment
2	Corrosion	Loss of steel due to interaction with environment
3	Settlement	Vertical movement of material behind sheet pile
4	Cavity formation	Loss of fill material behind or within sheet pile
5	Interlock separation	Failure of sheet interlocks
6	Holes	Broad opening in sheet
7	Dents	Depression in sheet without rupture
8	Cracks	Narrow break in sheet

Table 5

X_{max} Values for Misalignment

WALLS Length of Misalignment (ft)	Lock Chamber (in.)	Lock Guide Wall (in.)	Transition Wall or Retaining Wall or Guard Walls	
			Near Lock (in.)	Remote (in.)
0 to 20	6	Formula below	12	18
20 to 100	6	"	18	24
100 to 500	6	"	24	32
> 500	6	"	24	40

Formula for Lock Guide Wall:

$$Xmax = 6 + 6 \frac{\text{distance from lock}}{\text{length of lock chamber}} \text{ in.}$$

SINGLE CELLS Ratio of Cell Diam./Height* Protection Cell	Misalignment (in./2 ft of height)			
	Upper Pool		Lower Pool	
	Protection Cell	Mooring Cell	Protection Cell	Mooring Cell
>0.75	4	2	2	1
<0.75 & >0.50	3	1.5	1.5	1
<0.50	2	1	1	0.67

*Height is distance from top of cell to dredge.

Table 6

Levels of Corrosion

Level	Description
0	New condition
1	Minor surface scale or widely scattered small pits
2	Considerable surface scale or moderate pitting
3	Severe pitting in dense pattern, thickness reduction in local areas
4	Obvious uniform thickness reduction (X_{max} value)
5	Holes due to thickness reduction and general thickness reduction

Table 7

Maximum Limits for Settlement

WALLS (anchored, cantilevered, and cellular)

Length of Settlement & Surface Cond.	At Lock Chamber (in.)	Near Lock (in.)	Remote (>1000 ft) (in.)
Supporting a structure	4	6	6
<20 ft & hard surfaced	4	12	18
>20 ft & hard surfaced	4	18	24
<20 ft & no surfacing	4	24	36
>20 ft & no surfacing	4	36	48

BACKFILL WITHIN SINGLE CELLS

Rule 1: For uniform settlement (from top of structure or design level)

X_{max} = 1/2 in. allowable increment per 1 ft of cell height

Rule 2: For differential settlement (slopes across top surface or the cap if tilted from level)

X_{max} = 3 in. slope per 10 ft diameter

Table 8

Maximum Volume Limits for Cavities

Above Grade Surfacing Condition	Walls (ft3)	Cells (ft3)
No surfacing	27	16
Surfacing	8	8
Supported structure	3.5	3.5

Table 9

Unadjusted Weighting Factors for Distresses

Distress Code	Distress	w_i	W_i (%)
1	Misalignment	8	24
2	Corrosion	5	15
3	Settlement	4	12
4	Cavities	4	12
5	Interlock separation	4	12
6	Holes	3	8
7	Dents	2	6
8	Cracks	4	11
		34	100

APPENDIX A: BASIC DATA

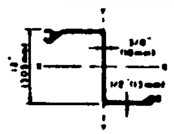
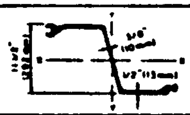
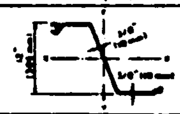
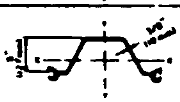
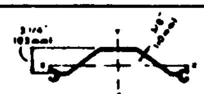
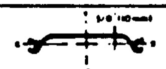
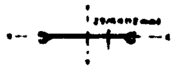
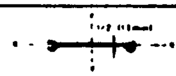
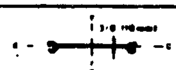
1. The following information describes the steel sheet pile profiles that are supported by the safety analysis program. The user can add steel sheet pile profiles to the program by editing the file **section.des** in the directory **SSPMGT**. The user must include the profile designation, section modulus (per foot of wall), and interlock tensile strength. For example, PZ38 is included in the file like this:

```
PZ38        46.8        12000.
```

If the inspection personnel are unable to include the section designation on the inspection sheet (pages 3A, 3B, or 3C), then they select the section designation from the following data that most correctly match the dimensions recorded on the inspection sheet.

Table 2
Standard Sheet Piling
A General Description

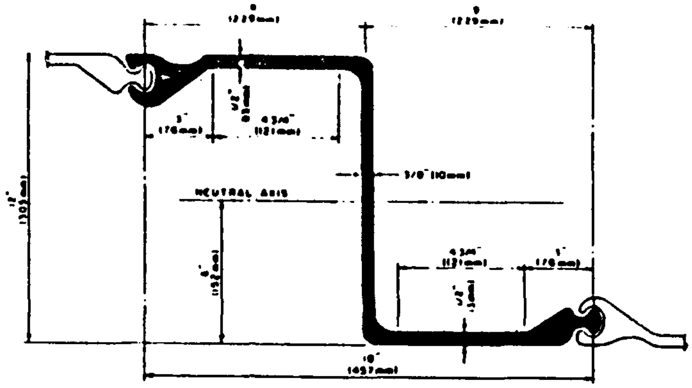
American Engineering Units

DESIGNATION	PROFILE	INTERLOCK	WEIGHT PER LINEAR FT (LB)	WEIGHT PER SQ FT OF WALL (LB)	AREA A (INCH²)	DRIVING WIDTH (INCH)	SECTION MODULUS PER FT WALL (INCH³)	SECTION MODULUS PER PILE (INCH³)
PZ38		INTERLOCK WITH EACH OTHER AND PSA 23, PSA 28	57.0	38.0	16.8	18	46.8	70.2
PZ32			56.0	32.0	16.5	21	38.3	67.0
PZ27		INTERLOCKS WITH ITSELF AND PSA 23, PSA 28	40.5	27.0	11.9	18	30.2	45.3
PDA27		INTERLOCK WITH EACH OTHER	36.0	27.0	10.6	16	10.7	14.3
PMA22			36.0	22.0	10.6	19⅝	5.4	8.8
PSA28			37.3	28.0	11.0	16	2.5	3.3
PSA23			30.7	23.0	9.0	16	2.4	3.2
PSX32		INTERLOCK WITH EACH OTHER	44.0	32.0	13.0	16½	2.4	3.3
PS32			40.0	32.0	11.8	15	1.9	2.4
PS28			35.0	28.0	10.3	15	1.9	2.4

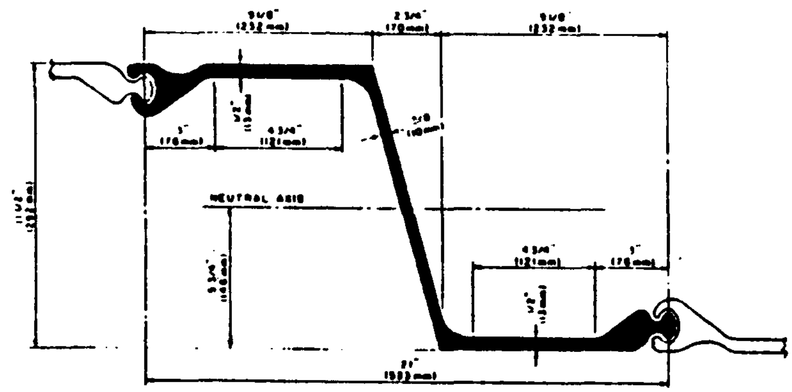
6

Details and Properties

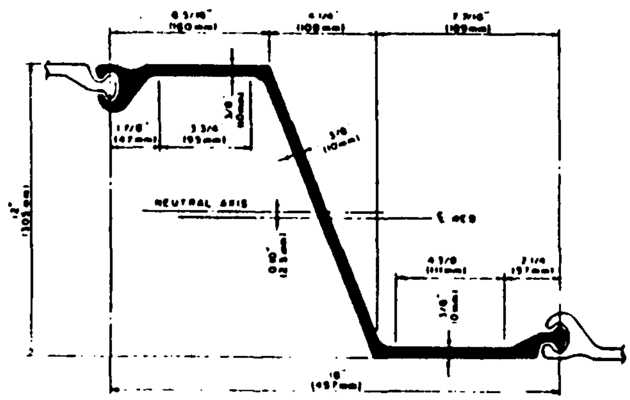
PZ38



PZ32

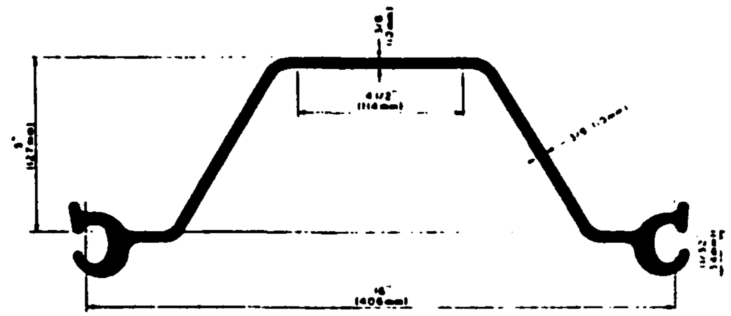


PZ27

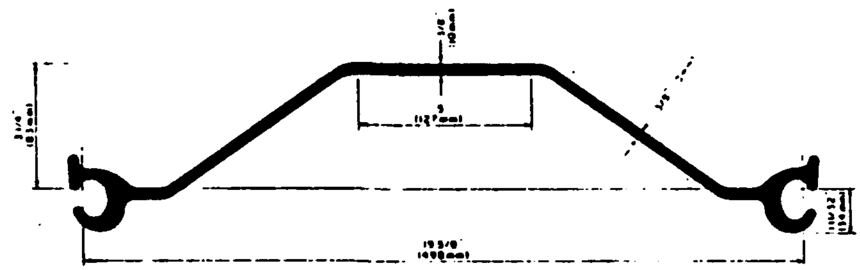


Details and Properties

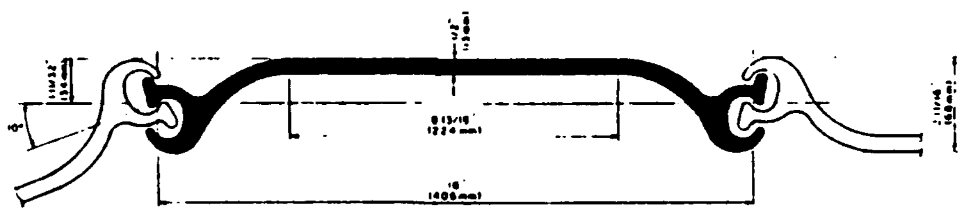
PDA27



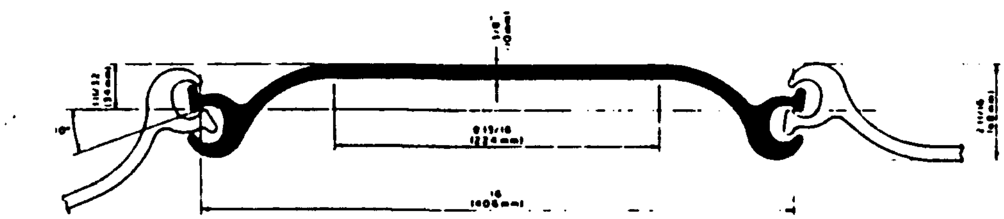
PMA22



PSA28

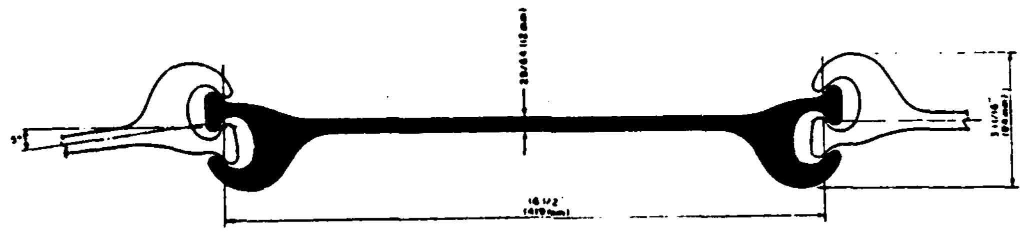


PSA23

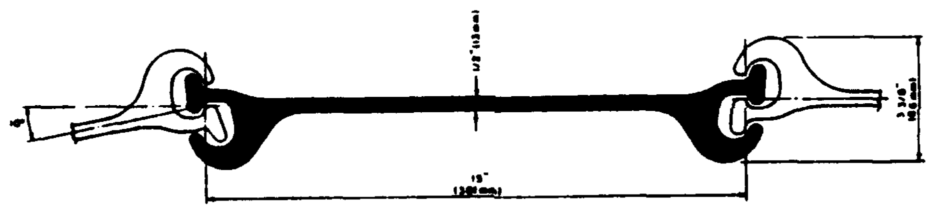


Details and Properties

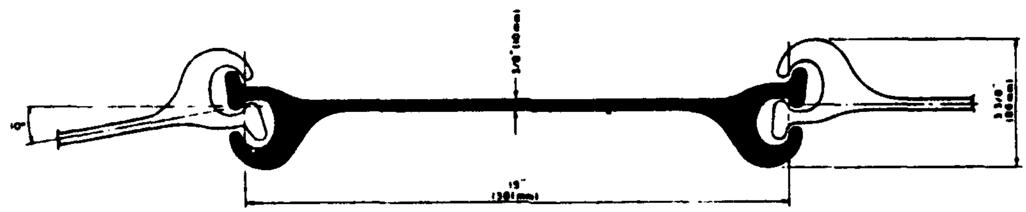
PSX32



PS32



PS28



APPENDIX B: USERS' GUIDE

Overview

1. An overview of the inspection and rating process and the maintenance and repair analysis is presented in Chapter 1. The software that performs many of the operations in the analysis is entitled SSP (Steel Sheet Pile). Once the program has been installed on a personal computer, it is menu-driven. All operations including file management, operation selection, and summary report writing are controlled by menu selection. This appendix will show the user how to use most menus and what to expect from certain selections. Because of the many combinations and permutations of paths through the menus, not all possi-bilities can be illustrated. Figure B1 illustrates the three primary menus and the general procedure for the use of the program. The steps that are listed in Figure B1 correspond with those in Figure 1. Each of the steps is described in more detail in the succeeding section.

Notation Conventions

2. The following notational conventions are used throughout this guide:

- a. **BOLD CAPITAL LETTERS** - File names, directory names, and DOS commands are printed in bold capital letters.
- b. **Bold face letters** - Plain, bold face letters are used to emphasize user selection options.
- c. Underline - Underlining is used to identify menu names and window names.

Software will be available from U.S. Army Engineer Waterways Experiment Station's Engineering Computer Program Library (ECPL). Address requests to: Commander and Director, U.S. Army Engineer Waterways Experiment Station, ATTN: CEWES-IM-DS, 3909 Halls Ferry Road, Vicksburg, MS 39180-6199 or call (601) 634-2581.

Installation of SSP

Hardware Requirements

3. The following computer hardware is required as a minimum:

- a. An IBM-PC compatible personal computer.
- b. At least 640 kilobytes (Kb) of memory (RAM).
- c. A hard disk.

The amount of disk space that should be reserved on the hard disk depends on the number of projects that will be recorded on the personal computer system. The executable program requires approximately 700 Kb of disk space. Each project structure (e.g., a steel sheet pile upper guide wall or a single protection cell) will require 10 Kb of disk space. A typical civilian project location may have two or three walls and also three or four single cells associated with the project. A project could be five to ten structures, each requiring 10 Kb of disk space or 50 to 100 Kb per project. Therefore, ten projects could require 500 to 1000 Kb of disk space. Initially, it is recommended that a minimum of one megabyte (Mb) be reserved, which will accommodate the program and three to six projects of approximately 30 project structures.

Customizing MS-DOS for SSP

4. To run SSP on the system, some of the MS-DOS operating system defaults must be extended. In general, this modification will improve performance of the other programs on the system as well. The changes to the operating system defaults are made by modifying the **CONFIG.SYS** file in the root directory of the system. Include the following statements to the **CONFIG.SYS** file:

```
FILES=20
BUFFERS=20
DEVICE=path\ANSI.SYS
BREAK=ON
```

where path = file path to **ANSI.SYS**. If the **CONFIG.SYS** is not already on the root directory of the system, one can be created using any text editor that produces a standard DOS text file (ASCII file). For example, **EDLINE**, which comes with the DOS, can be used to create the file. Be sure to place the **CONFIG.SYS** in the root directory of the C:drive.

Installing SSP on the Computer System

5. The program SSP is distributed on three 5 1/4 in. 360K floppy disks. The installation utility program will automatically install the SSP program and support files on the C:drive of the computer. The utility program **INSTALL.BAT** starts on Disk A of the diskette set and continues on each of the Disks B and C. **INSTALL.BAT** executes the following DOS commands to create a directory called **SSPMGT** on the root directory and several additional subdirectories to install SSP:

See that the computer is on and the DOS prompt is displayed

Place the SSP program distribution Disk A in Drive A:

Type **A:INSTALL.BAT** and press **ENTER**. The following commands are executed automatically

Command	Function
C:	go to C: drive
MD SSPMGT	create directory called **SSPMGT**
CD SSPMGT	change directory to **SSPMGT**

MD DATA	create directory called **DATA**
MD TEMP	create directory called **TEMP**
MD SAMPLE	create directory called **SAMPLE**
CD SAMPLE	change directory to **SAMPLE**
MD WALL	create directory called **WALL**
MD CELL	create directory called **CELL**
CD C:\SSPMGT	change directory to **SSPMGT**
COPY A:SSP.EXE	copy **SSP.EXE** to **SSPMGT** directory

Insert Disk B in Drive A: and type **A:INSTALL** and press **ENTER**.

Program and sample data files are copied to **SSPMGT** and **SAMPLE**.

Insert Disk C in Drive A: and type **A:INSTALL** and press **ENTER**

Program and data files are copied to **SSPMGT** and **DATA**.

If you wish to install **SSP** on a drive other than C:, or use another name for the SSP directory, you must either modify **INSTALL.BAT** or install **SSP** manually. In this guide, we will assume that you have used the unmodified **INSTALL.BAT** to install **SSP** and use **SSPMGT** to refer to the **SSP** directory.

Organization of Project Files

6. The **SSP** program and all related project data files are normally installed one level down from the root directory on the C:drive of the computer system in a directory called **SSPMGT**. All executable program files and program support files are at this directory level.

7. The **SSP** program has been designed to operate at the project level. The organization of projects and **SSP** structure inspection data files utilize the DOS hierarchy structure of subdirectories. Project files are identified and organized into separate subdirectories in the directory **SSPMGT**. For example, the project Lagrange Lock & Dam located at Beardstown, Illinois on the Illinois River Waterway system has several steel sheet pile structures, one being the upper guide wall. The project inspection data files for the Lagrange Lock upper guide wall would be organized in the following manner:

```
Root directory
|
|---- SSPMGT                          program directory
      |
      |---- LAGRANGE LOCK             project subdirectory
      |     |
      |     |---- UG_WALL             SSP structure subdirectory
      |     |     |
      |     |     |---- files         structure data files
      |     |
      |     |---- another SSP structure
      |
      |---- another project
```

This organization of project inspection data files allows the user multiple **SSP** structures under a particular project name. This organization of project inspection data clearly maintains the integrity and transportability of individual project files. The user can readily copy the inspection data from the hard disk system to archive data files or to transport to another system.

8. There are other subdirectories under **SSPMGT** that are not project files but are required to support the maintenance and repair analysis module of SSP.

They are called DATA and TEMP and support all the project files, not a specific project file. If a user transports individual inspection data files to another system, the maintenance and repair modeling solutions can only be transorted by paper copy and then reentered on the new system. However, if a user is making a system change and all the projects are being transported, routine DOS file handling techniques will transport the data as a directory block.

9. It is possible for the user to organize the data at a higher system level, such as a waterway system. This can be done by renaming the program directory level to a waterway system acronym, for example, **ILLRVR** for Illinois River waterway. The program does not readily support this system level of project organization, but the user can accomplish it by installing the SSP program in each waterway system directory. Each time the SSP program is installed, it does require approximately 700 Kb of disk space.

Project Identification

10. Utilizing the DOS subdirectory hierarchy places a restriction on the freedom of naming project structures. Each project name or structure name is limited to eight characters and also to DOS conventions. If you are unfamiliar with DOS conventions and encounter difficulty, refer to the DOS system manual for guidance.

11. In the example project used in the manual, the project name used was **LAGRANGE** and the structure name was **UG_WALL**, short for upper guidewall. Another example might be a structure name such as **UPCELL3** for an upper pool protection cell number 3.

General Procedure Starting and Using SSP

12. Figure B1 illustrates the three primary menus that:

a. control the flow of the program.

b. input data from the inspection form.

c. calculate the condition index.

d. evaluate maintenance and repair options.

Figure B2 follows Figure B1 and is a flow diagram through the three primary menus as well as several additional submenus.

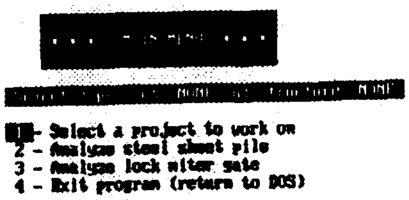
Getting Started

13. At the system prompt, change the directory to **SSPMGT**:

Type **SSP** and press **ENTER**

The screen will display the Main Menu (see Figure B3).

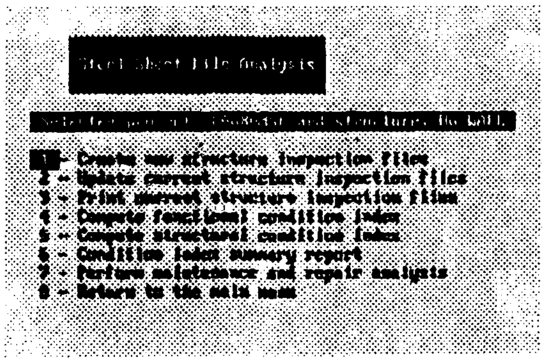
Primary Menu Structure of SSP and Procedure Guide



1. Select project
   e.g., **Lagrange upper guide wall**

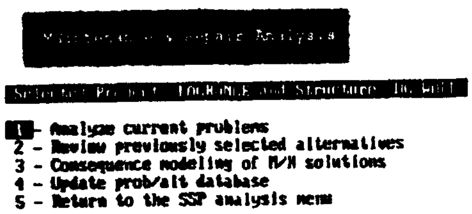
2. Select operation to perform
   e.g., **2-Analyze steel sheet pile**

3. Input data from inspection form
   Use **1-Create** for a new inspection or **2-Update** if updating a previous inspection record. As required, the user edits the input for errors.



4. Compute condition indexes
   4-Compute functional condition index 5-Compute structural condition index

5. Review condition index summary
   6-Condition index summary report
   The user must diagnose the problems that have been identified and understand why the condition indexes are as reported.



6. Review maintenance & repair (M&R) options 7-Perform maintenance & repair analysis
   a. Develop M&R solutions
      1. Analyze current problems, or
      2. Review previously selected alt.
   b. Analyze and model M&R solutions **3-Consequence modeling of M&R solutions**
   c. Review results of analysis and modeling to recommend maintenance or repair management

Figure B1. Primary menus for SSP and procedure guide

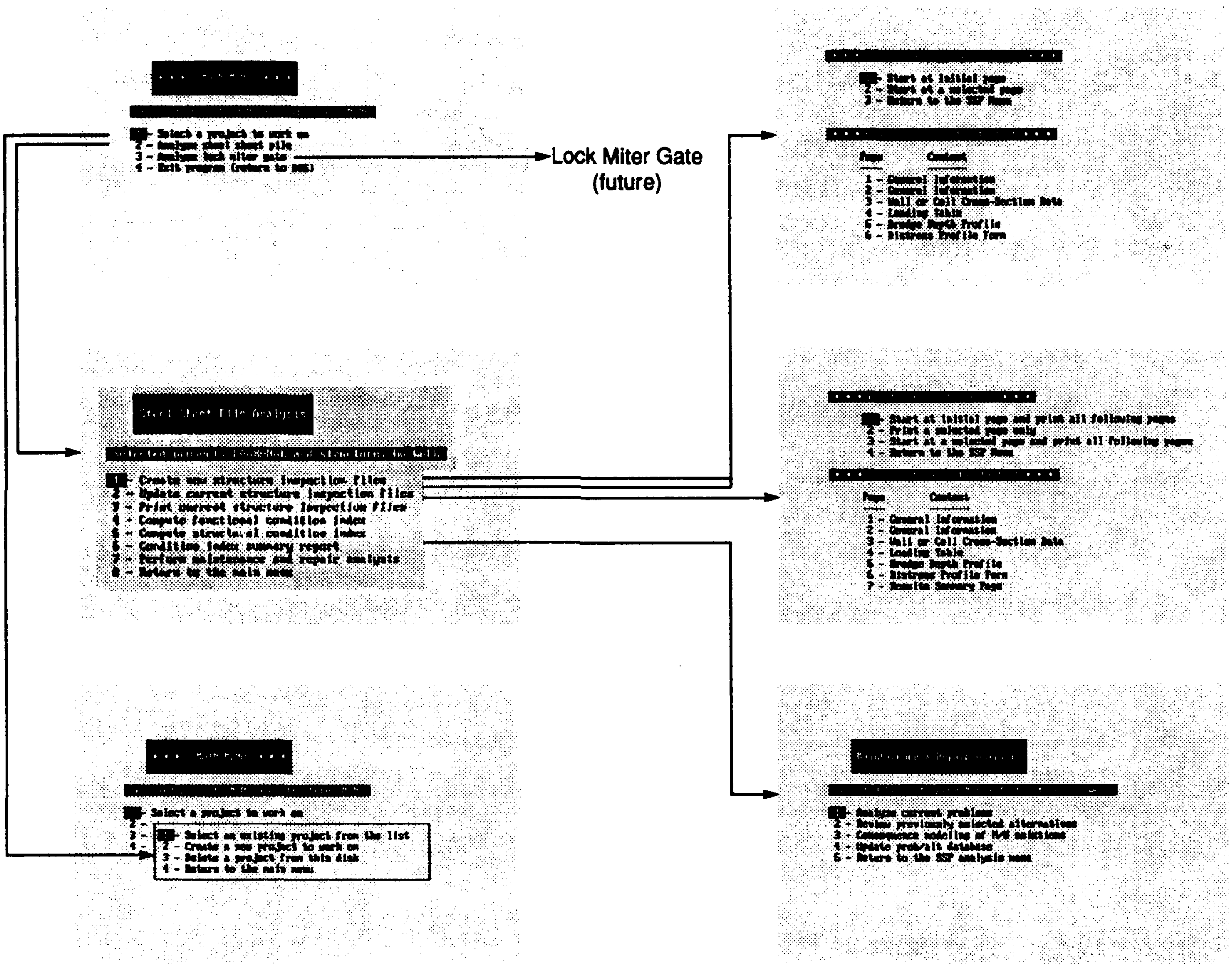


Figure B2. <u>Organization of SSP menus</u>

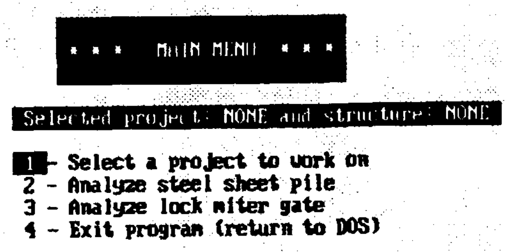


Figure B3. <u>Main Menu</u>.

14. The user selects **1-Select a project to work on** and proceeds to the next selection menu, Figure B4. Figure B4 illustrates the file maintenance menu that keeps the project data structure. Three file processing choices manage the project list contained in the file **PROJECTS.DAT**. The file **PROJECTS.DAT** must be present in the directory **SSPMGT**.

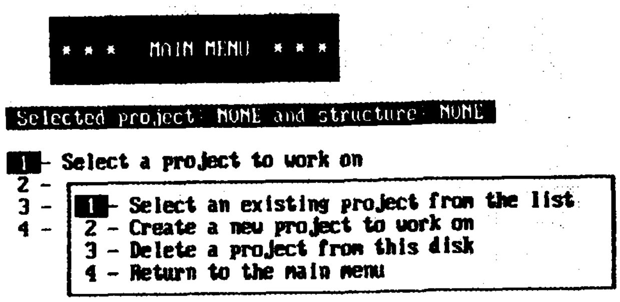


Figure B4. <u>File maintenance menu</u>

1 - Select an existing project from the list allows the user to select a project and structure from the list that appears in the Projects on this data disk window. (See Figure B5 for an example.)

2 - Create a new project to work on sets up a new directory and subdirectory for a new projects data file and adds the name to the project list. NOTE: This procedure must be used to create directories or the project name will not appear on the project list and cannot be accessed by SSP. (See Figure B6 for an example.)

3 - Delete a project from this disk displays the project list window for the user to select the project. The user will be prompted to confirm the removal of the selected project. NOTE: This procedure must be used to delete a project or the name will not be deleted from the project list.

15. Following selection of a project, the user will return to Main Menu (Figure B3).

and select **2 - Analyze steel sheet pile**

NOTE: The third selection **3 - Analyze lock miter gates** is not functional in this distribution.

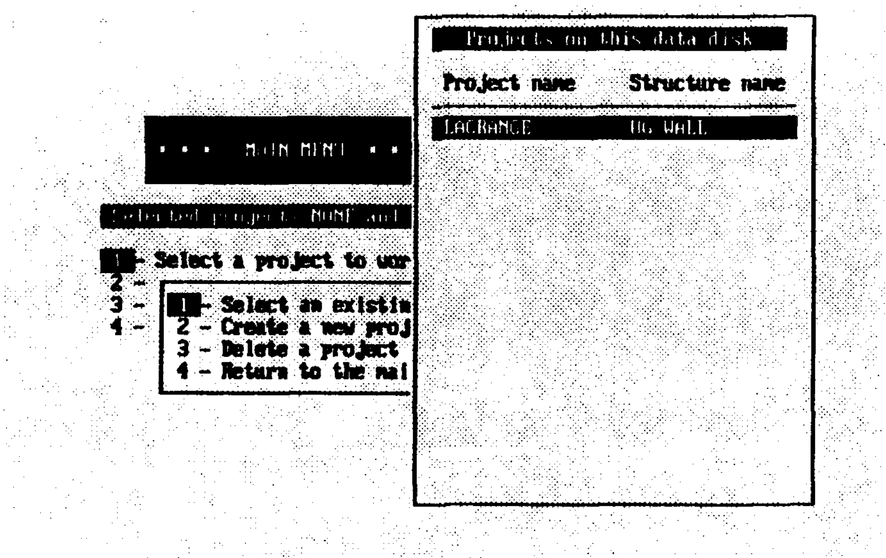


Figure B5. Projects on this data disk

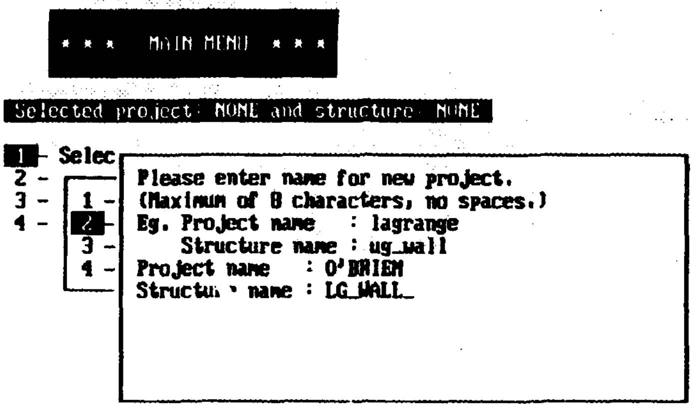


Figure B6. Create new project files

16. The Steel Sheet Pile Analysis (Figure B7) menu provides the functions to input, store, and print data; to compute condition indexes; and to go to the maintenance and repair menu.

1 - Create new structure inspection files is the data input function for the user to transfer inspection data into the computer.

2 - Update current structure inspection files is the data editing function to change or add to inspection data.

3 - Print current structure inspection files is the print function to produce documentation and reports, including condition indexes, if they have been calcuted.

4 - Compute functional condition index performs calculations.

5 - Compute structural condition index performs calculations.

6 - Condition index summary report is a screen display of basic project identification and the computed condition index.

7 - Perform maintenance and repair analysis is a module to assist in the development of maintenance and repair solutions.

8 - Return to the main menu returns to the previous menu.

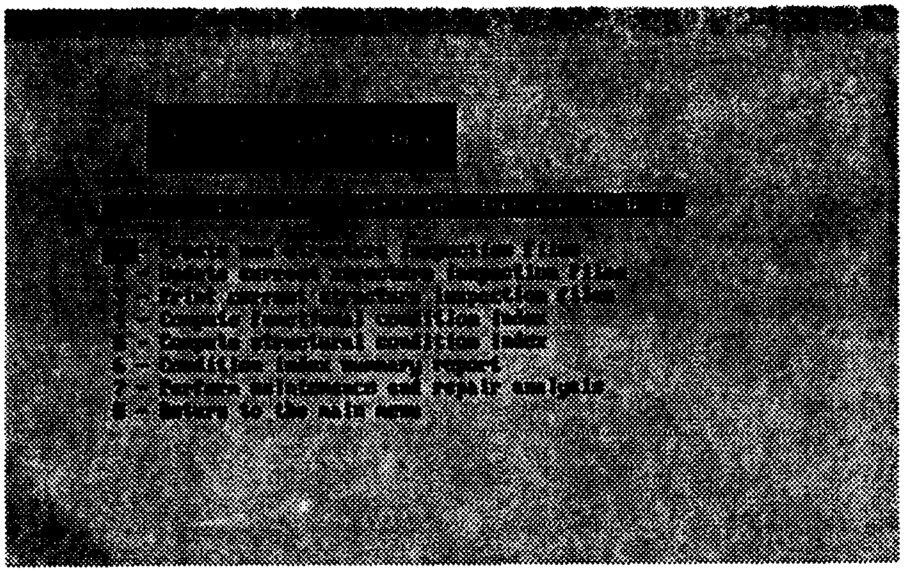


Figure B7. <u>Steel Sheet Pile Analysis</u> menu

<u>Inspection Sheet Input</u>

17. Selecting **1 - Create new structure inspection files** is the data input function that creates data files under the selected SSP structure subdirectory. The subdirectory is the storage space for the inspection data.

18. Three rules apply to the input of data and must be adhered to.

Rule 1: The user must create each page of data with this selection. The user may stop after page 3 to edit page 1, but create must be used to start entering data at page 4.

Rule 2: Pages 1, 3, and 6 must exist before the program will allow the user to calculate the subjective condition index. Page 6 has to be created even when there are no distresses noted on the distress profile form, so that the program can calculate a condition index.

Rule 3: Pages 1, 3, 4, and 5 must exist before the program can calculate the safety condition index. Page 4 has to be created even when there is no load, in which case enter a zero (0) in the first record. Page 5 has to be created and should have at least one station location and depth recorded.

19. Selecting **2 - Update current structure inspection files** is the data editing function to change or add to recorded inspection data. A submenu for **Update** is very similar to Figure B8.

20. The following section has specific details about entering and editing data to the SSP structure data files.

```
* * * Create new SSP input File(s) * * *

1 - Start at initial page
2 - Start at a selected page
3 - Return to the SSP Menu

* * * Choice of pages to start at * * *

Page        Content
----        -------
1 - General Information
2 - General Information
3 - Wall or Cell Cross-Section Data
4 - Loading Table
5 - Dredge Depth Profile
6 - Distress Profile Form
```

Figure B8. Create SSP data files

Data Entry

21. The SSP program is fully menu-driven and guides the user through the pages of forms in a straightforward manner. SSP does perform an error check on certain data fields that must have restricted input of a particular character or number. The error checks are:

a. Only allowable characters are accepted; illegal characters are rejected with a "beep."

b. A valid range check is performed on some numeric data at the completion of the entry. If the number entered is out of range, SSP will "beep" and prompt you to enter the data again. Valid data must be entered in order to move on to the next data item.

The majority of the data entries are not restricted.

Editing data

22. After the data is entered, the user will find it necessary to edit the data. Some of the typical word processor routines work well but a review of those working in this program is helpful.

a. Changing data entry mode--SSP supports two different modes for data entry: the "Insert" and "Overwrite" modes. In the "Insert" mode, the characters that you type are inserted at the current cursor location, whereas, in the "Overwrite" mode, the character at the cursor is replaced with your entry. Press **INSERT** key to toggle between the "Insert" and "Overwrite" modes. The cursor symbol for the "Insert" mode is a small flashing square, whereas the cursor for "Overwrite" mode is a flashing underscore character. The default mode is the "Overwrite" mode.

b. Cursor Control--Several commands are available for moving within the data entry line for editing:

(1) Use the **RIGHT** or **LEFT** arrow keys to move right or left by one
(2) Use the **CTRL-RIGHT ARROW** or **CTRL-LEFT ARROW** keys to move a word right or left
(3) Press **HOME** key to go to the beginning of the line
(4) Press **END** key to go to the end of the line

c. Delete--Press **DEL** key to delete a character at the cursor position and **BACKSPACE** key to delete a character to the left of the cursor position.

NOTE: The data on Page 6--Distress Profile Form is particularly sensitive to the techniques used in editing. To delete a distress line of data, press **HOME**, enter "Z" in the first character space, and press **ENTER**.

23. Selecting **3 - Print current structure inspection files** will display the submenu in Figure B9.

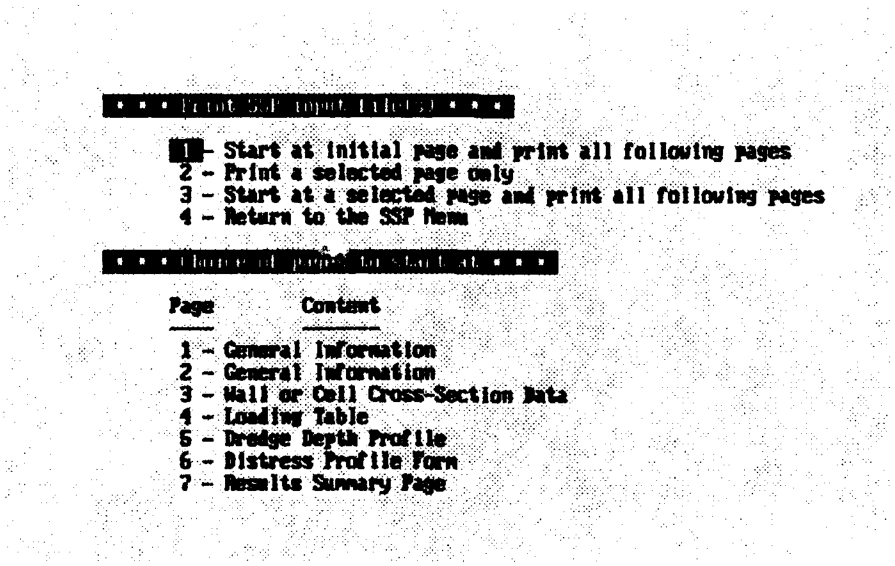


Figure B9. Print SSP data files

Condition Index Calculation

24. Selecting **4 - Compute functional condition index** performs the calculation of observed distress measurements versus the "expert rules" embedded in SSP.

25. The functional condition index window, Figure B10, lists the observed distresses, their distress coefficient, and the calculated subjective condition index. These data are also summarized in the condition index summary report. The number of occurrences is later read into the maintenance and repair module **Problem List**, Figure B15. Please refer to PART V for details about the functional condition index.

26. Selecting **5 - Compute structural condition index** performs the calculation of the minimum factors of safety. The computed factors of safety and the station location of the most critical sections are displayed in the Safety Factors window displayed in Figure B11. Refer to Part IV for details about the structural condition index. Refer to Appendix A if the program is unable to calculate the structural condition index because the sheet pile shape is not supported.

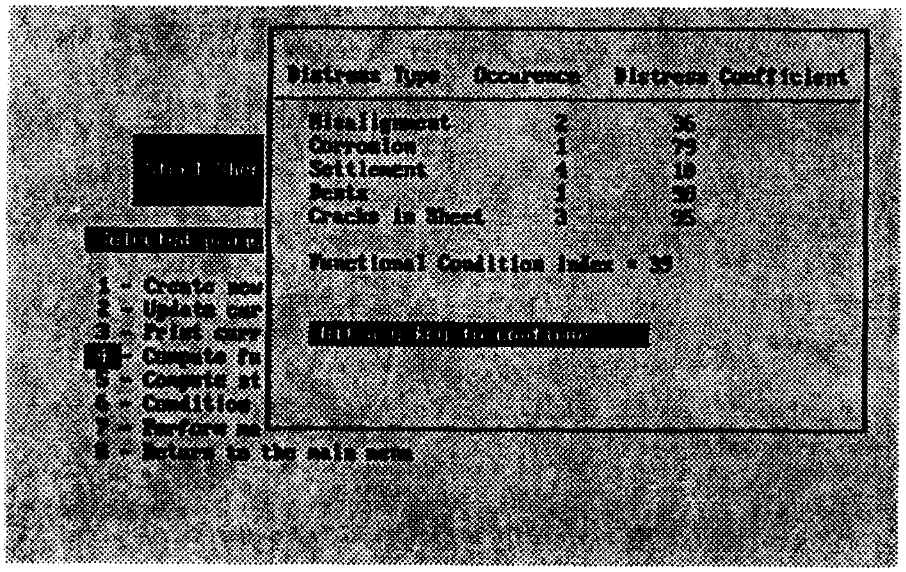


Figure 10. Calculation of functional condtion index

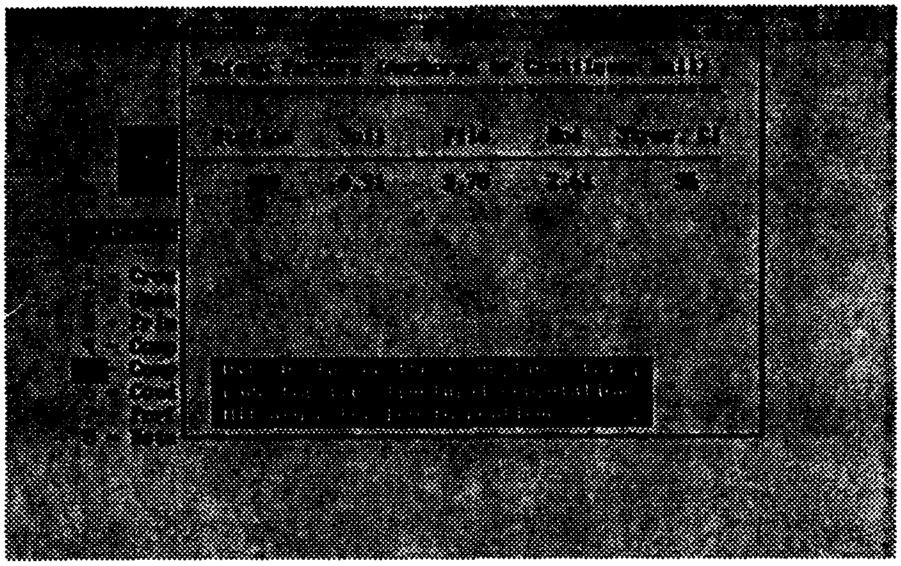


Figure B11. Safety Factors

27. Selecting **6--Condition index summary report** will provide the user with a screen display of basic project identification and a summary of the condition indexes. This selection is a quick way to see more data about the project without performing three separate operations. The summary report is reproduced in its entirety as print choice, Page 7--Results Summary.

28. Selection **7--Perform maintenance and repair analysis** is discussed in detail in the next section.

29. Selection **8--Return to the main menu** returns the user to the beginning of the SSP program to end the session or select another project.

Maintenance and Repair Analysis

30. Selection of **7--Perform Maintenance and Repair Analysis**, at the Steel Sheet Pile Analysis menu (Figure B7) allows the user to define multiple scenarios for maintenance and repair of problems or deficiencies observed in the inspection or identified by the condition index evaluation. Each of these scenarios, or Maintenance & Repair (M&R) solutions, enables the user to fix, correct, or replace problems or deficiencies by selecting alternatives and building M&R solutions. The solutions may be little fixes, like replace a sheet pile, or big fixes, like replace a sheet pile wall section. The user can then model each of the M&R solutions to evaluate the improvement in condition index as a result of the fix. The user can also perform life cycle cost analysis (LCCA) to evaluate relative costs of each scenario or M&R solution.

31. Figure B12 illustrates the menu to begin Maintenance and Repair (M&R) analysis. The selected project is displayed for user information. Five menu choices are available for user control of the procedure.

1 - **Analyze Current Problems** is the selection to create or add new M&R solutions to the project files,

2 - **Review Previously Selected Alternatives** is the selection to review the list of previously defined solutions.

NOTE: A maximum of five M&R solutions can be active on a file for any one project structure. The user may edit existing M&R solutions to redefine another M&R solution or the user may delete alternatives from an existing M&R solution and start fresh.

3 - **Consequence Modeling** of the defined M&R Solutions. This allows the user to analyze the impact of each M&R solution and is discussed in detail later in the manual.

4 - **Update Problem/Alternatives Data Base** allows the user to edit or add to the initial M&R alternatives database.

NOTE: This particular function must be used carefully. The problem list is predefined for a structure type. Only the M&R alternatives should be added to or revised by the user. This process will be described in more detail later in the manual.

5 - **Return to the SSP Menu** backs the user up one level to the <u>Steel Sheet Pile Analysis menu</u>.

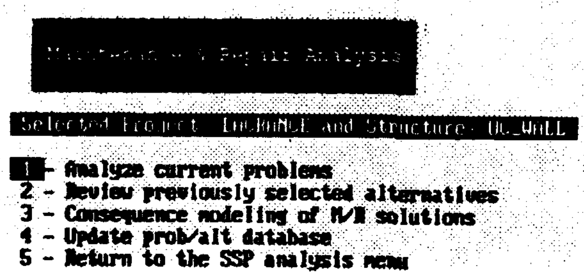


Figure B12. Maintenance & Repair analysis menu

M&R Solutions

32. Selecting **1--Analyze Current Problems** will display a blank form for the user to begin the development of a M&R solution. The first procedure is to select several analysis parameters that are specific to this M&R solution. The user is prompted to input or edit the parameters.

33. The parameters are

- Analysis Date: Date of the analysis, for future reference.
- Beginning Year: First year for the analysis period; it can be the current year or a future year. This date is used as the initial year in the life cycle cost analysis.
- Analysis Period: Length of the analysis period, for example, 1 year, 5 years, or 20 years

After the analysis parameters are correct, the user selects **(yes)** and automatically goes to the next selection level, where the Problem List window appears.

M&R Solution Sheet

34. At this point, a brief explanation of the background form is in order.

Figure B14 shows the blank sheet that is the basic building block for each M&R solution. The normal operation will not display this screen with all blank rows. Normal operation will have a user selection window displayed, such as Analysis Parameters (Figure B13) or Problem List (Figure B15) or have selected alternatives displayed for user action. Features of the sheet are

a. The title line informs the user whether the sheet is in a mode to Analyze Current Problems (for creating a new solution), or in a mode to Review Current Problems (edit an existing solution).

b. Columns to input the year, description, expected life, and cost($) of the selected alternative. A more detailed description of the input in each column will be given in a later section.

c. Active user option keys are displayed at the bottom of the screen and described in the following paragraphs.

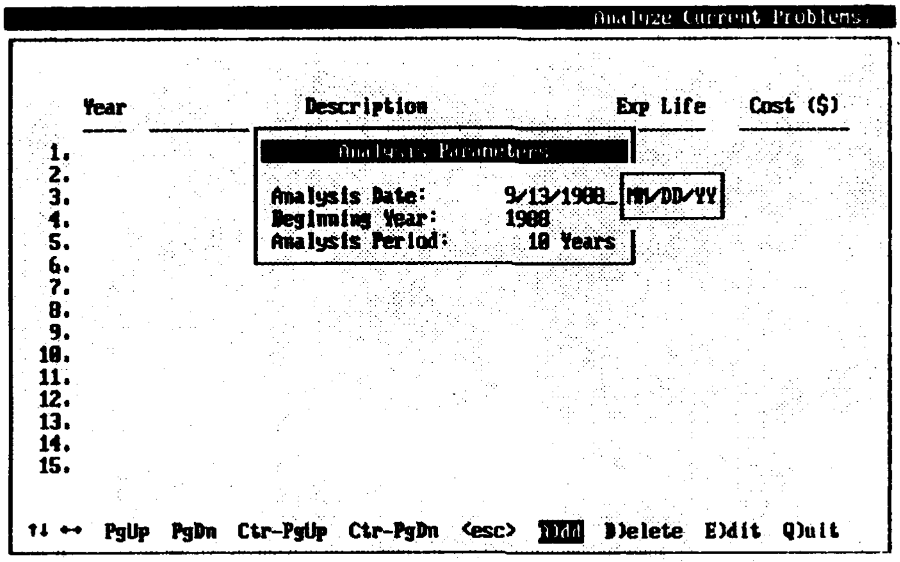


Figure B13. Analysis Parameters

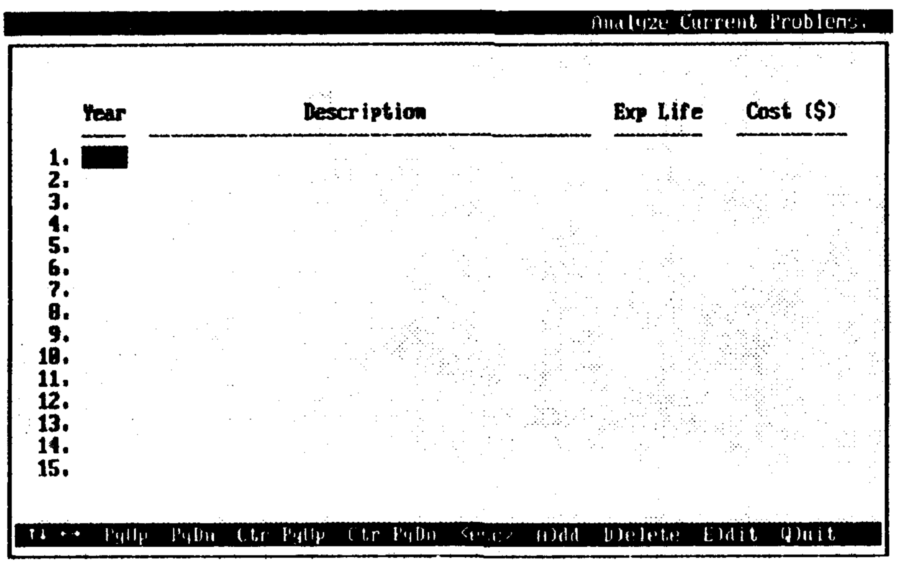


Figure B14. M&R solution sheet

35. If all selections in the row are highlighted, it means all the selection keys are active. If only one is highlighted, for example, **Edit,** the form is in edit mode at the location of the cursor in the form. The default location of the cursor is in the first column of row one. The cursor can be moved to other locations in the form to execute option keys. The cursor movement keys act as follows:

a. **Arrow** keys move the cursor from row to row or field to field

b. **PgUp** or **PgDn** moves the cursor between window pages

c. **Ctr-PgUp** and **Ctr-PgDn** moves the cursor only if there is more than one page of alternatives. Ctr-PgUp will return the cursor to the default location at row one. Ctr-PgDn will move the cursor to the top row of the last full screen page display.

36. The remaining option key actions depends on the location of the cursor within the M&R solution sheet.

a. First case: When the cursor is in a row that is not blank, then:
- **<esc>** or **Edit** enters edit mode at the cursor location
- **Add** inserts a blank row at the cursor location and displays the Problem List window (Figure B15) for user selection of an alternative
- **Quit** ends the selection process and exits to save the M&R solution

b. Second case: When the cursor is in a row that is blank (e.g., the row below a list of alternatives or a blank form), then:
- **<esc>, Add,** or **Edit** displays the Problem List window (Figure B15) for user selection of an alternative
- **Quit** ends the selection process and exits to save the M&R solution

Continue to the next selection level, where the <u>Problem List</u> window appears.

<u>Problem List</u>

37. A typical problem list, Figure B15, has been developed for a project structure, in this case, steel sheet pile. The typical problem list for steel sheet pile includes 15 problem definitions that are displayed each time this screen appears. The list of problems that appears may be more than one page long, as is the case with steel sheet pile. The user can view or select from the problems on the second page with cursor movement. The problem types that are present are identified in the column **No. Occur**(rences). The project inspection data file is used to generate the list. In the example window (Figure B15) there are two occurrences of misalignment, one of corrosion, and none, or zero for many of the other problems. The number of occurrences noted will correspond directly to the number of entries recorded for each problem on the Distress Profile form of the inspection file or to the calculated low factor of safety (low FS) in the case of a structural problem.

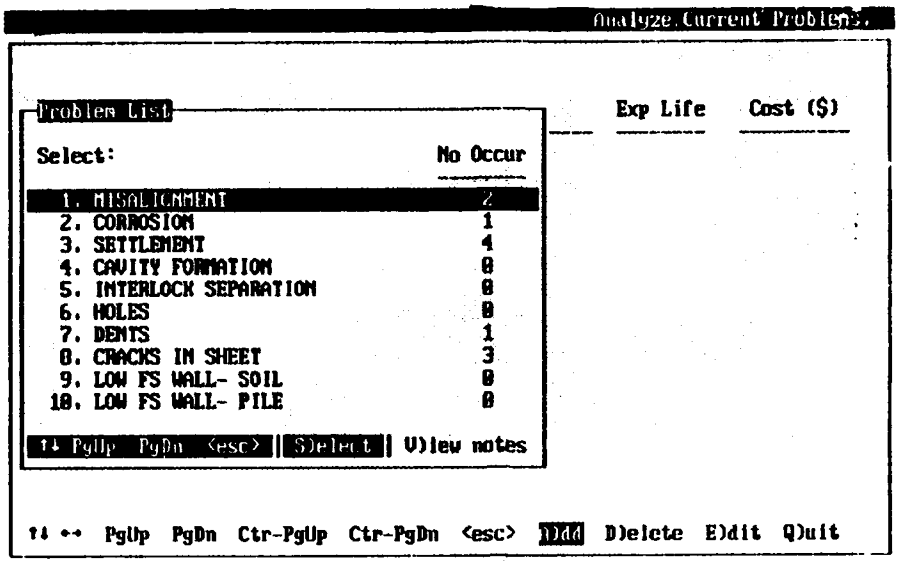


Figure B15. Problem List window.

38. At the bottom of the Problem List window are active user keys including cursor movement keys and user option keys. The cursor movement keys act as follows:

a. **Arrow(s)** up and down move the cursor from line to line on the displayed window page

b. **PgUp** and **PgDn** move the cursor between window pages

The user option keys act as follows:

a. **<ESC>** returns to the background **M&R** solution sheet

b. **Select** calls for the M&R Alternative List window to be displayed. The contents of this list are dependent on the problem list (see the next section). The user selects the problem by moving the cursor to the specific problem line and **ENTER**. This is the default user option key.

c. **View notes** is an option to see more information about a problem. This option is activated by typing **V** to select view notes and then **ENTER**. A window will display notes pertaining to the selected problem. (See Figure B16.)

Developing an M&R Solution

39. The user develops an M&R solution by selecting a problem from the Problem List and a corresponding maintenance or repair procedure from the M&R Alternative List (Figure B17). The user can refer to the inspection form to identify specific details about the problem location, severity, and so on, then make decisions about which problems to solve in a specific M&R solution.

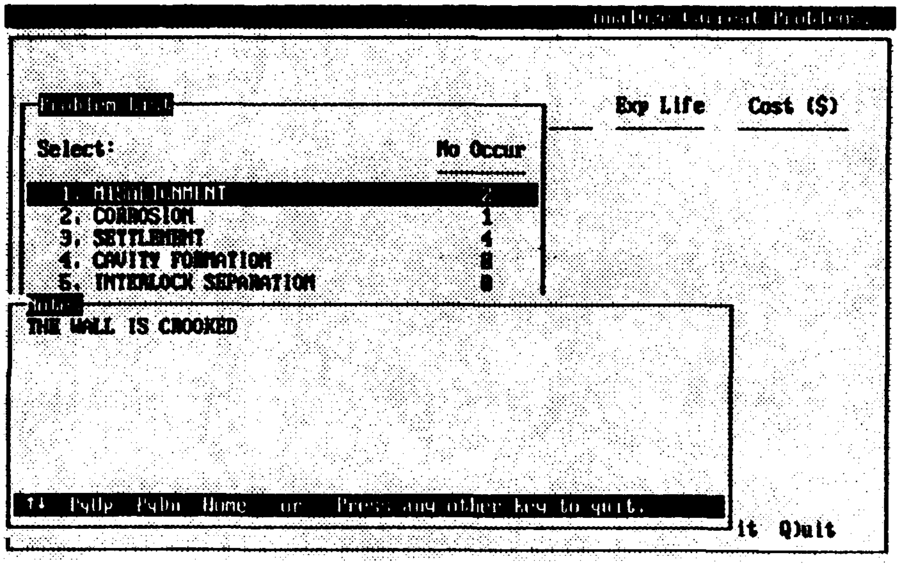


Figure B16. Notes window

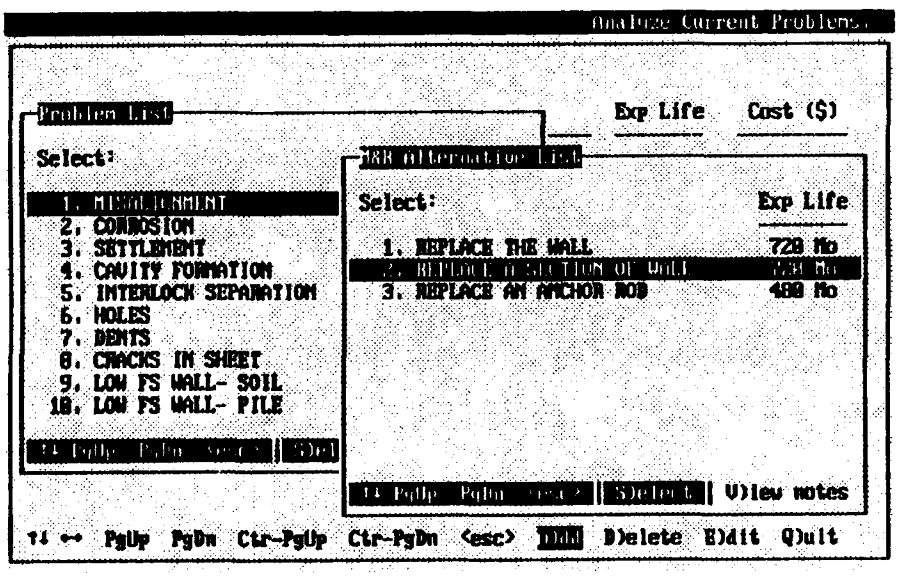


Figure B17. M&R Alternative List window

The user can define up to five different M&R solutions for analyzing in consequence modeling. Each of the M&R solutions can be edited, added to, and the like before consequence modeling or after modeling to study a different approach.

M&R Alternative List

40. The M&R Alternative List, which is the right-hand window in Figure B17, is a list read into the M&R module from the problems and alternatives data file. The data list is typical for all projects of a like structure type, in this case steel sheet pile. The list of M&R alternatives that appears may be one alternative or more than one page of alternatives. The description of each M&R alternative is brief and is intended to be edited and made specific to a M&R solution. The right-hand column is a estimate of the expected service life of the alternative. Figure B18 displays an example of an alternative selected to fix a problem like misalignment, a hole, a dent, or a crack.

41. The user selects an alternative on the list and it is added to the M&R solution form. The user is prompted to enter the Year the alternative would start, edit the Description of the alternative, edit the Exp(ected) Life, and finally enter an estimate of the current Cost to implement the alternative. Once the user enters the cost, the program automatically returns to the Problem List window (Figure B15) to allow the user to select another alternative to add to the M&R solution. This continues until the user is finished selecting alternatives. To stop the selection process, the user selects **<esc>** at the Problem List (Figure B15). This returns the user to the M&R solution sheet and the user selects **Quit** to exit and save the defined M&R solution.

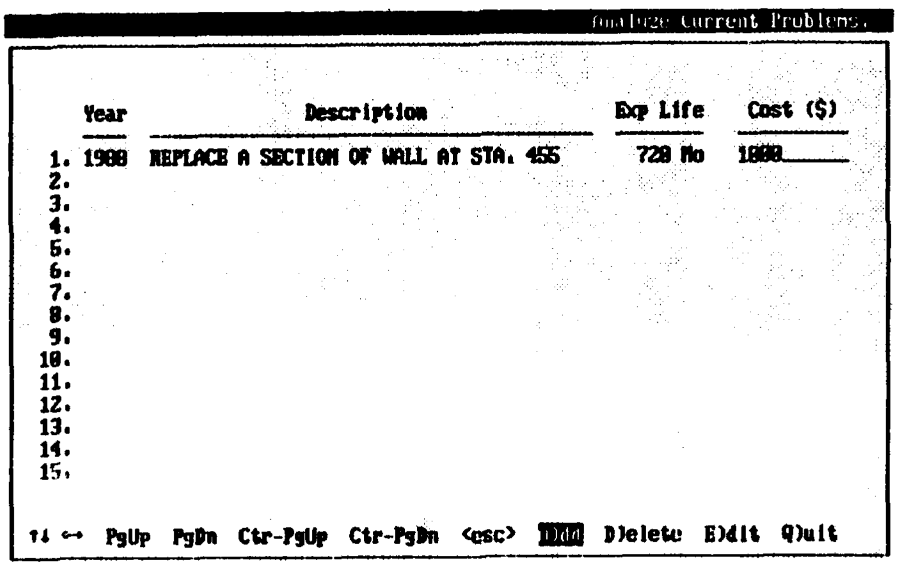


Figure B18. Example of selected M&R alternative

42. Input of an estimate of the current cost is optional. This information is required to perform a life cycle cost analysis in consequence modeling, but it is not required to evaluate changes in the condition index. The user can bypass the cost entry to perform condition index evaluation in consequence modeling and later return and edit the cost estimate into the M&R solution.

<u>Saving an M&R Solution</u>

43. When **Quit** is selected, the user is prompted to select a solution number and enter a name to describe the M&R solution. Figure B19 illustrates the selection of a solution number 1. The description MINOR REPAIR AND REPAINT WHOLE WALL has been affixed to the M&R solution with two alternatives (displayed behind window). After saving the M&R solution, the user is prompted <u>Add/Edit another version? (y)</u>. The user can enter **y** to continue and enter another M&R solution, or enter n and return to the <u>Maintenance & Repair Analysis</u> menu. If **y** is selected, the M&R solution form will be displayed and new analysis parameters must be defined for the new M&R solution.

44. The user does have another choice when beginning to save an M&R solution. Selecting **<esc>** (instead of a number) (see Figure B19) will let the user abandon an M&R solution that has just been created or edited. The user is prompted to confirm the intent to discard the data or to back up and save the M&R solution.

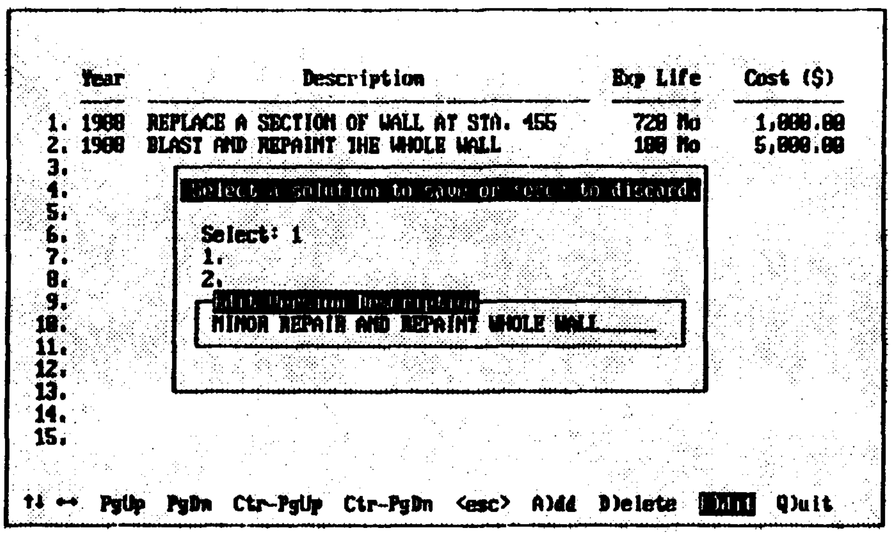


Figure B19. Saving an M&R solution

45. Returning to the Maintenance and Repair Analysis menu, selecting 2--**Review Previously Selected Alternatives**, will display a window (Figure B20) allowing the user to select from the list of M&R solutions previously defined and saved to the project structure file. Once the user selects an M&R solution, the completed M&R solution form and defined parameters will be displayed. The user can then edit or add to the M&R solution by changing analysis parameters, selecting additional alternatives, or deleting previously selected alternatives from the list.

Consequence Modeling of M&R Solutions

46. After at least one **M&R** solution has been defined and saved, selecting **3--Consequence Modeling of M&R solutions** initiates a "What if?" scenario in the M&R module. This modeling permits the user to correct the problems or deficiencies observed in the inspection or identified by the condition index evaluation. The user is directed to model each of the previously defined M&R solutions to analyze the consequences of the maintenance and repair scenario in two ways:

a. What will be the change in condition index of the structure if the fixes are made? The functional condition index and the structural condition index are each evaluated separately and then combined.

b. What will be the first cost and the annual cost of this M&R solution? Life cycle cost analysis is optional. The user must enter costs at the M&R Alternative selection level for this calculation to be executed.

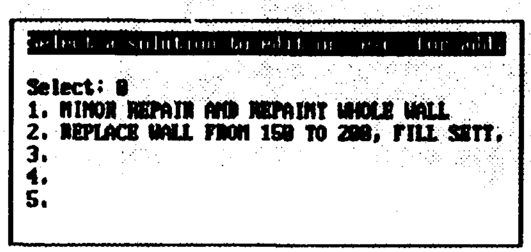


Figure B20. Review list of previously selected alternatives

NOTE: <u>Consequence Modeling</u> does not have any effect on the original structure inspection data files or on the actual computed condition index values. The condition index values calculated in this model are stored in a a temporary file structure and are not accessed by any routines outside of consequence modeling.

47. Selecting **3--Consequence Modeling** displays all of the M&R solutions and allows the user to make one of these choices.

1 to 5--Choose one of five M&R solutions for consequence modeling

6--Print the M&R solutions--This prints a brief schedule of the alternatives that are components of the M&R solutions. This print selection is also used to get a final print report of the M&R solutions after all the solutions have been modeled and the revised indexes and annual costs have been posted to the data file.

7--Return to Maintenance & Repair Analysis menu

48. Figure B21 illustrates a typical display of M&R solutions. Each solution displays the Old Combined CI (from SSP evaluation), the New Combined CI, First Cost ($), and Annual Cost ($), if these have been previously computed.

49. After an M&R Solution is selected, the next screen, Figure B22 displays more detail about the subjective and safety condition indexes and lists all of the alternatives attached to the M&R solution. At the bottom of the screen is a menu to allow the user to choose condition index modeling, life cycle cost analysis (LCCA), or print reports of the selected M&R solution.

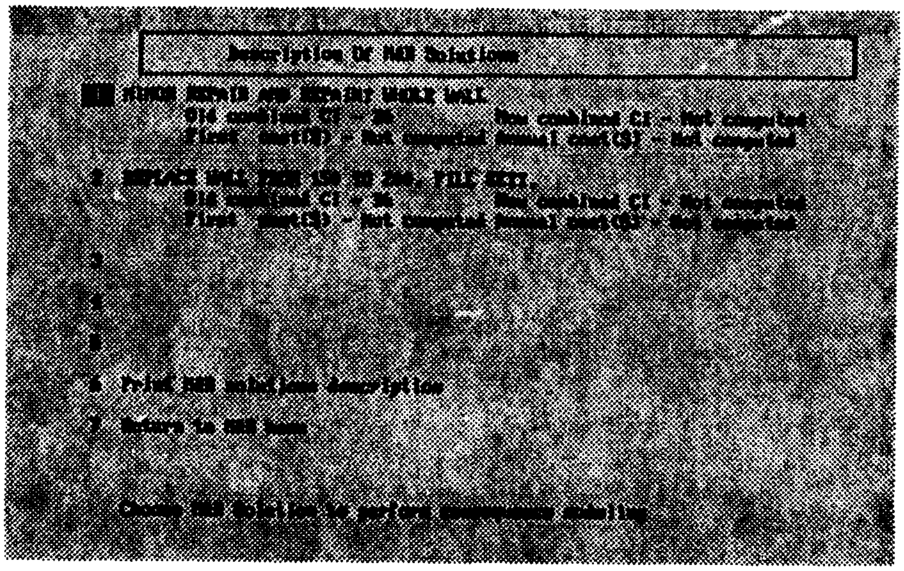


Figure B21. <u>Description of M&R Solutions</u>

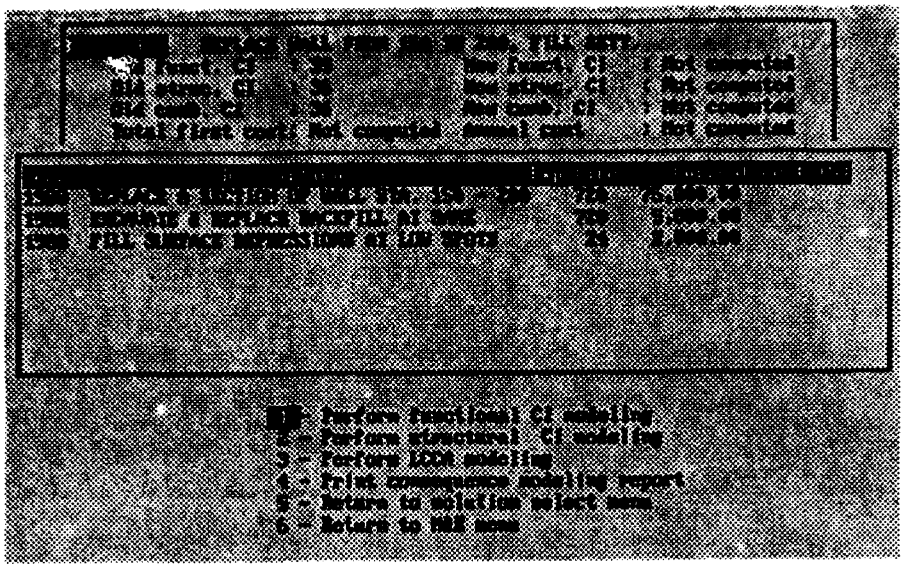


Figure B22. M&R modeling menu.

50. The menu choices are

1- **Perform functional CI modeling** calls for the Distress Profile data file to be edited by the user to reflect changes that would occur to the functional condition index if this solution were implemented.

2- **Perform structural CI Modeling**--The structural condition index may also change as a result of the alternatives proposed in the M&R solution being modeled. If the combined condition index is controlled by a low structural CI, then a message is displayed immediately after the calculation of the Functional CI advising the user to perform Structural CI modeling.

3- **Perform LCCA modeling**--This selection calculates total first cost and annual cost of the proposed M&R solution.

4- **Print consequence modeling report**--This selection produces a hard copy of the current M&R solution data. To get a complete print of the Consequence Model report, the user should perform options 1, 2, and 3 prior to selecting this print. This is the only print call that will produce documentation of the changes made to the distress profile, the changes made to safety parameters, and the backup cost data for LCCA in the current M&R solution. Many of the edited changes in the modeling routines are not recorded to a data file. The temporary data is overwritten the next time a new M&R solution is modeled.

5- **Return to solution select menu** returns the program to the M&R Solutions menu illustrated in Figure B21.

6- **Return to Maintenance & Repair Analysis menu** illustrated in Figure B12. This is the last menu and user selection point in the consequence modeling module. Choices 1 through 4 will each return to this menu for further selection. This selection exits from consequence modeling.

7- **Return to review previous screen of solution alternatives** returns (or pages up) to the previous partial window display of M&R alternatives.

NOTE: This choice does not display if only one window is required to display the alternatives.

Functional Condition Index Modeling

51. Selection of **1--Perform subjective CI modeling** displays Figure B23. The M&R solution title appears at the top of the display and a list of the selected alternatives appears below. Each of the distress records from the Distress Profile data file are displayed in the lower left corner window for the user to edit. The user may find it convenient to have a copy of the original data file to facilitate this editing process. The user reviews each distress line item and decides how each distress line should be changed or if it should be deleted. The decision reflects whether the distress is changed or corrected by the alternatives proposed in the M&R solution being modeled. In the example illustrated in Figure B23, the M&R solution calls for replacement of the wall from Sta. 150 to 200; therefore, the first distress line for misalignment from Sta. 150 to 200 is being deleted by inserting a Z in the first character space of the distress line. Other distresses are modified in a similar manner. After the last distress is modified, the model recalculates the functional condition index and displays it for the user to review.

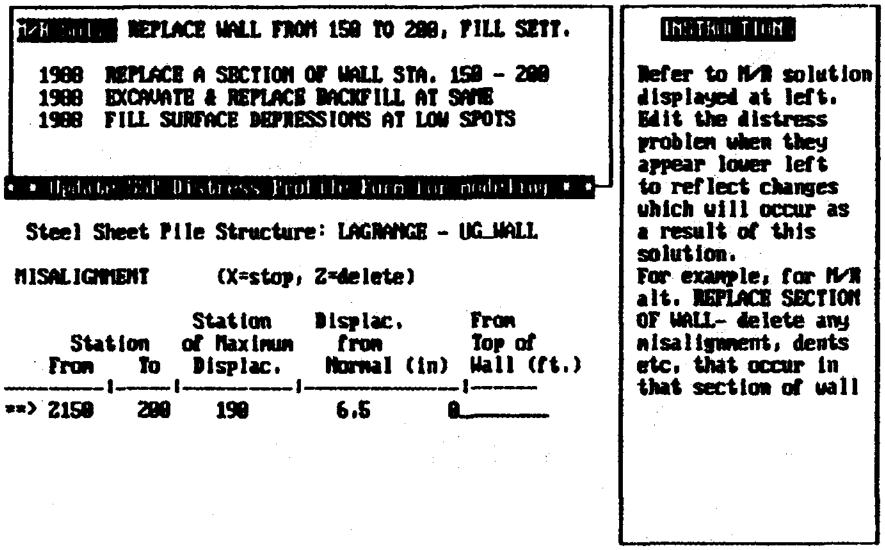


Figure B23. Edit distresses

52. Figure B24 then follows.

53. After the user follows screen instructions to continue, the program returns to the M&R Modeling menu (Figure B22). The user makes another modeling choice 1, 2 or 3; returns to the just completed model to change a parameter, selects the print option, or returns to another menu.

Structural Condition Index Modeling

54. Selection of **2--Perform Structural CI** will direct the program to several succeeding windows that will prompt the user to confirm or change data pertinent to the evaluation of the structural condition index. Figure B25 illustrates the first window. The data presented corresponds to structural characteristics input on page 3 of the inspection form. The user can confirm or edit the data. The second window (not shown) presents Load Table data and the third window (not shown) presents Dredge Depth data for confirmation or editing.

55. Following calculations, an intermediate screen similar to the functional condition index model can be reviewed. After the user follows screen instructions to continue, the program returns to the M&R Modeling menu (Figure B22). The user makes another modeling choice 1, 2, or 3; returns to the just completed model to change a parameter, selects the print option, or returns to another menu.

Life Cycle Cost Analysis (LCCA)

56. Selection of **3--Perform LCCA** will direct the program to LCCA Parameters window that the user can confirm or edit.

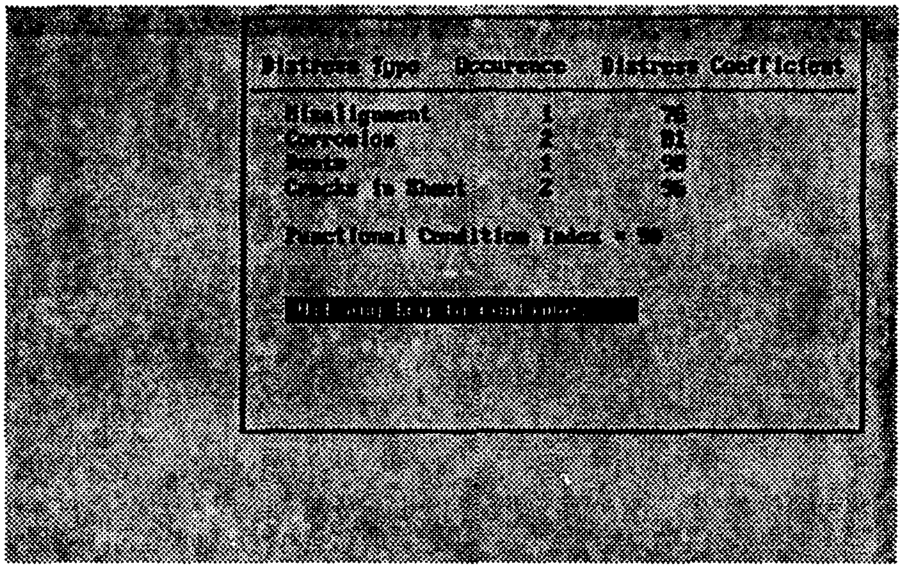


Figure B24. Modeled functional condition index

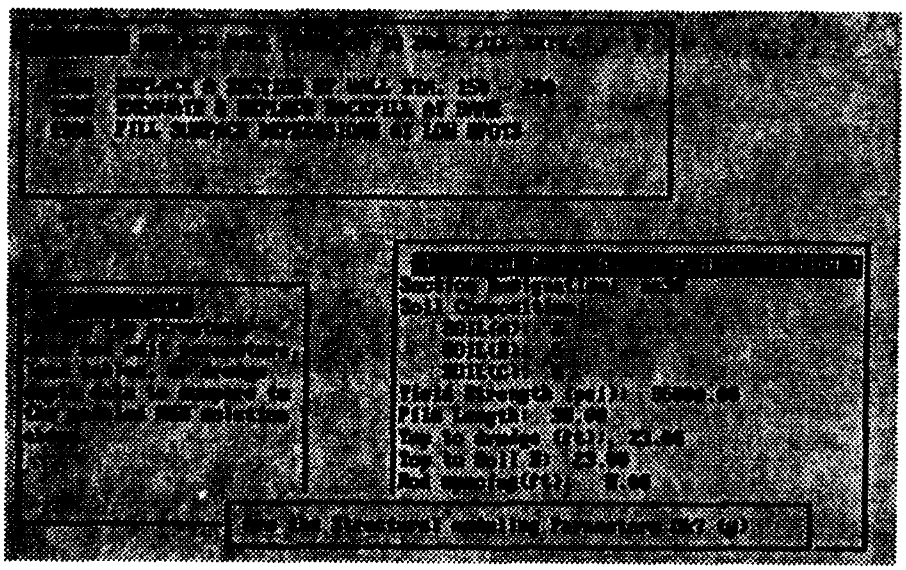


Figure B25. Structural Modeling Parameters

Figure B26 illustrates the type of data the user must provide to perform LCCA. Part VI describes the method for calculating the first cost and annual cost. The first three parameters have been entered previously at the beginning of the M&R solution development. They can be changed at this time. The interest rate and inflation rate must be entered at this time. The downtime and out-of-service cost are optional entries. A second window (Figure B27) displays a schedule of intermediate cost data in the computation of first cost and annual cost.

57. Following screen instructions to continue, the program returns to the M&R Modeling menu (Figure B22). The user makes another modeling choice 1, 2, or 3; returns to the just completed model to change a parameter, selects the print option, or returns to another menu.

Problem and Alternative Database

58. The problem and alternative (PNA) database is a single large file designed to be a single source file for M&R alternatives selection. The problem list in the problems and alternatives database is a standard list of problems or safety deficiencies that have been identified and related to steel sheet pile. The alternative list in the problems and alternatives database is a standard list of M&R alternatives that can be applied to a steel sheet pile structure.

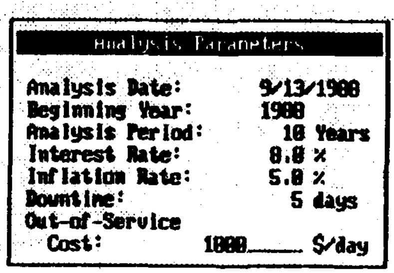


Figure B26. Life cycle cost parameters

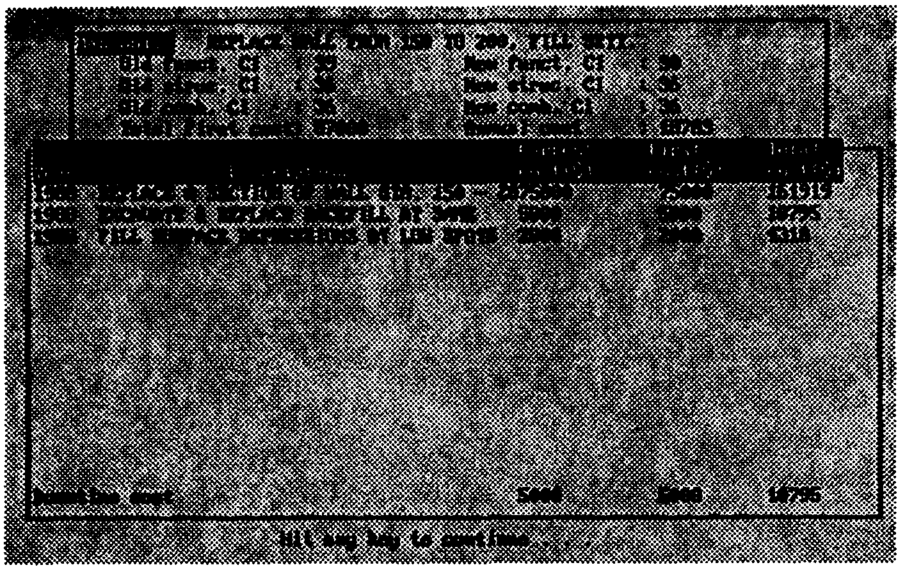


Figure B27. Life cycle cost data

<u>Problem List</u>

59. The list of problems for steel sheet pile consists of 15 items. The number of items on the problem list, 15, and the order of the problems on the list should not be changed by the user. The number of occurrences passed to the Problem List (Figure B15) in maintenance & repair analysis is relative to a fixed order of problems in steel sheet pile analysis data. The description and order of steel sheet pile problems is as follows:

1. Misalignment
2. Corrosion
3. Settlement
4. Cavity formation
5. Interlock separation
6. Holes
7. Dents
8. Cracks in sheet
9. Low FS wall- Soil
10. Low FS wall- Pile
11. Low FS wall- Rod
12. Low FS cell- Vertical Shear
13. Low FS cell- Bursting
14. Low FS cell- Pile
15. Low FS cell- Foundation sliding

60. The first eight problems correlate to the eight distresses that are identified on the Distress Profile form in the inspection. If an occurrence of one of the distresses is recorded on the form, then it will be listed as one occurrence of a problem on the Problem List in Maintenance & Repair analysis. The last seven problems (nine through fifteen) correlate safety deficiencies identified in the calculation of the structural condition index. Problems nine through eleven correlate to factors of safety for components of wall type structures. Problems twelve through fifteen correlate to factors of safety for components of cell type structures. If the computed factor of safety is less than 2.0 for any component, the deficiencies are reported as a safety problem on the Problem List in Maintenance & Repair analysis.

61. Each project problem list is unique to the particular steel sheet pile structure. The uniqueness of the list is defined by the identified distresses and safety deficiencies from the inspection data files for the particular steel sheet pile structure.

Maintenance and Repair Alternatives

62. The list of M&R alternatives is the part of the problems and alternatives database that is designed to be updated by the user. The program is distributed with a short list of M&R Alternatives that can be used to formulate M&R solutions. However, the real intent of the list is for the user to add to the list of M&R Alternatives from personal experience with successful projects or new technology and product solutions. A user can make the problems and alternatives database a personal resource of information about maintenance and repair alternatives.

Update Problem or Alternative Database

63. Selecting **3--Update Prob/Alt Database** from the Maintenance & Repair Analysis menu (Figure B12) calls up a program routine to allow the user to edit or add to the initial M&R Alternatives database. The initial screen display lists the structure types that are included in the database. For this distribution, only steel sheet pile (SSP) is included. See Figure B28. Selecting **1 - SSP** proceeds to the next user option. Selecting **Esc** returns to the Maintenance & Repair Analysis menu.

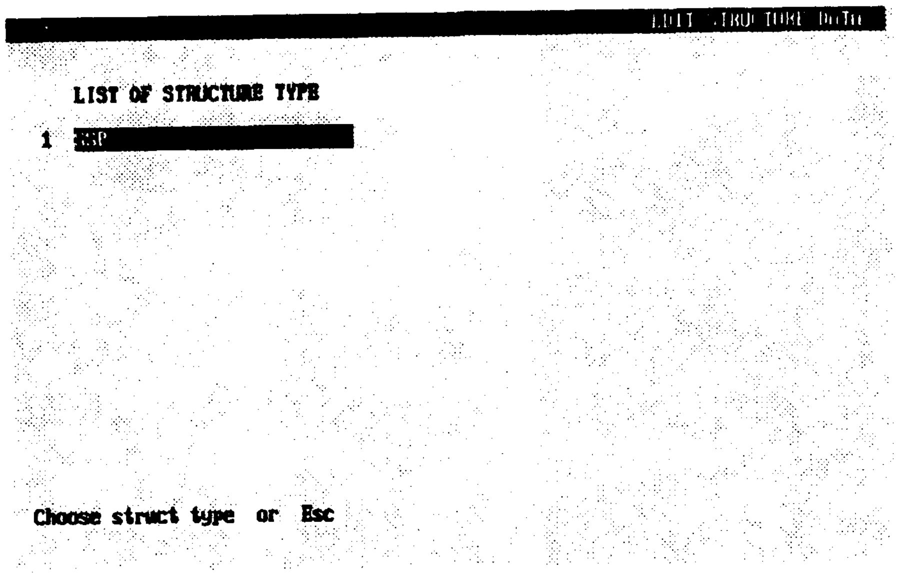


Figure B28. Select structure type

64. Continuing to the next screen, Figure B29, allows the user several options to edit structure data. They are displayed at the bottom of the screen.

a. **Change** by typing C allows editing of the description of the structure type. Do not change the structure type SSP because the M&R solutions are keyed to the description term SSP. Adding new structure types will not affect SSP nor will SSP be able to access data in any other structure type.

b. **Delete** by typing D allows deleting a structure type. Do not use on SSP.

c. **Edit Problems** by typing P displays the list of problems identified with SSP (Figure B30). Do not change the order of the first 15 problems. This will cause erroneous reporting of problem occurrences. NOTE: It is possible for the user to add undefined problems to the end of the list and tag M&R Alternatives to the problem. However, these added problems will never report an occurrence out of the inspection data file. The user can use this for defining very specific problems for an SSP structure.

d. **Edit Alternatives** by typing A displays the list of maintenance alternatives identified with SSP. This will be the primary selection of the user to change, update, and improve the M&R Alternatives list.

Edit Problems

65. Selecting **Edit Problems** by typing P displays the following screen, Problems List.

EDIT STRUCTURE DATA

LIST OF STRUCTURE TYPE

1 SSP

OPTIONS: (C)hange, (D)elete, Edit (P)roblems, Edit (A)lternatives, Esc

Figure B29. Edit Structure Data

EDIT PROBLEM DATA

TYPE: SSP

PROBLEMS

1 MISALIGNMENT
2 CORROSION
3 SETTLEMENT
4 CAVITY FORMATION
5 INTERLOCK SEPARATION
6 HOLES
7 DENTS
8 CRACKS IN SHEET
9 LOW FS WALL- SOIL
10 LOW FS WALL- PILE
11 LOW FS WALL- ROD
12 LOW FS CELL- VERTICAL SHEAR
13 LOW FS CELL- BURSTING
14 LOW FS CELL- PILE
15 LOW FS CELL- FOUNDATION SLIDE

OPTIONS: (A)dd, (C)hange, (D)elete, (P)rint, (V)iew alternatives, Esc

Figure B30. Problem list

The user option keys at the bottom of the screen do the following:

a. **Add** will insert a row at the location of the cursor to create a new problem description. The user will be prompted to enter a note to further describe the problem. (See Figure B31.) This is the same note the user can view in M&R solution development when viewing a note attached to a problem.

b. **Change** will edit the description of the problem and also the note attached to the problem.

c. **Delete** will delete a problem from the list.

d. **Print** will generate a printout of the problem list.

e. **View alternatives** will display a window, <u>Alternatives for this problem</u>. Selecting the alternative that is highlighted will display a note window describing the alternative. (See Figure B32.)

f. **Esc** will return to the initial structure type selection.

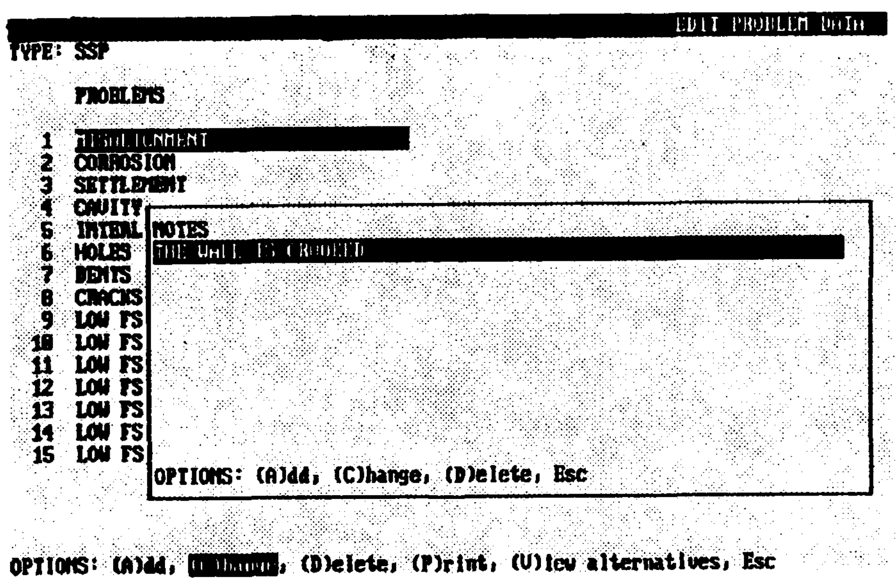


Figure B31. <u>Problem notes</u>

EDIT PROBLEM DATA

TYPE: SSP

PROBLEMS

1 MISALIGNMENT
2 CORROSION
3 SETTLEMENT
4 CAVITY FORMATION
5 INTERLOCK SEPARATION
6 HOLES
7 DENTS
8 CRACKS IN SHEET
9 LOW FS WALL- SOIL
10 LOW FS WALL- PILE
11 LOW FS WALL- ROD
12 LOW FS CELL- VERTICAL SHEAR
13 LOW FS CELL- BURSTING
14 LOW FS CELL- PILE
15 LOW FS CELL- FOUNDATION SLIDE

ALTERNATIVES FOR THIS PROBLEM

1.REPLACE THE WALL
2.REPLACE A SECTION OF WALL
3.REPLACE AN ANCHOR ROD

Choose alternative or Esc

OPTIONS: (A)dd, (C)hange, (D)elete, (P)rint, (V)iew alternatives, Esc

Figure B32. Alternatives for this problem

EDIT ALTERNATIVE DATA

TYPE: SSP

MAINTENANCE ALTERNATIVES

1 REPLACE THE WALL
2 REPLACE A SECTION OF WALL
3 REPLACE A SINGLE SHEET
4 REPLACE AN ANCHOR ROD
5 EXCAVATE & REPLACE BACKFILL
6 FILL A DEPRESSION AT SURFACE
7 ADD PROTECTIVE COATING
8
9
10
11
12
13
14
15

OPTIONS: (A)dd, (C)hange, (D)elete, (P)rint, (V)iew Prob, Esc

Figure B33. Edit Alternative Data

Edit Alternatives

66. Returning to Edit Structure Data (Figure B29) and selecting **Edit Alternatives** (Figure B33) by typing A displays the following screen, Maintenance Alternatives.

The user option keys at the bottom of the screen do the following:

a. **Add** will insert a row at the location of the cursor to create a new alternative description. The user will be prompted to enter the **Expected Life** of the alternative. The user is asked to identify problems this alternative can solve by adding them to a list (see Figure B24). The user will be prompted to enter a note to further describe the alternative. This is the same note the user can view in M&R solution development when viewing a note attached to an alternative.

b. **Change** will edit the description of the alternative, the Expected Life, the attached problem list, and also the note attached to the alternative.

c. **Delete** will delete a alternative from the list.

d. **Print** will generate a printout of the alternative list.

e. **View problems** will display a window, Possible problems list (Figure B34). Selecting the problem that is highlighted will display a note window listing the problems solved by this alternative. (See Figure B35.)

f. **Esc** will return to the initial structure type selection.

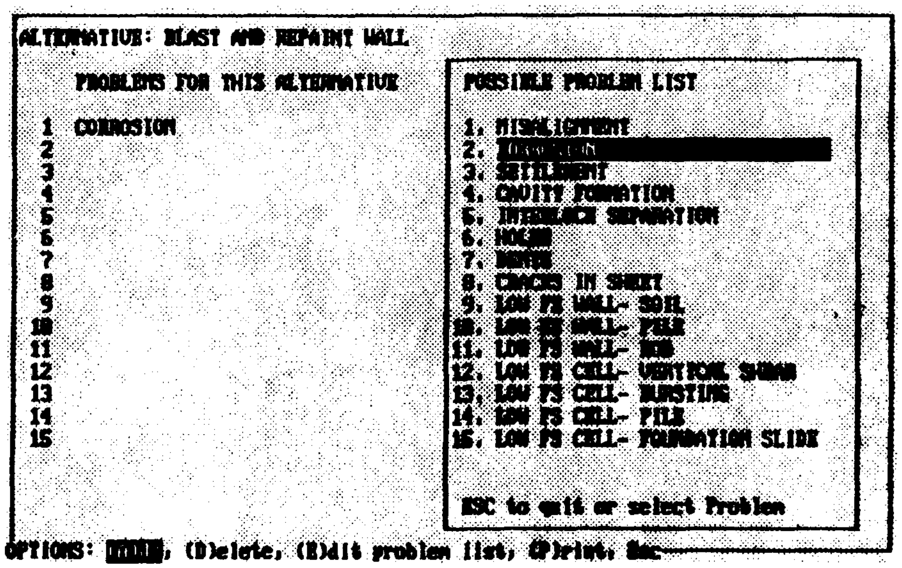


Figure B34. Edit problem list

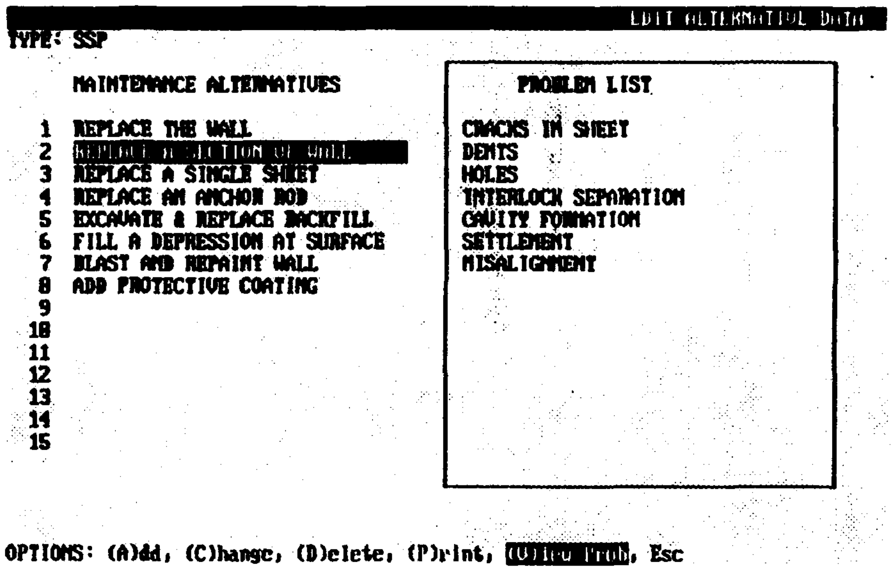


Figure B35. Edit maintenance alternatives

APPENDIX C: SAMPLE REPORTS

1. The following figures illustrate the report output available from SSP.

2. Inspection Report (Figure C1) - output file of data that corresponds to the inspection sheets pages 1 through 6.

3. Summary Report (Figure C2) - summary data of the structure condition index and detail about the functional and structural condition indices. The sample summary report is in substance the same report included in the User's Manual by Greimann and Stecker (1988). There is a slight variation in functional condition index value because minor changes have been made to interpreting the field data by the rules base.

4. Description of M&R Solutions (Figure C3) - summary output of the defined M&R solutions and a listening of the selected alternatives for each solution. Also lists the status of condition indices and costs for each M&R solution.

5. Consequence Modeling Report (Figure C4) - detail output for a specific M&R solution that includes data on life cycle cost of each alternative, the status of condition indices, and finally the backup parameters and temporary changes made to data files to generate the results in the current model.

Steel Sheet Pile Structure: LAGRANGE - UG_WALL

SSP data sheet 1

Name of the civil works project
(1): Lagrange Lock & Dam
(2): Upper Guide Wall

Location
(1): Illinois Waterway
(2): Beardstown, IL.

Date of inspection : 8-5-86
Inspected by : L Greimann, J Stecker

Type of steel sheet pile structure
1. Lock chamber wall 4. Guard wall
2. Lock guide wall 5. Single cell
3. Transition or retaining wall
Structure type: 2

Type of wall system (if applicable)
1. Anchored(tie-back) or cantilever
2. Cellular wall
Wall system: 1

Structure length or circumference(ft): 565

Location of structure:
Facing downstream, which side of stream
(1: Right, 2: Left) : 2
In relation to the lock
(1: Upstream, 2: Downstream, 3: No lock) : 1
Proximity to the lock
(1: Near, 2: Remote, 3: No relation to lock):1

Length of lock chamber (ft.) : 600
Construction date : 1939

Drawings available for reference ? yes
Drawings included with this file ? no

Present river level (datum Elevation) : 429.0
Record low water level (ft) : ?
Record high water level (ft) : 447.25

Figure C1. Sample inspection report (Sheet 1 of 6)

Steel Sheet Pile Structure: LAGRANGE - UG_WALL

SSP data sheet 2

Past 10 year history of:
=======================

a.) Major maintenance, repairs, or other modifications.

```
    Date         Description  ('X' to stop, 'Z' to delete current line)
==> ?      CURVED SECTION @ END EXTENSIVELY REPAIRED
==> AFTER IMPACT DAMAGE
```

b.) Changes in backfill, building structures, roads, equipment, etc.

```
    Date         Description  ('X' to stop, 'Z' to delete current line)
==> NONE
```

c.) Previous inspection or reviews.

```
    Date         Description  ('X' to stop, 'Z' to delete current line)
==> NONE
```

Present day:
============

Accessories (cap, railing, fender, etc.)

```
     Stations
    From    To   Description  ('X' to stop, 'Z' to delete current line)
==> 0       565  TIMBER FENDERS, 3 ROWS 8x12 OAK
==> 0       565  STEEL PLATE CAP
==> 0       565  CABLE HANDRAIL
==> 0       565  MOORING POSTS AT 50' INTERVALS
```

Figure C1. (Sheet 2 of 6)

Steel Sheet Pile Structure: LAGRANGE - UG_WALL

SSP data sheet 3

ANCHORED OR CANTILEVER WALL SECTION
===================================

From station : 0
To station : 565

Wall type (1 = Anchored, 2 = Cantilever): 1

Anchor system drawings attached ? NO

Soil composition:

1. Sand
2. Gravel
3. Rock
4. Soft Clay
5. Medium Clay
6. Stiff Clay
7. Unknown
8. Not applicable

Soil(A): 2
Soil(B): 5
Soil(C): 5

Wall Cross-Section

1. Datum elevation (ft) : 434
2. Pile length (ft) : 38
3. Top-to-dredge (ft) : 23
4. Top-to-soil(B) (ft) : 23
5. Top-to-water (ft) : 5.5
6. Top-to-Soil(A) (ft) : 0
7. Top-to-anchor rod (ft) : 7
8. Anchor rod diameter (in): 2.25
9. Anchor rod spacing (ft) : 8
10. Anchor depth (ft) : 7
11. Anchor rod coating : ?

Pile cross-section

1. Section designation : MZ38
2. Driving width (in) :
3. Flange width (in) :
4. Flange thickness (in) :
5. Web thickness (in) :
6. Cross-section depth (in):
7. Yield strength (psi) :

Figure C1. (Sheet 3 of 6)

Steel Sheet Pile Structure: LAGRANGE - UG_WALL

SSP data sheet 4

LOADING TABLE

('X' to stop, 'Z' to delete the current line)

	Stations From	To	Loading (psf)	Distance to Wall (ft)	Description of Loading
==>	0	350	0		
==>	350	450	300	6	STORAGE AREA ON CONC. PEDESTAL SLAB

Steel Sheet Pile Structure: LAGRANGE - UG_WALL

SSP data sheet 5

DREDGE DEPTH ALONG STRUCTURE

('X' to stop, 'Z' to delete the current line)

	Station	Depth
==>	100	23
==>	150	23
==>	200	24
==>	230	25
==>	250	28
==>	300	28.5
==>	350	29.5
==>	400	30
==>	450	29.5
==>	500	30
==>	550	28.5
==>	565	28

Figure C1. (Sheet 4 of 6)

Steel Sheet Pile Structure: LAGRANGE - UG_WALL

SSP data sheet 6

DISTRESS PROFILE FORM

MISALIGNMENT (X=stop, Z=delete)

	Station From	Station To	Station of Maximum Displac.	Displac. from Normal (in)	From Top of Wall (ft.)
==>	150	200	190	6.5	0
==>	200	250	230	2.5	0

CORROSION (X=stop, Z=delete)

	Station From	Station To	Severity Level (1-5)
==>	0	565	2

SETTLEMENT (X=stop, Z=delete)

	Station From	Station To	Station of Maximum Displac.	Displac. from Normal (in)	Surface Discrp. Type
==>	160	200	190	10	2
==>	300	350	340	8	2
==>	390	400	398	14	2
==>	480	505	500	6	2

CAVITY FORMATION (X=stop, Z=delete)

	Cavity at Station	Cavity Size (ft) Length	Width	Height	Surface Type
==>					

INTERLOCK (X=stop, Z=delete)

Interlock at Station	Length (ft)	From Top of Wall (ft)

Figure C1. (Sheet 5 of 6)

```
==>

 HOLES              (X=stop, Z=delete)

    Hole at   Size (ft)     From Top
    Station  Length  Width  of Wall (ft)
-----------§-------§------§--------------
==>

 DENTS              (X=stop, Z=delete)

    Dent at  Dent Size(ft/ft/in)  From Top
    Station  Length Width Depth     of Wall (ft)
-----------§-------§------§------§-------------
==> 250        3       2     .5     3

 CRACKS (SHEET)     (X=stop, Z=delete)

   Crack at   Size                      From Top
    Station  Length(ft)   Width(in)     of Wall (ft)
-----------§------------§-----------§--------------
==> 125        2       0      0
==> 180        2       0      0
==> 220        2       0      0
```

Figure C1. (Sheet 6 of 6)

Steel Sheet Pile Structure: LAGRANGE - UG_WALL

SUMMARY REPORT
==============

PROJECT NAME:
Lagrange Lock & Dam
Upper Guide Wall

LOCATION:
Illinois Waterway
Beardstown, IL.

INSPECTION DATE: 8-5-86

INSPECTED BY: L Greimann, J Stecker

STRUCTURE TYPE: Lock Guide Wall

The overall functional condition and structural condition have been analyzed and compiled in the following indices:

FUNCTIONAL CONDITION INDEX = 39
STRUCTURAL CONDITION INDEX = 36

COMBINED CONDITION INDEX = 36

NUMBER OF DISTRESSES AND THEIR CALCULATED DISTRESS COEFFICIENTS :

2	Misalignment	:	36
1	Corrosion	:	79
4	Settlement	:	10
1	Dents	:	98
3	Cracks in Sheet	:	95

FUNCTIONAL CONDITION INDEX = 39

LOCATION OF CRITICAL STRUCTURAL CALCULATION AND COMPONENT FACTORS OF SAFETY:

Safety Factors (Anchored or Cantilever Wall)
==

Station	Soil	Pile	Rod	Struc. CI
400	0.91	3.78	2.61	36

Figure C2. Summary report

Steel Sheet Pile Structure: LAGRANGE - UG_WALL

DESCRIPTION OF M&R SOLUTIONS

PROJECT NAME:
Lagrange Lock & Dam
Upper Guide Wall

LOCATION:
Illinois Waterway
Beardstown, IL.

M&R Solutions and Alternatives:

M&R SOLUTION - MINOR REPAIR AND REPAINT WHOLE WALL

Year	Description	Exp Life	Current cost ($)
1988	REPLACE A SECTION OF WALL AT STA.455	720	1,000.00
1988	BLAST AND REPAINT THE WHOLE WALL	180	5,000.00

Old functional CI	= 39
New functional CI	= Not computed
Old structural CI	= 36
New structural CI	= Not computed
Old comb. CI	= 36
New comb. CI	= Not computed
Total first Cost ($)	= Not computed
Annual Cost ($)	= Not computed

M&R SOLUTION - REPLACE WALL FROM 150 TO 200, FILL SETT.

Year	Description	Exp Life	Current cost ($)
1988	REPLACE A SECTION OF WALL STA. 150 - 200	720	75,000.00
1988	EXCAVATE & REPLACE BACKFILL AT SAME	720	5,000.00
1988	FILL SURFACE DEPRESSIONS AT LOW SPOTS	24	2,000.00

Old functional CI	= 39
New functional CI	= 90
Old structural CI	= 36
New structural CI	= 36
Old comb. CI	= 36
New comb. CI	= 36
Total first Cost ($)	= 87000
Annual Cost ($)	= 18783

Figure C3. Description of M & R solutions

Steel Sheet Pile Structure: LAGRANGE - UG_WALL

CONSEQUENCE MODELING REPORT

PROJECT NAME:
Lagrange Lock & Dam
Upper Guide Wall

LOCATION:
Illinois Waterway
Beardstown, IL.

M&R SOLUTION - REPLACE WALL FROM 150 TO 200, FILL SETT.

Year	Description	Current cost($)	First cost($)	Total cost($)
1988	REPLACE A SECTION OF WALL STA. 150 - 200	75000	75000	161919
1988	EXCAVATE & REPLACE BACKFILL AT SAME	5000	5000	10795
1988	FILL SURFACE DEPRESSIONS AT LOW SPOTS	2000	2000	4318

Old functional CI = 39
New functional CI = 90
Old structural CI = 36
New structural CI = 36
Old comb. CI = 36
New comb. CI = 36
Total first Cost ($) = 87000
Annual Cost ($) = 18783

LCCA PARAMETERS
Begining Year = 1988
Period of Analysis (years) = 10
Inflation Rate(%) = 5.00
Interest Rate(%) = 8.00
Down Time (days) = 5
Out Of Service Cost
($ per day) = 1,000.00

Figure C4. Consequence modeling report (Sheet 1 of 3)

THE FOLLOWING DATA REFLECTS CHANGES MADE DURING MODELING
TO FUNCTIONAL AND STRUCTURAL PARAMETERS:

Steel Sheet Pile Structure: LAGRANGE UG_WALL

SSP data sheet 6

DISTRESS PROFILE FORM

MISALIGNMENT (X=stop, Z=delete)

	Station From	Station To	Station of Maximum Displac.	Displac. from Normal (in)	From Top of Wall (ft.)
==>	200	250	230	2.5	0

CORROSION (X=stop, Z=delete)

	Station From	Station To	Severity Level (1-5)
==>	0	150	2
==>	201	565	2

SETTLEMENT (X=stop, Z=delete)

	Station From	Station To	Station of Maximum Displac.	Displac. from Normal (in)	Surface Discrp. Type
==>					

CAVITY FORMATION (X=stop, Z=delete)

	Cavity at Station	Cavity Size (ft) Length	Width	Height	Surface Type
==>					

INTERLOCK (X=stop, Z=delete)

	Interlock at Station	Length (ft)	From Top of Wall (ft)
==>			

HOLES (X=stop, Z=delete)

Hole at Station	Size (ft) Length	Width	From Top of Wall (ft)

Figure C4. (Sheet 2 of 3)

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==>

 DENTS              (X=stop, Z=delete)

    Dent at  Dent Size(ft/ft/in)  From Top
    Station  Length Width Depth     of Wall (ft)
-------------|--------|-------|-------|-------------
==> 250         3        2      .5      0

 CRACKS (SHEET)     (X=stop, Z=delete)

   Crack at   Size                          From Top
    Station  Length(ft)    Width(in)     of Wall (ft)
-------------|-------------|-----------|--------------
==> 125         2        0       0
==> 220         2        0       0
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Figure C4. (Sheet 3 of 3)