

US Army Corps
of Engineers

EVALUATION PROCEDURE FOR REINFORCED CONCRETE BOX CULVERTS UNDER AIRFIELD PAVEMENTS

by

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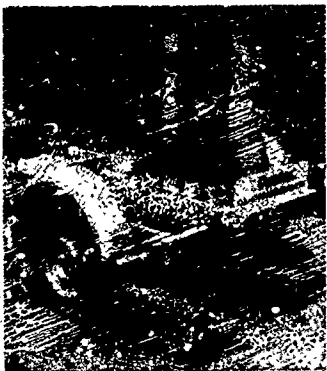
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DEPARTMENT OF THE ARMY

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OCT. 31 1990
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September 1990

Final Report

Approved for Public Release; Distribution Unlimited

Prepared for DEPARTMENT OF THE ARMY
US Army Corps of Engineers
Washington, DC 20314-1000

and

DEPARTMENT OF THE AIR FORCE
Engineering and Services Center
Tyndall Air Force Base, Florida 32403-6001



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REPORT DOCUMENTATION PAGE				Form Approved OMB No. 0704-0188	
1a. REPORT SECURITY CLASSIFICATION Unclassified			1b. RESTRICTIVE MARKINGS		
2a. SECURITY CLASSIFICATION AUTHORITY			3. DISTRIBUTION / AVAILABILITY OF REPORT Approved for public release; distribution unlimited.		
2b. DECLASSIFICATION / DOWNGRADING SCHEDULE			5. MONITORING ORGANIZATION REPORT NUMBER(S)		
4. PERFORMING ORGANIZATION REPORT NUMBER(S) Technical Report GL-90-25			7a. NAME OF MONITORING ORGANIZATION		
6a. NAME OF PERFORMING ORGANIZATION See reverse		6b. OFFICE SYMBOL (If applicable) See reverse	7b. ADDRESS (City, State, and ZIP Code)		
6c. ADDRESS (City, State, and ZIP Code) 3909 Halls Ferry Road Vicksburg, MS 39180-6199			9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER		
8a. NAME OF FUNDING / SPONSORING ORGANIZATION See reverse		8b. OFFICE SYMBOL (If applicable) AFESC-DEMP	10. SOURCE OF FUNDING NUMBERS		
8c. ADDRESS (City, State, and ZIP Code) Washington, DC 20314-1000 AFESC-DEMP Tyndall Air Force Base, FL 32403-6001			PROGRAM ELEMENT NO.	PROJECT NO.	TASK NO.
11. TITLE (Include Security Classification) Evaluation Procedure for Reinforced Concrete Box Culverts under Airfield Pavements					
12. PERSONAL AUTHOR(S) Coleman, David M.; Harrison, James A.; Woodson, Stanley C.					
13a. TYPE OF REPORT Final report		13b. TIME COVERED FROM Jan 83 TO Mar 90		14. DATE OF REPORT (Year, Month, Day) September 1990	
15. PAGE COUNT 86					
16. SUPPLEMENTARY NOTATION Available from National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161.					
17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)		
FIELD	GROUP	SUB-GROUP	Airfield drainage Culvert evaluation		
			Airfield pavements Structural analysis		
			Box culverts		
19. ABSTRACT (Continue on reverse if necessary and identify by block number)					
While most airfield pavements are periodically evaluated to determine their structural capacity, often little thought is given to the structural capacity of the culverts and other drainage structures beneath the pavement. The Department of Defense has never had a standard means of evaluating box culverts under airfields or landing strips. This capacity has been needed on several occasions, particularly overseas where landing strips are sometimes built into the local highway system. The research reported herein evaluated several different methods for performing the structural evaluation of reinforced concrete box culverts under aircraft loads, selected two computer programs (CANDE-1980 and CORTCUL) for detailed testing, and then developed a culvert evaluation methodology based on the CORTCUL program. (Continued)					
20. DISTRIBUTION / AVAILABILITY OF ABSTRACT ☐ UNCLASSIFIED / UNLIMITED ☒ SAME AS RPT ☐ DTIC USERS			21. ABSTRACT SECURITY CLASSIFICATION Unclassified		
22a. NAME OF RESPONSIBLE INDIVIDUAL			22b. TELEPHONE (Include Area Code)		22c. OFFICE SYMBOL

OVER

6a. NAME OF PERFORMING ORGANIZATION (Continued).

USAEWES
Geotechnical Laboratory
Structures Laboratory

6b. OFFICE SYMBOL (Continued).

CEWES-GP-N
CEWES-SS-R

8a. NAME OF FUNDING/SPONSORING ORGANIZATION (Continued).

US Army Corps of Engineers
US Air Force Engineering and Services Center

19. ABSTRACT (Continued).

To assist in determining the aircraft loads, an additional computer program was developed. This program, CULVERT, uses elastic layer theory and predefined aircraft data to calculate the vertical stress acting on the top of the culvert due to the aircraft and also provides output and plotting capabilities. Stress is then applied to the culvert model along with the member loads, soil loads, and other loads such as internal water. The CORTCUL program evaluates the culvert based on the requirements of ACI 318, "Building Code Requirements for Reinforced Concrete."

(KR)

PREFACE

The initial research reported herein was conducted for the Headquarters, US Army Corps of Engineers under an O&M,A project entitled "Development of an Evaluation Procedure for Reinforced Concrete Culverts under Airfield Pavements." The Technical Monitor at Headquarters was Mr. S. S. Gillespie. Follow-on work was conducted and this report prepared and published under the sponsorship of the US Air Force Engineering and Services Center (AFESC). Technical Monitor at AFESC was Mr. J. L. Greene.

The research effort reported herein was conducted from January 1983 to March 1990 by Messrs. D. M. Coleman, J. A. Harrison, and Dr. R. S. Rollings, Pavement Systems Division (PSD), Geotechnical Laboratory (GL), US Army Engineer Waterways Experiment Station (WES). Other WES personnel who assisted in the study that led to the preparation of this report were Messrs. D. M. Ladd and H. H. Ulery, PSD, and Dr. R. Mosher, Ms. V. Knowles, and Mr. W. H. Jones, Information Technology Laboratory (ITL), and Mr. S. C. Woodson, Structures Laboratory. Non-government personnel assisting in this study under contract to PSD were Drs. G. C. Feng, Choctaw Engineering Company, Houston, TX, and C. H. Juang, Associate Professor of Civil Engineering, Clemson University. This report was prepared by Messrs. Coleman, Harrison, and Woodson under the general supervision of Mr. H. H. Ulery, Chief, PSD, and Dr. W. F. Marcuson III, Chief, GL. This report was edited by Ms. Odell F. Allen, Visual Production Center, ITL.

The Commander and Director of WES during the conduct of this study and the preparation of this report was COL Larry B. Fulton, EN. Technical Director was Dr. Robert W. Whalin.



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Unannounced	☐
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Availability Codes	
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CONTENTS

	<u>Page</u>
PREFACE.....	1
CONVERSION FACTORS, NON-SI TO SI (METRIC)	
UNITS OF MEASUREMENT.....	4
PART I: INTRODUCTION.....	5
Background.....	5
Purpose.....	6
Scope.....	6
PART II: REVIEW OF DESIGN AND EVALUATION PROCEDURES.....	7
Army and Air Force.....	7
Navy.....	7
Federal Aviation Administration.....	7
International Civil Aviation Organization.....	8
PART III: SELECTION OF EVALUATION MODEL.....	10
CANDE-1980.....	10
CORTCUL.....	11
Comparison of Programs.....	12
Selection of Program.....	14
PART IV: DEVELOPMENT OF EVALUATION PROCEDURE.....	17
Introduction to CORTCUL.....	17
Application of Loads.....	19
Determination of Aircraft Live Loads.....	27
Verification of Aircraft Loading Methods.....	28
Parameter Studies Performed.....	28
PART V: PROCEDURE FOR EVALUATING REINFORCED CONCRETE	
BOX CULVERTS UNDER AIRCRAFT LOADS.....	32
General.....	32
Field Inspection of Culverts.....	32
Tools and Equipment.....	33
Inspection of Reinforced Concrete Box Culverts.....	33
Evaluation of Reinforced Concrete Box Culverts.....	35
Data Input.....	35
Data Output.....	38
Analysis of Output.....	41
Example Problem.....	41
PART VI: SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS.....	43
Summary.....	43
Conclusions.....	43
Recommendations.....	43
REFERENCES.....	45
APPENDIX A: USER'S GUIDE FOR CULVERT: EVALUATION PACKAGE FOR THE	
EVALUATION OF REINFORCED CONCRETE BOX CULVERTS UNDER	
AIRCRAFT LOADS.....	A1

	<u>Page</u>
APPENDIX B: RESULTS OF CORTCUL PARAMETER STUDIES.....	B1
APPENDIX C: EXAMPLE PROBLEM.....	C1

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:

<u>Multiply</u>	<u>By</u>	<u>To Obtain</u>
degrees (angle)	0.01745329	radians
feet	0.3048	metres
inches	2.54	centimetres
pounds (force)	4.448222	newtons
pounds (force) per square foot	47.88026	pascals
pounds (force) per square inch	6.894757	kilopascals
pounds (mass)	0.4535924	kilograms
pounds (mass) per cubic foot	16.01846	kilograms per cubic metre
square inches	6.4516	square centimetres

EVALUATION PROCEDURE FOR REINFORCED CONCRETE

BOX CULVERTS UNDER AIRFIELD PAVEMENTS

PART I: INTRODUCTION

Background

1. Most airfield pavements are periodically evaluated to determine the structural capacity of the pavement system and to determine if strengthening is required to meet anticipated future traffic needs. Most of these pavement evaluations consider only the pavement structure itself with little consideration given to other facilities such as drainage structures. Although it is usually assumed that the drainage structures under airfield pavements have been designed to support both the dead (earth) and live (aircraft) loads imposed on them, this assumption may not be true in all cases. The technical manual covering airfield drainage structures is Army and Air Force TM 5-820-3/AFM 88-5, Chap. 3 entitled "Drainage and Erosion-Control Structures for Airfields and Heliports" (Headquarters, Departments of the Army and the Air Force 1978). This manual contains tables giving the minimum cover requirements for several different types and numerous sizes of circular pipes; however, reinforced concrete box culverts are not mentioned. The lack of any data on reinforced concrete box culverts or presentation of a means for evaluating these structures in the airfield drainage manual could present problems for personnel designing or evaluating airfields.

2. The problem of not having a standard procedure for evaluating reinforced concrete box culverts became readily apparent during an overseas airfield evaluation program in 1982. As part of an overseas airfield evaluation program, the US Army Engineer Waterways Experiment Station (WES) was tasked with evaluating the structural capacity of several emergency landing strips built into the host nation's expressway system. Included in this pavement evaluation was the evaluation of drainage structures under the pavement. The drainage structures included both circular pipes and reinforced concrete box culverts. While evaluating the circular pipes could be accomplished rapidly with information presented in current technical manuals, an evaluation method for the reinforced concrete box culverts had to be developed. Due to time and

funding restrictions that existed on the pavement evaluation project, an existing Corps of Engineers computer program was used to model each of the subject culverts on a site-specific basis. That exercise in evaluating approximately 30 concrete box culverts indicated the need for a standard method of evaluating reinforced concrete box culverts under aircraft loads.

Purpose

3. The purpose of this research project was to develop a standard procedure for determining the structural capacity of reinforced concrete box culverts (hereafter called box culverts) under aircraft loads. Specific objectives were to investigate the various methods available for rapidly evaluating the structural capacity of box culverts, select one of these methods for use, and develop a rational method of evaluating culverts under aircraft loadings using the selected method.

Scope

4. This report describes the development of a procedure for determining the structural capacity of reinforced concrete box culverts under aircraft loads. The evaluation procedure is described in detail along with the inputs required in the culvert evaluation computer program. A computer program to assist in determining the stresses on the culvert due to the aircraft loads was developed and is also presented in this report. Appendix A provides the Users Guide for this program. Appendix B gives the results of parameter studies. Appendix C presents a complete example problem to demonstrate the evaluation procedure. A floppy disk containing all of the computer programs discussed herein is available from the authors.

PART II: REVIEW OF DESIGN AND EVALUATION PROCEDURES

Army and Air Force

5. Technical Manuals TM 5-820-1/AFM 88-5, Chap. 1, TM 5-820-2/AFM 88-5, Chap. 2, TM 5-820-3/AFM 88-5, Chap. 3, and TM 5-820-4/AFM 88-5, Chap. 4 (Headquarters, Departments of the Army and Air Force 1983, 1979, 1978, and 1977) provide guidance of the design of drainage facilities for the Army and Air Force. While emphasizing the use of circular conduits, none of these technical manuals mention box culverts except for TM 5-820-4/AFM 88-5, Chap. 4. This technical manual gives capacity curves for several different sizes of box culverts but does not provide information on designing the culvert structure or minimum required cover depths. Technical Manual TM 5-330/AFM 86-3, Vol II (Headquarters, Departments of the Army and Air Force 1968) gives no information on box culverts under airfields. From this review, it is apparent that the design and evaluation of reinforced concrete box culverts have been given only limited consideration in the Army and Air Force technical manuals.

Navy

6. Airfield drainage is discussed in Section 6 of NAVFAC Design Manual DM-21 (Naval Facilities Engineering Command 1973). This design manual refers to the Army and Air Force technical manuals listed in paragraph 5 for "design procedures and criteria" related to "drainage and erosion control structures."

Federal Aviation Administration

7. Federal Aviation Administration (FAA) criteria for airfield drainage are given in FAA Advisory Circular 150/5320-5B (Federal Aviation Administration 1970). Section 15 of Chapter 4 in Advisory Circular 150/5320-5B addresses the loads on drainage structures such as box culverts. The design live load recommendations given in this Advisory Circular are:

- a. For spans 2 ft or less in the least direction, a uniform live load of 250 psi.
- b. For spans between 2 and 10 ft in the least direction, a uniform live load varying between 50 and 250 psi in direct proportion to the span length.

- c. For spans of 10 ft or greater in the least direction, the design should be based on the most critical loading condition applied by the various aircraft gear configurations.

While the design and installation of circular conduits and the design loads for box culverts are discussed, the advisory circular does not address the evaluation of existing in situ drainage structures.

International Civil Aviation Organization

8. The International Civil Aviation Organization (ICAO) Aerodrome Design Manual (1983) contains a chapter entitled "Structural Concerns for Culverts and Bridges" in which a large part of the chapter is devoted to the evaluation of subsurface structures. The Aerodrome Design Manual states that every subsurface structure beneath a pavement must be considered in connection with the evaluation of the pavement. This manual also states that the likelihood of a particular structure would prove more critical than the pavement in limiting the aircraft loads on the type, size, and location of the structure.

9. The Aerodrome Design Manual suggests some general guidance to assist in determining which structures can be considered not limiting and which structures are marginal or limiting thereby needing careful study and analysis. This general guidance is presented in Table 1 which is Table 7-1 in the Aerodrome Design Manual. This table indicates the thickness of protective cover of soil and pavement structure above drainage structures which will spread the load sufficiently, considering combining effects from adjacent wheels to reduce the pressure induced on the structure by the aircraft (live) load to less than 10 percent of the earth (dead) load. The guidance is based on aircraft wheel loads of 200 kN (approximately 44,866 lb) or less, and the premise that the live load on deeply buried structures tends to be only a small portion of the dead load so that small and medium size pipes or culverts will not accumulate a large share of the live load and limit surface loadings. Pipes or culverts with diameters or spans up to about one-third the listed depth of cover and at depths equal to or greater than that listed should not require a separate load limitation. Structures at depths shallower than those in Table 1 would require a more detailed analysis, and possibly would require a load limitation depending on the rigidity of the culvert, the bedding and backfill conditions, the existing pavement structure, and the amount of conservatism in the original design. The Aerodrome Design Manual recommends that

Table 1
Protective Cover Needed over Structures beneath
Aerodrome Pavements

<u>Number of Wheels*</u>	<u>Cover Depth, m</u>	<u>Cover Depth, ft**</u>
1	4	13.1
2	5	16.4
4	6	19.7
8	7.5	24.6
16	9.5	31.2

* Consider all wheels within or touching a circle whose diameter equals the depth of protective cover over the structure.

** This column was not in original table but added for reference in this report.

sufficient analysis be made either to confirm that the structure does not require a more critical load limitation than the pavement or to establish appropriate load limitations. This document also recommends that any structure whose span exceeds approximately one-third of the cover depth be carefully analyzed to determine the surface load limits or the need for strengthening.

10. From the design perspective, the Aerodrome Design Manual indicates that the dead load due to the weight of the pavement and soil over the structure and the live load induced by the aircraft or other vehicles on the pavement should be considered. The stress on the structure due to the dead loads can be determined directly from the weight of the material over the structure. The stresses induced by the aircraft wheel loads can be calculated using the theory for a uniformly distributed circular load on the surface of a continuum. The manual recommends the theory for an elastic layered continuum with suitable elastic constants (E,u) as the preferred method but states that a single-layer system (i.e. Boussinesq) will provide reasonable stress determinations.

11. The Aerodrome Design Manual gives some general guidance for the evaluation of culverts under aircraft loads; however, specific analysis procedures are not given.

PART III: SELECTION OF EVALUATION MODEL

12. In the initial stages of this study a literature review was performed to determine if computer codes were available that would allow rapid analysis of box culverts under aircraft loadings. Based on this review two programs were chosen for detailed evaluation. The two programs selected were the Federal Highway Administration's CANDE-1980 program and the US Army Corps of Engineers CORTCUL program.

CANDE-1980

13. The CANDE (Culvert Analysis and Design) computer program is a finite element computer program for the structural analysis and design of buried culverts. After its introduction in 1976 additional refinements and modifications were made and incorporated into the program which was renamed "CANDE-1980." The major capabilities of the CANDE-1980 program listed in the program documentation are:

- a. Automated finite element analysis of precast culverts with simplified input of embankment and trench installations is available. This is the so-called Level 2 solution. Two other solution levels are available in the program. They are Level 1, which is a closed form solution applicable only to circular conduits, and Level 3, which is a full finite element model requiring definition of the finite element grid and the culvert.
- b. Soil-structure interaction techniques are used for solutions.
- c. The Duncan nonlinear soil model option employing hyperbolic functions of the soils elastic and bulk moduli is available for use.
- d. Standard soil model parameters are stored in the program, thereby simplifying input requirements.
- e. Simplified data input options for the overburden dependent soil model are available.
- f. Iterative redistribution of stresses due to concrete cracking is modeled.
- g. Trilinear compression stress-strain concrete model with elastic unloading is available.
- h. Incremental load application is provided so that steel and concrete stress-strain relations are incremented tangent relations iteratively derived.

- i. Fourteen beam-rod elements are available for modeling a half cell or 28 beam-rod elements are available for modeling a whole cell.
- j. There is good correlation with out-of-ground tests including prediction of mode of failure either in flexure or diagonal cracking.
- k. There is good agreement between predictions of soil pressures at intermediate and final burial depths and measured values on a full scale installation.

14. Additional details on the CANDE-1980 program can be found in the program documentation which consists of four reports. These reports are CANDE-1980: Box Culverts and Soil Models (Katona et al. 1981); CANDE - A: Modern Approach for the Structural Design and Analysis of Buried Culverts (Katona et al. 1976); CANDE User Manual (Katona et al. 1976); and CANDE System Manual (Katone et al. 1976).

CORTCUL

15. The CORTCUL program can be used for the design or analysis of orthogonal, reinforced concrete culverts by either the working stress design (WSD) or the strength design (SD) procedures. The CORTCUL program follows as a minimum the procedures outlined in Engineer Manual EM 1110-2-2902 (Headquarters, Department of the Army 1969) dated March 1969 and is based on ACI 318-89 (American Concrete Institute 1989). The program models the culvert as a two-dimensional, linearly elastic, plane frame. The matrix stiffness method, modified to account for conditions at the member intersections is used to analyze the frame structure. Major features of the CORTCUL program are:

- a. It can be used in either the design or analysis mode.
- b. Design or analysis can be performed using either the working stress design or strength design procedures.
- c. The program determines the required thicknesses and reinforcement areas in the design mode.
- d. The program determines stresses and factors of safety in the analysis mode.
- e. The program provides single or multicell capability up to nine cells.
- f. The program allows a different value of concrete cover at four different locations in the culvert cross-section (e.g. exterior face of exterior members, interior face of roof and exterior walls, interior face of base slab, and tension face of interior walls).

- g. The program allows inclusion of the effects of the ground water level and internal water at various depths within one or more cells.
- h. The program allows up to eight special load types to be used in the analysis mode.

16. Additional details on the CORTCUL can be found in Users Guide: Computer Program For Design Or Investigation Of Orthogonal Culverts (CORTCUL) (Dawkins 1981).

Comparison of Programs

17. An evaluation of the CANDE-1980 and CORTCUL programs was performed by the Choctaw Engineering Company under contract to WES. The results of this evaluation were presented in a letter report entitled Development of an Evaluation Procedure for Reinforced Concrete Culverts under Airfield Pavements (Feng 1985). As a part of this evaluation, several test cases were run with each program. These test cases included several loading configurations (soil only, soil plus HS-20 highway load, and soil plus C-141 aircraft load) acting on two different culvert sizes (3 ft by 3 ft by 4 in. and 10 ft by 10 ft by 10 in.) with the culverts located at two different depths (3 and 10 ft). These test cases were run on a mainframe computer to evaluate the versatility, operating characteristics, data input and output formats, and feasibility for use in a culvert evaluation procedure. For the CANDE-1980 program only the Level 2 solution was used.

18. Because of the differences in the output of these two programs, a direct comparison of the results for the various test cases was difficult. In this evaluation Feng reported that the input for both programs was straightforward and that a structural engineer with 1 to 2 weeks training should be able to prepare the inputs and use the programs. The CANDE-1980 program required approximately 3 min more CPU time than did the CORTCUL program for the test cases run in the evaluation. Another difference in the programs is the difference in the way the live loads are applied to the culvert. The finite element nature of CANDE-1980 allows the live loads to be applied to the pavement surface with the program calculating the pressures acting on the culvert due to the live loads as well as the soil dead loads. However, the live loads cannot be applied directly, as in an aircraft wheel, but must be modeled as an equivalent transverse strip loading. With CORTCUL, the actual

live load cannot be applied to the surface with the program transmitting the stresses to the culvert. Instead, the pressures resulting from aircraft live load must be determined separately and applied to the culvert along with the pressures resulting from the soil dead load.

19. Feng summarized his analysis of the programs as follows:

- a. Both CANDE-1980 and CORTCUL are relatively easy to use and fast in computation.
- b. CANDE-1980 provides several capabilities such as different soil models, nonlinear analysis, incremental construction loading, and the ability to handle different culvert types that CORTCUL does not have.
- c. CANDE-1980 is more versatile of the programs, however a preprocessor for preparing the input files on a terminal is needed to expedite use of the program.
- d. CANDE-1980 is recommended for use in developing an evaluation procedure.

20. Upon completion of the evaluation by Choctaw Engineering Company, an additional evaluation was performed by WES personnel. One of the original goals of this research was to develop a rational, straight-forward culvert evaluation procedure for culverts under airfields that could be used by civil engineers with minimum effort. The additional evaluation was performed to determine which of the two programs was best suited to practicing general civil engineer (as opposed to researchers) with an average working knowledge of culverts, pavements, computers, and computer programs.

21. The additional evaluation consisted of running additional test cases using both CORTCUL and CANDE-1980. Several CANDE-1980 runs were made using the Level 2 option and the built-in finite element mesh. Additional runs were made using the Level 3 option with a user defined mesh. For the test cases used in this study, it was found that the results obtained with CANDE-1980 varied some, depending on whether the Level 2 solution or the Level 3 solution was used. Part of this disparity may have been because of differences in the mesh used in the Level 3 solution and the built-in Level 2 mesh. This additional evaluation of the CANDE-1980 program indicated that there are several different methods for applying the aircraft load to the culvert model. It was found that the manner in which the load was applied (i.e. as a strip, point, etc.) changed the results of the analysis. No standard method for defining the applied loads was given in the users guide which makes proper selection of the CANDE live loads difficult. As with the

Choctaw Engineering Company evaluation of the programs, direct comparison of the CANDE-1980 results versus the CORTCUL results was difficult because of the differences in the output data.

22. From the results obtained in this study, it appears that both CANDE-1980 and CORTCUL produce reasonable results. Although a complete check of each program's accuracy was beyond the scope of this research effort, both the literature and limited hand computations performed as a part of this study indicate that both programs provide accurate results.

Selection of Program

23. Based on the evaluations performed, it was found that each of the two candidate programs had its major advantages and disadvantages. Table 2 summarizes these advantages and disadvantages. In the selection of a program for use as the basis of a culvert evaluation procedure, one of the key points for consideration was the intended user of the evaluation procedure. It is anticipated that the typical user will be a civil engineer at a military installation or other government design agency or a private engineering organization.

24. Based on the advantages and disadvantages of the candidate programs outlined in Table 2 and experience using both of the programs, the CORTCUL program was selected for use in the development of the culvert evaluation procedure. The CANDE-1980 program appears to be a good, powerful analytical tool for evaluating all types of culverts. However, the major disadvantages outlined in Table 2, especially the difficulty in defining the method of live load application and the difficult and time-consuming data input requirements, make the CANDE-1980 program less attractive for use in the development of a routine evaluation procedure. The CANDE-1980 program will continue to be an excellent tool for researchers and in other applications where there is sufficient data and need to require the use of a sophisticated analytical model. The CORTCUL program, while lacking some of the versatility of the CANDE-1980 program, is better suited for the intended application. The strength design and working stress design procedures for reinforced concrete design used in CORTCUL are familiar to structural engineers. Data input is easier using CORTCUL and the analysis results are output in a logical, easy-to-use format. An additional important consideration was the availability of the CORTCUL

Table 2

Advantages and Disadvantages of Candidate Programs
for Use in an Evaluation Procedure

<u>Program</u>	<u>Advantages</u>	<u>Disadvantages</u>
CANDE-1980	Finite Element Analysis. Provides powerful modeling capabilities, and good level of detail when used properly. Soil-structure interaction techniques used in program assist in modeling effects of soil backfill/overburden of structure and structure effects on soil. Various soil models available for use in the problem solutions.	Requires mainframe computer. Four documents comprising User's Guide and Systems Manual are often hard to follow. Data input requires formatted data cards. Working knowledge of the finite element method required for effective use of the program. Data output often difficult to interpret. Method of live load application is uncertain.
CORTCUL	Can be used for design or evaluation. Problem solution using either working stress design or strength design procedures using standard ACI-318 procedures. Data may be input interactively from a terminal or from a data file. Interactive data input is "user friendly." Data output is straightforward and easy to use. Available for microcomputer (personal computer) or mainframe.	All loads acting on structure, including soil effects, must be input. Aircraft load cannot be applied directly but must be applied as pressure acting at the depth of the culvert. Does not use soil-structure interaction techniques.

program on floppy disk which allows rapid use of the program on a personal computer without having to access a mainframe system.

25. The remainder of this report deals with the development of an evaluation procedure for reinforced concrete box culverts using the CORTCUL program.

PART IV: DEVELOPMENT OF EVALUATION PROCEDURE

26. The culvert evaluation procedure reported herein is based on the CORTCUL computer program for the design and investigation of orthogonal culverts. The specific procedures developed herein are applicable to aircraft loads; however, the general procedures are applicable to any highway or aircraft type of loading. In the development of this procedure the strength design procedure is used in the analysis of the structure.

27. The CORTCUL program is readily available through the Corps of Engineers Conversationally Oriented Real-Time Program Generating System (CORPS) library. The program is designated X0024 in the CORPS system and is available for use on either a mainframe computer or on a personal computer. The development of this evaluation procedure for airfield culverts did not require any modifications to the CORTCUL program itself. The major part of the development consisted of determining the best means for applying the aircraft loads to the structure, developing the CULSTR program for determining the live load acting on the culvert due to the aircraft and conducting parameter studies using the CORTCUL program.

Introduction to CORTCUL

28. CORTCUL allows the user to select either the SD or the WSD procedures for the design or analysis of an orthogonal, reinforced concrete culvert. The WSD procedures used by the program are in accordance with the Corps' most recent manual on culverts which is Engineer Manual EM 1110-2-2902 (Headquarters, Department of the Army 1969). The SD procedures are in accordance with ACI 318-63 (American Concrete Institute 1963). These procedures are generally the same in later editions of the ACI Code, most recent version ACI 318-89, for the types of computations performed by CORTCUL. CORTCUL also includes a computation developed specifically for computing the allowable shear stress on thick-walled culverts as described in University of Illinois Structural Research Series No. 440 (Gamble 1977).

29. In the CORTCUL program a 1-ft-wide slice of the culvert is assumed to behave as a linearly elastic, plane frame structure. The culvert slice is reduced to an assemblage of line frame members which lie along the center lines of the culvert walls and slabs. Joints are defined at the intersections

of these members. A matrix stiffness method that has been modified to account for conditions at the intersections of the members is used to analyze the structure. CORTCUL assigns infinite axial and flexural stiffness to portions of the members in the vicinity of the joints as recommended in the University of Illinois Structural Research Series No. 164 (Diaz De Cossio and Siess 1959) and the University of Illinois Structural Research Series No. 440 (Gamble 1977). In structural frames of normal proportions the frame is usually idealized as a line structure with member stiffnesses that are unaffected by material in the joints. However, as the widths of the supporting members become larger relative to the span, the effects of these widths on the moment distribution should be considered. The analytical procedure in CORTCUL modifies the stiffness matrix to account for the effects that the joint areas have on the flexural stiffnesses of the members. The result is increased accuracy in determining the forces acting within the members of a culvert.

30. The culvert used in the analysis is assumed to be a monolithic reinforced concrete structure with the following characteristics:

- a. A constant thickness horizontal roof slab covers the width of the structure.
- b. The exterior vertical walls have the same thickness.
- c. All interior vertical walls have the same thickness.
- d. The horizontal base slab has a constant thickness throughout the width of the structure.
- e. The culvert encloses from one to nine openings (cells).
- f. All cell heights are constant.
- g. Cell widths may differ in the investigation mode, but must be constant in the design mode.
- h. Haunches may be specified at the intersections of vertical and horizontal members with 45 deg haunches of equal size assumed at every intersection.
- i. The invert elevation is fixed.
- j. Non-prestressed reinforcement is assumed to exist in each member of the culvert.

Additional details on the program can be found in the CORTCUL User's Guide (Dawkins 1981).

Application of Loads

31. The loads applied to the culvert structural model are the dead load of the roof member, dead load of the vertical walls applied to the bottom slab, lateral earth pressure on the vertical side walls, vertical earth loads applied to the roof member, vertical and horizontal loads imparted by the internal water, and vertical loads applied to the roof member by the various aircraft. Figure 1 shows the general culvert/soil/water system used in CORTCUL along with the member designations. In this culvert evaluation procedure the standard load cases that are available in CORTCUL are not used. All loads are applied as special loads using from one to four special load cases. This means that all of the loads acting on the culvert are applied directly on the member as program inputs. Figure 2 presents the typical loading conditions used in a culvert evaluation. Figure 3 is a worksheet that is used for determining the loads to be applied to the members. Each of these loads will be discussed in detail in the following paragraphs.

Load factors

32. The SD procedure used in CORTCUL is based on ACI 318 and requires that the load, shear, or moment be obtained by applying load factors to the service values. Typically, the dead load factor is 1.4 and the live load factor is 1.7. Load factors are to account for the possibility that service loads may be exceeded. Obviously, it is more probable that a specified live load will be exceeded than will a dead load, which is generally fixed by the weight of the construction. Although the soil surrounding a culvert is considered to be somewhat permanent, it is not considered a dead load in the sense of being as well defined as the dead weight of the reinforced concrete structure. Therefore, in the design and/or analysis of a structure the earth pressure is typically accompanied by a load factor of 1.7 as specified in ACI 318-89 (American Concrete Institute 1989) and Engineer Technical Letter ETL 1110-2-312 (Headquarters, Department of the Army 1988). All of the dead loads due to the weight of the culvert members should be increased by a 1.4 dead load factor. Since the analytical procedure described in this report uses the CORTCUL special load cases, and since CORTCUL assumes that all of the special loads are live loads and automatically applies the 1.7 live load factor, an additional factor of $1.4/1.7 = 0.8235$ must be applied to the dead loads.

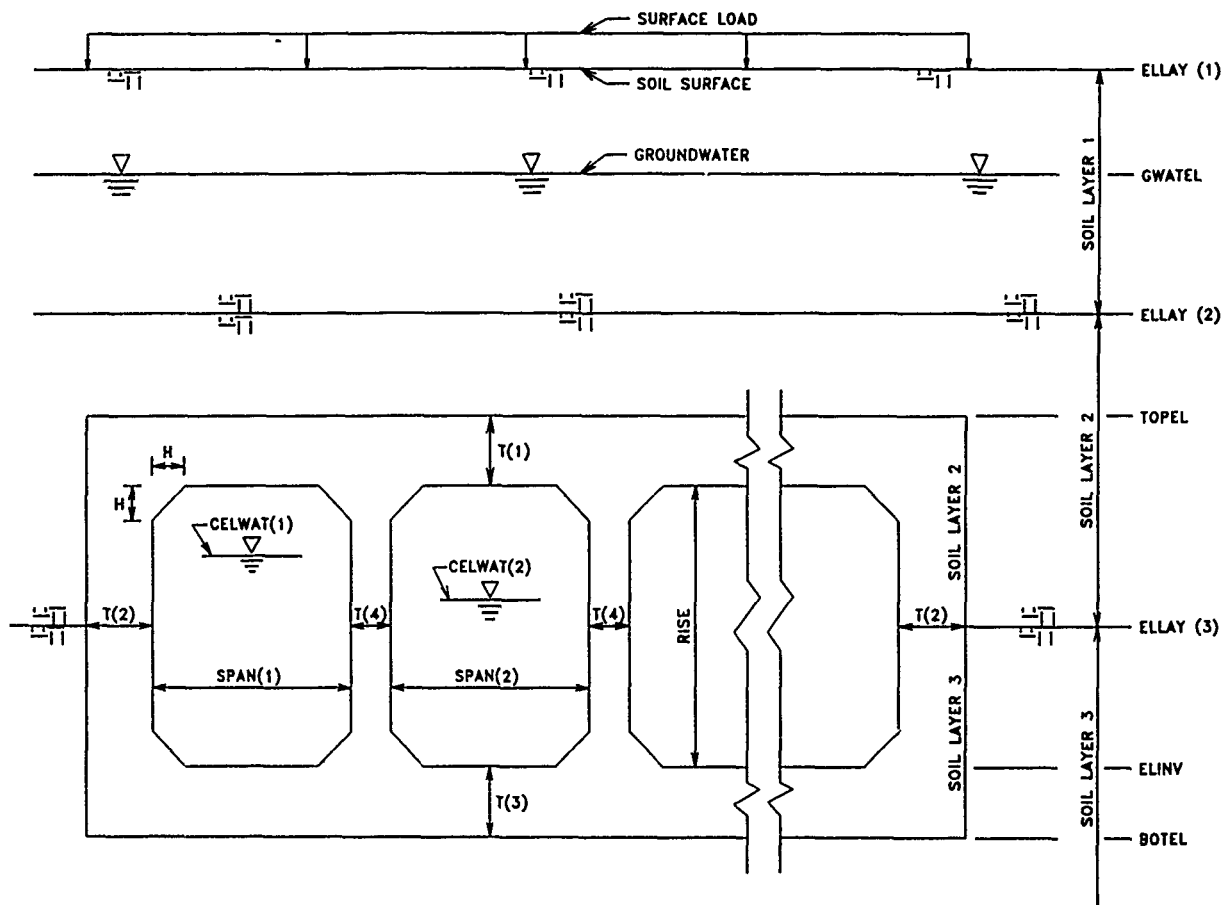


Figure 1. Culvert soil water system

Roof member dead load

33. The roof member dead load is calculated from the dimensions of the member assuming a unit weight of reinforced concrete of 150 pcf. The equation for calculating this load is:

$$DWPR = (\gamma_c) \times T(1) \times (1.4/1.7) \quad (1)$$

where

DWPR = roof member dead load in pounds per linear foot

γ_c = unit weight of reinforced concrete (normally assume 150 pcf)

T(1) = roof member thickness in feet

The roof member dead load is applied as a uniform load across the top members as shown in Figure 2.

Vertical wall dead load

34. The dead load of the vertical walls acting on the bottom slab is applied as a vertical concentrated load acting at the joints between the

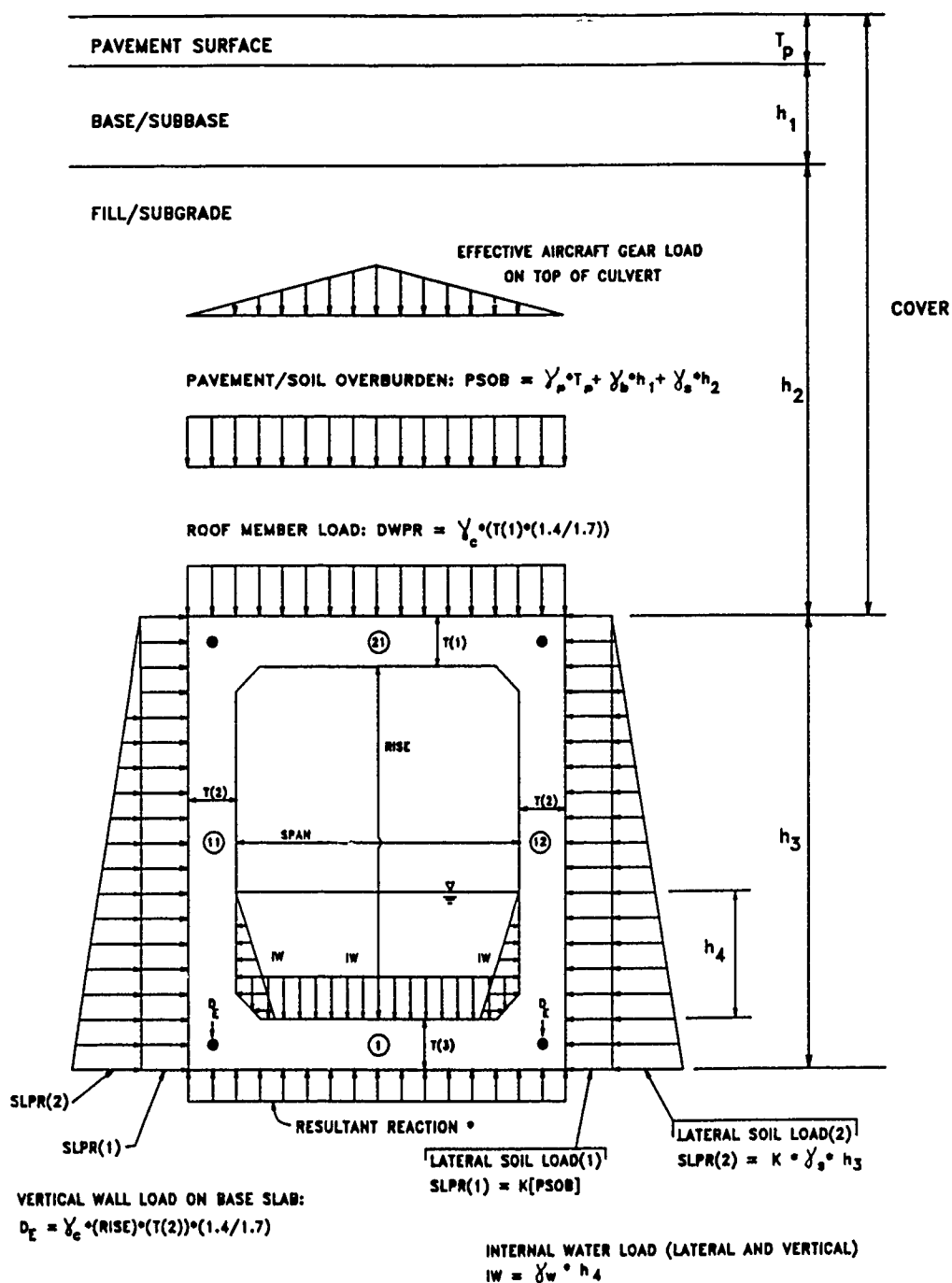


Figure 2. Loading conditions for evaluation

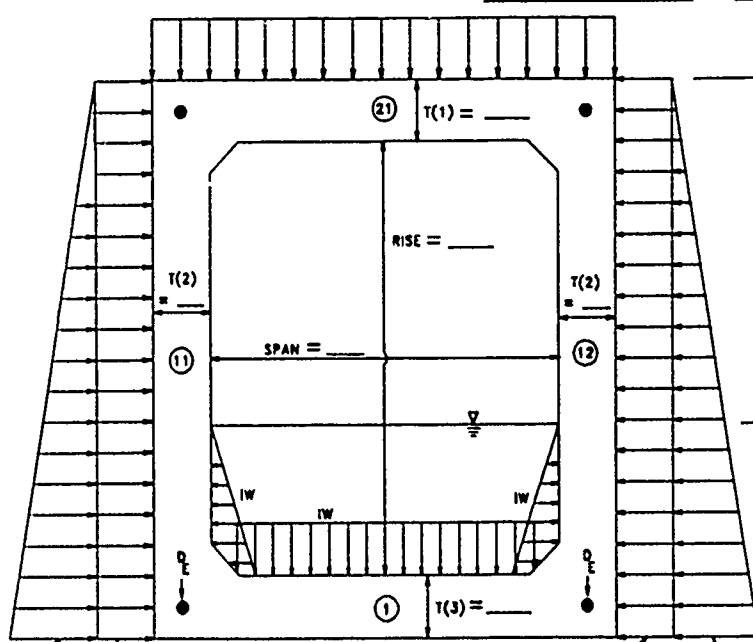
PAVEMENT SURFACE	$\gamma_p =$ _____	$T_p =$ _____	
BASE/SUBBASE	$\gamma_b =$ _____	$h_1 =$ _____	
FILL/SUBGRADE	$\gamma_s =$ _____ $K =$ _____		

COVER
= _____

PAVEMENT/SOIL OVERBURDEN: $PSOB = \gamma_p \cdot T_p + \gamma_b \cdot h_1 + \gamma_s \cdot h_2$
 = _____ + _____ + _____ = _____ psf


 $h_2 =$ _____

ROOF MEMBER LOAD: $DWPR = \gamma_c \cdot (T(1)) \cdot (1.4/1.7)$
 = _____ = _____ psf



$h_3 =$ _____

 $h_4 =$ _____

VERTICAL WALL LOAD ON BASE SLAB:
 $D_E = \gamma_c \cdot (RISE) \cdot (T(2)) \cdot (1.4/1.7)$
 = _____
 = _____ psf

LATERAL SOIL LOAD(1)
 $SLPR(1) = K[PSOB]$
 = _____
 = _____ psf

LATERAL SOIL LOAD(2)
 $SLPR(2) = K \cdot \gamma_s \cdot h_3$
 = _____
 = _____ psf

INTERNAL WATER LOAD (LATERAL AND VERTICAL)
 $IW = \gamma_w \cdot h_4 =$ _____ = _____ psf

Figure 3. Load application worksheet

vertical walls and the bottom slab. The loads, due to the external vertical walls, are calculated using the equation:

$$DE = [(\gamma_c) \times \text{Rise} \times T(2)] + [DWPR/2] \times (1.4/1.7) \quad (2)$$

where

DE = load of exterior vertical wall acting on the base slab in pounds

γ_c = unit weight of reinforced concrete (normally assume 150 pcf)

Rise = height of the culvert opening in feet

T(2) = exterior wall thickness in feet

DWPR = roof member dead load in pounds per linear foot

If the culvert is a multicell culvert, the load on the base slab due to the interior wall is calculated from Equation 3 as follows:

$$DI = [(\gamma_c) \times \text{Rise} \times T(4)] + [DWPR/(NIW + 2)] \times (1.4/1.7) \quad (3)$$

where

DI = load of interior vertical wall acting on the base slab in pounds

γ_c = unit weight of reinforced concrete (normally assume 150 pcf)

Rise = height of the culvert opening in feet

T(4) = interior wall thickness in feet

DWPR = roof member dead load in pounds per linear foot

NIW = number of interior walls

The weight of the base slab is assumed to have no influence on the internal forces in the structure.

Soil pavement overburden

35. The vertical load applied to the roof member by the overlying soil and pavement is taken to be the unit weight of the material multiplied by the depth of the material. This load is calculated from Equation 4 and is applied as a uniform load across the roof member, as shown in Figure 2.

$$PSOB = \gamma_p * T_p + \gamma_b * h_1 + \gamma_s * h_2 \quad (4)$$

where

PSOB = uniform load due to the pavement and soil in pounds per foot

γ_p = unit weight of the pavement surface material in pcf

T_p = thickness of the pavement surface material in feet

γ_b = unit weight of the granular pavement materials (base/subbase) in pcf

h_1 = thickness of granular or soil material between the bottom of the pavement surface and the top of subgrade in feet

γ_s = unit weight of soil (backfill or subgrade) in pcf

h_2 = thickness of soil between bottom of granular layer and top of culvert in feet

Note that if the pavement is a composite pavement (asphalt over concrete) then there would be two different values for γ_p and T_p . In general for this evaluation, the layers of granular material (base and subbase) can be considered as one layer providing that the density of both layers is approximately the same. The same is true for layers of soil backfill over the culvert. If there is a significant difference in material density, the different material should be treated separately, adding another $\gamma \cdot h$ term to Equation 4.

Lateral earth pressure

36. The lateral earth pressure against the vertical exterior walls is calculated assuming a triangular distribution with depth. For input into the program the loads are broken into two components, a uniform load and a triangular load, as shown in Figure 2. The equations for calculating the lateral earth pressure against the culvert walls are:

$$SLPR(1) = k * [PSOB] \quad (5)$$

where

SLPR(1) = uniform load component of the lateral soil load in pounds per foot

k = coefficient of lateral earth pressure

PSOB = pavement/soil overburden load

and

$$SLPR(2) = k * \gamma_s * h_3 \quad (6)$$

where

SLPR(2) = triangular load component of the lateral soil load in pounds per foot

k = coefficient of lateral earth pressure

γ_s = unit weight of soil in pcf

h_3 = distance from top to bottom of culvert

American Society for Testing and Materials (ASTM) C-789 recommends a minimum lateral earth pressure coefficient, k , of 0.25 (ASTM 1989). While it is impossible to accurately access the actual lateral earth pressure loads on the

culvert walls, analysis of the adequacy of the culverts under aircraft loads is not very sensitive to the assumed lateral earth pressure coefficient. This will be discussed in the section dealing with parameter studies.

Internal water

37. For the standard load cases, CORTCUL computes the hydrostatic pressures that result from a specified internal water level in each cell of the culvert. Because only the special load cases are used in this evaluation, all of the internal water loads must be input. These loads are appropriately considered to be live loads. The effects of the internal water should be included in the analysis if the water is present the majority of the time. As shown in Figure 2, the force of the internal water will act on both the culvert walls and the base slab. The force on the walls will be proportional to the water depth with the maximum pressure at the bottom of the wall. The force on the base slab is equal to the maximum force at the bottom of the wall and is calculated as follows:

$$IW = \gamma_w * h_4 \quad (7)$$

where

IW = internal water pressure in pounds per foot

γ_w = unit weight of water or 62.4 pcf

h_4 = height of internal water in feet

Aircraft live load

38. For this evaluation, the aircraft live load applied at the pavement surface is the static load that is equal to the gross weight of the aircraft traversing the culvert. The aircraft live load applied to the culvert is the vertical stress at the top of the culvert resulting from the aircraft load on the pavement surface. The recommended method for determining the vertical stress on the culvert due to the aircraft is presented in the following section. Figure 4 is a worksheet that will be helpful in determining the effective aircraft loads.

Reactions

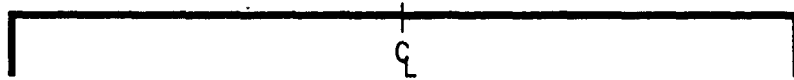
39. Resultants due to vertical loads are automatically balanced by vertical distributed forces acting on the horizontal members of the culvert. Resultants due to horizontal loads are balanced by uniformly distributed horizontal force on the top and bottom culvert members. Only compressive

EFFECTIVE AIRCRAFT LOADS

CULVERT LOCATION: _____

CULVERT SIZE: _____ COVER DEPTH: _____

AIRCRAFT: _____



AIRCRAFT: _____

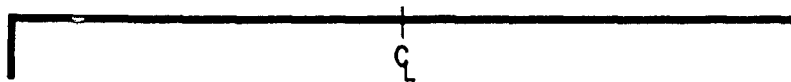


Figure 4. Aircraft load worksheet

reactions are permitted. All of the reactions are accounted for automatically within the computer program, and no user input is required for them.

Determination of Aircraft Live Loads

40. To assist in determining the aircraft load acting on top of the culvert, an existing layered-elastic computer code was modified. The layered-elastic approach was chosen because it is applicable to any type of pavement construction (flexible, rigid, composite, and unsurfaced), provides a realistic estimation of the stresses acting on the culvert due to the aircraft, and provides one method for estimating the aircraft live load acting on the culvert regardless of pavement type, and it could be developed with relative ease using available layered-elastic computer programs. CULSTR uses the WES5 layered-elastic program (Van Cauwelaert, Delaunois, and Beaudoint 1987) along with pavement structure and aircraft data to calculate the vertical stress at the specified depth and preset offsets under the aircraft gear. An interactive data input program INSTR was also developed and is used to build the data file of the pavement structure and aircraft data that are required by CULSTR. CULSTR uses WES5 as its basic calculation routine and has been preprogrammed with the aircraft characteristics for a number of military and civilian aircraft. These aircraft characteristics are contained in the data file VEHDATA. For a given aircraft and depth below the pavement surface, CULSTR determines the location of maximum vertical stress and then calculates the vertical stress at a number of longitudinal offsets through that location. The program then gives the user a choice of looking at a plot of the stress distribution on the screen, printing the plot, or printing the calculated stresses.

41. To provide the user with a complete culvert evaluation package, the program CULVERT has been developed and included in this report. This program includes the files INSTR, CULSTR, VEHDATA, QUIKVIEW, X0024, and file manipulation utilities. Computer requirements for running this package are a personal computer running the DOS operating system (Version 3.3 or higher) with a 5-1/4-in. high-density floppy disk drive and a hard disk drive with at least 1 megabyte (mb) free. The system should have at least 512 kilobytes (k) of RAM, a math co-processor and a graphics adapter card. A brief user's guide for the CULVERT program is presented in Appendix A. The procedures and programs developed in this study and the information given on CORTCUL in this

report are presented as a supplement to the detailed information given in the CORTCUL User's Guide (Dawkins 1981). It is recommended that the user obtain and study the CORTCUL User's Guide prior to performing the culvert analysis presented herein.

Verification of Aircraft Loading Methods

42. To verify that the method discussed above does provide a reasonable estimate of the vertical stress that is to be applied to the top of the culvert, a parameter study using a general purpose two-dimensional finite element program and a general purpose three-dimensional finite element program was performed. A typical reinforced concrete box culvert was modeled in the finite element mesh. The aircraft wheel loads were applied to the mesh as a surface load in the same manner as the aircraft would load the pavement. The vertical stresses and displacements in the soil above the culvert and at the top of the culvert were determined. Comparisons of the results from the layered elastic analysis with the results from the general finite element programs indicated that the layered elastic analysis provided a reasonable estimate of the vertical stress due to the aircraft load. Based on this verification, it is recommended that a layered elastic procedure be used to determine the vertical stress acting on the roof of the culvert.

Parameter Studies Performed

43. During the development of this culvert evaluation procedure several parameter studies were performed using CORTCUL to determine the effect of varying the lateral earth pressure coefficient, varying amount of internal water, and using various combinations of live load and dead load factors. The results of these parameter studies are presented in Appendix B and will be discussed in the following paragraphs.

Varying lateral earth pressure

44. The first parameter that was varied to determine its effect on the analysis was the lateral earth pressure coefficient, k . The CORTCUL program was run for a 13-ft span with 3.0-ft cover. Runs were made using lateral earth loads calculated using k values of 0.25, 0.40, and 0.50. The program multiplies these loads by the load factor of 1.7 thereby increasing the

effective lateral earth pressure coefficient to 0.425, 0.68, and 0.85, respectively. Detailed results of these evaluation runs are presented in Table B1 of Appendix B. Based on the results of this study, it was concluded that, although the midspan moment ratio is sensitive to the lateral earth pressure coefficient for the soil only case, the change in midspan moment ratios for culverts under aircraft loadings is relatively insensitive to changes in the lateral earth pressure coefficient. This indicates that the evaluation of box culverts under aircraft loads is relatively insensitive to changes in the lateral earth pressure coefficient.

Varying internal water depth

45. CORTCUL runs were made for the 13-ft span by 11.5-ft rise culvert with 3.0 ft of cover using the soil only load case, four different aircraft loadings, and internal water depths of 0 ft (no water), 5.75 ft (50 percent full), and 11.5 ft (100 percent full). These results are presented in Table B2 of Appendix B. Comparison of the results indicates that for the soil only case, the 100 percent full condition was the most critical in regard to the moment ratio at the midspan of the top and side members. In this case the top member midspan moment ratio was 10 percent lower for the 100 percent full condition as compared to the no water condition. In the side members the midspan moment ratio for the completely full culvert was 80 percent lower than the no water case. Analysis of the culvert under aircraft loadings continued to show the 100 percent full condition as the most critical; however, the change in moment ratio between the no internal water case and 100 percent full case decreased as the aircraft load applied increased. For the relatively light C-123 aircraft, the moment ratio at the midspan of the top member with the culvert full was 10 percent less than the empty condition. However, the midspan moment ratio of the side members decreased by approximately 27 percent when the culvert was full. As the aircraft load increased the difference between these side member moment ratios decreased to less than 10 percent. As in the soil only case for aircraft loadings, the internal water has the greatest effect on the sidewall midspan moment ratio. However, the change in the sidewall moment ratio due to changes in the internal water level is considerably smaller when the culvert is subjected to the aircraft loadings. Analysis for different aircraft indicates that as the aircraft load on the culvert increases, the effect of the internal water on the culvert members decreases.

Varying load factors

46. For this analysis four different load cases were considered. The first case was the normal evaluation where the required strength was

$$\begin{aligned} \text{Required Strength} = & (1.4 \times \text{roof member load}) + (1.7 \times \text{overburden}) \\ & + (1.7 \times \text{aircraft load}) + (1.7 \times \text{lateral earth load}). \end{aligned}$$

The second case was where the required strength was

$$\begin{aligned} \text{Required Strength} = & (1.2 \times \text{roof member load}) + (1.2 \times \text{overburden}) \\ & + (1.2 \times \text{lateral earth load}) + (1.44 \times \text{aircraft load}). \end{aligned}$$

The required strength for load case three was defined by

$$\begin{aligned} \text{Required Strength} = & (1.2 \times \text{roof member load}) + (1.2 \times \text{overburden}) \\ & + (1.2 \times \text{lateral earth load}) + (1.74 \times \text{aircraft load}). \end{aligned}$$

The fourth load case required strength was defined by

$$\begin{aligned} \text{Required Strength} = & (1.2 \times \text{roof member load}) + (1.2 \times \text{overburden}) \\ & + (1.2 \times \text{lateral earth load}) + (2.24 \times \text{aircraft load}). \end{aligned}$$

Detailed results of this part of the parameter study is presented in Table B3 of Appendix B. Comparison of these results indicates that the moment and shear ratios at the midspan of the top member increased by approximately 15 to 20 percent by reducing the load factors. Reduction of the load factors resulted in the midspan moment ratios of the side members to be decreased by approximately 28 to 31 percent while the shear ratios at midspan increased from 7 to 18 percent.

Conclusions from parameter studies

47. It was concluded from the parameter studies that

- a. Using a lateral earth pressure coefficient, k , of 0.25 is conservative with respect to the moment ratio at the midspan of the top member.
- b. Changing the lateral earth pressure coefficient, k , has little effect on the analysis of box culverts under aircraft loads.
- c. Assuming no internal water in the culvert is unconservative in regard to the moment ratio at the midspan of the top and side members; however, this unconservatism decreases as the aircraft load on the culvert increases. If the culvert being evaluated carries water the majority of the time, the effect of this internal water should be considered in the analysis.
- d. If it is assumed that the loads are well-defined (possibly justifying use of lower load factors), then a reduction of the evaluation load factors as shown in the combinations above will produce an increase in the moment ratio at the midspan of the top member by as much as 20 percent. While the use of the larger load factors is conservative and could possibly result in some culverts being rated as inadequate, the uncertainties

in this procedure prohibit the reduction in the load factors from those specified in Chapter 9.2.4 of the ACI Code (ACI 1989).

PART V: PROCEDURE FOR EVALUATING REINFORCED CONCRETE
BOX CULVERTS UNDER AIRCRAFT LOADS

General

48. A general procedure is provided for the evaluation of reinforced concrete box culverts under airfield pavements using the computer program CORTCUL. Prior to using this procedure and the CORTCUL program, a field inspection of the culvert is necessary. This field inspection should include determination of the pavement structure that exists over the culvert. In addition the culvert itself should be inspected. Details of the inspection procedures are beyond the scope of this report but are covered in detail in the FAA's Culvert Inspection Manual (Arnoult 1986). A recommended list of tools and equipment and a summary of key items that should be documented during the field inspection and data collection are given in the next section.

49. Evaluation of culverts under airfield pavements is not required each time an airfield pavement is evaluated. It is recommended that culvert evaluations be performed if the using agency planned to apply an aircraft class not considered in the original design (e.g. a light duty airfield is to support heavier aircraft), a highway or similar facility is being considered for or transformed into an emergency landing strip, or if there are indications in the pavement over the culvert or in the culvert itself indicating that the culvert is being overstressed.

Field Inspection of Culverts

50. Prior to conducting the field inspection of culverts under airfields or landing strips, the evaluation team should obtain a set of plans or a listing showing the location, type, and size of all of the culverts under the facility. For the box culverts a set of as-built or construction drawings showing details including the wall thicknesses, reinforcement steel sizes and locations and other details is required. If available, a copy of the construction specifications should also be obtained. Having these on hand will aid in the culvert inspections.

Tools and Equipment

51. Tools and equipment that will be helpful in the inspections include:

- a. Cloth tape (100 or 200 ft).
- b. Tape (25 ft).
- c. Ruler (6 ft).
- d. Caliper (6 in.).
- e. Geologist's hammer.
- f. Wire brush.
- g. Ice pick.
- h. Surveyors level.
- i. Level rod.
- j. Brush hook or machete.
- k. Flashlight (hat-mounted preferable to hand held).
- l. Camera and flash.
- m. Marking instruments such as lumber crayon or paint.

Inspection of Reinforced Concrete Box Culvert

52. Items that must be documented during field inspections include:

- a. Location: Station number
Skew (If any)
- b. Geometry: Overall height (ft)
Overall width (ft)
Number of cells
Cell rise, internal height (ft)
Cell span internal width for each cell (ft)
Haunch width (in.)
Roof thickness (in.)*
Exterior wall thickness (in.)*
Base slab thickness (in.)*
Interior wall thickness (in.)

* May not be able to determine in the field.
- c. Structural properties: (All Items Determined from Plans, Specifications, and Quality Control Reports)
Ultimate concrete strength (psi)
Reinforcement steel yield strength (psi)
Unit weight of concrete (pcf)
Reinforcement steel areas (sq in.)
Reinforcement steel cover distance (in.)

d. Pavement/soil layers:

Number of layers from top of pavement to top of culvert.

Layer thickness, density, and strength (CBR) for each layer. (This can be determined from nearby test pit or boring data.)

Elevation of water table, if above the bottom of culvert.

- e. Depth: Distance from top of pavement to top of culvert and to culvert invert. In many cases you will not be able to find the top of the culvert. The invert elevation combined with measurements of cell rise and roof thickness data will allow the elevation of the top of the culvert to be determined. Also, do not be fooled by the headwall that is normally located at the ends of a box culvert. This is typically a foot or more higher than the actual top of the culvert. This is a critical measurement and should be determined with care. If unsure of the amount of cover over the top of the culvert, one should excavate (dig or auger) down to accurately determine the cover depth.

- f. Internal water: Record if there is water present in the culvert. If there is, record the depth of the water in the culvert and, if possible, inspect for any high water marks that will indicate the maximum elevation of the water in the culvert.

- g. Condition: Note the condition of the culvert. Record the occurrence of major cracks, breaks, broken joints, sags, and other abnormalities. These indicate that the culvert is or has been overstressed and may not support the full load that an undamaged culvert would support.

- h. Overall condition: Note the condition of the pavement over the culvert. Record any signs of settlement or cracking in the pavement directly over or adjacent to the culvert. Pavement cracking or depressions over the culvert indicate that settlement is occurring that may be increasing the loads acting on the culvert. Note the condition of the waterways on both the upstream and downstream side of the culvert indicating whether the waterways are clear or if there is vegetation growing, blocking the flow of water. Look for scour or blowouts at the downstream end of the culvert that would undermine the culvert. Record any of these conditions or any other suspicious condition.

Evaluation of Reinforced Concrete Box Culverts

53. The structural capacity of reinforced concrete box culverts is determined using the CORTCUL computer program. To use this, program information on the culvert is input along with the live loads due to the aircraft and the dead loads due to the surrounding soil and the members themselves. As previously discussed, the CULSTR program can be used to estimate the aircraft live loads. Details of using CULSTR are presented in Appendix A, and the details of the analysis using CORTCUL are presented in the report User's Guide: Computer Program For Design Or Investigation Of Orthogonal Culverts (CORTCUL) (Dawkins 1981) hereafter referred to as the User's Guide.

54. It is recommended that each aircraft be evaluated for at least two positions on the culvert. The first position should be with the aircraft load centered over the center line of the culvert midspan. The second position should have the aircraft load centered over one of the quarter points on the culvert span. In the event the culvert under evaluation is a multicell culvert the evaluation should be performed with the aircraft load centered over the midspan of one cell, at the quarter-point of one cell, and over the interior wall. The most critical evaluation for each member will then be taken as the evaluation for the culvert.

55. Much of the information necessary to evaluate a box culvert will be determined from pavement test data taken in the vicinity of the culvert, a visual inspection of the culvert, and the culvert's design data. Even with this information the engineer may have to make decisions about some parameters required by the program. The following paragraphs provide an overview of the steps in using the CORTCUL program. For details on the procedures, assumptions, and other requirements of using CORTCUL, see the CORTCUL User's Guide (Dawkins 1981).

Data Input

56. All data input into the CORTCUL program is read in free field format which means that each data input must be separated by one or more blanks. There are two ways in which data can be input into the CORTCUL program. Input data may be provided interactively from the user terminal during execution or from a previously prepared data file. Data entered during execution can be

stored to a file for later use or can be used in the executed run only. Several options are available regarding the amount and destination of output from the program. The user may direct the output to the terminal, to an output file, or to both. It is recommended that the output be saved in a permanent file and subsequently listed on a high speed printer. Appendix A in the CORTCUL User's Guide provides additional detailed information on the data input. Note that analysis of the culverts for aircraft loadings must be performed using the special load cases. The standard load cases are set up to run the "soil only" analysis and cannot take into account the aircraft loadings. When using the special load cases, all of the load data including the member loads, internal water loads, soil loads, and aircraft loads must be input into the data file. A brief step-by-step input data sequence and description is listed below.

- a. Heading--Alphanumeric characters used for job identification.
- b. Mode--Choose investigation mode (I) for culvert evaluations.
Method--Either working stress design (WSD) or strength design (SD). Normally choose SD.
- c. Material properties--Ultimate concrete strength (psi), reinforcement yield strength (psi), and the concrete unit weight (pcf).
Design factors--Maximum tension steel ratio and strength reduction factor. Omit both if method = WSD. The maximum tension steel ratio, $\rho = A_s/bd$ where A_s = area of tension steel, b = width of member, and d = effective depth of member (distance from compression face to centroid of the tension steel). The strength reduction factor, ϕ , can be computed by CORTCUL or may be user specified. ACI 318-89 specifies $\phi = 0.90$ for flexure without axial load, or with axial tension $\phi = 0.70$ for axial compression, or flexure with axial compression $\phi = 0.85$ for shear and torsion.
- d. Culvert geometry--Number of cells, height of cell opening (ft), haunch width (in.), elevation of invert (ft), and width of cell opening (ft).
- e. Reinforcement cover--Distance in inches from centroid of reinforcement to exterior surface of all exterior members, to interior surface of roof and exterior walls, to interior face of base, and to tension face for all interior walls (Omit last item if number of cells = 1).
- f. Member thicknesses--Thickness in inches of roof member, exterior walls, base, and interior walls (Omit last item if number of cells = 1).
- g. Maximum reinforcement areas. (Omit for mode = Investigation)--These are the maximum permissible reinforcement areas for culvert design and are not used in investigation.

- h. Soil data--Number of soil layers, elevation at top of layer (ft), saturated unit weight of layer (pcf), and the moist (submerged) unit weight of layer (pcf).
- i. Standard load case data--For this evaluation procedure standard load cases are not used, enter 0 for number of standard load cases, and none of the other data are required. Number of standard load cases, unit weight of water (pcf), standard load case coefficients: coefficient for vertical soil pressures, coefficient for horizontal soil pressures, surface surcharge (pcf), and groundwater elevation (ft).
- j. Special load data--All loads applied to the culvert in this evaluation procedure are applied using the special load cases. Each load is input separately. Data for the special load cases include number of special load cases (enter 1 to 4) and special load case data to be entered for each special load case. Special load case data are number of member load lines (enter 1 to 84) and member load line data as follows for each load:
 - (1) Member number
 - (2) Load type
 - (a) C for concentrated load
 - (b) U for uniform load
 - (c) T for triangular load
 - (3) Load magnitude
 - (a) pounds per linear foot for concentrated load (C)
 - (b) pounds per square foot for uniform load (U)
 - (c) maximum load magnitude in pounds per square foot for triangular load (T)
 - (4) Distance from member coordinate origin to concentrated load or to start of distributed load (ft).
 - (5) Distance to end of distributed load (ft). Omit if load type = C
 - (6) Indicator for triangular load
 - (a) L if maximum occurs at the left end
 - (b) R if maximum occurs at the right end
 - (c) Omit for load type = C or U
- k. Load factors--Input live load factor and dead load factor. Omit if method = WSD.
- l. Internal water data--Input 0 for no internal water and 1 if there is internal water and the effective elevation (ft) of the internal water in the cell or cells.
- m. Member data for investigation--Number of members to be investigated.

Member data:

Area (sq in.) of steel in top of member at left end, at the center line, and at the right end.

Area (sq in.) of steel in the bottom of member at left end, at the center line, and at the right end.

Note that for vertical members CORTCUL assumes the lower end to be the left end and the location of the origin.

Data Output

57. The CORTCUL program provides several options in outputting the results of an investigation. The user may choose to have all of the input data echo-printed in the output file or the input data may not be printed. The results of an investigation may be separated into two parts, a summary of results and detailed member load/force results listing. Figure 5 presents a typical summary of results output listing for a special load case. This summary is the minimum amount of data output available. For each culvert member the bending moment, axial force, flexure factor of safety, strength reduction, shear forces and shear factors of safety are tabulated for the left end, the center line, and the right end of the member. When the SD procedures are used, CORTCUL investigates shear at a critical section that is located a distance equal to the effective depth, d , but denoted as D in the output from the face of the supporting member. However, when the clear-span to effective-depth ratio (l_n/d) is less than 9, the expression given in the University of Illinois Structural Research Series No. 440 (Gamble 1977) is used. In this case the critical section is located at $0.15 \cdot l_n$, which is denoted as $0.15L_N$ in the output. Whenever l_n/d is greater than 11.5, CORTCUL outputs the message "U-of-I 440 shear procedure does not apply for this member."

58. Figure 6 presents the typical format of the member load/force results. This is a tabulation of the bending moment, shear, axial load, and axial force data for points across each member investigated. Output of the member load/force results is optional but is recommended to ensure that the maximum flexure and shear locations have been output in the summary of results.

THIS IS AN EXAMPLE PROBLEM

2.B.--SUMMARY OF RESULTS FOR SPECIAL LOAD CASE 1
INVESTIGATION USING ACI STRENGTH DESIGN PROCEDURE

MEMBER 21		LEFT END	CENTERLINE	RIGHT END
BENDING MOMENT	(K-FT)	-4.65	10.04	-4.65
AXIAL FORCE	(KIPS)	1.42	1.42	1.42
FLEXURE FACTOR OF SAFETY		5.20	1.34	5.21
STRENGTH REDUCTION (PHI)		.87	.89	.87
SHEAR FORCE AT D	(KIPS)	7.04		-7.04
SHEAR FS AT D (ACI63)		1.09		1.09
SHEAR FORCE AT 0.15LN (KIPS)		NNNNNN		NNNNNN
SHEAR FS AT 0.15LN (UI440)		NNNNNN		NNNNNN
NNNNNN - U-OF-I 440 SHEAR PROCEDURE DOES NOT APPLY FOR THIS MEMBER				

MEMBER 11		LEFT END	CENTERLINE	RIGHT END
BENDING MOMENT	(K-FT)	-4.51	-3.81	-6.81
AXIAL FORCE	(KIPS)	8.63	8.63	8.63
FLEXURE FACTOR OF SAFETY		6.18	3.19	3.13
STRENGTH REDUCTION (PHI)		.70	.71	.77
SHEAR FORCE AT D	(KIPS)	.69		-1.20
SHEAR FS AT D (ACI63)		-----		5.69
SHEAR FORCE AT 0.15LN (KIPS)		NNNNNN		NNNNNN
SHEAR FS AT 0.15LN (UI440)		NNNNNN		NNNNNN
----- - SHEAR FS IS GREATER THAN TEN NNNNNN - U-OF-I 440 SHEAR PROCEDURE DOES NOT APPLY FOR THIS MEMBER				

MEMBER 12		LEFT END	CENTERLINE	RIGHT END
BENDING MOMENT	(K-FT)	4.51	3.81	6.81
AXIAL FORCE	(KIPS)	8.64	8.64	8.64
FLEXURE FACTOR OF SAFETY		6.19	3.19	3.13
STRENGTH REDUCTION (PHI)		.70	.71	.77
SHEAR FORCE AT D	(KIPS)	-.69		1.20
SHEAR FS AT D (ACI63)		-----		5.69
SHEAR FORCE AT 0.15LN (KIPS)		NNNNNN		NNNNNN
SHEAR FS AT 0.15LN (UI440)		NNNNNN		NNNNNN
----- - SHEAR FS IS GREATER THAN TEN NNNNNN - U-OF-I 440 SHEAR PROCEDURE DOES NOT APPLY FOR THIS MEMBER				

MEMBER 1		LEFT END	CENTERLINE	RIGHT END
BENDING MOMENT	(K-FT)	2.49	-9.32	2.49
AXIAL FORCE	(KIPS)	1.31	1.31	1.31
FLEXURE FACTOR OF SAFETY		11.30	1.56	11.30
STRENGTH REDUCTION (PHI)		.83	.89	.83
SHEAR FORCE AT D	(KIPS)	-5.94		5.94
SHEAR FS AT D (ACI63)		1.51		1.51
SHEAR FORCE AT 0.15LN (KIPS)		NNNNNN		NNNNNN
SHEAR FS AT 0.15LN (UI440)		NNNNNN		NNNNNN
NNNNNN - U-OF-I 440 SHEAR PROCEDURE DOES NOT APPLY FOR THIS MEMBER				

Figure 5. Typical output, summary of results

3.B.--RESULTS FOR SPECIAL LOAD CASE 1
INVESTIGATION USING ACI STRENGTH DESIGN PROCEDURE

RESULTS FOR MEMBER 21, LOAD CASE 1

DIST FROM LEFT END (FT)	LATERAL LOAD (KSF)	BENDING MOMENT (K-FT)	SHEAR (KIPS)	AXIAL LOAD (KSF)	AXIAL FORCE (KIPS)
.00	-1.19	-7.30	8.28	.00	1.42
.33	-1.39	-4.65	7.86	.00	1.42
.66	-1.59	-2.15	7.37	.00	1.42
2.13	-2.50	6.66	4.35	.00	1.42
3.61	-3.40	10.04	.00	.00	1.42
3.61	-3.40	10.04	.00	.00	1.42
5.08	-2.50	6.67	-4.35	.00	1.42
6.56	-1.59	-2.15	-7.37	.00	1.42
6.89	-1.39	-4.65	-7.86	.00	1.42
7.22	-1.19	-7.29	-8.28	.00	1.42

RESULTS FOR MEMBER 11, LOAD CASE 1

DIST FROM LEFT END (FT)	LATERAL LOAD (KSF)	BENDING MOMENT (K-FT)	SHEAR (KIPS)	AXIAL LOAD (KSF)	AXIAL FORCE (KIPS)
.00	-.51	-4.88	1.13	.00	8.63
.36	-.50	-4.51	.94	.00	8.63
.69	-.48	-4.23	.78	.00	8.63
2.17	-.41	-3.57	.12	.00	8.63
3.64	-.34	-3.81	-.43	.00	8.63
5.12	-.27	-4.80	-.89	.00	8.63
6.59	-.21	-6.39	-1.24	.00	8.63
6.92	-.19	-6.81	-1.31	.00	8.63
7.25	-.17	-7.25	-1.37	.00	8.63

RESULTS FOR MEMBER 12, LOAD CASE 1

DIST FROM LEFT END (FT)	LATERAL LOAD (KSF)	BENDING MOMENT (K-FT)	SHEAR (KIPS)	AXIAL LOAD (KSF)	AXIAL FORCE (KIPS)
.00	.51	4.88	-1.13	.00	8.64
.36	.50	4.51	-.94	.00	8.64
.69	.48	4.23	-.78	.00	8.64
2.17	.41	3.57	-.12	.00	8.64
3.64	.34	3.81	.43	.00	8.64
5.12	.27	4.81	.89	.00	8.64
6.59	.21	6.39	1.24	.00	8.64
6.92	.19	6.81	1.31	.00	8.64
7.25	.17	7.25	1.37	.00	8.64

RESULTS FOR MEMBER 1, LOAD CASE 1

DIST FROM LEFT END (FT)	LATERAL LOAD (KSF)	BENDING MOMENT (K-FT)	SHEAR (KIPS)	AXIAL LOAD (KSF)	AXIAL FORCE (KIPS)
.00	2.19	4.97	-7.92	.00	1.31
.33	2.19	2.49	-7.20	.00	1.31
.66	2.19	.24	-6.48	.00	1.31
2.13	2.19	-6.93	-3.24	.00	1.31
3.61	2.19	-9.32	-.00	.00	1.31
5.08	2.20	-6.93	3.24	.00	1.31
6.56	2.20	.24	6.48	.00	1.31
6.89	2.20	2.49	7.20	.00	1.31
7.22	2.20	4.97	7.92	.00	1.31

Figure 6. Typical output member load/force results

Analysis of Output

59. The material stresses and factors of safety due to flexure and shear are calculated for each member investigated and reported for cross sections at the left and right ends of the clear span, excluding haunches, and at the center line of the clear span. The flexure factor of safety is simply the nominal pure moment capacity, M_N , multiplied by the calculated strength reduction factor, ϕ , and divided by the applied moment, M . Throughout the remainder of this report, we will refer to this as the moment ratio. The shear factor of safety is calculated as the shear capacity, V_c , divided by the applied shear, V . Throughout the remainder of this report, the shear factor of safety will be referred to as the shear ratio.

60. Using the moment and shear ratios calculated by CORTCUL and reported in the summary of results, the box culvert can be rated as structurally adequate to support operations of a particular aircraft when both the moment and shear ratios for each member of the culvert are equal to or greater than one 1.0. The structure is inadequate if any of these ratios are less than one 1.0. A culvert with an inadequate rating for a particular aircraft must be upgraded or strengthened to sustain operations of that aircraft. When evaluating culverts under an airfield, one will normally have to evaluate several different structures for several different aircraft. Figure 7 presents a convenient way of reporting the results.

Example Problem

61. Appendix C presents a complete example problem which demonstrates the use of the INSTR, CULSTR, QUICKVIEW, and CORTCUL programs. In this example a 6.56-ft. span by 6.56-ft rise reinforced concrete box culvert under a flexible pavement with 3.0 ft of cover is evaluated for two different types of aircraft. All of the input data and assumptions are given in Appendix C.

Summary of Reinforced Concrete Box Culvert Evaluation

Station	Culvert Span ft	Size x Rise ft	Cover Depth ft	Member	F-15			C-130		
					Mc	Vc	Condition	Mc	Vc	Condition
45+00	6.56	6.56	3.0	Top (21)	1.32	1.09	Adequate	0.98	0.85	Inadequate
				Sides (11)	2.83	6.49		1.76	6.58	
				Bottom (1)	1.41	1.38		0.88	0.88	

Figure 7. Example of reporting culvert analysis

PART VI: SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

Summary

62. This report presents a method for evaluating the structural capacity of reinforced concrete box culverts under aircraft type loadings. The procedure used the computer code CORTCUL which is based on the requirements of the American Concrete Institute Building Code Requirements for Reinforced Concrete (ACI 318). Additional data input and file handling codes were developed to assist in the determination of the aircraft live loads that must be included in the analysis.

63. Other methods (e.g. finite element methods) are also available to perform this type of analysis. These methods were investigated and considered for use as the basis for this procedure. Consideration of the audience that would be the primary user of this evaluation program and the inherent complexities of using finite element computer codes lead to CORTCUL being chosen as the base for this evaluation procedure.

Conclusions

64. This report provides a means of evaluating the structural adequacy of reinforced concrete box culverts under airfield pavements. This evaluation, while based on sound technical principles, is only as good as the data and assumptions used in the analysis.

Recommendations

65. The evaluation procedure for reinforced concrete box culverts described herein is recommended for use in evaluating culverts under airfields. While periodic evaluations of each culvert are not required, the procedure is recommended for use when:

- a. The using agency is planning to apply an aircraft class not considered in the original design (e.g. a light duty airfield is to support heavier aircraft).
- b. A highway or similar facility is being considered for or has been transformed into an emergency landing strip.

- c. If there are indications in the pavement over the culvert or in the culvert itself indicating that the culvert is being overstressed.

66. It is also recommended that when culverts must be evaluated to determine their structural capacity under aircraft loads, a detailed inspection of the culvert must be performed. This data along with the construction plans and specifications and any nondestructive testing or possibly even sampling and testing data will help ensure a complete and accurate evaluation of the culvert.

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APPENDIX A: USER'S GUIDE FOR CULVERT: EVALUATION PACKAGE FOR THE
EVALUATION OF REINFORCED CONCRETE BOX CULVERT UNDER AIRCRAFT LOADS

WHAT YOU NEED:

- A personal computer running the DOS operating system with a 5 1/4 inch, high density, floppy disk drive [A or B] and a hard disk drive [C or D] with at least 1 MB free
- At least 512 k of RAM
- Graphics adapter card
- DOS 3.3 or higher
- Math co-processor

TO INSTALL OR UNINSTALL PROGRAMS

1. Turn on computer
2. Enter the date and time if DOS prompts for this
3. Put CULVERT disk no. 1 in drive A OR B and close the door
4. Type A: or B: (depending on selected floppy drive) and press ENTER
5. Type INSTALL and press ENTER
6. Follow the instructions on the screen.

Notice: CULVERT uses the PROMPT command to facilitate screen input for execution of BAT files. Upon exiting CULVERT, a PROMPT command is issued to display the current DRIVE and DIRECTORY. In order to have the original PROMPT restored after each CULVERT execution, the file 6.BAT must be modified as follows:

File: \CORTCUL\CULVERT\AUTO\6.BAT

```
ECHO OFF
CD\EVAL\LEEP
prompt $p$g ----> change $p$g to original values from AUTOEXEC.BAT
CLS
CULPATH
```

STARTING CULVERT

1. Turn on computer
2. Enter date and time if DOS prompts for this

3. If the computer does not boot from the hard drive on which CULVERT was installed,

Type C: or D: (depending on the location of CULVERT files) and press ENTER

4. Type CULVERT at the system prompt and press ENTER

5. Follow the instructions on the screen and execute programs by typing the appropriate number and pressing ENTER

RUNNING CULVERT

The CULVERT program is very user friendly with on-screen prompts and a series of questions that lead you through the program. Please refer to the program for additional information.

VEHDATA FILE

A copy of the VEHDATA file, which contains the aircraft characteristics used in determining the stress distributions, is provided for reference. For each of the 21 aircraft, the file contains the following information:

Line 1: Group Number; Aircraft; Design load, Kips; % load on main gear;
Total number of wheels on main gear; Load radius, inches;
Symmetrical/non-symmetrical; Number of controlling wheels;
Number of evaluation positions.

Line 2: X-y coordinates of controlling wheels.

Line 3: Evaluation positions on the x-axis.

VEHDATA

```

21
'GROUP 1: C-23'      25      .900 2      6.680      1 1 1
0.0 0.0
0.0
'GROUP 2: F-15 C-D'  81      .9 2      5.230      1 1 1
0.0 0.0
0.0
'GROUP 3: F-111 '    114      .95 2      8.759      1 1 1
0.0 0.0
0.0
'GROUP 4: C-130 '    175      .957 4      11.284      1 2 1
0.0 0.0 0.0 60.0
0.0
'GROUP 5: C-9 '      60      1.00 2      5.910      1 2 2
0.0 0.0 20.0 0.0
0.0      10.0
'GROUP 6: T-43'      125      .928 4      7.442      1 2 2
0.0 0.0 30.5 0.0
0.0      15.25
'GROUP 7: B-727'     210      .924 4      8.686      1 2 2
0.0 0.0 34.0 0.0
0.0      17.0
'GROUP 8: KC-135/E3' 400      .935 8      8.330      1 4 2
0.0 0.0 0.0 56.0 34.5 0.0 34.5 56.0
0.0      17.25
'GROUP 9: C-141/B1 ' 477      .944 8      8.137      1 4 2
0.0 0.0 0.0 48.0 32.5 0.0 32.5 48.0
0.0      16.25
'GROUP 10: C-5A '     840      .942 24      9.525      2 6 3
0.0 0.0 34.0 0.0 87.0 0.0 121.0 0.0 36.5 65.0 84.5 65.0
17.0      34.0      60.5
'GROUP 11: KC-10 '    590      .922 10      9.674      1 4 2
0.0 0.0 0.0 64.0 54.0 0.0 54.0 64.0
0.0      27.0
'GROUP 12: E4/747'    850      .935 16      8.831      1 4 2
0.0 0.0 0.0 58.0 44.0 0.0 44.0 58.0
0.0      22.0
'GROUP 13: B-52 '     488      .52 4      9.219      1 4 3
0.0 0.0 37.0 0.0 99.0 0.0 136.0 0.0
18.5 37.0 68.0
'GROUP 14: F-14'      75      .95 2      6.695      1 1 1
0.0 0.0
0.0
'GROUP 15: P-3B'      175      .95 4      7.265      1 2 2
0.0 0.0 26.0 0.0
0.0      13.0
'GROUP 16: C-141 '    360      .944 8      8.137      1 4 2
0.0 0.0 0.0 48.0 32.5 0.0 32.5 48.0
0.0      16.25
'GROUP 17: F-4 '      60      .877 2      5.642      1 1 1
0.0 0.0
0.0
'GROUP 18: OV-1'      18      .9 2      4.720      1 1 1

```

VEHDATA

```

0.0 0.0
0.0
'GROUP 19: B-1'      477 .9  8    8.560      1 4 2
0.0 0.0 0.0 54.0 40.0 0.0 40.0 54.0
0.0    20.0
'GROUP 20: CH-54'    47    .9  4    5.809      1 2 2
0.0 0.0 18.0 0.0
0.0    9.0
'GROUP 21: C-17A'    570 .90 12  10.0      2 6 3
0.0 0.0 0.0 97.0 40.5 97.0 40.5 0.0 83.0 12.0 83.0 109.0
0.0 20.25 40.5

```

APPENDIX B: RESULTS OF CORTCUL PARAMETER STUDIES

Table B-1

COMPARISON OF LATERAL EARTH PRESSURE COEFFICIENT EFFECTS

Load Case	Member	Moment Ratio (M)* or Shear Ratio (S)**	K = 0.25 K Effective = 0.425			K = 0.40 K Effective = 0.68			K = 0.50 K Effective = 0.85		
			Left	Midspan	Right	Left	Midspan	Right	Left	Midspan	Right
			End	End	End	End	End	End	End	End	End
Soil Only	Top	M	4.00	2.54	4.00	3.61	3.03	3.61	3.39	3.46	3.39
	Sides	S	1.99		1.99	1.96		1.96	1.94		1.94
	Bottom	M	2.64	6.58	3.45	2.48	28.8	3.21	2.39	6.04	3.06
C-123 Aircraft	Top	M	3.66		6.08	2.46		3.69	2.05		2.97
	Sides	S	3.27	1.99	3.27	2.98	2.40	2.98	2.81	2.76	2.81
	Bottom	M	1.63		1.63	1.60		1.60	1.59		1.59
F-4 Aircraft	Top	M	1.76	0.95	1.76	1.68	1.01	1.68	1.63	1.06	1.63
	Sides	S	0.94		0.94	0.94		0.94	0.93		0.93
	Bottom	M	2.23	1.21	1.48	2.12	2.72	1.43	2.05	7.57	1.40
F-111 Aircraft	Top	M	4.92		4.10	2.88		2.81	2.28		2.23
	Sides	S	2.83	1.27	2.83	2.61	1.43	2161	2.48	1.57	2.48
	Bottom	M	1.23		1.23	1.23		1.23	1.23		1.23
C-9 Aircraft	Top	M	1.66	0.89	1.67	1.60	0.95	1.60	1.55	0.99	1.55
	Sides	S	0.89		0.89	0.89		0.89	0.89		0.89
	Bottom	M	2.14	1.09	1.40	2.04	2.22	1.36	1.98	5.42	1.33
F-111 Aircraft	Top	M	5.02		4.02	2.91		2.77	2.30		2.30
	Sides	S	2.72	1.20	2.72	2.53	1.35	2.53	2.41	1.46	2.41
	Bottom	M	1.18		1.18	1.18		1.18	1.18		1.18
C-9 Aircraft	Top	M	1.05	0.52	1.05	1.02	0.54	1.02	1.00	0.55	1.00
	Sides	S	0.57		0.57	0.57		0.57	0.56		0.57
	Bottom	M	1.49	0.53	0.87	1.44	0.70	0.85	1.41	0.90	0.84
C-9 Aircraft	Top	M	6.64		3.32	3.32		2.41	2.51		2.04
	Sides	S	1.92	0.74	1.92	1.83	0.80	1.83	1.77	0.84	1.77
	Bottom	M	0.79		0.78	0.79		0.78	0.79		0.78
C-9 Aircraft	Top	M	1.31	0.67	1.32	1.27	0.70	1.27	1.24	0.73	1.25
	Sides	S	0.72		0.72	0.71		0.71	0.71		0.71
	Bottom	M	1.81	0.74	1.10	1.73	1.14	1.07	1.68	1.76	1.05
C-9 Aircraft	Top	M	5.65		3.66	3.08		2.59	2.38		2.17
	Sides	S	2.31	0.95	2.31	2.17	1.04	2.17	2.08	1.10	2.08
	Bottom	M	0.97		0.97	0.97		0.97	0.97		0.97

NOTES: * $M = \frac{M \text{ Capacity}}{N \text{ Applied}}$

** $S = \frac{V \text{ Capacity}}{V \text{ Applied}}$

Table B-2

COMPARISON OF INTERNAL WATER EFFECTS

Load Case	Member	Moment or Shear Ratio	No Internal Water			1/2 Full			Full		
			Left End	Midspan	Right End	Left End	Midspan	Right End	Left End	Midspan	Right End
Soil Only	Top	M	3.80	2.72	3.80	3.95	2.58	3.95	4.10	2.46	4.10
	Sides	S	1.97	17.40	1.97	1.99	6.57	1.99	2.00	3.41	2.00
	Bottom	M	3.67		3.33	3.72		3.43	3.77		3.54
C-123 Aircraft	Top	M	4.22	2.89	5.10	6.13	2.59	5.85	10.0+	2.33	6.88
	Sides	S	4.46		4.46	4.70		4.70	4.95		4.95
	Bottom	M	2.25		2.25	2.26		2.26	2.26		2.26
F-4 Aircraft	Top	M	1.76	0.95	1.76	1.79	0.93	1.79	1.82	0.92	1.82
	Sides	S	0.94	1.21	0.94	0.94	1.02	0.95	0.95	0.88	0.95
	Bottom	M	2.23	1.27	1.48	2.25	1.21	1.50	2.27	1.15	1.52
F-111 Aircraft	Top	M	4.92		4.10	8.14	1.23	4.59	10.0+		5.23
	Sides	S	2.83		2.83	2.91		2.91	3.00		3.00
	Bottom	M	1.23		1.23	1.23		1.23	1.23		1.23
C-9 Aircraft	Top	M	1.66	0.89	1.67	1.69	0.88	1.69	1.72	0.86	1.72
	Sides	S	0.89	1.09	0.89	0.90	0.94	0.90	0.90	0.82	0.90
	Bottom	M	2.14	1.20	1.40	2.16	1.14	1.42	2.18	1.09	1.43
F-111 Aircraft	Top	M	5.02		4.02	8.44		4.50	10.0+		5.10
	Sides	S	2.72		2.72	2.80		2.80	2.88		2.88
	Bottom	M	1.18		1.18	1.18		1.18	1.18		1.18
C-9 Aircraft	Top	M	1.05	0.52	1.05	1.06	0.52	1.06	1.07	0.51	1.07
	Sides	S	0.57	0.53	0.57	0.57	0.49	0.57	0.57	0.45	0.57
	Bottom	M	1.49	0.74	0.87	1.50	0.72	0.87	1.51	0.70	0.88
C-9 Aircraft	Top	M	6.64		3.32	10.0+		3.64	10.0+		4.03
	Sides	S	1.92		1.92	1.96		1.96	2.00		2.00
	Bottom	M	0.79		0.78	0.79		0.78	0.79		0.78
C-9 Aircraft	Top	M	1.31	0.67	1.32	1.33	0.66	1.33	1.35	0.66	1.35
	Sides	S	0.72	0.74	0.72	0.72	0.66	0.72	0.72	0.60	0.72
	Bottom	M	1.81	0.95	1.10	1.82	0.91	1.11	1.83	0.88	1.12
C-9 Aircraft	Top	M	5.65		3.66	10.0+		4.05	10.0+		4.54
	Sides	S	2.31		2.31	2.37		2.37	2.42		2.42
	Bottom	M	0.97		0.97	0.97		0.97	0.97		0.97

Table B-3

COMPARISON OF CHANGES IN LOAD FACTOR

Test Case	Member	C-123			F-4			F-111			C-130			C-9			C-141		
		MC	VC	VA	MC	VC	VA	MC	VC	VA	MC	VC	VA	MC	VC	VA	MC	VC	VA
1	Top	0.83	0.88		0.82	0.90		0.43	0.50		0.45	0.40		0.59	0.66		0.31	0.28	
	Sides	1.04	3.97		1.06	3.96		0.43	3.07		0.37	3.10		0.64	3.51		0.25	2.62	
	Bottom	1.20	1.19		1.22	1.21		0.66	0.71		0.51	0.45		0.88	0.92		0.36	0.32	
2	Top	0.99	1.08		0.98	1.10		0.51	0.60		0.53	0.48		0.70	0.80		0.37	0.33	
	Sides	1.13	5.36		1.16	5.35		0.49	4.01		0.43	4.13		0.72	4.66		0.28	3.39	
	Bottom	1.43	1.45		1.46	1.48		0.89	0.86		0.61	0.54		1.05	1.11		0.43	0.38	
3	Top	0.86	0.95		0.85	0.97		0.43	0.52		0.45	0.41		0.60	0.70		0.31	0.28	
	Sides	0.94	5.08		0.96	5.07		0.41	3.67		0.35	3.79		0.60	4.34		0.24	3.06	
	Bottom	1.26	1.30		1.28	1.33		0.67	0.74		0.52	0.46		0.90	0.98		0.36	0.32	
4	Top	0.70	0.80		0.69	0.82		0.34	0.42		0.36	0.33		0.48	0.57				
	Sides	0.73	4.67		0.74	4.66		0.32	3.21		0.27	3.33		0.46	3.89				
	Bottom		1.11		1.07	1.14		0.54	0.61		0.41	0.37		0.74	0.81				

NOTE: Test Case 1: Required Strength = $(1.4 \times \text{Roof Member Load}) + (1.7 \times \text{Overburden}) + (1.7 \times \text{Aircraft Load}) + (1.7 \times \text{Lateral Earth Load})$.

Test Case 2: Required Strength = $(1.2 \times \text{Roof Member Load}) + (1.2 \times \text{Overburden}) + (1.44 \times \text{Aircraft Load}) + (1.2 \times \text{Lateral Earth Load})$.

Test Case 3: Required Strength = $(1.2 \times \text{Roof Member Load}) + (1.2 \times \text{Overburden}) + (1.74 \times \text{Aircraft Load}) + (1.2 \times \text{Lateral Earth Load})$.

Test Case 4: Required Strength = $(1.2 \times \text{Roof Member Load}) + (1.2 \times \text{Overburden}) + (2.24 \times \text{Aircraft Load}) + (1.2 \times \text{Lateral Earth Load})$.

APPENDIX C: EXAMPLE PROBLEM

1. In this example an 8-ft by 8-ft reinforced concrete box culvert (6.56-ft span and a 6.56-ft rise) is located under an airfield. The culvert has 3.0 ft of cover and is to be evaluated for the F-15 and the C-130 aircraft. Figure C1 presents the completed load application worksheet. The data used to complete the load application worksheet was obtained during an airfield evaluation and field inspection of the culvert.

2. To determine the vertical stress (load) acting on the culvert due to the aircraft, the program CULSTR was run. The output file from this program was named EXAMP.OUT and is presented in Figure C2. To provide a visual plot of the data the vertical stresses were plotted using the program QUIKVIEW. These plots are shown in Figures C3 and C4. Since the CORTCUL program must have the load data input as either a concentrated, uniform, or triangular load the effective aircraft load worksheet is used to determine the applied loads and their coordinates on the culvert. Figures C5 and C6 show these completed worksheets for the F-15 and C-130, respectively. Note that for each aircraft the load was centered over the midspan and then at the quarter point of the top member.

3. After determining the soil and aircraft loads that are to be applied to the culvert, the X0024 option of the CULVERT program was chosen and the data input interactively. Figure C7 presents the CORTCUL input file which is called EXAMPLE.IN. Note that all four special load cases were used in this data file with Cases 1 and 2 being the F-15 aircraft (midspan and quarter point, respectively) and Cases 3 and 4 being the C-130 aircraft at the midspan and quarter point. After interactively building the data file the CORTCUL program is run. Figure C8 presents a copy of the output file for this analysis.

4. The moment and shear ratios are extracted from the output file and summarized in the results table presented in Table C1 completing the culvert analysis for these two aircraft.

Example
STATION 45+00 6.56' x 6.56'

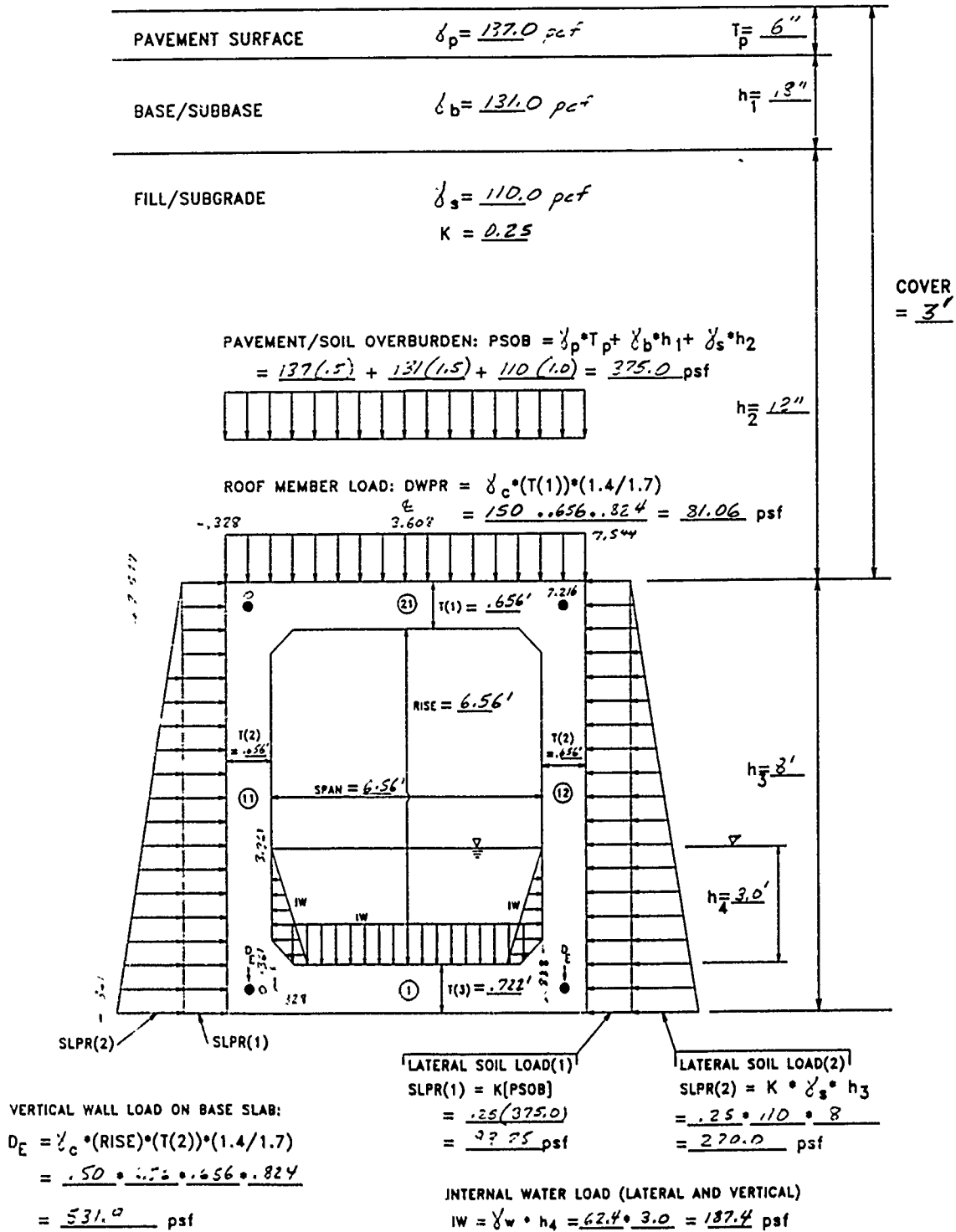


Figure C1. Completed load application worksheet

EXAMP.OUT

```
*****CULSTR DRA-03.90.07*****
      P R O B L E M   N U M B E R   =   1
*****EXECUTED:  5-11-1990 @ 10:48*****
```

PROBLEM TITLE

EXAMPLE PROBLEM

STRUCTURE INFORMATION

MATERIAL TYPE	MODULUS PSI	POISSON RATIO	THICKNESS IN	INTERFACE 1=NO SLIP >1=PARTIAL SLIP
*****	*****	*****	*****	*****
AC	250000.	0.35	6.00	
BASE OR SUBBASE	52500.	0.35	18.00	1.
SUBGRADE	15000.	0.40	12.00	1.
RIGID BOUNDARY	1000000.	0.50	1.00	1.
RIGID BOUNDARY	1000000.	0.50		

Figure C2. CULSTR output file EXAMP.OUT (Sheet 1 of 3)

EXAMP.OUT

PROBLEM TITLE

EXAMPLE PROBLEM

***** AIRCRAFT: GROUP 2: F-15 C-D *****

LOAD INFORMATION

LOAD NO.	RADIUS IN	LOAD LB	CO-ORDINATES, IN X	Y
****	*****	*****	*****	*****
1	5.23	27000.	0.00	0.00

STRESS DISTRIBUTION

LONGITUDINAL OFFSET, IN	MAXIMUM STRESS, PSF
*****	*****
-120.000	-2.724
-96.000	-10.913
-72.000	-7.521
-48.000	123.148
-42.000	212.829
-36.000	342.041
-30.000	518.823
-24.000	744.983
-18.000	1007.538
-12.000	1269.487
-6.000	1469.947
0.000	1545.965
6.000	1469.947
12.000	1269.487
18.000	1007.538
24.000	744.983
30.000	518.823
36.000	342.041
42.000	212.829
48.000	123.148
72.000	-7.521
96.000	-10.913
120.000	-2.724

Figure C2. (Sheet 2 of 3)

EXAMP.OUT

PROBLEM TITLE

EXAMPLE PROBLEM

***** AIRCRAFT: GROUP 4: C-130 *****

LOAD INFORMATION

LOAD NO.	RADIUS IN	LOAD LB	CO-ORDINATES, IN X	Y
1	11.28	35887.	0.00	0.00
2	11.28	35887.	0.00	60.00

STRESS DISTRIBUTION

LONGITUDINAL OFFSET, IN	MAXIMUM STRESS, PSF
-120.000	-15.986
-96.000	7.557
-72.000	282.510
-48.000	1283.000
-42.000	1597.826
-36.000	1841.648
-30.000	1956.857
-24.000	1924.328
-18.000	1778.444
-12.000	1592.053
-6.000	1443.297
0.000	1387.295
6.000	1443.297
12.000	1592.053
18.000	1778.444
24.000	1924.328
30.000	1956.857
36.000	1841.648
42.000	1597.826
48.000	1283.000
72.000	282.510
96.000	7.557
120.000	-15.986

Figure C2. (Sheet 3 of 3)

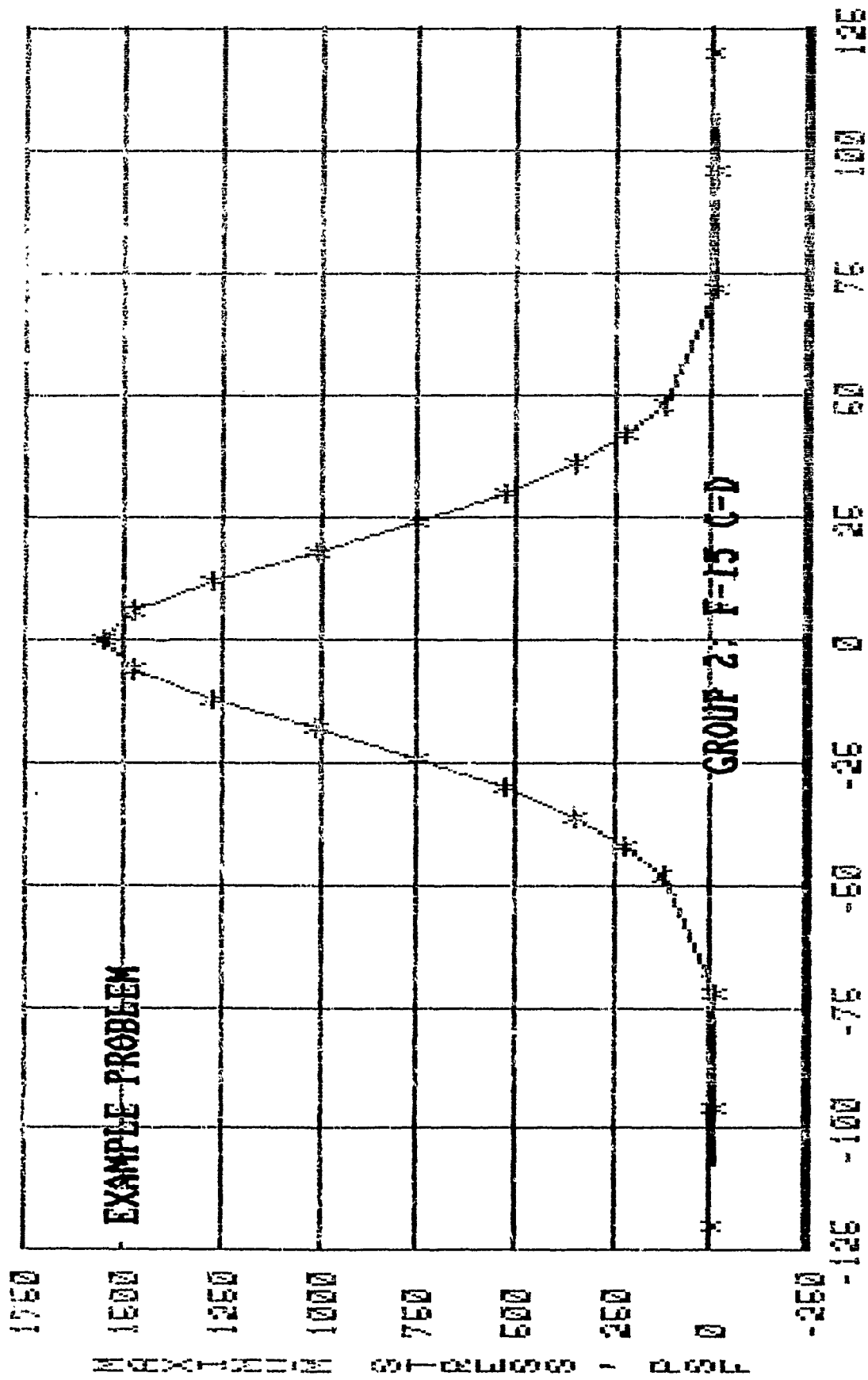


Figure C3. Stress distribution plot for F-15

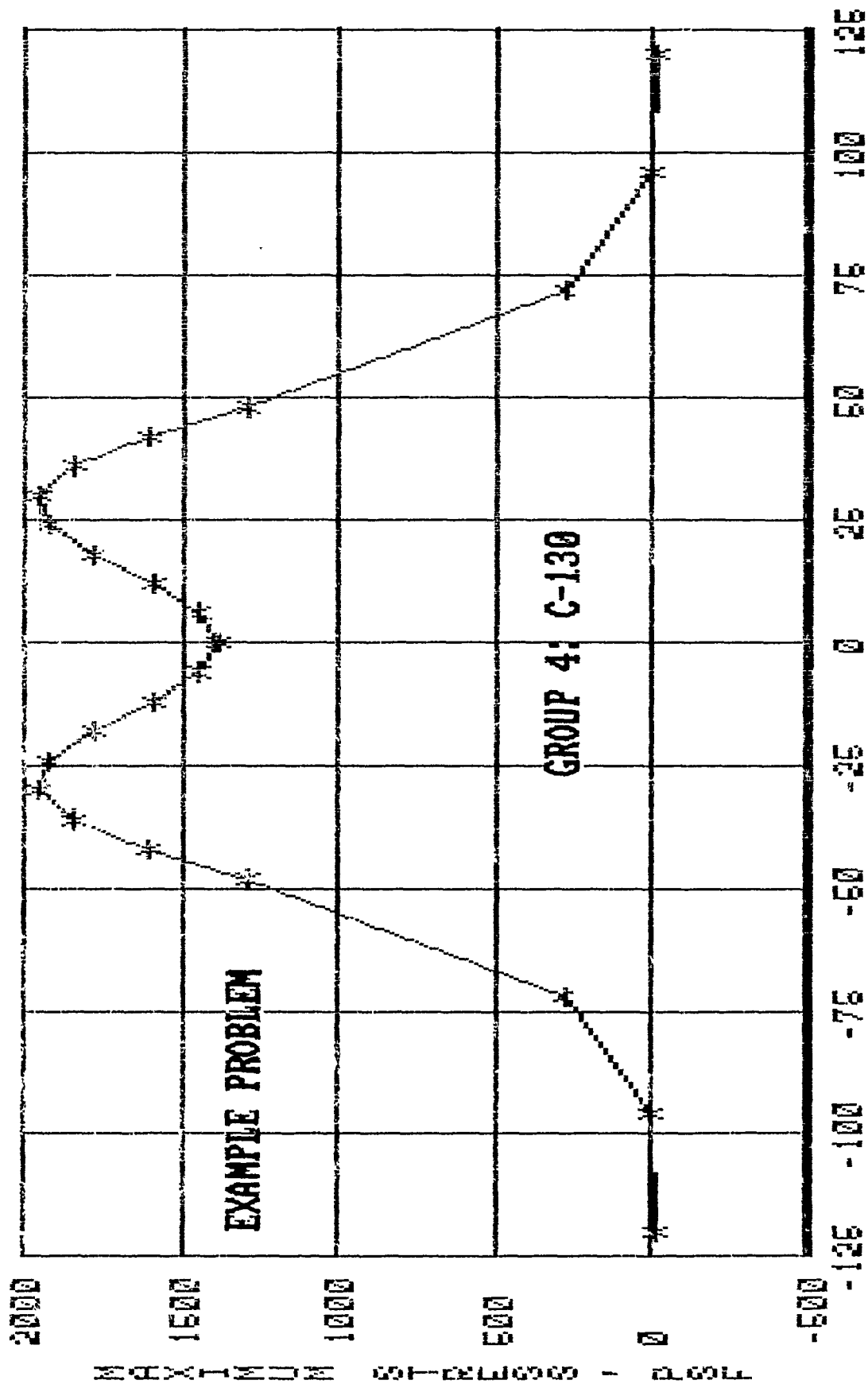


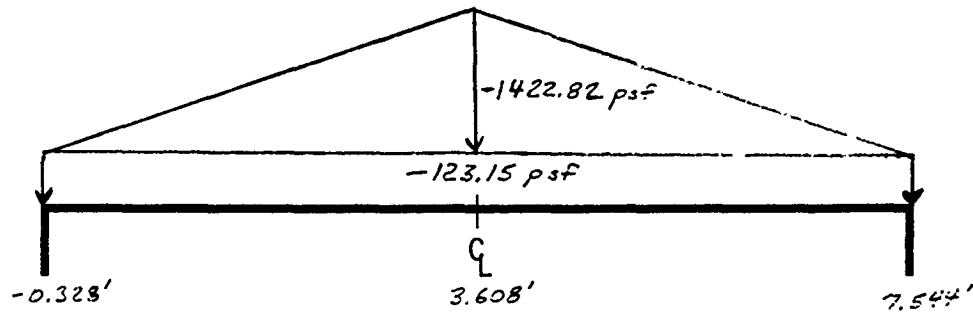
Figure C4. Stress distribution plot for C-130

EFFECTIVE AIRCRAFT LOADS

CULVERT LOCATION: Example Problem

CULVERT SIZE: 8.0 ft x 8.0 ft COVER DEPTH: 3.0 ft

AIRCRAFT: F-15 (60,000 lb) Centered



AIRCRAFT: F-15 (60,000 lb) 1/4 Point

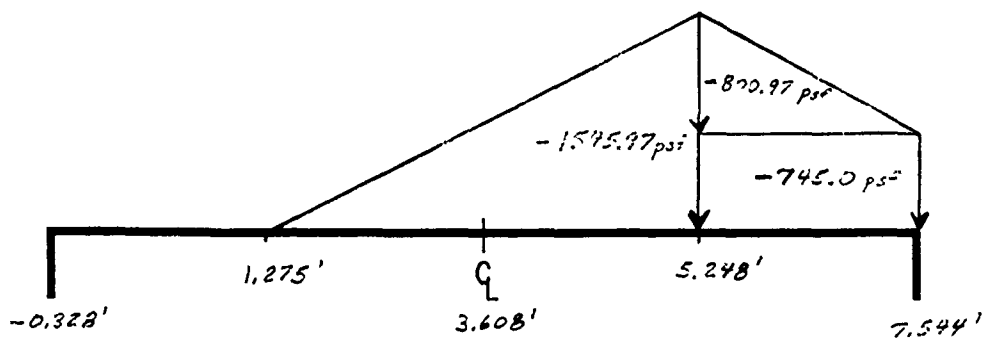


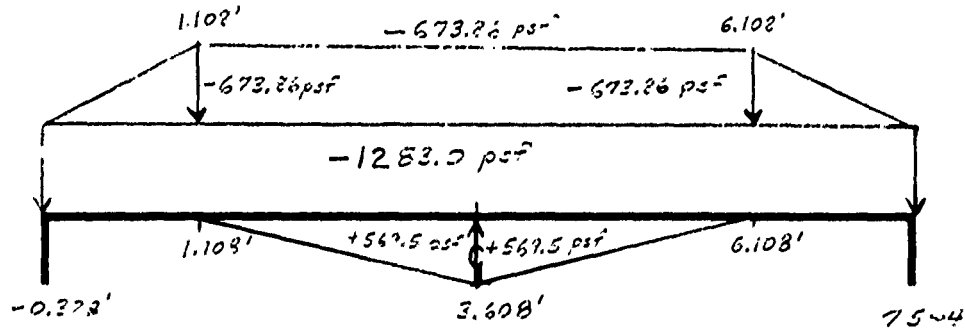
Figure C5. Completed aircraft load worksheet for F-15

EFFECTIVE AIRCRAFT LOADS

CULVERT LOCATION: EXAMPLE PROFILE

CULVERT SIZE: 8.0 ft x 8.0 ft COVER DEPTH: 3.0 ft

AIRCRAFT: C-130 (152,000 lb) Centered



AIRCRAFT: C-130 (152,000 lb) 1/4 Point

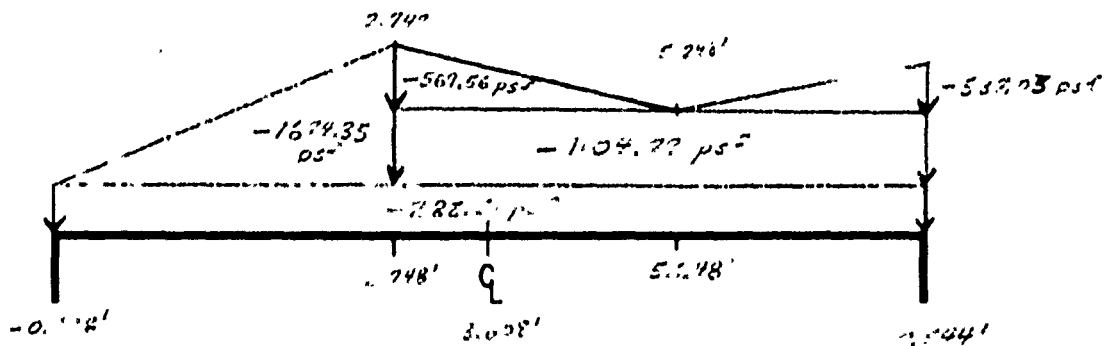


Figure C6. Completed aircraft load worksheet for C-130

```

1000 1 EXAMPLE PROBLEM
1010 I SD
1020 3000.0 34135.0 150.0 .7500 .0000
1030 1 6.56 3.94 .00 6.56
1040 1.57 1.57 1.97
1050 7.87 7.87 8.66
1060 0
1070 4
1080 14
1090 21 Y T -1422.8200 -.3280 3.6080 R
1100 21 Y T -1422.8200 3.6080 7.5440 L
1110 21 Y U -123.1500 -.3280 7.5440
1120 21 Y U -375.0000 -.3280 7.5440
1130 21 Y U -81.0600 -.3280 7.5440
1140 11 Y T -220.0000 -.3610 7.5770 L
1150 11 Y U -93.7500 -.3610 7.5770
1160 11 Y T 187.4000 .3610 3.3610 L
1170 12 Y T 220.0000 -.3610 7.5770 L
1180 12 Y U 93.7500 -.3610 7.5770
1190 12 Y T -187.4000 .3610 3.3610 L
1200 1 Y U -187.4000 .3280 6.8880
1210 1 Y C -531.9000 .0000
1220 1 Y C -531.9000 7.2160
1300 14
1310 21 Y T -1545.9700 1.2750 5.2480 R
1320 21 Y T -800.9700 5.2480 7.5440 L
1330 21 Y U -745.0000 5.2480 7.5440
1340 21 Y U -375.0000 -.3280 7.5440
1350 21 Y U -81.0600 -.3280 7.5440
1360 11 Y T -220.0000 -.3610 7.5770 L
1370 11 Y U -93.7500 -.3610 7.5770
1380 11 Y T 187.4000 .3610 3.3610 L
1390 12 Y T 220.0000 -.3610 7.5770 L
1400 12 Y U 93.7500 -.3610 7.5770
1410 12 Y T -187.4000 .3610 3.3610 L
1420 1 Y U -187.4000 .3280 6.8880
1430 1 Y C -531.9000 .0000
1440 1 Y C -531.9000 7.2160
1500 17
1510 21 Y T -673.8600 -.3280 1.1080 R
1520 21 Y U -673.8600 1.1080 6.1080
1530 21 Y T -673.8600 6.1080 7.5440 L
1535 21 Y U -1283.0000 -.3280 7.5440
1536 21 Y T 569.5600 1.1080 3.6080 R
1537 21 Y T 569.5600 3.6080 6.1080 L
1540 21 Y U -375.0000 -.3280 7.5440
1550 21 Y U -81.0600 -.3280 7.5440
1560 11 Y T -220.0000 -.3610 7.5770 L
1570 11 Y U -93.7500 -.3610 7.5770
1580 11 Y T 187.4000 .3610 3.3610 L
1590 12 Y T 220.0000 -.3610 7.5770 L

```

Figure C7. CORTCUL input file EXAMPLE.IN (Continued)

1600	12	Y	U	93.7500	-.3610	7.5770
1610	12	Y	T	-187.4000	.3610	3.3610 L
1620	1	Y	U	-187.4000	.3280	6.8880
1630	1	Y	C	-531.9000	.0000	
1640	1	Y	C	-531.9000	7.2160	
1700	16					
1710	21	Y	T	-1674.3500	-.3280	2.7480 R
1720	21	Y	T	-569.5600	2.7480	5.2480 L
1730	21	Y	T	-537.0300	5.2480	7.5440 R
1740	21	Y	U	-1104.7900	2.7480	7.5440
1750	21	Y	U	-282.5100	-.3280	7.5440
1540	21	Y	U	-375.0000	-.3280	7.5440
1550	21	Y	U	-81.0600	-.3280	7.5440
1560	11	Y	T	-220.0000	-.3610	7.5770 L
1570	11	Y	U	-93.7500	-.3610	7.5770
1580	11	Y	T	187.4000	.3610	3.3610 L
1590	12	Y	T	220.0000	-.3610	7.5770 L
1600	12	Y	U	93.7500	-.3610	7.5770
1610	12	Y	T	-187.4000	.3610	3.3610 L
1620	1	Y	U	-187.4000	.3280	6.8880
1630	1	Y	C	-531.9000	.0000	
1640	1	Y	C	-531.9000	7.2160	
1700	1.70			1.40		
1710	4					
1720	21	.48	.89	.00	.89	.48 .89
1730	11	.48	.00	.48	.00	.48 .00
1740	12	.00	.48	.00	.48	.00 .48
1750	1	.89	.48	.89	.05	.89 .48

Figure C7. (Concluded)

1. INPUT DATA

1.A.--HEADING

EXAMPLE PROBLEM

1.B.--MODE AND PROCEDURE

INVESTIGATION USING ACI STRENGTH DESIGN PROCEDURE

1.C.--MATERIAL PROPERTIES

CONCRETE:

ULTIMATE STRENGTH	=	3000.	(PSI)
ULTIMATE STRAIN	=	.003	
COMP. BLOCK RATIO	=	.85	
UNIT WEIGHT	=	150.	(PCF)

REINFORCEMENT:

YIELD STRENGTH	=	34135.	(PSI)
MODULUS OF ELASTICITY	=	29.E+06	(PSI)
MAXIMUM REINF RATIO	=	.75	

STRENGTH REDUCTION FACTOR = VARIABLE

1.D.--GEOMETRY

NO OF CELLS	CELL HEIGHT (FT)	HAUNCH WIDTH (IN)	INVERT ELEV (FT)	CELL WIDTH (FT)
1	6.56	3.94	.00	6.56

REINFORCEMENT COVER (IN):

EXTERIOR SURFACES	= 1.57
INTERIOR ROOF/END WALLS	= 1.57
INTERIOR BASE SLAB	= 1.97

THICKNESS (IN):

ROOF SLAB	= 7.87
EXTERIOR WALLS	= 7.87
BASE SLAB	= 8.66

Figure C8. CORTCUL output file EXAMPLE.OUT (Sheet 1 of 11)

1.E.--LOAD DATA

1.E.1.--STANDARD LOAD CASES
NO STANDARD LOAD CASES

1.E.2--SPECIAL LOAD CASES

SPECIAL LOAD CASE NO. 1

MEM	LOAD	LOAD	LOAD	DISTANCE (FT)		WEIGHTED
NO	DIRECT	TYPE	(LB)(PLF)	START	END	END
21	Y	TRIA	-1422.82	-.33	3.61	R
21	Y	TRIA	-1422.82	3.61	7.54	L
21	Y	UNIF	-123.15	-.33	7.54	
21	Y	UNIF	-375.00	-.33	7.54	
21	Y	UNIF	-81.06	-.33	7.54	
11	Y	TRIA	-220.00	-.36	7.58	L
11	Y	UNIF	-93.75	-.36	7.58	
11	Y	TRIA	187.40	.36	3.36	L
12	Y	TRIA	220.00	-.36	7.58	L
12	Y	UNIF	93.75	-.36	7.58	
12	Y	TRIA	-187.40	.36	3.36	L
1	Y	UNIF	-187.40	.33	6.89	
1	Y	CONC	-531.90	.00		
1	Y	CONC	-531.90	7.22		

SPECIAL LOAD CASE NO. 2

MEM	LOAD	LOAD	LOAD	DISTANCE (FT)		WEIGHTED
NO	DIRECT	TYPE	(LB)(PLF)	START	END	END
21	Y	TRIA	-1545.97	1.28	5.25	R
21	Y	TRIA	-800.97	5.25	7.54	L
21	Y	UNIF	-745.00	5.25	7.54	
21	Y	UNIF	-375.00	-.33	7.54	
21	Y	UNIF	-81.06	-.33	7.54	
11	Y	TRIA	-220.00	-.36	7.58	L
11	Y	UNIF	-93.75	-.36	7.58	
11	Y	TRIA	187.40	.36	3.36	L
12	Y	TRIA	220.00	-.36	7.58	L
12	Y	UNIF	93.75	-.36	7.58	
12	Y	TRIA	-187.40	.36	3.36	L
1	Y	UNIF	-187.40	.33	6.89	
1	Y	CONC	-531.90	.00		
1	Y	CONC	-531.90	7.22		

Figure C8. (Sheet 2 of 11)

SPECIAL LOAD CASE NO. 3

MEM	LOAD	LOAD	LOAD	DISTANCE (FT)		WEIGHTED
NO	DIRECT	TYPE	(LB) (PLF)	START	END	END
21	Y	TRIA	-673.86	-.33	1.11	R
21	Y	UNIF	-673.86	1.11	6.11	
21	Y	TRIA	-673.86	6.11	7.54	L
21	Y	UNIF	-1283.00	-.33	7.54	
21	Y	TRIA	569.56	1.11	3.61	R
21	Y	TRIA	569.56	3.61	6.11	L
21	Y	UNIF	-375.00	-.33	7.54	
21	Y	UNIF	-81.06	-.33	7.54	
11	Y	TRIA	-220.00	-.36	7.58	L
11	Y	UNIF	-93.75	-.36	7.58	
11	Y	TRIA	187.40	.36	3.36	L
12	Y	TRIA	220.00	-.36	7.58	L
12	Y	UNIF	93.75	-.36	7.58	
12	Y	TRIA	-187.40	.36	3.36	L
1	Y	UNIF	-187.40	.33	6.89	
1	Y	CONC	-531.90	.00		
1	Y	CONC	-531.90	7.22		

SPECIAL LOAD CASE NO. 4

MEM	LOAD	LOAD	LOAD	DISTANCE (FT)		WEIGHTED
NO	DIRECT	TYPE	(LB) (PLF)	START	END	END
21	Y	TRIA	-1674.35	-.33	2.75	R
21	Y	TRIA	-569.56	2.75	5.25	L
21	Y	TRIA	-537.03	5.25	7.54	R
21	Y	UNIF	-1104.79	2.75	7.54	
21	Y	UNIF	-282.51	-.33	7.54	
21	Y	UNIF	-375.00	-.33	7.54	
21	Y	UNIF	-81.06	-.33	7.54	
11	Y	TRIA	-220.00	-.36	7.58	L
11	Y	UNIF	-93.75	-.36	7.58	
11	Y	TRIA	187.40	.36	3.36	L
12	Y	TRIA	220.00	-.36	7.58	L
12	Y	UNIF	93.75	-.36	7.58	
12	Y	TRIA	-187.40	.36	3.36	L
1	Y	UNIF	-187.40	.33	6.89	
1	Y	CONC	-531.90	.00		
1	Y	CONC	-531.90	7.22		

1.E.3.--LOAD FACTORS FOR ACI STRENGTH DESIGN:

LIVE LOAD FACTOR = 1.70

DEAD LOAD FACTOR = 1.40

Figure C8. (Sheet 3 of 11)

1.F.--REINFORCEMENT AREAS (SQIN) FOR INVESTIGATION

MEMBER NO	LEFT END		CENTERLINE		RIGHT END	
	TOP	BOTTOM	TOP	BOTTOM	TOP	BOTTOM
21	.48	.89	.00	.89	.48	.89
11	.48	.00	.48	.00	.48	.00
12	.00	.48	.00	.48	.00	.48
1	.89	.48	.89	.05	.89	.48

SCHEMATIC OF CULVERT:

```

*--21--*
!       !
!       !
11      12
!       !
!       !
*--1--*

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LOCAL COORDINATE SYSTEMS:

HORIZONTAL MEMBERS: ORIGIN AT LEFT END, X-AXIS TO RIGHT, Y-AXIS UP
 VERTICAL MEMBERS : ORIGIN AT BOTTOM, X-AXIS UP, Y-AXIS TO LEFT

SIGN CONVENTIONS:

POSITIVE LATERAL LOAD ACTS IN PLUS Y DIRECTION
 POSITIVE BENDING MOMENT PRODUCES COMPRESSION
 ON PLUS Y FACE OF MEMBER

POSITIVE SHEAR TENDS TO MOVE MEMBER IN PLUS Y DIRECTION

POSITIVE AXIAL LOAD ACTS IN PLUS X DIRECTION

POSITIVE AXIAL INTERNAL FORCE IS COMPRESSION

UNLESS OTHERWISE NOTED, FACTOR OF SAFETY FOR
 INVESTIGATION USING ACI STRENGTH DESIGN PROCEDURE
 IS DEFINED BY $FS = \phi * P_N / P$

WHERE P_N = ULTIMATE STRENGTH AT ACTUAL ECCENTRICITY
 P = ACTUAL AXIAL FORCE

Figure C8. (Sheet 4 of 11)

EXAMPLE PROBLEM

2.B.--SUMMARY OF RESULTS FOR SPECIAL LOAD CASE 1
 INVESTIGATION USING ACI STRENGTH DESIGN PROCEDURE

MEMBER 21		LEFT END	CENTERLINE	RIGHT END
BENDING MOMENT	(K-FT)	-4.46	10.23	-4.46
AXIAL FORCE	(KIPS)	1.27	1.27	1.27
FLEXURE FACTOR OF SAFETY		5.40	1.32	5.40
STRENGTH REDUCTION (PHI)		.87	.89	.87
SHEAR FORCE AT D	(KIPS)	7.04		-7.04
SHEAR FS AT D (ACI63)		1.09		1.09
SHEAR FORCE AT 0.15LN (KIPS)		NNNNNN		NNNNNN
SHEAR FS AT 0.15LN (UI440)		NNNNNN		NNNNNN

NNNNNN - U-OF-I 440 SHEAR PROCEDURE DOES NOT
 APPLY FOR THIS MEMBER

MEMBER 11		LEFT END	CENTERLINE	RIGHT END
BENDING MOMENT	(K-FT)	-4.89	-4.17	-6.67
AXIAL FORCE	(KIPS)	8.64	8.64	8.64
FLEXURE FACTOR OF SAFETY		5.30	2.83	3.24
STRENGTH REDUCTION (PHI)		.70	.73	.77
SHEAR FORCE AT D	(KIPS)	.52		-1.05
SHEAR FS AT D (ACI63)		-----		6.49
SHEAR FORCE AT 0.15LN (KIPS)		NNNNNN		NNNNNN
SHEAR FS AT 0.15LN (UI440)		NNNNNN		NNNNNN

----- - SHEAR FS IS GREATER THAN TEN
 NNNNNN - U-OF-I 440 SHEAR PROCEDURE DOES NOT
 APPLY FOR THIS MEMBER

MEMBER 12		LEFT END	CENTERLINE	RIGHT END
BENDING MOMENT	(K-FT)	4.89	4.17	6.67
AXIAL FORCE	(KIPS)	8.64	8.64	8.64
FLEXURE FACTOR OF SAFETY		5.30	2.83	3.24
STRENGTH REDUCTION (PHI)		.70	.73	.77
SHEAR FORCE AT D	(KIPS)	-.52		1.05
SHEAR FS AT D (ACI63)		-----		6.49
SHEAR FORCE AT 0.15LN (KIPS)		NNNNNN		NNNNNN
SHEAR FS AT 0.15LN (UI440)		NNNNNN		NNNNNN

----- - SHEAR FS IS GREATER THAN TEN
 NNNNNN - U-OF-I 440 SHEAR PROCEDURE DOES NOT
 APPLY FOR THIS MEMBER

Figure C8. (Sheet 5 of 11)

MEMBER 1		LEFT END	CENTERLINE	RIGHT END
BENDING MOMENT	(K-FT)	2.57	-10.18	2.57
AXIAL FORCE	(KIPS)	1.00	1.00	1.00
FLEXURE FACTOR OF SAFETY		10.55	1.41	10.55
STRENGTH REDUCTION (PHI)		.85	.89	.85
SHEAR FORCE AT D	(KIPS)	-6.41		6.42
SHEAR FS AT D (ACI63)		1.40		1.40
SHEAR FORCE AT 0.15LN (KIPS)		NNNNNN		NNNNNN
SHEAR FS AT 0.15LN (UI440)		NNNNNN		NNNNNN

NNNNNN - U-OF-I 440 SHEAR PROCEDURE DOES NOT
APPLY FOR THIS MEMBER

2.B.--SUMMARY OF RESULTS FOR SPECIAL LOAD CASE 2
INVESTIGATION USING ACI STRENGTH DESIGN PROCEDURE

MEMBER 21		LEFT END	CENTERLINE	RIGHT END
BENDING MOMENT	(K-FT)	-3.89	8.36	-3.50
AXIAL FORCE	(KIPS)	1.15	1.15	1.15
FLEXURE FACTOR OF SAFETY		6.21	1.61	6.96
STRENGTH REDUCTION (PHI)		.87	.89	.86
SHEAR FORCE AT D	(KIPS)	5.03		-7.03
SHEAR FS AT D (ACI63)		1.53		1.22
SHEAR FORCE AT 0.15LN (KIPS)		NNNNNN		NNNNNN
SHEAR FS AT 0.15LN (UI440)		NNNNNN		NNNNNN

NNNNNN - U-OF-I 440 SHEAR PROCEDURE DOES NOT
APPLY FOR THIS MEMBER

MEMBER 11		LEFT END	CENTERLINE	RIGHT END
BENDING MOMENT	(K-FT)	-4.37	-3.23	-5.33
AXIAL FORCE	(KIPS)	5.94	5.94	5.94
FLEXURE FACTOR OF SAFETY		5.09	3.50	3.74
STRENGTH REDUCTION (PHI)		.76	.75	.80
SHEAR FORCE AT D	(KIPS)	.64		-.93
SHEAR FS AT D (ACI63)		-----		7.35
SHEAR FORCE AT 0.15LN (KIPS)		NNNNNN		NNNNNN
SHEAR FS AT 0.15LN (UI440)		NNNNNN		NNNNNN

----- - SHEAR FS IS GREATER THAN TEN
NNNNNN - U-OF-I 440 SHEAR PROCEDURE DOES NOT
APPLY FOR THIS MEMBER

MEMBER 12		LEFT END	CENTERLINE	RIGHT END
BENDING MOMENT	(K-FT)	4.95	3.82	5.92
AXIAL FORCE	(KIPS)	9.85	9.85	9.85
FLEXURE FACTOR OF SAFETY		5.81	3.44	4.19
STRENGTH REDUCTION (PHI)		.70	.70	.71
SHEAR FORCE AT D	(KIPS)	-.64		.93
SHEAR FS AT D (ACI63)		-----		7.38

Figure C8. (Sheet 6 of 11)

SHEAR FORCE AT 0.15LN (KIPS) NNNNNN NNNNNN
 SHEAR FS AT 0.15LN (UI440) NNNNNN NNNNNN
 ----- - SHEAR FS IS GREATER THAN TEN
 NNNNNN - U-OF-I 440 SHEAR PROCEDURE DOES NOT
 APPLY FOR THIS MEMBER

MEMBER 1		LEFT END	CENTERLINE	RIGHT END
BENDING MOMENT	(K-FT)	2.66	-9.17	2.50
AXIAL FORCE	(KIPS)	1.12	1.12	1.12
FLEXURE FACTOR OF SAFETY		10.27	1.58	11.03
STRENGTH REDUCTION (PHI)		.85	.89	.85
SHEAR FORCE AT D	(KIPS)	-5.31		6.50
SHEAR FS AT D (ACI63)		1.69		1.38
SHEAR FORCE AT 0.15LN (KIPS)		NNNNNN		NNNNNN
SHEAR FS AT 0.15LN (UI440)		NNNNNN		NNNNNN
NNNNNN - U-OF-I 440 SHEAR PROCEDURE DOES NOT APPLY FOR THIS MEMBER				

2.B.--SUMMARY OF RESULTS FOR SPECIAL LOAD CASE 3
 INVESTIGATION USING ACI STRENGTH DESIGN PROCEDURE

MEMBER 21		LEFT END	CENTERLINE	RIGHT END
BENDING MOMENT	(K-FT)	-5.33	13.71	-5.33
AXIAL FORCE	(KIPS)	1.18	1.18	1.18
FLEXURE FACTOR OF SAFETY		4.45	.98	4.45
STRENGTH REDUCTION (PHI)		.88	.89	.88
SHEAR FORCE AT D	(KIPS)	10.06		-10.06
SHEAR FS AT D (ACI63)		.85		.85
SHEAR FORCE AT 0.15LN (KIPS)		NNNNNN		NNNNNN
SHEAR FS AT 0.15LN (UI440)		NNNNNN		NNNNNN
NNNNNN - U-OF-I 440 SHEAR PROCEDURE DOES NOT APPLY FOR THIS MEMBER				

MEMBER 11		LEFT END	CENTERLINE	RIGHT END
BENDING MOMENT	(K-FT)	-7.78	-6.74	-8.94
AXIAL FORCE	(KIPS)	14.11	14.11	14.11
FLEXURE FACTOR OF SAFETY		3.42	1.76	2.70
STRENGTH REDUCTION (PHI)		.70	.72	.72
SHEAR FORCE AT D	(KIPS)	.62		-.96
SHEAR FS AT D (ACI63)		-----		7.09
SHEAR FORCE AT 0.15LN (KIPS)		NNNNNN		NNNNNN
SHEAR FS AT 0.15LN (UI440)		NNNNNN		NNNNNN
----- - SHEAR FS IS GREATER THAN TEN NNNNNN - U-OF-I 440 SHEAR PROCEDURE DOES NOT APPLY FOR THIS MEMBER				

Figure C8. (Sheet 7 of 11)

MEMBER 12		LEFT END	CENTERLINE	RIGHT END
BENDING MOMENT	(K-FT)	7.78	6.74	8.94
AXIAL FORCE	(KIPS)	14.11	14.11	14.11
FLEXURE FACTOR OF SAFETY		3.42	1.76	2.70
STRENGTH REDUCTION (PHI)		.70	.72	.72
SHEAR FORCE AT D	(KIPS)	-.62		.96
SHEAR FS AT D (ACI63)		-----		7.09
SHEAR FORCE AT 0.15LN (KIPS)		NNNNNN		NNNNNN
SHEAR FS AT 0.15LN (UI440)		NNNNNN		NNNNNN
----- - SHEAR FS IS GREATER THAN TEN				
NNNNNN - U-OF-I 440 SHEAR PROCEDURE DOES NOT				
APPLY FOR THIS MEMBER				

MEMBER 1		LEFT END	CENTERLINE	RIGHT END
BENDING MOMENT	(K-FT)	3.99	-16.24	3.99
AXIAL FORCE	(KIPS)	1.09	1.09	1.09
FLEXURE FACTOR OF SAFETY		6.58	.88	6.58
STRENGTH REDUCTION (PHI)		.87	.89	.87
SHEAR FORCE AT D	(KIPS)	-10.18		10.18
SHEAR FS AT D (ACI63)		.88		.88
SHEAR FORCE AT 0.15LN (KIPS)		NNNNNN		NNNNNN
SHEAR FS AT 0.15LN (UI440)		NNNNNN		NNNNNN
NNNNNN - U-OF-I 440 SHEAR PROCEDURE DOES NOT				
APPLY FOR THIS MEMBER				

2.B.--SUMMARY OF RESULTS FOR SPECIAL LOAD CASE 4
INVESTIGATION USING ACI STRENGTH DESIGN PROCEDURE

MEMBER 21		LEFT END	CENTERLINE	RIGHT END
BENDING MOMENT	(K-FT)	-5.49	13.58	-5.37
AXIAL FORCE	(KIPS)	1.25	1.25	1.25
FLEXURE FACTOR OF SAFETY		4.33	.99	4.43
STRENGTH REDUCTION (PHI)		.87	.89	.87
SHEAR FORCE AT D	(KIPS)	9.38		-9.52
SHEAR FS AT D (ACI63)		1.33		1.31
SHEAR FORCE AT 0.15LN (KIPS)		NNNNNN		NNNNNN
SHEAR FS AT 0.15LN (UI440)		NNNNNN		NNNNNN
NNNNNN - U-OF-I 440 SHEAR PROCEDURE DOES NOT				
APPLY FOR THIS MEMBER				

MEMBER 11		LEFT END	CENTERLINE	RIGHT END
BENDING MOMENT	(K-FT)	-6.93	-6.13	-8.57
AXIAL FORCE	(KIPS)	11.51	11.51	11.51
FLEXURE FACTOR OF SAFETY		3.58	1.86	2.57
STRENGTH REDUCTION (PHI)		.71	.75	.76
SHEAR FORCE AT D	(KIPS)	.54		-1.03
SHEAR FS AT D (ACI63)		-----		6.58

Figure C8. (Sheet 8 of 11)

SHEAR FORCE AT 0.15LN (KIPS)	NNNNNN	NNNNNN
SHEAR FS AT 0.15LN (UI440)	NNNNNN	NNNNNN
----- - SHEAR FS IS GREATER THAN TEN		
NNNNNN - U-OF-I 440 SHEAR PROCEDURE DOES NOT		
APPLY FOR THIS MEMBER		

MEMBER 12	LEFT END	CENTERLINE	RIGHT END
BENDING MOMENT (K-FT)	7.10	6.31	8.74
AXIAL FORCE (KIPS)	14.02	14.02	14.02
FLEXURE FACTOR OF SAFETY	4.04	1.92	2.78
STRENGTH REDUCTION (PHI)	.70	.71	.72
SHEAR FORCE AT D (KIPS)	-.54		1.03
SHEAR FS AT D (ACI63)	-----		6.59
SHEAR FORCE AT 0.15LN (KIPS)	NNNNNN		NNNNNN
SHEAR FS AT 0.15LN (UI440)	NNNNNN		NNNNNN
----- - SHEAR FS IS GREATER THAN TEN			
NNNNNN - U-OF-I 440 SHEAR PROCEDURE DOES NOT			
APPLY FOR THIS MEMBER			

MEMBER 1	LEFT END	CENTERLINE	RIGHT END
BENDING MOMENT (K-FT)	3.72	-14.83	3.42
AXIAL FORCE (KIPS)	1.02	1.02	1.02
FLEXURE FACTOR OF SAFETY	7.07	.97	7.74
STRENGTH REDUCTION (PHI)	.87	.89	.87
SHEAR FORCE AT D (KIPS)	-8.89		9.62
SHEAR FS AT D (ACI63)	1.01		.94
SHEAR FORCE AT 0.15LN (KIPS)	NNNNNN		NNNNNN
SHEAR FS AT 0.15LN (UI440)	NNNNNN		NNNNNN
NNNNNN - U-OF-I 440 SHEAR PROCEDURE DOES NOT			
APPLY FOR THIS MEMBER			

Figure C8. (Sheet 9 of 11)

EXAMPLE PROBLEM

3.B.--RESULTS FOR SPECIAL LOAD CASE 1
 INVESTIGATION USING ACI STRENGTH DESIGN PROCEDURE

RESULTS FOR MEMBER 21, LOAD CASE 1

DIST FROM LEFT END (FT)	LATERAL LOAD (KSF)	BENDING MOMENT (K-FT)	SHEAR (KIPS)	AXIAL LOAD (KSF)	AXIAL FORCE (KIPS)
.00	-1.19	-7.11	8.28	.00	1.27
.33	-1.39	-4.46	7.86	.00	1.27
.66	-1.59	-1.96	7.37	.00	1.27
2.13	-2.50	6.85	4.35	.00	1.27
3.61	-3.40	10.23	.00	.00	1.27
5.08	-2.50	6.85	-4.35	.00	1.27
6.56	-1.59	-1.96	-7.37	.00	1.27
6.89	-1.39	-4.46	-7.86	.00	1.27
7.22	-1.19	-7.11	-8.28	.00	1.27

RESULTS FOR MEMBER 11, LOAD CASE 1

DIST FROM LEFT END (FT)	LATERAL LOAD (KSF)	BENDING MOMENT (K-FT)	SHEAR (KIPS)	AXIAL LOAD (KSF)	AXIAL FORCE (KIPS)
.00	-.52	-5.15	.81	.00	8.64
.36	-.50	-4.89	.62	.00	8.64
.36	-.18	-4.89	.62	.00	8.64
.69	-.20	-4.70	.56	.00	8.64
2.16	-.29	-4.12	.20	.00	8.64
3.36	-.36	-4.10	-.18	.00	8.64
3.64	-.34	-4.17	-.28	.00	8.64
5.12	-.28	-4.93	-.74	.00	8.64
6.59	-.21	-6.30	-1.10	.00	8.64
6.92	-.19	-6.67	-1.16	.00	8.64
7.25	-.17	-7.06	-1.22	.00	8.64

RESULTS FOR MEMBER 12, LOAD CASE 1

DIST FROM LEFT END (FT)	LATERAL LOAD (KSF)	BENDING MOMENT (K-FT)	SHEAR (KIPS)	AXIAL LOAD (KSF)	AXIAL FORCE (KIPS)
.00	.52	5.15	-.81	.00	8.64
.36	.50	4.89	-.62	.00	8.64
.36	.18	4.89	-.62	.00	8.64
.69	.20	4.70	-.56	.00	8.64
2.16	.29	4.12	-.20	.00	8.64

Figure C8. (Sheet 10 of 11)

3.36	.36	4.10	.18	.00	8.64
3.64	.34	4.17	.28	.00	8.64
5.12	.28	4.93	.74	.00	8.64
6.59	.21	6.30	1.10	.00	8.64
6.92	.19	6.67	1.16	.00	8.64
7.25	.17	7.06	1.22	.00	8.64

RESULTS FOR MEMBER 1, LOAD CASE 1

DIST FROM LEFT END (FT)	LATERAL LOAD (KSF)	BENDING MOMENT (K-FT)	SHEAR (KIPS)	AXIAL LOAD (KSF)	AXIAL FORCE (KIPS)
.00	2.69	5.26	-8.66	.00	1.00
.33	2.69	2.57	-7.78	.00	1.00
.33	2.37	2.57	-7.78	.00	1.00
.66	2.37	.14	-7.00	.00	1.00
2.13	2.37	-7.60	-3.50	.00	1.00
3.61	2.37	-10.18	.00	.00	1.00
5.08	2.37	-7.60	3.50	.00	1.00
6.56	2.37	.14	7.00	.00	1.00
6.89	2.37	2.57	7.78	.00	1.00
6.89	2.69	2.57	7.78	.00	1.00
7.22	2.69	5.26	8.66	.00	1.00

Figure C8. (Sheet 11 of 11)

Table C1
Summary of Reinforced Concrete Box Culvert Evaluation

Station	Culvert Span ft.	Size x Rise ft.	Cover Depth ft.	Member	F-15			C-130		
					Mc	Vc	Condition	Mc	Vc	Condition
45+00	6.56	6.56	3.0	Top (21)	1.32	1.09	Adequate	0.98	0.85	Inadequate
				Sides (11)	2.83	6.49		1.76	6.58	
				Bottom (1)	1.41	1.38		0.88	0.88	