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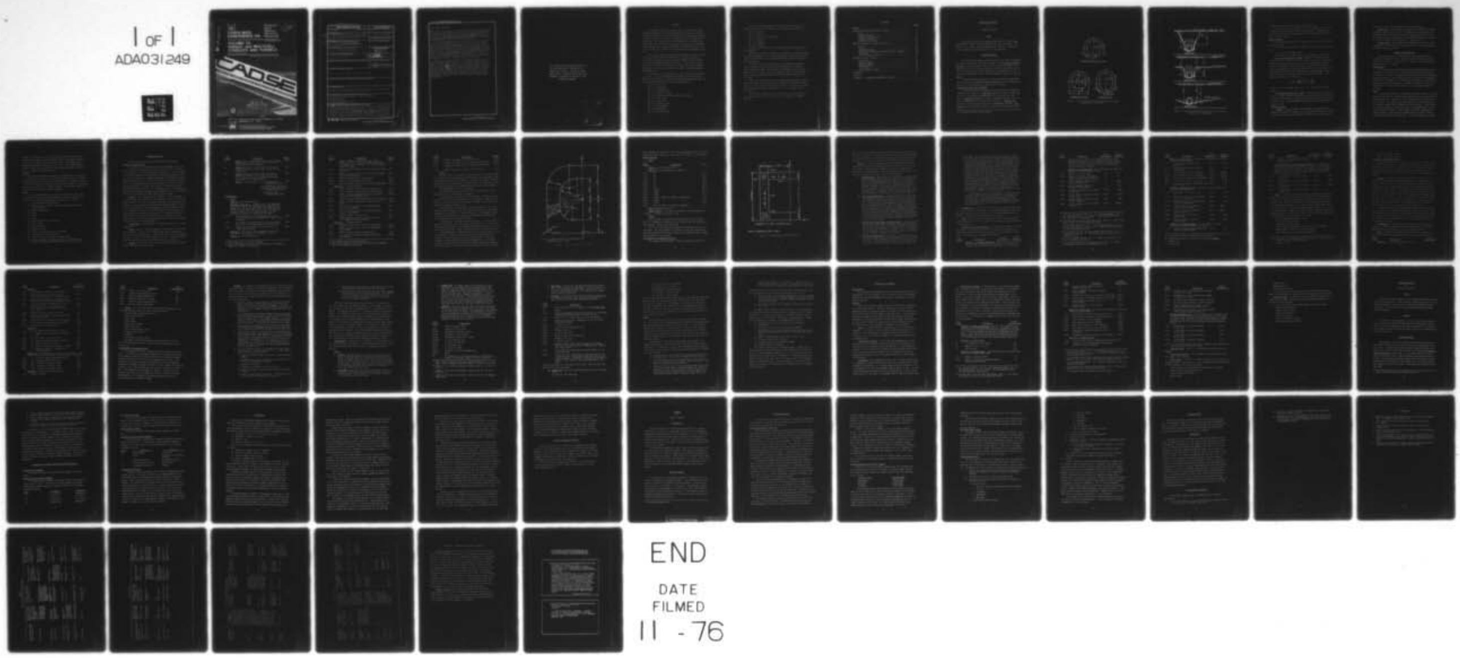

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CORPS-WIDE CONFERENCE ON COMPUTER AIDED DESIGN IN STRUCTURAL ENGINEERING

22-26 September 1975

VOLUME VII
SINGLE - and MULTICELL CONDUITS AND TUNNELS

Edited by N. RADHAKRISHNAN

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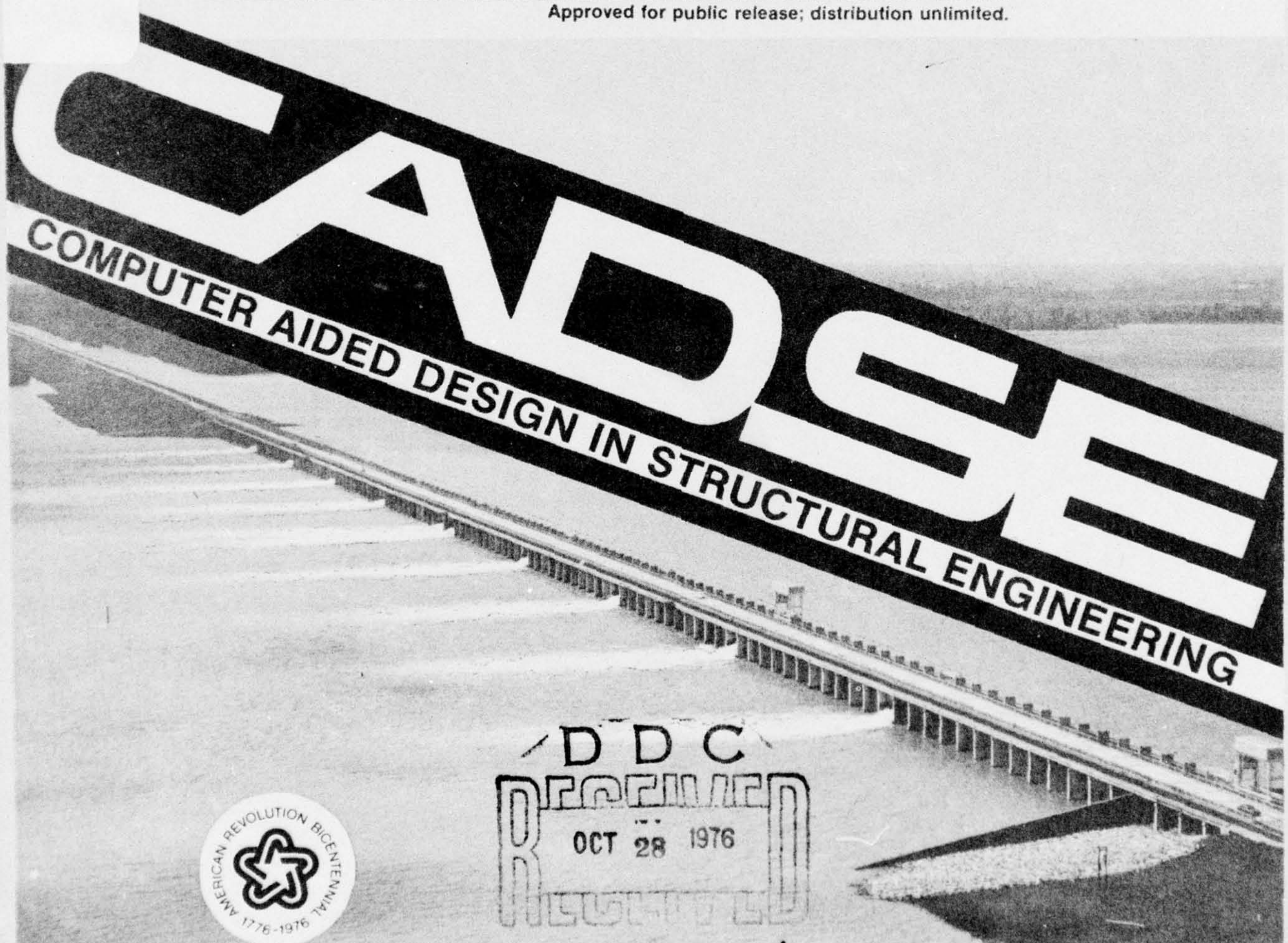

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20. ABSTRACT (*Continue on reverse side if necessary and identify by block number*)

This paper examines the computer-aided design of cast-in-place single-barrel conduits through embankment type dams and levees. Circular and oblong shapes under high fill are emphasized. The paper uses design criteria defined in EM 1110-2-2902, Conduits, Culverts and Pipes. Design loads are groundwater and surcharge water, internal water pressure, concentrated live loads, and backfill. The circular shapes are analyzed as rings of uniform thickness. Shearing and diagonal tension stresses are less critical for
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20. ABSTRACT (Continued).

these circular shapes than for beams and slabs, so Corps shear requirements for conduits are less rigid than those in the ACI code. For rectangular box culverts, shearing stresses and safety factors are determined by the University of Illinois criteria. In addition to discussing design requirements, the paper also suggests desirable computer design program requirements and evaluates several available computer programs.

A computer program rating procedure composed of 15 elements was devised to evaluate programs useful for the design of multicell conduits. These concrete conduits are typically used for river diversion through urban areas and in earthen dam embankments under high fills. Nine existing programs were evaluated; four single purpose and five general purpose. Program 713-G1-M1070 from Albuquerque received the top rating for a single purpose program. In the general purpose category MCAUTO's STRUDL was top rated. An alternate rating procedure was devised using four major function areas. The top three programs in each area were: (a) simulation - STRUDL, SAP IV, EFFRAM; (b) execution - STRUDL, SAP IV, EFFRAM; (c) design - STRUDL, M1070, A407; (d) results - STRUDL, SAP IV, M1070.

Most Corps constructed tunnels are either water conveyance or transportation tunnels driven through rock. This paper is limited to ways in which the computer can be used to aid the structural engineer in the design of such tunnels. The engineer must design the temporary (steel sets, rock bolts, spiling, shotcrete) and permanent tunnel supports. The paper discusses programs available for designing steel sets, concrete linings, and steel tunnel liners, surveys the finite element method, and suggests developing programs for rock bolts, spiling, and shotcrete. The paper concludes that although the computer cannot be used to automate the design of tunnel supports, it can be used to aid in making sound engineering judgements.

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PREFACE

In December 1974, the Automatic Data Processing (ADP) Center, Waterways Experiment Station (WES) submitted a proposal to conduct a Corps-wide Conference on Computer-Aided Design in Structural Engineering to the Office of the Chief of Engineers (OCE). OCE approved the proposal and efforts were started in February 1975 to conduct this Conference. The Conference was conducted in New Orleans, Louisiana, 22-26 September 1975 and was attended by 175 engineers from 48 Corps field offices, OCE, Construction Engineering Research Laboratory, and WES.

This volume contains the papers from Specialty Session C, State-of-the-Corps Art on Single- and Multicell Conduits and Tunnels. Mr. George W. Henson, Structural Engineer, SWTED-DT, Tulsa Distruct, was session chairman and presented a paper. Other papers were presented by Mr. Carney M. Terzian, Chief, Structural Section, NEDED-T, New England Division, and Mr. Robert J. Smith, Structural Engineer, DAEN-CWE-D, OCE.

The Conference was successful due to the efforts of a multitude of people. The roles they played were different but they were all directed toward making a concept on "instant dissemination" work. The Organizing Committee for the Conference consisted of:

COL G. H. Hilt, WES
Mr. F. R. Brown, WES
Mr. D. L. Neumann, WES
Mr. J. B. Cheek, Jr., WES
Dr. N. Radhakrishnan, WES--Conference Coordinator
Mr. W. A. Price, WES
Mr. G. S. Hyde, WES
Mr. D. R. Dressler, LMVD
Mr. W. B. Dodd, LMNDE
Ms. E. Smith, LMNDE
Mr. L. H. Manson, LMNDE

An OCE Coordinating Committee also worked enthusiastically to ensure the success of the Conference. This Committee consisted of:

Mr. C. F. Corns

Mr. R. L. Delyea

Mr. R. F. Malm, OCE Coordinator

Mr. L. G. Guthrie

Mr. D. B. Baldwin

Mr. R. A. McMurrer

The New Orleans District did a remarkable job in playing hosts to the Conference.

There were 13 Division speakers, 25 moderators, 2 invited speakers, 4 technical speakers, and 10 session chairman, who shared the technical load of the Conference. Also, 8 computer vendors showed their ware to the participants.

The editor would like to thank all the individuals who served on the committees and the speakers and the moderators for sharing their time and thoughts. Without them the Conference would not have been the success it was. Mr. Donald Dressler, LMVD, and Mr. William Price, WES, are specially thanked for their technical guidance and assistance.

This report was edited by Dr. N. Radhakrishnan, Research Civil Engineer, Computer Analysis Branch (CAB) and Special Technical Assistant, ADP Center, under the direct supervision of Mr. J. B. Cheek, Jr., Chief, CAB, and under the general supervision of Mr. D. L. Neumann, Chief, ADP Center.

The Director of WES during the Conference and the preparation of this report was COL G. H. Hilt, CE. Mr. F. R. Brown was Technical Director.

CONTENTS

	Page
PREFACE	2
SINGLE-CELL CONDUITS by George W. Henson	5
Scope	5
Design Philosophy	5
Computer Design/Analysis	9
Programs Available	11
Discussion of Programs	32
MULTICELL CONDUITS by Carney M. Terzian	37
Scope	37
Purpose	37
Design Philosophy	37
Evaluations of Single and General Purpose Programs . . .	38
Conclusions	40
Notes on Specialty Session C	43
TUNNELS by Robert J. Smith	45
Introduction	45
Types of Support	45
Programs Available	46
Programs Needed	50
Conclusions	50
Postconference Comments	50
REFERENCES	52
TABLES 1-2	
APPENDIX A: BIOGRAPHICAL SKETCHES OF AUTHORS	A1

SINGLE-CELL CONDUITS

by

George W. Henson*

Scope

This paper discusses the computer-aided design of cast-in-place single-barrel conduits through embankment-type dams and levees. Emphasis is on circular and oblong shapes under high fill. General purpose programs which could be used will not be dicussed.

Design Philosophy

The criteria for design of conduits used in the Corps of Engineers (CE) are defined in EM 1110-2-2902 of March 3, 1969, Conduits, Culverts anu Pipes. The EM recommends that circular shapes (see Figure 1) be analyzed as a ring of uniform thickness, since the variations in thickness in the lower half of the conduit may be disregarded in the design without appreciable error. The following is a summary of this EM.

Loads

The EM describes when loads are to be used and their magnitude. These loads are (a) groundwater and surcharge water, (b) internal water pressure, (c) concentrated live loads, and (d) backfill.

Loading conditions due to backfill

The backfill loads are described for the following construction conditions (see Figure 2). Condition I applies to conduits completely buried in a ditch without superimposed fill above the top of the ditch. Condition II applies to conduits completely buried in a ditch with superimposed fill above the top of the ditch. Condition III applies to conduits that project above an embankment subgrade. Condition IV (not illustrated) applies to special conditions encountered

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* Structural Engineer, Tulsa District.

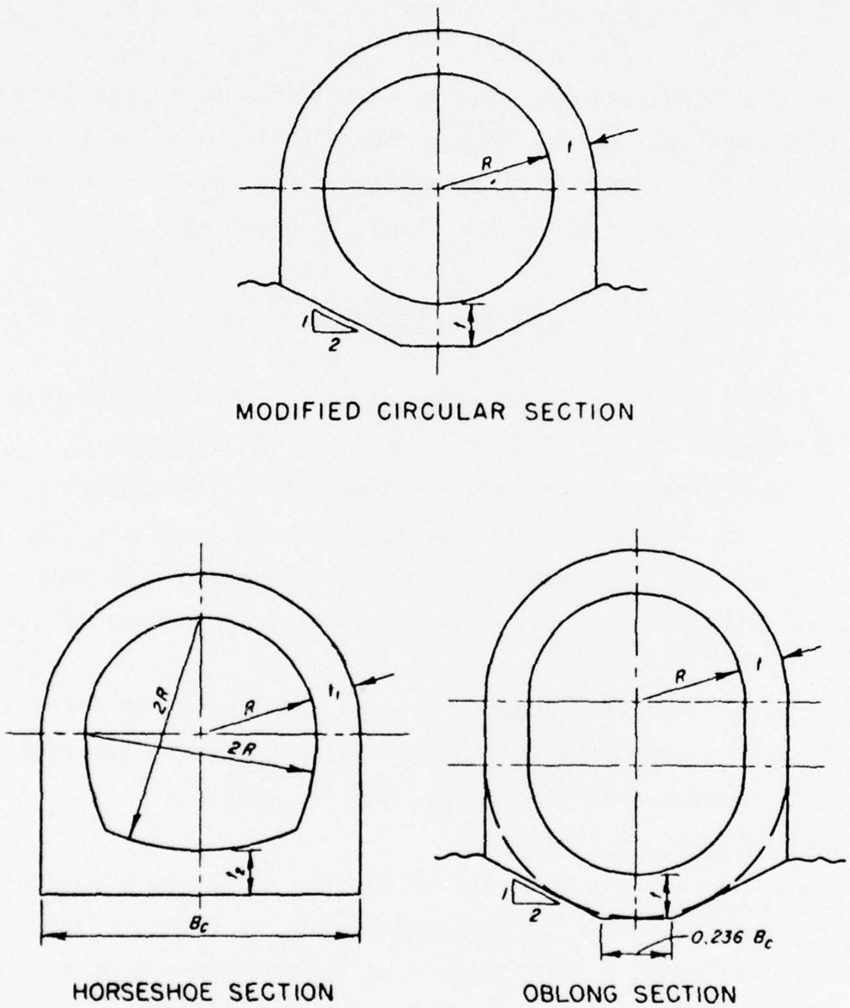


Figure 1. Typical conduit sections (from EM 1110-2-2902, Appendix III, 3 Mar 1969)

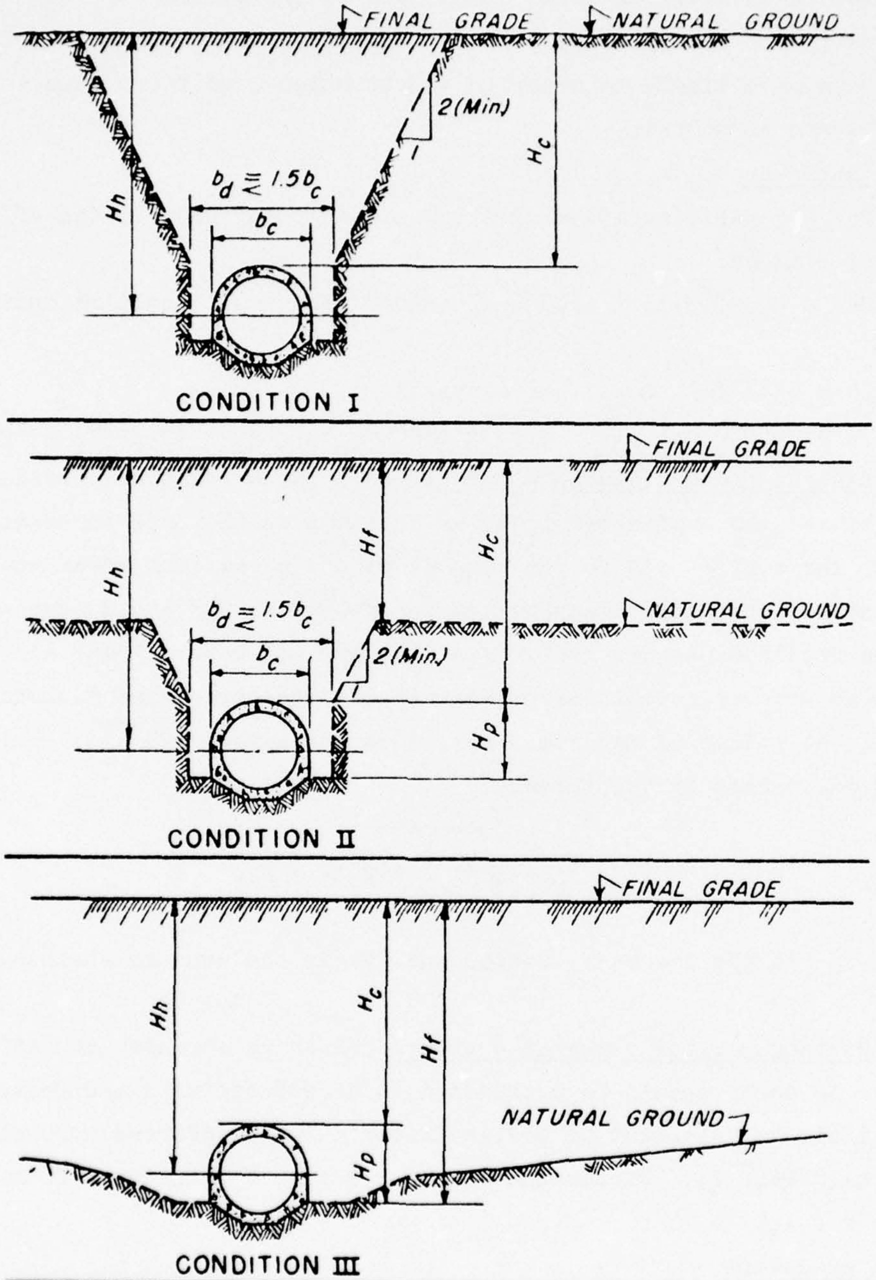


Figure 2. Loading condition diagrams (from EM 1110-2-2902, Appendix III, 3 Mar 1969)

to warrant deviation from the above loading conditions.

The loads given in Conditions I and II are similar to those used in industry for the types of construction described. Conditions III and IV are more likely to describe construction conditions used in CE outlet works structures.

Design stresses

The allowable stresses are the same as those used in the ACI code except for shear.

$f_c' = 4{,}000$ psi or $5{,}000$ psi (except for small conduits under low fill)

$f_c = 0.45\ f_c'$ (max fiber stress)

$f_s = 20{,}000$ psi allowable tension on intermediate grade steel

Cast-in-place conduits - shear. Shearing or diagonal tension stresses are not considered to be as critical as they are in beams and slabs. The compression in the ring at points of maximum shear acts to decrease the principal diagonal tension stresses, and the diagonal tension requirements are less rigid than the ACI code. Shear and diagonal tension requirements have been met when the principal diagonal tension, at points of maximum shear, does not exceed $2\sqrt{f_c'}$. This may be determined by the formula:

$$f_t = \frac{f_c}{2} - \sqrt{\left(\frac{f_c}{2}\right)^2 + v^2} \leq 2\sqrt{f_c'}$$

where f_t is the diagonal tension and v is the average shearing stress.

Rectangular box culverts - shear. Shearing stresses and safety factors in shear should be determined in accordance with the University of Illinois "Development of Design Criteria for Reinforced Concrete Box Culverts," Part II, "Recommendations for Design," Structural Research Series No. 164.

Design procedure

General. Several methods of determining the maximum moments, thrusts, and shears for conduits with curved shells are given in the EM. Both steel and concrete stresses at the inside face of conduits with curved shells should be corrected for curved beam effects.

Calculations. Cast-in-place conduits must be designed for bending moment combined with thrust. The EM recommends designing by the transformed-section method and then investigating the critical sections by ultimate strength design methods. The minimum load factor should be 1.8, and the capacity reduction factor ϕ should be 0.7.

Reinforcement. The minimum steel requirement of 0.002 bt (depth × thickness) in each face and a minimum cover of 4 inches are the major deviations from the ACI code.

Computer Design/Analysis

The program should be so well written and documented that a structural engineer with little computer experience can tell what the program does and how to correctly use it. Some of the more pertinent stipulations are as follows:

Documentation

The write-up should completely describe the problem solved by the program and the restrictions or limitations which should be observed. It should have a series of statements describing the solution techniques, input requirements, output definitions, and any additional information that would be of assistance in understanding the manner of solutions and answers supplied by the program. An example case with a detailed description of all input data and how it is to be prepared should be included.

Input

Problem identification is information read and listed at the beginning of the printout to identify the problem, the user, or anything else pertaining the run. Geometry is input describing the size and shape of the structure. The program should generate most of the dimensions for the standard shapes shown in Figure 2 of EM 1110-2-2902. When conduits of constant thickness are being designed, the program should also increase the wall thickness of these shapes if they are inadequate in shear or moment. Loads include the magnitude and location of loads that will be placed on the structure. It should be possible to check several loading cases on one run without reentering the geometry and design data. Design criteria include the input of allowable stress or safety factors, strength of concrete and steel, and minimum and/or maximum reinforcement to be used in the design. The format statements should be written so that blanks or zeros cause the program to insert the most commonly used values as input.

Analysis

The analysis and design should be in accordance with the criteria set forth in EM 1110-2-2902. If any other information such as the permissible shear stress, according to the ACI code, is computed, it should be listed as information only and not as part of the design. The program should have the option of a complete design or of analyzing a section with preset wall thickness and reinforcement.

Output

All output data should have a neat and easily read format. All data should be labeled; and where appropriate, the units should be indicated. The following items should be included in the output.

a. The input, printed and labeled.

b. Location on the structure where the moments and shears are being computed.

c. Concrete thickness.

d. Thrust.

e. Shear.

f. Moment.

g. Reinforcing ratio or steel area.

h. Steel stress.

i. Concrete stress.

j. Diagonal tension.

k. Points of contraflexure for box culverts.

l. Curved beam correction factor.

m. Factor of safety in ultimate strength design.

n. A printed summary (if more than one case is computed in a single run) giving the maximum stresses at each voussoir.

Programs Available

The following programs have been written by CE personnel.

713C2390 - Omaha District

The Conduit Design Program was written in FORTRAN IV with a required machine storage capacity of approximately 11.5K. The purpose of the program is to design single-barrel conduits. It is also capable of designing symmetrical double-barrel conduits with symmetrical loadings, but this mode is not completely debugged. The program computes geometry, required areas of reinforcing steel, and stresses. Two basic modes of the program, circular and rectangular, are to be considered. The circular mode is the most versatile as it encompasses horseshoe sections and oblong sections. The rectangular mode of the program considers only rectangular openings with rectangular walls. The two-barrel mode will not be discussed except where input data apply.

Analysis. The program has three segments. The first segment is a geometry phase that provides the coordinate description of the elements (voussoirs) for which the analysis is made. The program has the capability of some variation in geometrical shape and number of voussoirs to be analyzed. The second segment is the arch analysis based on the examples set forth in the PCA information sheet--Analysis of Arches, Rigid Frames, and Sewer Sections. This segment provides the moment, thrust, and shear at the centerline of each voussoir. The third segment is the stress analysis phase that is based on the design criteria set forth in EM 1110-2-2902.

Documentation. Omaha District is revising the write-up to a more usable form.

Input. There is a different number of input cards for each mode of the program. The first card contains fixed point variables that control the mode and the output. Sample data coding sheets and sketches are used to clarify formats and geometry. Card No. 1 will be defined; then the input and the output for each mode will be described.

CARD NO. 1. The first input card contains fixed point variables ISENS1, ISENS2, ISENS3, and ISENS4.

Card Column	Description	Format
10	ISENS1 controls intermediate printout for debugging the program; -1 and 0 = YES, and +1 = NO; i.e., suppresses intermediate printout.	I10*
20	ISENS2 applies only to the two-barrel mode; +1 = straight leg and 0 = arch on leg. Use +1 for all other modes.	I10*
30	ISENS3 produces punch card output for moment, thrust, and shear; -1 and 0 = YES, and +1 = NO. This permits use of a second program for design with input cards already punched.	I10*
40	ISENS4 controls the mode. -1 = rectangular mode -1 geometry data card 0 = circular mode (includes horseshoe and oblong sections) -4 geometry data cards 1 = two-barrel mode -2 geometry data cards	I10*

CIRCULAR MODE

Input:

CARD NO. 1. As described above.

CARDS NO. 2 thru NO. 5. Geometry cards. All dimensions are in feet. Note: All horizontal or X dimensions are negative (-) for input cards (except when they are zero). Except for three values on Card No. 2, all the data are defined in Figure 3 of the user's manual. The three variables not defined are THET, MID, and KOTAL.

11-20	THET = One-half of the incremental angle of each voussoir** (floating point variable). THET is noted in Figure 3.	F10.0
21-30	MID = Number of voussoirs** plus one (fixed point variable). The maximum number of voussoirs is 34.	I10*
31-40	KOTAL = Twice the number of voussoirs plus one (fixed point variable).	I10*

CARD NO. 6. Title card. Any alphanumeric description of a project may be written in columns 1 thru 80.

CARD NO. 7. As described below.

---

* These values are to be right justified.

** The circular mode divides the conduit radially by incremental angles into elements or voussoirs.

Card Column	Description	Format
1-5	NCARDS = Number of loading cases for a given geometry. Cards 8 and 9 are a loading case, and any number of sets of Cards 8 and 9 may be included in the data deck.	I5*
6-10	LIMIT = Twice the number of voussoirs plus one (same as KOTAL).	I5*
11-20	BIGK = 1/2 $f_c k_j$ as selected from concrete working stress design handbooks.	F10.3
21-30	STDEST = Allowable steel stress in psi.	F10.3
31-40	DESJ = j for working stress design.	F10.3
41-50	COVER = Minimum concrete cover on reinforcing steel.	F10.3
	CARD NO. 8. As described below.	
1-10	UVINT = Loading uniform vertical intensity psf.	F10.0
11-20	UHINT = Loading uniform horizontal intensity psf.	F10.0
21-30	THINT = Loading triangular horizontal intensity psf (conduit height** wt/cu ft).	F10.0
31-40	CVINT = Loading concentrated vertical at loc pounds.	F10.0
41-50	CVINT1 = Loading concentrated vertical at loc1 pounds.	F10.0
51-55	LOC = Selected location for concentrated load (must be even number).	I5*
56-60	LOC1 = Selected location for concentrated load (must be even number).	I5*
61-70	WTCONC = Weight of concrete pcf.	F10.0
71-75	SYMM = Blank for fixed end (two-barrel mode); 1 for symmetrical single opening.	I5*
	CARD NO. 9. As described below.	
1-10	AASUBS = Initial area of tension steel assumed.	F10.0
11-20	APSUBS = Initial area of steel in compression face assumed.	F10.0
21-30	FPSUBS = Concrete 28-day strength in psi.	F10.0
31-40	XN = N ratio of modulus of elasticity of steel and concrete.	F10.0

* These values are to be right justified.

** The circular mode divides the conduit radially by incremental angles into elements or voussoirs.

Card Column	Description	Format
41-50	ASTSTR = Allowable steel stress in psi.	F10.0
51-60	AFSUBC = Allowable concrete flexure stress in psi.	F10.0
61-70	R = Interior radius used in computing curved beam factor.	F10.0
71-80	XINC = Increment of increase in steel area.	F10.0

Output:

THE FIRST PAGE of output gives interior (XI, YI) and exterior (XO, YO) rectangular coordinates along a radial line at an angle ZETA. ZETA is measured from the Y axis clockwise. Note that the origin of ZETA is not the same as the rectangular coordinate axis. The voussoirs are created by an incremental angle radially from the center of the opening.

THE SECOND PAGE is the input geometry.

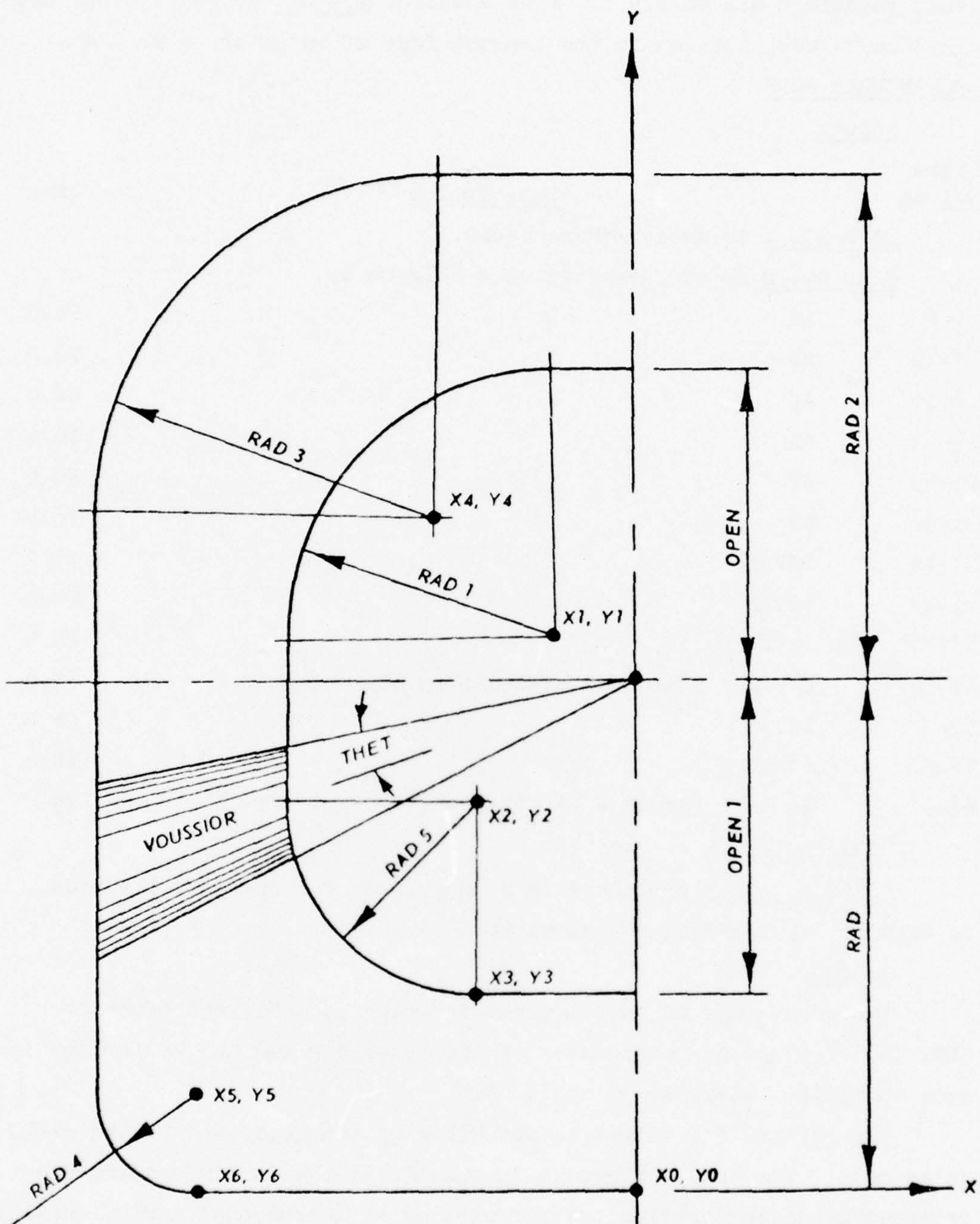
THE THIRD PAGE gives interior (XI, YI), exterior (XO, YO), and centerline (XC, YC) rectangular coordinates.

THE FOURTH PAGE of output gives three values. The total voussoir area is the total cross-sectional area of the conduit. VTOTAL is one-half the total vertical pressure (pounds). UBASEP is the uniform base pressure in pounds per square foot.

THE FIFTH PAGE of output prints the input loads, then lists the moment thrust and shear at the centerline of each section. The actual thickness of each voussoir is the next column. The following columns are the eccentricity of the axial load, the maximum and minimum concrete stresses, and the diagonal tension.

THE SIXTH PAGE of output shows the required d of the concrete for balance design (WSD). The next column gives the actual d provided. Following these columns are the Fixed End Movement, Thrust at Fixed End, and Shear at Fixed End. These are useful only in the two-barrel mode.

THE SEVENTH PAGE of output prints on the first line input material specifications. Below follows the concrete and reinforcing steel stresses; also the required areas of reinforcing steel. The input minimum steel area was that required for temperature and shrinkage stresses. Negative signs in the column TENSION, STEEL (PSI) indicates that iteration for kd (WSD) did not converge and erroneous value was



NOTE: ALL INPUT VALUES OF X ARE NEGATIVE
DIMENSIONS ARE IN FEET

Figure 3. Input geometry, circular mode

used; therefore all values for that voussior are not correct. This usually occurs when tension in the tension face of voussior is very small.

RECTANGULAR MODE

Input:

Card Column	Description	Format
	CARD NO. 1 is described earlier.	
	CARD NO. 2 is the geometry card (Figure 4).	
1-6	AA	F6.0
7-12	AB	F6.0
8-18	AC	F6.0
19-24	AD	F6.0
25-30	AF	F6.0
31-36	AG	F6.0
37-40	DIVAA	F4.0
41-44	DIVAB	F4.0
45-48	DIVAC	F4.0
49-52	DIVAD = number of elements in segment AD	F4.0
53-56	DIVAF	F4.0
57-60	DIVAG	F4.0
61-65	NO = 2* (DIVAF + 2* DIVAG = 2* DIVAD) + 1	I5

CARDS 3 thru 5 are omitted.

CARDS 6 thru 9 are the same as described for the circular mode. On Card No. 7, LIMIT is now equal to NO.

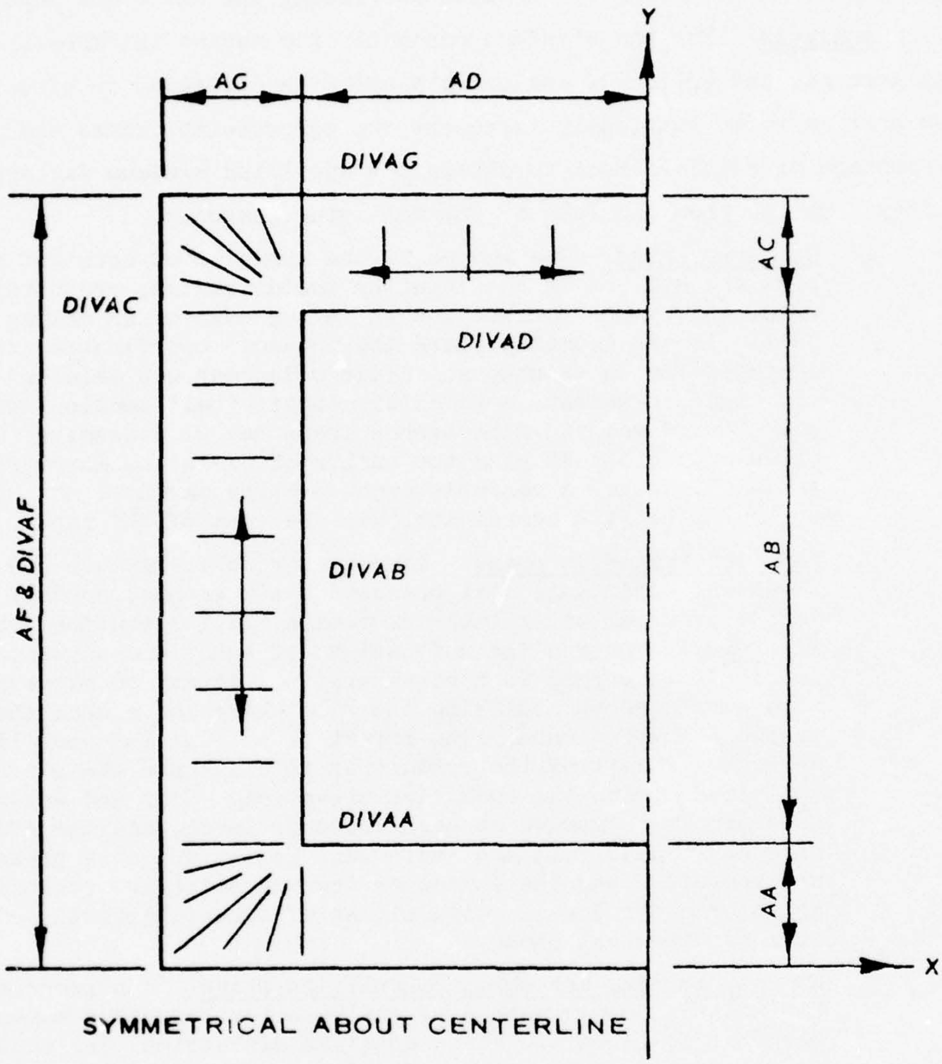
Output:

The first page of output gives interior (XI, YI) and exterior (XO, YO) rectangular coordinates of each voussoir and the centerline of each voussoir. There is no angle ZETA.

The rest of the output is described by the write-up for the circular mode. The only difference in results is that the voussoirs are irregularly defined rather than created by an incremental angle radially from the center of the opening.

713-G1-M0090 - Southwestern Division

This program computes moments, thrusts, shears, and factors of



NOTE: DIMENSIONS ARE IN FEET

Figure 4. Input geometry, rectangular mode

safety in shear and combined axial load and flexure for conduits under high fill. It designs or analyzes circular, oblong, and horseshoe shapes of constant thickness. Conduits with a variable cross section may be analyzed if the voussoir coordinates describing the shape are input.

Analysis. For the standard conduits of constant thickness, the designer has the option of analyzing a specific situation or of using the program to automatically increment the concrete thickness and percentage of reinforcement to obtain the specified minimum factors of safety. The program consists of the following phases:

a. Geometry phase. The shapes of the conduits of constant thickness are defined in the input by inside radius, crown thickness, and by the tangent length in the case of an oblong conduit. In the geometry phase the voussoir coordinates are computed for these shapes. Since 9 degrees was selected as the angle increment, a circular conduit (half section) will have 20 voussoirs. A horseshoe shape has 21 voussoirs. An oblong shape has 20 plus the number of divisions input for the tangent length. A variable cross section may have any number up to 30, but the coordinates will be part of the input.

b. Load determination phase. Loading variables include the vertical and horizontal soil pressure coefficients, conduit invert elevation, water table elevation, soil elevation, rock line elevation, and the unit weight of moist and saturated soil. If live load is a consideration, it may be expressed as a surcharge by modifying the fill elevation and/or the soil pressure coefficients. The effect of placing the rock line above the invert of the conduit is to eliminate the horizontal soil loads below the rock line elevation. Soil and water pressure are computed at each voussoir level, and the effects of conduit dead load are included. Uplift and base pressure are computed, and the forces on the voussoirs are subscripted and stored for use in calculations of moment, thrust, and shear in the next phase.

c. Moment, thrust, and shear calculation phase. The program uses the elastic center method of analysis for computing moments, thrusts, and shears. For a detailed discussion, the reader is referred to PCA pamphlet ST 53, Analysis of Arches, Rigid Frames, and Sewer Sections. The moment correction discussed in the PCA pamphlet was used in order to yield more realistic values for moments throughout the conduit.

d. Ultimate strength phase. This phase of the program computes factors of safety in shear, and combined axial load and flexure, based on the principles of Ultimate Strength Design in ACI 318-63. The depth from the face of the concrete to the centroid of the tensile steel is assumed to be 5 inches at any point. If a design (rather than an analysis) is being performed, the factor of safety in shear is compared with the factor of safety required by the input; if the computed value is less than the required value, a new concrete thickness is computed and the program returns to the geometry phase. This computation is made only for the conduits of constant thickness, and the minimum thickness increase is set at 3 inches. It should be noted that the shear is checked by the formulas given in the ACI code and not those given in the EM. Under ordinary loading, this will give thicker sections than would be required by the EM. The factor of safety in flexure is compared as it was in shear; and if inadequate, the minimum percentage of reinforcement input will be increased by 0.005 and the flexural computations repeated. If the flexural factor of safety is adequate or if the maximum percentage of reinforcement input is reached, the output will be printed. While the program increments the wall thickness until a section adequate in shear is obtained, the upper limit of p may cause the computations to stop at a point where the flexural factor of safety is still inadequate.

In the analysis mode, the percentage of reinforcement and the wall thickness will remain constant. If more than one configuration of reinforcement is desirable, an analysis should be made, using each different percentage. In this case, the designer should realize that the factors of safety are valid only at the voussoirs where the indicated steel ratios actually occur.

Documentation. The write-up is very good. It describes the solution routine and gives references. The input requirements and the output descriptions are very clearly listed. Several example runs are attached. Sense-switch settings are a little vague.

Input. A sense switch is required to control selection between design and analysis. It would be better if a control card had been used for this function.

Conduits of constant thickness. Five cards are required for a run. Any change in loading or design criteria requires an additional run. Twenty-four items of input data are required for the smallest possible input. The following is a summary of the cards.

Card Column	Description	Format Specification	Probable Magnitude
1-5	CARD NO. 1 - Header information. The first 70 columns of this card are used for problem identification. Information contained in the card will be read and listed at the beginning		

Card Column	Description	Format Specification	Probable Magnitude
	of the printout. The last 10 columns, if used, will be ignored by the computer. In the IBM 1620 version of the program, this record is entered under a Hollerith specification. In the GE 225 version, it is entered under series "A" specifications (11A6, A4).		
	CARD NO. 2 - Geometry data. The second record of input data contains the following eight values.		
1-5	Number of voussoirs (NV)*	I5	XX
6-10	Number of divisions of tangent length in oblong section (NDIV)**	I5	X
11-15	Control parameter denoting type of standard section (M)†	I5	(+)X (-)
16-20	Control parameter denoting a variable section (MM)††	I5	(+)X (-)
21-30	Thickness of section at the crown, in feet (TC)	F10.0	X.XXX
31-40	Inside radius of standard section, in feet (RI)‡	F10.0	X.XXX
41-50	Tangent length of oblong section, in feet (TANL)‡‡	F10.0	X.XXX
51-60	Invert elevation, in feet (ELINV), positive only	F10.0	XXX.XX

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* For circular conduit, NV = 20 . For horseshoe conduit, NV = 21 . For oblong conduit, NV = 20 + NDIV . For nonstandard section, NV = any number not exceeding 30 .

** For any type of section other than oblong, NDIV = 0 . May be left blank if data is to be processed by GE 225.

† For circular conduit, M = -1 . For horseshoe conduit, M = +1 . For any other type of section, M = 0 . May be left blank if data is to be processed by GE 225.

†† For variable section, MM = any number other than zero. For standard section, MM = 0 . May be left blank if data is to be processed by GE 225.

‡ For a nonstandard section, RI = 0 . May be left blank if data is to be processed by GE 225.

‡‡ For anything other than an oblong section, TANL = 0 . May be left blank if data is to be processed by GE 225.

Card Column	Description	Format Specification	Probable Magnitude
	CARD NO. 3 - Soils data. The third record consists of the following soils data elements.		
1-10	Coefficient of vertical earth pressure (VK)	F10.0	X.XX
11-20	Coefficient of horizontal earth pressure (HK)	F10.0	.XX
21-30	Soil elevation, in feet (SELEV)*	F10.0	XXX.XX
31-40	Water elevation, in feet (WELEV)*	F10.0	XXX.XX
41-50	Rock line elevation, in feet (RELEV)*	F10.0	XXX.XX
51-60	Unit weight of moist soil, in kcf	F10.0	.XX
61-70	Buoyant unit weight of saturated soil, in kcf (WES)	F10.0	.XX
	CARD NO. 4 - Design criteria. The fourth record contains the following seven items.		
1-10	Unit weight of concrete in kcf (WC)	F10.0	.XX
11-20	Minimum percentage of reinforcement in tension face (PMIN)	F10.0	.XX
21-30	Maximum percentage of reinforcement in tension face (PMAX)	F10.0	.XX
31-40	28-day compressive strength of concrete, in psi (FC)**	F10.0	XXXX.
41-50	Yield strength of reinforcing steel, in psi (FY)	F10.0	XXXXX.
51-60	Required factor of safety in shear (FSSR)†	F10.0	X.XX
61-70	Required factor of safety in flexure (FSFR)†	F10.0	X.XX
	CARD NO. 5 - Design criteria. The fifth record of input contains only two data elements, as follows.		
1-10	Ultimate strength capacity reduction factor for shear (PHIS)††	F10.0	.XX

* All elevations must be entered as positive values.

** Compressive strength of concrete (FC) = 4000 psi minimum.

† Usually 1.8.

†† Usually 0.85.

Card Column	Description	Format Specification	Probable Magnitude
11-20	Ultimate strength capacity reduction factor for combined axial load and flexure (PHIF)*	F10.0	.XX

REMAINING CARDS - Voussoir definition data. The remaining cards of the input deck are used to define the shape of a variable-section conduit and are therefore not required for the standard conduits of constant thickness. There should be one card for each voussoir of the variable section, and each card contains four data elements as follows.

1-10	X-coordinate of voussoir extrados, in feet (X_i)	F10.0	X.XXX
11-20	Y-coordinate of voussoir extrados, in feet (Y_i)	F10.0	X.XXX
21-30	X-coordinates of voussoir intrados, in feet (Z_i)	F10.0	X.XXX
31-40	Y-coordinate of voussoir intrados, in feet (W_i)	F10.0	X.

Output. All output from this program is produced on the on-line printer (or on the console typewriter, if being run on the IBM 1620). For purposes of visual verification, the basic input data is listed along with the computed output values. The input items are printed in the same sequence and format (i.e., one line per card) in which they are entered, and are identified by their mnemonic labels. The voussoir coordinates--whether computed or entered as input data--are listed following printout of the basic input data. Output of the computed values (excluding voussoir coordinates) is as follows:

Voussoir number (beginning at zero)

Voussoir thickness (inches)

Percentage of reinforcement

Thrust (axial load) acting at center of voussoir (pounds)

Shear acting at center of voussoir (pounds)

Final moment due to all loading (inch-pounds)

Note: All voussoir coordinates have their origin at crown extrados and must be entered as positive values.

* Ususally 0.70.

Factor of safety in shear

Factor of safety in flexure

13-K2-H223 - Louisville District

The program was written to design a variable seciton conduit with water and/or earth loading. This is a revised version of Tulsa District program 13-G1-G523 written in GE WIZ for a GE 225 computer. The Load Determination Phase and the Moment, Thrust, and Shear Phase of the Southwestern Division program were also taken from the Tulsa District program.

Analysis. The cross section of the conduit is divided into a maximum of 30 wedge-shaped pieces by inputing the coordinates of the corners of the voussoirs. All moments, shears, and thrusts are computed by the elastic center method on a line bisecting the outside and inside edge of each voussoir. The external loads are applied on free-bodies at the outside face of the conduit. Moments are computed to the center of horizontal and vertical loads. Moments are then summed about the center of the voussoirs. This is opposed to the PCA type of analysis where all load is assumed to be concentrated at the center of each voussoir. The procedure used in the program produces lower moments than other methods, but the results may be more accurate.

Loading may be varied by adjusting the height of water, saturated soil or moist soil; by adjusting the weight of saturated or moist soil; or by adjusting the coefficients of horizontal and vertical earth pressure. The horizontal external soil load is eliminated below the rock line elevation. This program corrects stresses at the interior face for curved beam effects.

Documentation. The write-up is the same as the Tulsa District program. It should be revised to include a description of the curved beam correction factor and how it is to be entered as input.

Input. The input described below is good for one loading case. Additional cases would require another complete set of input data.

Card Column	Description	Format Specification

CARD NO. 1. Project identification card.

Card Column	Description	Format Specification
	CARD NO. 2.	
2-8	(CC) Distance to tensile steel (inches)	F7.2
9-16	(HD) Height of water above (+) or below (-) extrados at top of transition (feet)	F8.2
17-18	(HES) Height of submerged soil above (+) or below (-) extrados at top of transition (feet)	F8.2
25-32	(WES) Unit weight of submerged soil (kcf)	F8.4
33-41	(HEM) Height of moist soil above HES if HES is (+). Above or below crown if HES is (-) (feet)	F8.2
41-48	(WEM) Unit weight of moist soil (kcf)	F8.4
49-56	(RL) Rock line distance below extrados at top of transition (feet)	F8.2
57-64	(KH) Coefficient of horizontal soil pressure	F8.2
65-72	(KV) Coefficient of vertical soil pressure	F8.2
73-80	(NR) Modulus of elasticity ratio	F8.2
	CARD NO. 3.	
2-8	FS - Allowable steel working stress (ksi)	F7.3
9-16	FC - Ultimate concrete compressive strength (ksi)	F8.3
17-24	WC - Unit weight of concrete (kcf)	F8.4
25-32	IV - Number of voussoirs (right justified)	I8
33-40	TC - Thickness of crown (feet)	F8.2
41-48	VC - Index of compressive strength of concrete	F8.4
49-56	IS - Continuous ends = 1; fixed ends = 0 (right justified)	I8
	CARD NO. 4. There should be one card for each voussoir of the section, and each card contains five data elements as follows.	
2-8	I - Voussoir number (right justified)	I7
9-16	X(I) - Abscissa of extrados (feet)	F8.2
17-24	Y(I) - Ordinate of extrados (feet)	F8.2
25-32	Z(I) - Abscissa of intrados (feet)	F8.2
33-40	W(I) - Ordinate of intrados (feet)	F8.2
	LAST CARD. Curved beam correction factor.	
2-3	Number of curves	I2

Card Column	Description	Format Specification
4-11	Radius of curvature at top	F8.0
12-13	Voussior number beginning curve	I2
14-15	Voussoir number ending curve	I2
16-23	Radius of curvature at bottom	F8.0
24-25	Voussoir number beginning curve	I2
26-27	Voussoir number ending curve	I2

Output. All of the input data are printed for references. The following computed values are output for each voussoir.

Voussoir number (beginning at zero)

Final moment (kip-ft)

Shear (kips)

Thrust (kips)

Concrete stress (ksi)

Steel stress (ksi)

Area of steel (square inches)

Diagonal tension (ksi)

Curvature

Curved beam correction factor

The weight in kips and the volume in cubic yards of a 1-foot-thick section described by the voussoir points are printed at the end of each run.

713-G9A4-060 - Vicksburg District

The program was written to design or analyze single-cell box culverts. It determines the minimum thicknesses of the horizontal and vertical members and the area of reinforcing steel to provide for moment and the required factor of safety for cracking load for shear. For a maximum of 30 loading conditions, the program will find the minimum thicknesses required to support the load or it will compute the resulting stresses, d's , steel reinforcing, and factors of safety in the members. The program does not compute for haunches. Backfill is considered to be level over the completed structure. Concrete cover for reinforcement is 2.5 inches in all cases except the bottom of the bottom slab where 3.5 inches are used.

Analysis. The design is in accordance with the criteria set forth in EM 1110-2-2902. Distributed moments are adjusted to the column face and at the center of the span by the method explained starting on page 28 of Continuity in Concrete Building Frame, Practical Analysis for Vertical Load and Wind Pressure, fourth edition, published by the Portland Cement Association.

a. The unit loading on the structure is computed at the beginning of computation of each case and each time there is a change in the thickness of any of the members. Vertical weight of the soil is controlled by vertical load factors for each case. A full culvert is used to compute the forces for internal load.

b. In the design phase (no member thickness input), the safety factor for cracking shear load is used to find the thickness of the top slab. The required safety factor (2 to 2.5) is based on the L/d ratio. The sidewall thickness is set equal to the top slab, and the bottom slab is set 1 inch thicker than the top slab. The minimum slab thickness is 9 inches.

c. Fixed end moments and moment distributions are made between the midpoints of the diagonals at the corners of the structure. Distributed moments are adjusted to the column face.

d. Computations are made to find the unit loads, moments, reactions, shears, thrust, and required d's for the structure, from external forces, then internal forces, and finally hydrostatic forces. In the design phase, the required d's are compared with the provided d's at the end of each force computation. If the required d is more than 0.1 inch greater than the provided d, the member thickness is increased 1 inch and the computations are repeated beginning with the external forces.

e. At this point the provided d's equal (or are less than 0.1 inch smaller) or exceed the required d's. Final computations or output are as follows:

(1) Search for maximum shear at the face of each structural member.

(2) Maximum moment, thrust, and Nd"/12 at each point used to compute the maximum steel moment.

(3) Maximum steel moment.

(4) Required and provided d's at each point.

(5) Equivalent areas of steel for the steel moment and the thrust.

(6) Area of steel reinforcing required. This area will not be less than the minimum factor times 12d.

(7) Distances between the points of contraflexure of top and bottom slabs for each maximum and external moment.

(8) True safety factor and required safety factor for cracking load for shear in the top and bottom slabs. The required d does not always control the thickness to be used. This is the reason for computing the true safety factor at the end of each computation.

After the starting thicknesses are computed, if the provided d is 1 inch larger than the largest required d of a member, the thickness is reduced 1 inch and the computations for the structure are repeated. If, however, the provided d does not contain the largest required d of a member or does not meet safety factor requirements, a flag is set so that the member cannot be reduced again, the thickness is increased 1 inch, and the computations for the structure are repeated. In the process of finding the structure with the least required safety factor and the minimum required d, several safe combinations of thicknesses may be found. For each safe combination, the cross-sectional area is computed. The safe combination with the minimum end area will be used in calculating the next case. These thicknesses cannot be reduced by subsequent cases; however, they can be increased if the loading conditions require more strength for moment or shear.

Documentation. The write-up is very good. It describes the solution routine and gives references. The input requirements and the output descriptions are very clearly listed. An example problem is attached.

Input.

a. USER ID. The first card of the input is to inform the computer operator who requested the run and where to send the output. Computer output is often saved on disks and is output by the printer at a later time. Thus, the output should contain the user identification to ensure that it is returned to the sender. This card should contain the requester's name, the office where he works, and the district office; e.g., Bill Jones, Minor Struct Sec, VXD.

b. TITLE CARD. The title card is the second type of input. It contains 80 alphanumeric characters to identify the culvert being designed. The contents of this card will be printed at the top of each sheet of output.

c. COMMENT CARD. A comment card is the third type of input. The first 79 card columns contain the comment (in alphanumerics); and card column 80 must contain a minus. Any number of comment cards may be used between the Title Card and the Constant Card. This card is optional. It may be used to add some special comment concerning the culvert design for later reference. The comments are printed under the title on the User ID sheet that is printed for the operator. When two or more culverts are designed, comments are printed on the sheet between the summary sheet of the preceding culvert and the first case of the next culvert.

d. CONSTANTS. The fourth type of input card contains constants that will be used in computing all of the cases. The first two entries, width and height, are required; but the remainder of the card may be left blank. The thicknesses of the top, side, and bottom are left blank for design applications; but they must be entered when an analysis is to be computed. Standard design factors are entered by the program when the remainder of the card is left blank.

Card Column	Explanation
6-10	Width of culvert, feet.
11-15	Height of culvert, feet.
16-20*	Thickness of top slab, inches.
21-25*	Thickness of side, inches.
26-30*	Thickness in bottom slab, inches.
31-35**	f'_c for concrete, psi.
36-40	K factor for concrete.
41-45†	f_s for steel, psi.
46-50	j factor for steel.
51-55††	Fraction of bd for minimum steel.
56-79	Blank.
80	If iterations of the design and backup computations are desired in the output, punch a C in card column 80.

* When slab thicknesses are entered, the design phase will not take place. Also, no summary sheet will appear at the end of the output.

** Blanks or zero cause the program to insert 4,000 for f'_c and 324 for K.

† Blanks or zero cause the program to insert 20,000 for f_s and 0.860 for j.

†† Blanks or zero cause the program to insert 0.0025 for the minimum steel factor.

e. CASE TITLE. A case title card must precede each case data card. This card uses the same format as the title card to input up to 80 alphanumeric characters. This data is used to label the cases in the output. It is printed as the second line of input for each case.

f. CASE DATA. The fifth type of input card gives the input used to compute the loading. Input consists of groundwater, as many as three soil conditions, and hydrostatic head.

Card Column	Explanation
1-3	The letters END are to be punched in the last case only.
4-5	Blank.
6-10	Depth of groundwater in feet above the top of the opening. Groundwater may extend above the ground surface.
11-15	Depth of soil in feet above the top of the opening.
16-20	Weight of soil in pcf. Submerged soils do not include the weight of water.
21-25	K factor for soil.
26-30	Depth of soil in feet above soil.
31-35	Weight of soil, pcf.
36-40	K factor for soil.
41-45	Depth of soil in feet above soil.
46-50	Weight of soil, pcf.
51-55	K factor for soil.
56-60	Height of head in feet above the top of the opening. Each case that contains head is recomputed as a separate case with no head.
61-65	First factor for computing the vertical weight of soil on the top slab.
66-70	Second factor for computing the vertical weight of soil on the top slab. This is left blank except on the rare occasion when it is desirable to compute a case using two factors. This causes a second case computation to be made.

Spaces not required for input may be left blank. Each case data card must follow a case title card.

g. INPUT SETUP Input for this program must be in the following order.

(1) User ID. One time only.

(2) Title card. One per culvert.

(3) Comment card. Optional.

(4) *Constants. One per culvert.*

(5) Case title. One per case.

(6) Case data. One per case.

The input setup should include as many pairs of case title and case data cards as there are loading conditions. The last data card must have "END" in card columns 1-3. The program is compiled for a maximum of 30 cases. When two or more culverts are to be processed in the same run, the last card of the first culvert is followed by the new title card (b above). The input setup after the title card is the same as it is for the first culvert.

Output

The information on the User ID card is the first line of output and is followed by the program number which references the program used. The next item printed is the title of the culvert. If there are any comment cards, they will be listed after the culvert title. When two or more culverts are computed in the same run, the title of the next culvert and any comment cards to be listed are printed on the sheet between the summary sheet of the preceding culvert and the first case of the next culvert.

The remainder of the output format except the summary is repeated for each case. Each case is output one time for each vertical load factor. If there are 10 cases, two of which have head, there will be 12 pages of case output. Each of the two having head will be recomputed for no head.

a. The first line of case output is the culvert title and data of computation. This line is followed by the case title.

b. The first data output are the thicknesses of the top, side, and bottom members, input constants, and case variables. This data has headings for identification.

c. Output for the external, internal, and hydrostatic head loading uses the same format. Adjusted moments (M), thrust (N), and shears (V) for each loading are listed for points 1-7. These are followed by maximum shear, working moment, thrust accompanying working moment, equivalent moment (ND"/12), steel moment, required d , provided d , area of steel for moment, equivalent area of steel for thrust (N/f_s), and area of reinforcing steel required in square inches for each point.

The items above that have separate calculations for inside and/or outside faces have two line entries with the inside face on top.

d. The safety factor and required safety factor for the cracking load for shear and the distances between the points of contraflexure for maximum and external loading are printed for the top and bottom slabs.

e. Notes explaining the sign convention are printed at the end of the output.

No summary sheet is made for analysis runs. In the design phase after all the cases have been processed to determine the most economic thicknesses, all cases are recomputed to obtain the moments, thrusts, shears, etc., for case output. During this recomputation the summary sheet information is extracted. The summary sheet contains:

a. The first line, giving the culvert title and date of computation.

b. Thicknesses of the top, side, and bottom numbers.

c. The maximum area of steel in square inches required to reinforce the inside and outside faces at the seven computation points.

d. Range of contraflexure in the top and bottom slabs.

e. Cross-sectional area of concrete.

f. Diagram to depict the computation points.

g. Program number for reference.

This output description is for normal output. Should the user have an interest in the computation cycles that are made or should he want to do some debugging, he must put a C in the constant card, as explained in the input section. This type of entry will increase the amount of output about four times. The greater part of the debugging output is self-explanatory. If the user elects to run an analysis for specific thicknesses, no design will be performed, nor will a summary sheet be printed.

Discussion of Programs

Box culverts

The Vicksburg program appears to be well written and meets all the requirements of a good program. With a minimum of input, the program produces the necessary information to design a single-cell box culvert without haunches.

Conduits

None of the conduit programs completely fulfills the requirements of a good design program. They will all analyze a section, and the Omaha and Louisville versions compute the amount of steel required; but the concrete cross sections remain as they were input. The Omaha and Louisville programs use the Working Stress Design method, while the Southwestern Division program uses the Ultimate Strength Design method. In each case this means the results must be checked manually by the alternate method. The following is a summary of the programs.

Omaha. The Omaha version is probably the best of the existing programs. It is the only one that allows multiple loading cases in a single run. The design mode is limited because the concrete wall thicknesses are not sized by the computer. The program does not have an analysis mode.

Southwestern Division. This is the only program with a true design mode, but is is almost useless because the wall thicknesses are sized by the ACI code instead of the EM formulas. If the program was revised to size the walls by the diagonal tension formula given in the EM, it would be a very good program. In its present form only the analysis mode should be used. The geometry routines in this program are very good.

Louisville. This program was written for a variable section, and the designer is required to input all the voussoir coordinates for the concrete cross section. If a circular shape of uniform thickness is to be analyzed, one of the other programs would be easier to use. It seems that the curved beam correction factor is applied only to the concrete stress and not to the steel. The program does not have an analysis mode.

New Conduits program. If the best parts of the existing programs were combined, a very useful program could be developed. The Geometry, the Load Determination, and Moment, Thrust, and Shear phases of the Southwestern Division program combined with the Design phase of the Omaha or Louisville programs would be the best combinations. The Ultimate Strength phase could be used as an investigation routine after the section was designed by the Working Stress method. When designing one of the conduits of constant thickness, the computer should increase the wall thickness if either the allowable concrete design stresses or the maximum area of steel input is exceeded. An analysis mode should be provided to investigate a section with predetermined wall thickness and area of steel. The following is a suggestion of how the input and output should appear.

Card Column	Description	Format Specification
	CARD NO. 1 - Header information. The first 70 columns of this card are used for problem identification. Information contained in the card will be read and listed at the beginning of the printout. The last 10 columns, if used, will be ignored by the computer. In the IBM 1620 version of the program, this record is entered under a Hollerith specification. In the GE 225 version, it is entered under a series of "A" specifications (11A6, A4).	
	CARD No. 2 - Control card.	
10	1 if analysis, zero if design	I10
20	Number of cases to be run	I10
30	Print control	I10
	CARD No. 3 - Geometry data. The second record of input data contains the following eight values.	
1-5	Number of voussoirs (NV)*	I5
6-10	Number of divisions of tangent length in oblong section (NDIV)**	I5

* For circular conduit, NV = 20 ; for horseshoe conduit, NV = 21 ; for oblong conduit, NV = 20 + NDIV ; for nonstandard section, NV = any number not exceeding 30.

** For any type of section other than oblong, NDIV = 0 ; (or may be left blank if data is to be processed by GE 225).

Card Column	Description	Format Specification
11-15	Control parameter denoting type of standard section (M)*	I5
16-20	Control parameter denoting a variable section (MM)**	I5
21-30	Thickness of section at the crown, in feet (TC)	F10.0
31-40	Inside radius of standard section, in feet (RI)†	F10.0
41-50	Tangent length of oblong section, in feet (TANL)††	F10.0
51-60	Invert elevation, in feet (ELINV), positive only	F10.0
	CARD No. 4 - Soils data. The third record consists of the following soils data elements.	
1-10	Coefficient of vertical earth pressure (VK)	F10.0
11-20	Coefficient of horizontal earth pressure (HK)	F10.0
21-30	Soil elevation, in feet (SELEV)‡	F10.0
31-40	Water elevation, in feet (WELEV)‡	F10.0
41-50	Rock line elevation, in feet (RELEV)‡	F10.0
51-60	Unit weight of moist soil, in kcf (WEM)	F10.0
61-70	Buoyant unit weight of saturated soil, in kcf (WES)	F10.0
71-80	Triangular horizontal loading, in ksf (THINT)	F10.0
	CARD NO. 5 - Design criteria.	
1-10	Interior radius used in computing curved beam factor	
11-20	Minimum cover of reinforcement (blank causes program to insert 4 inches)	

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* For circular conduit, M = 1 ; for horseshoe conduit, M = +1 ; for any other type of section, M = 0 (may be left blank if data is to be processed by GE 225).

** For variable section, MM = any number other than zero; for standard section, MM = 0 (or blank if data to be processed by GE 225).

† For a nonstandard section, RI = 0 (may be left blank if data is to processed by GE 225).

†† For anything other than an oblong section, TANL = 0 (may be left blank if data is to be processed by GE 225).

‡ All elevations must be entered as positive values.

Card Column	Description	Format Specification
21-30	Minimun area of steel (blank causes program to insert 0.6 sq in.)	
31-40	Maximum area of steel (blank causes program to insert 3.12 sq in.)	
41-50	f_y (blank causes program to insert 40,000 psi)	
51-60	f'_c (blank causes program to insert 4,000 psi)	
61-70	Index of compressive strength of concrete (blank causes program to insert 0.45)	
71-80	Required factor of safety in Ultimate Strength (blank causes program to insert 1.8)	

VOUSSOIR DEFINITION DATA. The following cards of the input deck are used to define the shape of a variable-section conduit and are therefore not required for the standard conduits of constant thickness. There should be one card for each voussoir of the variable section, and each card contains four data elements as follows.

Card Column	Description	Format Specification
1-10	X-coordinate of voussoir extrados, in feet (X_i)	F10.0
11-20	Y-coordinate of voussoir extrados, in feet (Y_i)	F10.0
21-30	X-coordinates of voussoir intrados, in feet (Z_i)	F10.0
31-40	Y-coordinate of voussoir intrados, in feet (W_i)	F10.0

Note: All voussoir coordinates have their origin at crown extrados and must be entered as positive values.

REMAINING CARDS. Card No. 4 is repeated for each loading case.

Output

Voussoir coordinates. The coordinates are always printed on the first page of the printout.

Basic output. If a zero or a blank is input in card column 30 of the print control card (Card No. 2), the following items will be printed for each loading case (one case per page).

Input items in the same sequence in which they are entered

Voussoir number (beginning at zero)

Voussoir thickness (inches)

Shear (kips)

Thrust (kips)

Moment (kip-ft)

Eccentricity (inches)

This would give a fairly clean printout and would allow the designer to decide where the changes in reinforcing steel should be made.

Extended output. If additional output is desired, punch a "1" in column 30 if the print control card and the following items will be printed (one case per page).

All the items listed in the Basic Output plus the following:

Diagonal tension (ksi)

Area of steel (sq in.)

Concrete stress (ksi)

Steel stress (ksi)

Factor of safety in flexure

Curved beam correction factor

MULTICELL CONDUITS

by

Carney M. Terzian*

Scope

This report is an evaluation of the computer-aided design of concrete multicell conduits. These conduits, typically, are used in river diversion through urban areas and in earthen dam embankments under high fills. I will discuss both single purpose and general purpose computer programs.

Purpose

The intent of this evaluation is to aid the structural engineer in facilitating his work while achieving the optimum analysis and design. I hope the programs available and discussed here will advance the program of conduit analysis and design, along with conserving engineer time and effort.

Design Philosophy

Methodology is the prime concern; two divisions are apparent in the evaluation and will be discussed separately and summarized in the conclusion. A common aspect between single and general purpose programs is the criteria for design contained in EM 1110-2-2902 Conduits, Culverts and Pipes (3 March 1969). If we assume that the EM represents the state of the art, then, presumably, many conflicts are resolved. The dissimilarity between single purpose and general purpose programs has been considerably reduced and one is as good as another. But, consider the state of the art. Three important references in the field are:

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* Chief, Structural Section, New England Division.

a. "Finite Element Analysis of Port Allen and Old River Locks" by Clough & Duncan, Sep 1969, University of California, Berkeley.

b. "Thick Walled Multiple Opening Reinforced Concrete Conduits" by Ryan, Salem, Gamble & Mohraz, Dec 1972, University of Illinois.

c. "Non-Linear Analysis of Planar Reinforced Concrete Structures" by Salem & Mohraz, Jul 1974, University of Illinois.

The findings of these Corps sponsored researches have not yet been incorporated by the subject EM. For example, Plates 3 and 4, note 3, of the EM specifies the assumption of uniform foundation pressures; Reference (a) suggest yielding foundation and its Appendix C contains a finite element computer program for Soil-Structure Interaction. References (b) and (c) include information developed on the use of the finite-element method of analysis, taking into account the progression of cracking with increasing load and the nonlinear stress-strain response of the materials. Obviously the researchers are using the finite-element method, the basis for general purpose programs. The subject EM should be revised to recognize these advances and others as they are developed.

Evaluations of Single and General Purpose Programs

Single purpose programs

The rating procedure for single purpose programs is shown in Table 1.

Rating of single purpose programs

The single purpose programs were evaluated using the rating procedure shown in Table 1. Checking the fifteen elements considered necessary for optimum analysis and design resulted in the following normalized grading:

Grade	Program	District
A+	713-G1-M1070	Albuquerque
A	13-G1-A407	St. Louis
B+	713-G2-L2-005	San Francisco
D+	713-x6-L2-22A	Sacramento

Discussion of ratings

In general the approach to analysis by moment distribution was similar for all programs rated (except L2-005); the difference occurs in the design function. Program No. 713-x6-L2-22A, Sacramento, as transmitted provided no design of elements, resulting in a low rating.

Genral purpose programs

The rating procedure for general purpose programs is shown in Table 2.

Ratings of general purpose programs

The general purpose programs were evaluated using the rating procedure given in Table 2. Checking the fifteen elements considered necessary for optimum analysis and design resulted in the following normalized gradings:

Grade	Program	District
A+	STRUDL/MCAUTO	Proprietary
B	SAP IV	University of California, Berkeley
C	EFFRAM(713-DOF7110)	New England Division
C-	Wilson 2D(713-G2-L3-002)	San Francisco
D	G-FRAME(713-F3-A1-030)	Memphis

Discussion of ratings

All general purpose programs used the forced displacement finite-element method. The primary differences in program capabilities is that MCAUTO provides 3-dimensional and dynamic analysis, interactive graphic (CRT), and design while SAP IV did not contain the design feature. The remaining three programs were rated low since only two-dimensional analysis is performed, with no dynamic analysis and no interactive graphics or design capabilities as yet. It is noted that STRUDL/MCAUTO with FASTDRAW is a total system while the others are programs only. The low ratings are not completely fair since EFFRAM, Wilson 2D, and G-FRAME provide excellent analytical and simulation procedures not found in the single purpose programs. They could be rated higher if compared to the single purpose programs.

Conclusions

Two views of the computer programs will be made, first by groupings, then followed by the best points of each program.

Four general areas of concern were defined in the comparison of the nine programs; these are simulation, execution, design, and results. Specifically, items shown in the rating procedure are grouped as follows:

a. Simulation - Items 1, 5, 6, 7, 10, 12, 14, & 15

b. Execution - Items 3, 4, 9, & 14

c. Design - Item 8

d. Results - Items 2, 11, 13, & 14

The top 3 of 9 programs are rated, based upon these four groupings, as follows:

a. Simulation - MCAUTO, SAP IV, & EFFRAM

b. Execution - MCAUTO, SAP IV, & EFFRAM

c. Design - MCAUTO, M1070, & A407

d. Results - MCAUTO, SAP IV, & M1070

It has been found that each of the programs studied has its own unique qualities that set it apart in one category or another from all the others. We feel that it would be useful to all of you, in your future program development, to keep these following ideas in mind.

Foundation springs, capable of taking tension or compression, should be provided with the option of eliminating any tension that occurs in order to accurately simulate any unique environmental conditions that may arise. This ability is present in EFFRAM by NED. Along the same reasoning, torsional or moment springs should be possible, as in SAP IV or Wilson 2D. A yielding foundation, we feel, is an essential element in any totally comprehensive structural analysis program.

The program should be capable of accepting as many types of loading as possible without the need to compute FEM's or resultant applied moments in place of the actual loading itself. EFFRAM gives the engineer the ability to apply surcharge, strip, and point loads at varying distance from a vertical wall as well as uniform, concentrated, and distributed loadings. FEM's are provided by the program rather than the engineer, therefore reducing the chance of error and the time needed to set up and check input data.

Program input and output should be arranged so that an engineer without a great working knowledge of the program itself can set up input data or, on the other hand, be able to readily interpret output. It is therfore advised that abreviations, codes, or symbols be avoided. Labels should be given so as to enable all engineers to understand the type of information being provided. Results can therefore be easily circulated throughout the country without the need for time consuming explanations which are usually not fully understood. Standard engineering notation should be used. G-FRAME is a good example of this. It is simply arranged and set up for everyone.

Programs that have design capabilities should contain as many "default" characteristics as possible so that when standard engineering parameters are used there will be no need to input them. STRUDL provides this excellent capability; it can also be seen to a limited degree in the programs "Concrete Box Culvert Frame Analysis and Design" (713-G1-M1070) and "Multi-Cell Box Culvert" (13-G1-A407).

SAP IV is unique; it will handle dynamic as well as static analysis. This feature is rarely seen in a single program and expands its potential use considerably.

Another very useful program aid is member, node, and load generation. This capability is of particular value in programs using finite-element techniques where a great many node coordinates and member properties and incidences must be input to simulate the design problem. Through this generation technique, the engineer is able to save considerable amounts of time setting up and inputting his design data. SAP IV, Wilson 2D, and EFFRAM exhibit this very useful characteristic.

The single- or multiple-culvert analysis by Los Angeles District has a unique idea for outputting program data. Conduit moments are printed in a diagrammatic shape of the structure under analysis. This method of formatting output provides the engineer with his required moments, showing their respective locations, while at the same time depicting the shape of the structure so that the engineer can readily keep it in mind. All this is done in one simple step.

With regard to any design procedures in addition to a pure analysis, STRUDL is a prime example of the capabilities that could be provided. The option of designing in either concrete or steel by WSD or USD is present along with numerous code checking procedures. Member property tables are also provided. The engineer need only call out the structural shape he desires without the need of determining member properties, such as area, section modules, or moment of inertia, to name just a few.

Graphic plotting and interactive graphics are other relatively new areas which many engineers have yet to explore. With the aid of those tools, the engineer acquires the ability to put his resultant design into an advanced analytical perspective. He has the ability to display his original model, graphically providing him with an efficient and economical way of checking his input data. He can ask for plots of moments, shears, or influence lines about any axis or display a two- or three-dimensional deflected shape of his structure under a particular loading condition. Through interactive graphics he can model a structure with the aid of a tablet and input pen. He can change the shape of a structure instantly and ask for a reanalysis without having to rearrange members and coordinates manually. The possibilities are limited only by the imagination of the engineer himself. McDonnel Douglas Automation Company provides this service with its propietary STRUDL package. The program, "Concrete Box Culvert Frame Analysis and Design," attempts to achieve some of the advantages graphics may provide by modeling the structural shape under consideration in its output format.

Finally, one last characteristic which all the programs exhibit should be commented on. FORTRAN has been chosen as the programming language in all cases. It really is the only appropriate language to use when dealing with engineering or scientific principles. It has been found, though, that some programs in the WES library are present in whole or in part in a language peculiar to the machine that they were written on. In order to achieve the ends of a Corps-wide library, programs must be written so that they are freely accessible to all potential users without the need to perform large conversion procedures that will put the program in a "ready to run" stage. Those in charge of the Corps computer systems should be able to provide the engineer who is constantly engaged in compter-aided design with the procedures necessary to run a program on a particular computing system. At present, this information has not been found to be readily available.

Notes on Specialty Session C

The session clarified the importance of simulation by stressing the use of the finite-element method, soil-interaction, and computer graphics. The Design phases of most programs are limited to the extent that the design may be for USD and not WSD or vice versa. None of the programs have Automatic Design based on Corps criteria (EM 1110-1-2101). Improvement in the Design phase is imperative.

The session also indicated the predominant use of time-shared terminals with acoustic pickups to WES or leased computer services such as CSC and MCAUTO.

TUNNELS

by

Robert J. Smith*

Introduction

This paper presents the "State-of-the-Corps-Art" for computer-aided design of tunnels. A tunnel may be defined as, "an underground passage made without removing the overlying rock or soil." Most Corps of Engineers tunnels are either water conveyance or transportation tunnels driven through rock. Therefore, this paper is limited to ways in which the computer can be used to aid the structural engineer in the design of such tunnels.

The structural engineer must work closely with the geologist and/or soils engineer and hydraulic engineer. The structural engineer's responsibility is to design the temporary and permanent supports necessary to stabilize the tunnel. Tunnel linings are designed using a combination of theory, intuition, and experience. As a result, tunnel lining design is more of an art than a science. Thus coordination with other disciplines is very important when designing tunnel support systems.

Types of Support

As stated above, the structural engineer is responsible for the design of temporary and permanent supports. The temporary support may consist of any one or combination of the following: (a) steel sets, (b) rock bolts, (c) spiling, or (d) shotcrete. The permanent support could be any one or combination of the above, but for a water conveyance tunnel it would probably be concrete. If the tunnel lining is to withstand internal water pressure, a steel lining inside the concrete lining will probably be required.

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* Structural Engineer, OCE.

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Programs Available

Now that we have identified the structural engineer's responsibilities and types of supports used to stabilize a tunnel, let us look at the computer programs that are available.

Computer program for steel sets

Steel sets may be designed using the program presented in Waterways Experiment Station (WES) Technical Report C-73-2, "Computer Study of Steel Tunnel Supports."[1] This program is written using the philosophy presented by R. V. Proctor and T. L. White.[2] This method of design is also presented in the draft of EM 1110-2-2901.[3] The Proctor and White method is basically a graphical solution. The steel set is assumed to be pinned at each blocking point with each blocking point carrying its proportionate share of the rock load. The rock load is determined by using the Terzaghi rock load concepts. The next step is to construct a force polygon. From this, stresses in the ribs can be determined. The method is illustrated in the two references mentioned above.

The computer program "Tunnel" uses information about geometry, loads, location of blocking points, and member properties to obtain shears, moments, thrusts, and displacements. The program uses the stiffness matrix method for analyzing the steel sets. The program is designed to handle all tunnel shapes and is written in a manner which will allow the user to have no knowledge of computer programming and very little knowledge of his operating systems.

There are several disadvantages to the graphical solution presented by Proctor and White.[2] The analysis yields no information on deflections within the structure. The method does not account for yielding (elastic) behavior of the steel sets. Both of the above conditions affect the loads acting upon the structure. Furthermore, the graphical method is tedious and time-consuming and causes the structural engineer to avoid consideration of several alternative designs.

The computer program is designed to alleviate many of the disadvantages of the above method. Although the loads are treated as being independent of the distortions in the system, the program is flexible enough to accept any type of loading. Not only is information obtained on the deflections of the structure, but member moments and shears as well as member thrusts are obtained directly. The speed with which the computations are performed allows the designer freedom to make and choose from several designs.

"Tunnel" is written in FORTRAN IV for a time-sharing computer system. The report contains an auxiliary program called "Horshu" which is used to automatically generate the required information for "Tunnel." The WES report consists of: an introductory section that presents current steel set tunnel support design procedures; a description of the main program, "Tunnel"; and a description of the auxiliary program, "Horshu." The mathematical basis for "Tunnel" is discussed in Appendix A. Appendix B contains a blank sample data input form. Appendix C is a listing of the program "Tunnel" and Appendix D is a listing of the program "Horshu."

The programs have not been used for design; however, the Corps has 39 tunnels in the planning stages, so perhaps they can be used in the future.

Computer programs for concrete linings

Responses to the questionnaire revealed that four different computer programs have been used for design of concrete tunnel linings. The computer program numbers and district offices that have used them are as follows:

District Office	Program Number
Albuquerque	713-G1-M0090
Huntington	713-K2-H1325
Portland	513-06-00321
Sacramento	713-61-L202A

The philosophy used in these programs was the same as discussed earlier in the conduit part of this specialty session (or in the papers on conduits written for this specialty session). Therefore, it will not be discussed here; but some of the loading assumptions that must be considered when using one of these programs for designing concrete tunnel linings are as follows: (a) resist hydrostatic water load acting alone, (b) resist rock load acting alone, (c) resist a combination of the water and rock loads, and (d) resist the grouting pressures.

The above-listed loading conditions are not to be construed as all inclusive but rather are given so the reader can have an idea of the minimum number of runs to make when designing concrete tunnel linings.

Computer program
for steel tunnel liners

Sacramento District has used program number 713-G1-L202C, "Liner," to design the cylindrical steel tunnel liners used for the New Melones Project. For external pressure the shell is assumed to be confined in a rigid cavity; stiffener rings are incorporated as needed. For internal pressure, division of load between liner and rock is based upon OCE criteria established for this project. Plane strain is assumed. Draft of EM 1110-2-2907[4] contains a discussion on the considerations to be given for this type of design. The program can be altered to satisfy the design requirements of a specific tunnel.

Finite-element method

The philosophy of this type of program will not be discussed here since it is documented in many other papers and books. What will be discussed are considerations to be made when using this type of analysis. An approach that can be taken is as shown in the following outline:

I. Isolate an appropriate geostructural block containing the opening or excavation from the rock mass for structural analysis.

II. Determine the geology of the geostructural block.

III. Determine forces (or stresses) acting upon or within the geostructural block.

  A. Surface forces

    1. External gravity (including lateral rock pressure)
    2. Tectonic
    3. Groundwater
    4. Earthquake
    5. Man-made

  B. Body forces within the model

1. Internal gravity
2. Residual
3. Groundwater
4. Earthquake
5. Man-made

C. Due to opening or cut

D. Due to varying stiffness of the rock

E. Due to relaxation or creep

IV. Determine the mechanical rock properties.

V. Develop the grid.

VI. Determine if failure conditions (fracture, slippage, excessive deflection) exist.

A. No failure conditions - analysis is complete. No structural support required.

B. Failure conditions - some type of structural support required.

VII. Determine structural support required to stabilize opening.

The above outline was extracted from a paper written by J. S. Dodd.[5]

Another discussion on the finite-element method of analysis can be found in a report prepared by J. J. K. Daemen.[6] This report discusses development of ground reaction curves, stiff and soft supporting methods, and limiting convergence of the tunnel walls. A computer program called Tunsup is presented in the report. This program goes beyond the analysis presented above by considering things such as ground-support interaction, incremental loading or unloading (equivalent mining), and strain-softening of the rock around the tunnel periphery. The program is written in FORTRAN IV. For the version presented, 135,000 central memory words are required on a Control Data Corporation CYBER 74 computer with KRONOS operating system and RUN compiler. Running times vary greatly with problem type. Computer times for an example given in the report ranged from 2 up to 18 minutes.

The program has not been used for design but may have a place in the design of the more complex tunnels. Use of "Tunsup" is presented in Appendix C of the MRD report.

Programs Needed

Rock bolts, spiling, and shotcrete have not been discussed thus far. These support systems could be modeled using the finite-element method of analysis. However, the short literature search that was made in preparing this paper did not reveal any designs that had used the computer as a design aid for these types of supports.

Conclusions

As was stated in the Introduction, tunnel lining design is more of an art than a science; thus, the computer cannot be used to automate the design of tunnel supports. The computer can, however, be used to assist in making sound engineering judgments. The size of steel sets, thickness of concrete linings, spacing and length of rock bolts, and thickness of shotcrete should not vary too much from the commonly used "rules of thumb." It should be remembered that the input is not exact, therefore, the temporary and permanent supports cannot be designed down to the last pound of steel or cubic yard of concrete. European trends (so called New Austrian Tunneling Method) are toward emphasis on observation and control of lining displacements as the primary variable in design. They put less emphasis on design before tunneling starts. United States and British procedures have tended to be concerned with loads, and advance designs to resist loads. The structural engineer should remember that the lining design can be strengthened (supplemented) with additional bolting, shotcreting, and/or jump sets when observations dictate. Both design concepts should be kept in mind when designing tunnel supports.

Postconference Comments

The following comments and/or recommendations were made by participants:

<u>a</u>. St. Louis District is using the WES computer program "Tunnel" as a design aid on Meramec Park tunnel.

b. The Bureau of Mines and Bureau of Reclamation have computer programs which may be useful.

c. Sacramento District program number 713-61-L202A should be deleted from the list of programs which may be used for concrete lining design. This was a recommendation by Mr. Haavisto of the Sacramento District.

REFERENCES

1. Technical Report C-73-2, "Computer Study of Steel Tunnel Supports," by G. I. Orenstein, dated August 1973.

2. "Rock Tunneling with Steel Supports," by R. V. Proctor and T. L. White.

3. Draft of EM 1110-2-2901, "Tunnels and Shafts in Rock," dated December 1973.

4. Draft of EM 1110-2-2907, "Rock Reinforcememt in Civil Engineering Work," dated February 1975.

5. "Structural Analysis of Rock Using A Finite Element Method," by Jerry S. Dodd, Bureau of Reclamation, Denver, Colorado, paper presented at 3rd Annual Intermountain Minerals Conference, August 3-5, 1967.

6. Technical Report MRD-3-75, "Tunnel Support Loading Caused by Rock Failure," by Jaak Joseph K. Daemen, dated May 1975.

Table 1

Basis for Ratings of Single Purpose Program

Items Considered in Ratings	Multicelled Box Culvert, 13-G1-A407, St. Louis, Missouri, 13-R3-13-19	Multicelled Gatewell Design 713-G2-L3-005, San Francisco District	Sacremento 713-x6-L2-22A	Concrete Box Culvert Frame Analysis and Design, J. J. Miller, Albuquerque, 713-G1-M1070
Types of loading allowed	Uniform on top and triangular on sides; program remains unchecked for 2 loading conditions	Unknown	Uniform, distributed; other loading conditions if FEM and simple beam moments at midspan are entered	Uniformly or triangularly loaded members; no sidesway permitted
Type of output given	Reinforcing, points of contraflexure, safety factor, moments, horizontal thrust, shears, D-req and D-provided	Thickness and as required for bottom slab along with volume and weight of concrete; side, end, and splitter wall thickness; bond stresses at face of support and at midspan of all members	Moments at end and centerline of members	Shears, thrusts, reinforcing, member spans, effective spans, bond perimeters, development lengths, load factors, moments, and unit shear capacities
Method of analysis	Hardy Cross moment distribution	Stiffness matrix (finite elements)	Moment distribution	Moment distribution
Ease of data input	Good--default values for design constants present	Need to input all design constants, no default?	Simple, no defaults necessary to manually calculate FEM and simple beam midspan moments for other than uniform and distributed loading conditions	O.K., some default parameters included
Types of members handled	Can handle variable members	Prismatic member output	Only prismatic	Haunched and/or prismatic members
Number of cells analyzable at one time	Limited by maximum number of nodes and members allowed (maximum probably depends on machine used)	One to five cells	Single, double, or triple box culvert	1-,2-,or 3-celled conduits/culverts
Type of cell configuration analyzable	Program will handle a wide variety of configurations	Standard gatewell configuration; may have 1-5 cells	Single, double, or triple box culvert	Square, octagonal, simulate round, 3-bay bents, 3-story frames, single or double "T" frames, 1-7 span beams
USD or WSD design	Apparently WSD	ACI Code A2202, Method 2, Case IV, WSD	Neither	USD (ACI-318-71, columns by USD)

(Continued)

Table 1 (Concluded)

Items Considered in Ratings	Multicelled Box Culvert, 13-G1-A407, St. Louis, Missouri, 13-R3-13-19	Multicelled Gatewell Design 713-G2-L3-005, San Francisco District	Sacremento 713-x6-L2-22A	Concrete Box Culvert Frame Analysis and Design, J. J. Miller, Albuquerque, 713-G1-M1070
Program language	FORTRAN	Apparently FORTRAN	FORTRAN	FORTRAN
Type of foundation incorporated	Unyielding, no spring	Unyielding, no spring	Unyielding, no spring	Unyeilding, B.P. mirror image of loading, no spring
Output format (good, fair, etc.)	Labels need explanation; general format O.K.	Good, simple, and self-explanatory	Good simple scheme, but input labels need index for proper identification; outputting moments in a diagrammatic structural shape is a unique idea	Good, but needs some explanation; not completely self-explanatory; diagramming of structural type and labeling very good
2D or 3D	2D only	2D only	2D only	2D only
Graphic plotting	No graphic capability	No graphic capability	Output moments printed in conduit shape; no real graphic capability	Will print out structural shape with node numbers
Interactive graphics (CRT)	No interactive capability	No interactive capability	No interactive graphic capability	No interactive graphic capability
Dynamic loading	No dynamic loading capability	No dynamic loading capability	No apparent dynamic loading capibility	No apparent dynamic loading capability

Table 2

Basis for Ratings of General Purpose Programs

Items Considered in Ratings	EFFRAM-NED 713-DOF7110	STRUDL-MCAUTO	Wilson 2D - Sacramento 713-G2-L3-002	SAP IV - Sacramento	G-FRAME - Memphis 713-F3-A1-030
Types of loading allowed	Uniform, triangular, trapezoidal, and concentrated loads for any type of structure; loads used in the determination of lateral soil pressures; uniform surcharge, point and line loads, strip loads parallel to the wall; applied moments can be input as loading condition	All standard types	For member loading must input FEM; this is unnecessary for node (point) loads	Same as Wilson 2D	Point, uniform, and distributed loads; also applied moments
Type of output given	Moments, shears, rotations, deflections, spring pressures, reprint of input data with applicable loading conditions; limits of integration used in determining spring pressures are output	Depending on problem, in general, everything you need	For stress elements: all member forces (moments, shears, and axial) plus reactions thru use of boundary elements and stresses. For beam elements, all except stresses	Same as Wilson 2D	Joint displacements and rotations and member and shears, moments, and axial loads
Method of analysis	Stiffness method, finite matrix analysis	Finite element	Stiffness matrix analysis of finite elements	Same as Wilson 2D	Stiffness matrix method
Ease of data input	Data easily input; member, nodal point, load generation subroutine available to reduce input amount needed to describe and analyze specific structural problem	Good, no real-generation technique as in EFFRAM	Very simple, generation of nodes, members, and loads is possible	Not as simple as Wilson 2D; generation capability available	O.K., no apparent generation capabilities
Types of members handled	Prismatic and variable (a variable number divided into its prismatic parts)	Prismatic and variable; cannot handle variable members when in design phase	Prismatic and variable	Prismatic and variable (a variable number divided into its prismatic parts)	Prismatic; can analyze haunched members by placing as in EFFRAM; rectangular members permitted
Number of cells analyzable at one time	Virtually limitless	Virtually limitless	Virtually limitless	Virtually limitless	Only the number that can be built from 60 joints and 100 members, unless array size is adjusted

(Continued)

Table 2 (Concluded)

Items Considered in Ratings	EFFRAM-NED 713-DOF7110	STRUDL-MCAUTO	Wilson 2D - Sacramento 713-G2-L3-002	SAP IV - Sacramento	G-FRAME - Memphis 713-F3-A1-030
Type of cell configuration analyzable	Any configuration possible; square, rectangular, round, octagonal, etc.	Any configuration possible; approximations must be used in USD design since variable members are not allowed	Any configuration possible	Any configuration possible	Any cell configuration can be simulated
USD or WSD design	No design capability	USD and WSD ('63 code)	No design capability	No design capability	No design capability
Program language	FORTRAN	Proprietary language, probably a combination of FORTRAN and machine language	FORTRAN	FORTRAN	FORTRAN
Type of foundation incorporated (environmental effects)	Spring capability, horizontal and vertical, will eliminate tension springs as required; option of tension or tensionless springs or no springs	Spring capability (not like a beam on elastic foundation) will not eliminate tension springs	Compression springs, torsional and axial, no ability to eliminate tension	Same as Wilson 2D	No springs available to produce yielding foundation capability
Output format (good, fair, etc.)	Output format is good, well-labeled, and easy to read	Output format is good; must be familiar with annotations to properly understand it, particularly in design phase	Good; need thorough understanding of all parameters and element types	Same as Wilson 2D	Good
2D or 3D	2D	2D or 3D, concrete or steel	2D	2D or 3D	2D
Graphic plotting	None	Wide range of capability thru proprietary software package called FASTDRAW	None	Capability available thru MCAUTO	None
Interactive graphics (CRT)	None	Capability with tablet has many potential uses; wide range of capabilities	None	Capability available thru MCAUTO (in use at WES)	None
Dynamic loading	None	Available thru STRUDL-Dynal	None, only static analysis	Static and dynamic analysis	None

APPENDIX A: BIOGRAPHICAL SKETCHES OF AUTHORS

Carney M. Terzian is Chief of the Structural Section, New England Division, Waltham, Massachusetts. He graduated from Northeastern University in 1948 with a B.S. in Mechanical Engineering. He has spent 28 years in engineering, 22 years of it with the Corps, and was registered as a Professional Engineer in Massachusetts in 1956. He has received four Sustained Superior Performance awards from NED, and has continuously worked for ADP development since 1960. From 1967 to 1970 he was with the NED area office for NASA construction at Cambridge, Massachusetts, assuming his present position in 1970. Mr. Terzian was a member of the ASCE Task Committee on Computer Graphics, Committee for Electronic Computation, for 1972-1973. He presented a paper on Computer Graphics and was a contributor to the ASCE Preprint 2024, "The State of the Art of Computer Graphics," for the 1973 ASCE Convention in San Francisco. Mr. Terzian is now an ASCE member-at-large.

Robert J. Smith is a structural engineer in the Civil Works Directorate, OCE. He has also worked as a structural engineer in the Omaha District. He holds a B.S. degree from Montana State University, an M.S. degree from the University of Minnesota, and is registered as a Professional Structural Engineer in Nebraska.

In accordance with ER 70-2-3, paragraph 6c(1)(b), dated 15 February 1973, a facsimile catalog card in Library of Congress format is reproduced below.

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[Proceedings ... held in New Orleans, Louisiana, 22-26 September 1975] Vicksburg, Miss., Automatic Data Processing Center, U. S. Army Engineer Waterways Experiment Station, 1976-
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Contents.-v.1. Management report.-v.2. List of computer programs for CADSE.-v.3. Invited speeches and technical presentations.-v.4. Division presentations.-v.5. State-of-the-Corps-Art (SOCA) reports on gravity monoliths, U-frame locks, and channels.-v.6. SOCA reports on gates, stoplogs, and trashracks.-v.7. SOCA reports on single- and multiple-cell conduits and tunnels.-v.8. SOCA reports on pile foundations and sheet pile cells.-v.9. SOCA reports on sheet pile walls and T-walls.-v.10. SOCA reports on stiffness methods, frames, and military construction.-v.11. SOCA reports on earthquake and dynamic analyses.-v.12. Interactive graphics, SEARCH and CORPS systems.

(Continued on next card)

Corps-Wide Conference on Computer-Aided Design in Structural Engineering, New Orleans, La., 1975.
[Proceedings ...] 1976-
(Card 2)

1. Computer-aided design -- Congresses. 2. Design -- Congresses. 3. Structural engineering -- Congresses. I. U. S. Army. Corps of Engineers. II. U. S. Waterways Experiment Station, Vicksburg, Miss.
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