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Technical Report 1674-TR

FIELD LOAD TEST OF COLLAPSIBLE  
CANVAS LINER FOR SHALLOW TUNNELS

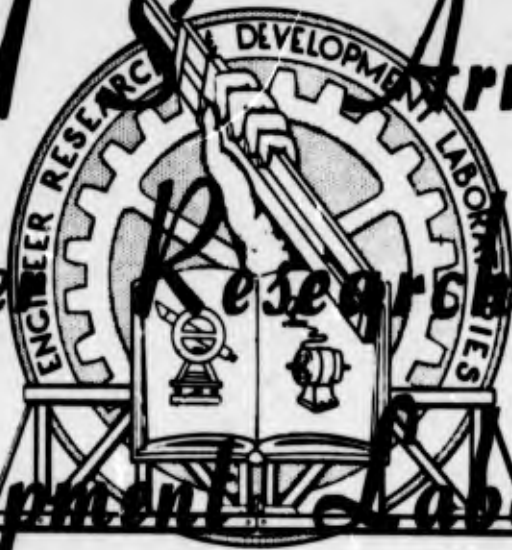
Task 8F07-10-001-02

7 June 1961

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Technical Report 1674-TR

FIELD LOAD TEST OF COLLAPSIBLE  
CANVAS LINER FOR SHALLOW TUNNELS

Task 8F07-10-001-02

7 June 1961

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The Director  
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## PREFACE

The test described in this report was conducted during the month of September 1959 under the authority of Task 8F07-10-001-02 (formerly Project 8-07-10-420). A copy of the project card is included as an appendix to the report. Test was conducted on Range 5A at the Engineer Proving Ground, Fort Belvoir, Virginia.

Test described was conducted by Robert G. Marshall, Senior Engineer, Fortifications Section; assisted by Thomas J. Johnson, Demolitions Testman, Mine Warfare and Barrier Branch Test Section. The investigation was made under the general supervision of Richard M. Flynn, Chief, Fortifications Section, Demolitions and Fortifications Branch.

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F7465

Collapsible canvas liner for shallow tunnels.

## SUMMARY

The load test described in this report was designed to furnish data concerning the ultimate crushing strength of a collapsible, reinforced, canvas liner for shallow tunnels in loose, unconsolidated earth.

A field load test using the sandbox method of loading was conducted. Vertical and horizontal field deflection measurements and laboratory tests of individual components were made.

The report concludes:

- a. Based on the criterion for liner failure, a conservative estimate of the load-carrying capacity of the liner is 4,713 pounds per lineal foot or a fill height of 12 feet of sand fill. (The ultimate crushing strength was never ascertained.)
- b. The bedding condition significantly affects settlement and, therefore, affects the supporting strength of the liner.
- c. The "imperfect trench" method of installation would materially increase the liner's load-carrying capacity.
- d. It is desirable to have the liner fabric yarn with the least ultimate elongation oriented parallel to the longitudinal axis of the liner. (Lack of knowledge of textile properties resulted in greater deformation of the canvas covering than anticipated.)
- e. Of the two types of ring joints tested, the steel insert and the pipe coupling, the latter appears to be the better.
- f. Method of welding of the pipe coupling appears critical and should be given proper consideration.
- g. The hollow pipe rings seem to have only a minimal advantage over the solid rod rings, but on the basis of military logistics a greater weight reduction can be achieved by the use of the pipe rings.

FIELD LOAD TEST OF COLLAPSIBLE  
CANVAS LINER FOR SHALLOW TUNNELS

I. INTRODUCTION

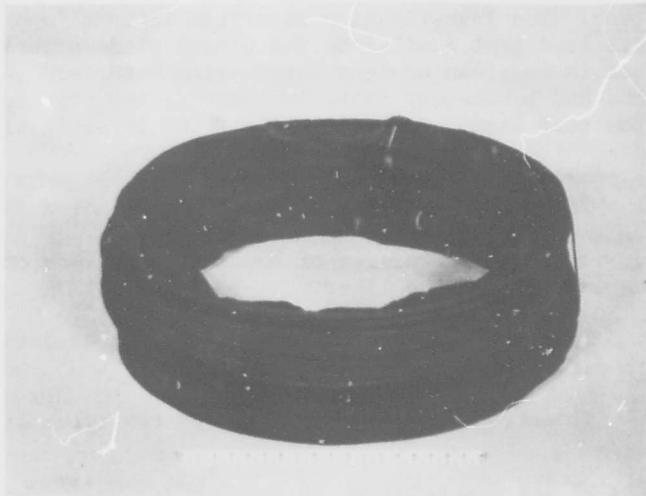
1. Purpose. The load test described in this report was designed to furnish data concerning the ultimate crushing strength of a collapsible, reinforced, canvas liner for shallow tunnels in loose, unconsolidated earth. The liner, an item of field fortification equipment contemplated for development by USAERDL, would enable combat troops to derive the maximum effectiveness of earth for battlefield protection. The liner is envisioned as an expedient structure to support the greater depth of overhead earth cover as demanded on nuclear battlegrounds. In tactical situations where a foxhole, trench, or emplacement is required to be recessed to use the resultant overhang as a protective shield, the soil may not be suitable or the necessary depth below the surface may be too excessive to be practical. In these instances, a liner can be installed, at any reasonable depths, while the excavation is being made and the "running" soil kept free of the excavation. Communication trenches and connecting trenches constructed between firing positions by the tunnel or cut-and-cover method would provide far more effective protection against nuclear effects than standard trenches found on previous conventional battlefields.

2. Scope. The investigation described in this report included a field load test similar to the pipe test described as Sand-Bearing Method in American Society for Testing Materials (ASTM) Specifications and laboratory tests to evaluate the principal components of the test item. Specific aims of the investigation were as follows:

- a. To determine the crushing load at liner failure.
- b. To study the effect of bedding conditions on the load-carrying capacity of the liner.
- c. To observe the performance of canvas covering in conjunction with ring deformations.
- d. To compare the effectiveness of two types of ring joints.
- e. To observe the influence of solid rings versus hollow rings.



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Fig. 1. Collapsed liner.

3. Specimen Description. The liner consisted of three components. A cotton duck fabric was sewn in a cylindrical envelope 30 inches inside diameter and 10 feet long. When collapsed, the liner makes a package approximately 34 inches in exterior diameter and 10 inches in height (Fig. 1). The envelope was held in shape by steel rings pocketed at 10-inch intervals in cotton webbing affixed to the fabric by cotton thread. At each end of the liner on the interior edge of the first web pocket, brass grommets were installed on approximately 3-inch centers around the circumference of the envelope for anchorage purposes. The canvas material used in the fabrication of the envelope was type I, No. 4, hard-texture cotton duck, vat-dyed olive drab shade No. 7, mildew-resistant treated, 72 inches wide, conforming to requirements of Federal Specification CCC-C-419, "Cloth, Cotton, Duck, Unbleached, Plied Yarns (Army and Numbered)." The webbing used to attach the rings was dyed to match the No. 7 shade of olive drab, mildew-resistant and water-repellent treated, type III, heavyweight, 2-inch, 2.65 ounce per linear yard, conforming to the requirements of Military Specification MIL-W-530B, "Webbing, Textile, Cotton, General Purpose, Natural or in Colors." The cotton thread used for all sewing was heavy thread, glazed, type III B, 5-ply, ticket No. 10/5 conforming to Table VI, Federal Specification V-T-276d, "Thread, Cotton." The seams and machine stitching used in the fabrication of the liner were in accordance with Federal Specification DDD-S-751. All sewing was done with stitch type 301, commonly known as the lock stitch, 6 to 8 stitches to the inch.

The 30-inch-inside-diameter steel rings were of two types: 1/2-inch, structural rod and 1/4-inch-nominal-diameter, galvanized pipe. Each of these types of rings had a different type of jointure. Two of the 13 rings were formed of pipe whose ends were joined together by a 2-inch-long, 3/8-inch-diameter, steel insert. About 1 inch of the insert was placed in each end of the pipe. The insert was secured by welding on one end and by a 1/4-inch Allen set screw on the other end. The remaining 11 rings were formed of structural steel rods whose ends were joined together by a 2-inch-long, 1/2-inch-nominal-diameter, pipe coupling. The coupling was slipped over the rod ends and secured by either a long fillet or a short fillet weld and an Allen set screw in the same manner as before. These rings and the No. 2 brass grommets and No. 10 steel wood screws composing the anchorage system all met requirements of applicable Service standards.

4. System of Identification. Each ring was given a distinguishing number to facilitate orientation of points of failure and presentation of test results. These numbers ran consecutively from one end of the liner to the other end. To distinguish between the rod and pipe rings, the two pipe rings were given Numbers 1 and 2.

## II. TEST PROGRAM

5. General. Two widely recognized tests for the determination of supporting strength of conduit are the Sand-Bearing Method (Fig. 2) and the Three-Edge Bearing Method. Both of these methods are described in applicable ASTM specifications and are considered equally acceptable. The sandbox test is based on simulation of the conditions found in a trench. A distinct advantage which the sandbox test has over the three-edge test is that the former presents direct results. Results of the three-edge test can be made applicable for comparison with actual trench loads only when adjusted by a factor based on bedding conditions. Since means were readily available to construct a sandbox and only one liner was to be evaluated, the sand-bearing method was selected to obtain the required data.

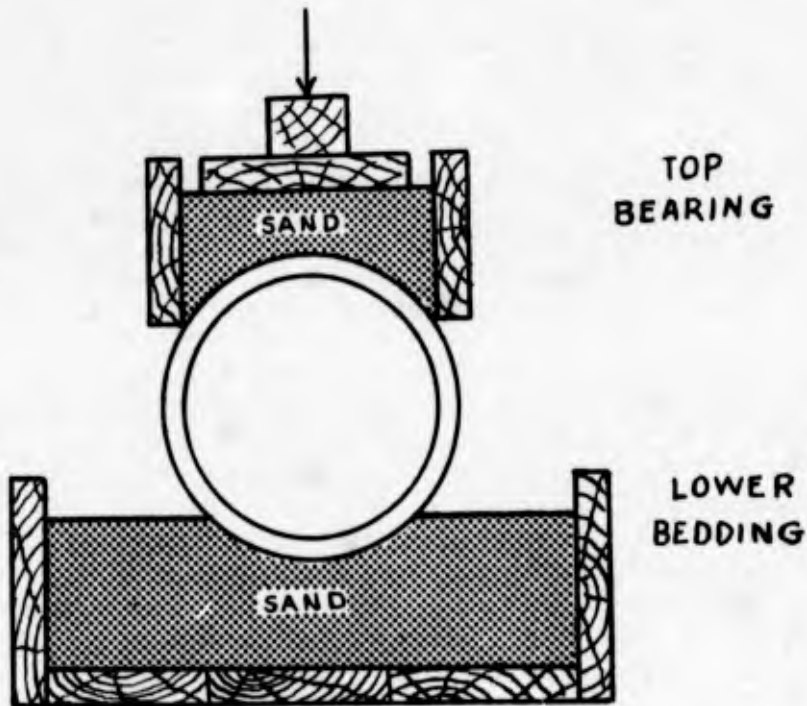


Fig. 2. Sand-bearing installation for testing of pipe.

6. Criterion for Liner Failure. The liner was expected to fail by a gradual shortening of the vertical axis and a spreading out of the sides. The safe maximum deflection of flexible conduit is normally about 20 percent of the vertical diameter. The maximum permissible design deflection has been set at 5 percent allowing a safety factor of 4. This percentage is subject to variation dependent upon the type of back fill material. The assumption has been made that upon a survival basis a safety factor of this

magnitude must be sacrificed. The allowable deflection for the liner was, therefore, set at 20 percent. (In no way is the implication made that the liner is equal to flexible corrugated metal pipe, but it was felt that an investigation was warranted.) Based on allowable deflection, the 30-inch vertical diameter of the liner can be shortened to 24 inches with a corresponding increase in horizontal diameter to about 34 inches.

By extrapolation of anthropometric measurements compiled by the Applied Psychology Corporation, Washington, D. C.,\* and material contained in Human Engineering Guide to Equipment Design, Chapter VIII, ONR, the cross-sectional clearance necessary for locomotion through and static occupation of such a structure has been ascertained. For locomotion, the 90 to 95 percentile man would require a minimum vertical clearance of 18 inches and a minimum lateral clearance of 32 inches. Movement through such an opening would be accomplished in the prone position, and propulsion forward would be made in spread-eagle fashion by elbow, knee, and foot. Any dimensional increase would offer a greater rate of locomotion. For a static situation, the man would have to have a minimum vertical clearance of 18 inches and horizontal clearance of 22 inches. The length of such structure should not be greater than about 85 inches. In both locomotive and static conditions, additional allowance should be made for equipment and heavy clothing.

By examination of the dimensions involved, it was determined that with a maximum vertical ring deflection of 20 percent the liner would provide adequate clearance for both passage and occupancy. Analysis of liner failure should be based on this criterion.

7. Test Installation. A schematic diagram of the test installation is shown in Fig. 3. The site selected for construction of the sandbox was at the base of a vertical 6-foot-high embankment to facilitate loading arrangements. On level grade, two 2-by-10 wooden stringers 12 feet long were laid with 42-inch, center-to-center spacing. Across these sills were placed nine 2-by-4 floor joists about 48 inches long with the seven interior joists on 18-inch centers. Wedges were placed under these members for any necessary leveling of floor or plumbing of walls. A solid flooring of one-by-sixes was next placed on the joists. Longitudinal wall panels made up of seven 2-by-4 studs 12 feet long and initially sheathed to a height of 6 feet were set up and nailed to the joists. A double 2-by-4 stud was used at the center of the walls.

\* Robert B. Sleight, "Human Engineering". Research & Engineering, Vol. II, No. 2, Section 1 (Feb 1956).

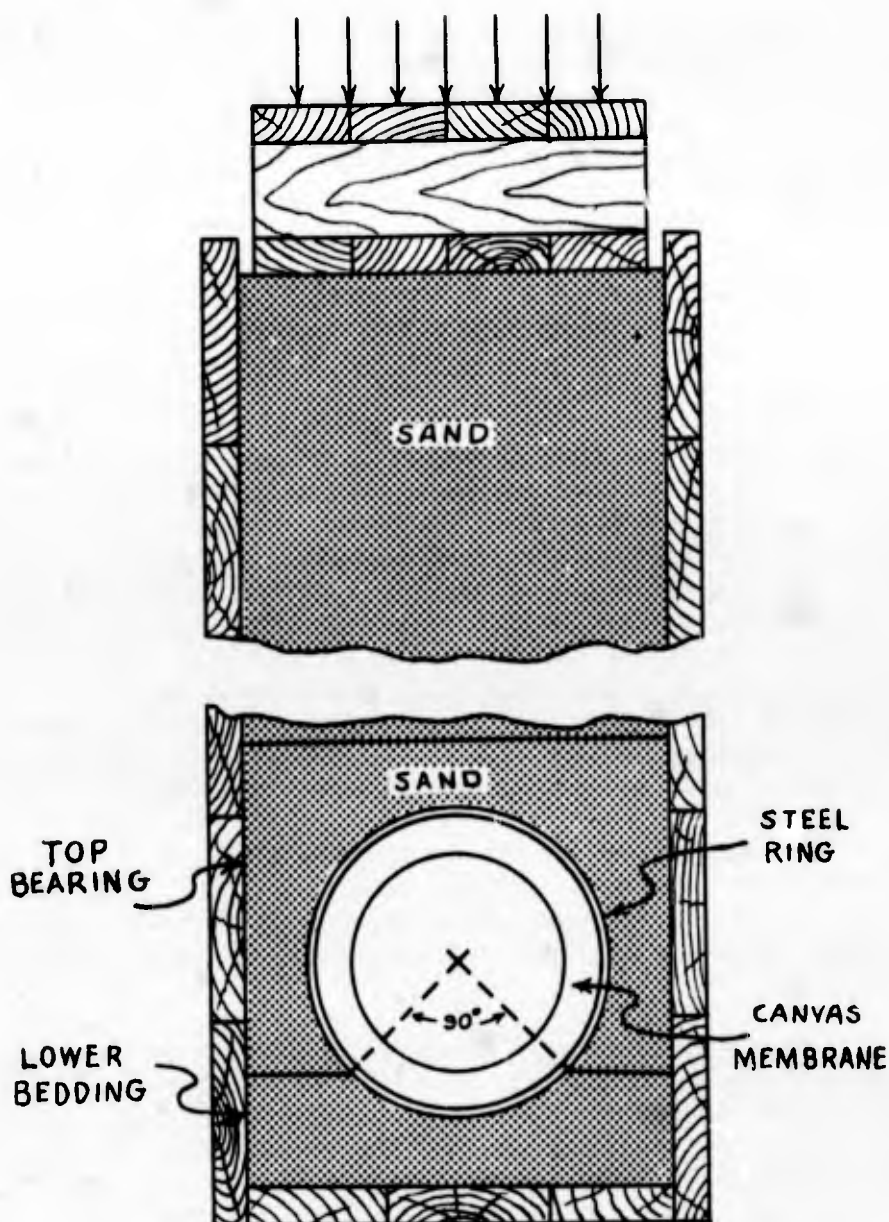


Fig. 3. Sand-loading installation for testing of liner.

The anchorage method resolved to secure the liner under loading consisted of a 42-inch-square bulkhead made up of 6 three-by-eights held together by a 3/4-inch-thick exterior plywood panel. A 31-inch-diameter opening was cut from the center of each bulkhead. Above the bulkheads, the ends of the box were sheathed by one-by-sixes nailed to the end studs of the walls. Figures 4 and 5 illustrate these construction features. The anchorage bulkheads were framed in place both inside and outside the box.

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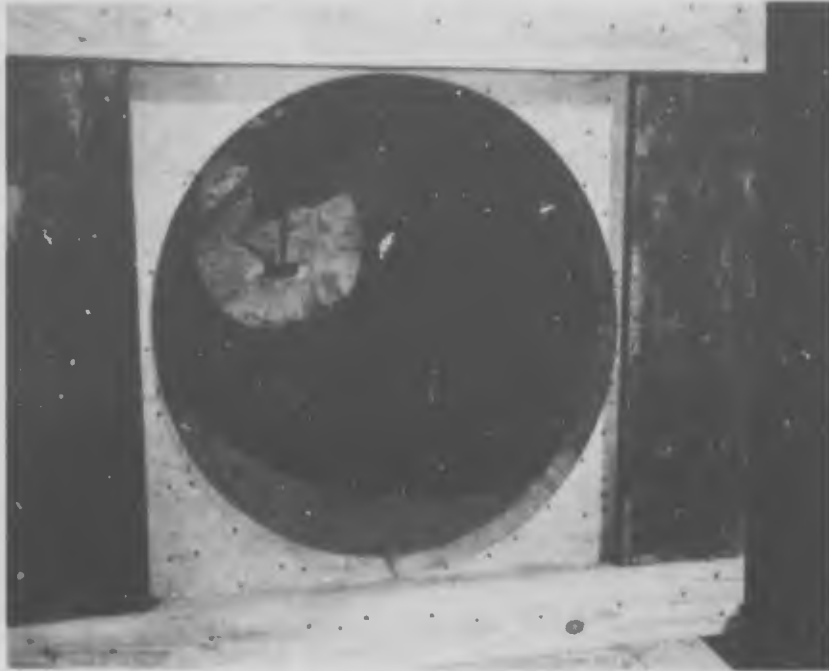
Fig. 4. Provisions  
for wall height  
extension.

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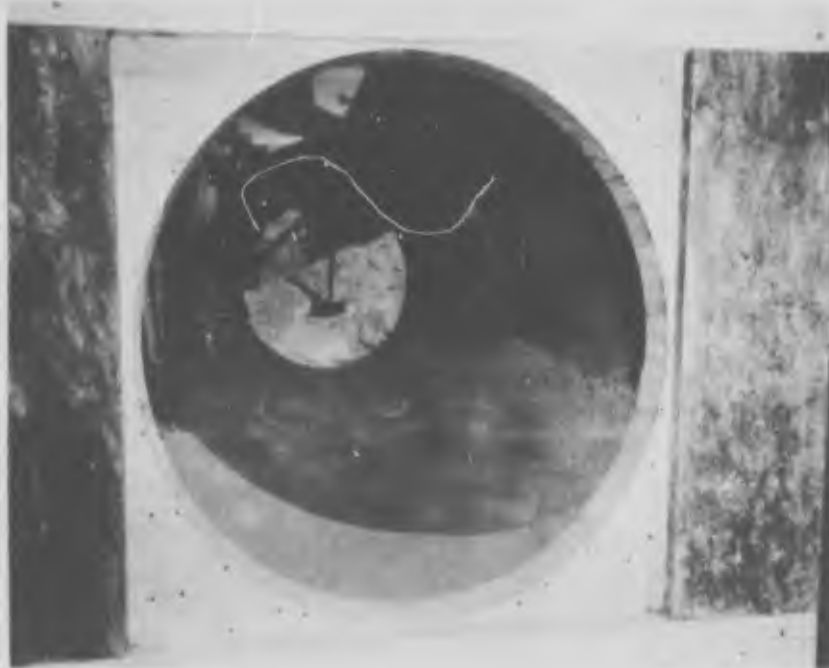
Fig. 5. Anchorage  
bulkhead was fabri-  
cated of 6 three-by-  
eights 42 inches  
long.

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F8079

Fig. 6. Lower bedding shaped to fit barrel of liner.



F8080

Fig. 7. Lower bedding hand tamped beneath the haunches of liner and between walls to a height above the bottom quadrant points of the barrel.

Before the liner was anchored, a lower bedding of sand about 6 inches in depth was placed in the box and shaped to fit the barrel of the liner with reasonable closeness for a width of more than 50 percent of the liner breadth (Figs. 6 and 7). The sand was a clean hand aggregate reasonably free from soft or flaky particles, salt, alkali, organic matter, or other extraneous substances and contained less than 3 percent clay. The material was well-graded from coarse to fine all passing a No. 4 (4,760-micron) sieve and less than 5 percent passing a No. 100 (149-micron) sieve. Moisture content of the sand averaged about 12 percent during the time of the test.

Upon completion of the lower bedding, the liner was anchored to each bulkhead (Fig. 8) through grommets by means of washers and screws. The liner was stretched taut (Fig. 9) with all rings positioned vertically and all ring joints oriented on the horizontal diameter (Fig. 10) to one side of the vertical axis.

After the liner was secured in place, the space between the walls and the liner (6 inches on each side) was filled with identical sand material as lower bedding in layers of 6-inch maximum depth to a height of about 6 inches above crown of the liner (Fig. 11). Compaction was accomplished by hand tamping. Interior bulging of canvas between rings was tamped from inside the liner to remove all slackness from the fabric and to aid surrounding sand in supporting the rings in a vertical position (Fig. 12).



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Fig. 8. Liner was secured to bulkhead by means of screws and washers through grommets affixed to liner.



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Fig. 9. Interior framing of bulkhead.

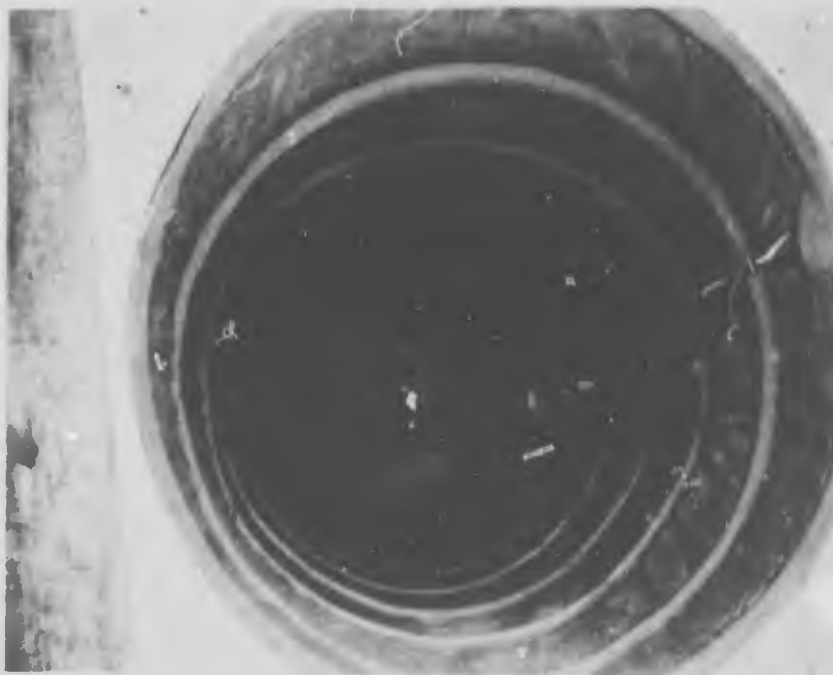


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Fig. 10. Ring joints oriented on horizontal diameter to right side of vertical axis; excess webbing covering joints.



F8077  
Fig. 11. Sand in top bearing struck off level at an elevation  
6 inches above liner crown.



F8091  
Fig. 12. Liner in place with all rings vertical and covered  
with top bearing material.

No field-strutting was made to elongate the vertical diameter of rings in order to reduce vertical deflections under test loading. This field construction practice would increase the load-carrying capacity by enabling the liner to build up side support as the rings settle back toward a full round shape under test loading. Preparation of test installation was kept to "ordinary" bedding conditions.

The upper surface of the sand was leveled off after the bearing fill was completed. Wall struts and braces were placed about 4 and 6 feet above floor grade (Fig. 13) to avoid appreciable bending from side pressure of the sand load. A timber collar made up of two-by-fours encircled the walls.



F8078

Fig. 13. Sandbox prepared for test loading; height of walls about 6 feet.

8. Test Procedure. The test load in 6-inch lifts was applied to the top bearing and was carefully placed and distributed over the entire width and length of the sandbox. Even distribution of the load material adjacent to and over the liner was necessitated by the flexibility of the structure. Dumping too much material to one side or equal dumping on both sides without enough fill placed on top to resist the upward thrust would cause the liner to shift sideways or to "peak up." This back-fill practice is equally desired in the installation of thin-wall, steel, flexible conduit. However, since the rings of the liner had no support longitudinally, it was doubly important that uneven loading of one end of the sandbox did not occur. Such a condition would cause the rings to lie down like the tumbling of a row of dominoes.

Test measurements were to be made of both vertical and horizontal deflections at 1-foot fill height increments above the crown of the liner. Figures 14 and 15 show the method used to determine these deflections.



F8083

Fig. 14. Five-foot-length, field-constructed calipers inserted into liner to determine deflections.



F8095

Fig. 15. Spread of calipers measured to nearest 1/8 inch.



F8073  
Fig. 16. Test load reaching initial 6-foot height of sandbox; height of fill over crown of liner is 3 feet.



F807C  
Fig. 17. Initial height of sandbox extended to 8 feet; height of fill over crown of liner is 5 feet.

On Friday, 25 September 1959, the fill height above the crown of the liner had reached the 3-foot level (Fig. 16), the extent of the original height of the wall panels. At this time, no appreciable deflections were noted or recorded. Since the liner was still intact, the wall height of the sandbox was increased from 6 to 8 feet with an additional timber collar, and the remaining sand supply was exhausted (Fig. 17). Liner deflections were recorded at the 4- and 5-foot levels.

The next test measurements were made on Monday, 28 September 1959, at which time 1,000-pound lead weights were substituted for the sand material. The surcharge was applied to the liner through a rigid top bearing plate. The plate was made of heavy timbers and was capable of reasonable uniform distribution of the test load without significant bending. The plate covered the upper surface of the sand fill completely except for a 2-inch clearance around the perimeter to permit free movement. A 20-ton crane was used to place the lead weights on the bearing plate. As each four weights (2 tons) were placed on the plate, deflection measurements were taken. The surcharge condition and deflections in the rings are shown in Figs. 18 through 26.

No deflection measurements could be taken after the surcharge reached the 12-ton level. Bulges or local bending of cotton duck fabric over the edges of the rings prevented any further use of the straight-leg calipers. At this stage of the test, the studs



Fig. 18. First 2-ton surcharge (note left corner of timber top bearing plate).

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F8075

Fig. 19. Six-ton surcharge covering complete surface of sand fill (note levelness of weights).



F8084

Fig. 20. Ring deflections at 6-ton level (note testman in background taking vertical deflection measurement of Ring No. 6)



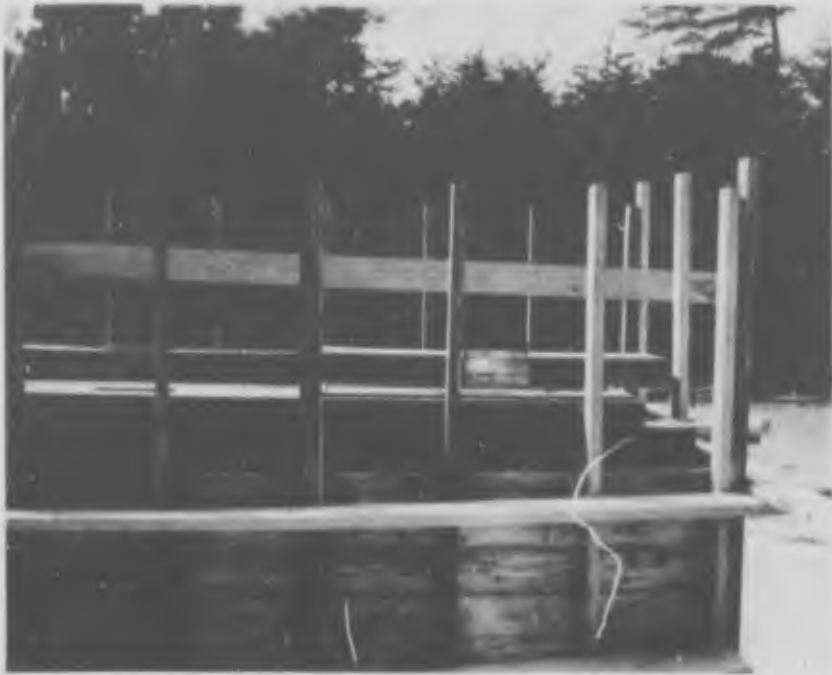
Fig. 21. Test load at 8-ton surcharge level.

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Fig. 22. Ring deflections from south end of liner at 8-ton level (Ring No. 1 in foreground).

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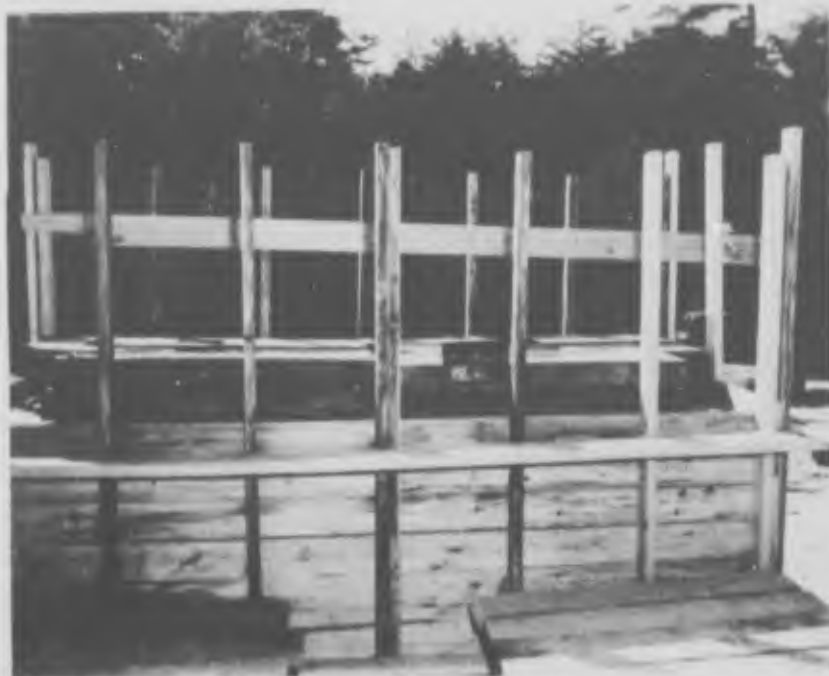
F8093

Fig. 23. Test load at 10-ton surcharge level.



F8087

Fig. 24. Ring deflections from south end of liner at 10-ton level.



F8094

Fig. 25. Test load at 12-ton surcharge level.



F8082

Fig. 26. Ring deflections from south end of liner at 12-ton level.



F8089

Fig. 27. North end of sandbox (note condition of wall panel studs).



F8085

Fig. 28. South end of sandbox at 12-ton surcharge level (note splitting of wall studs and addition of jury braces).



Fig. 29. Failure of sandbox at  $13\frac{1}{2}$ -ton surcharge level (note additional 1,000 pounds being applied). F8069



Fig. 30. Collapse of wall with lead weights crashing down. F8074



F8096

Fig. 31. Liner damage viewed from north end after sandbox failure; Ring No. 13 intact.



F8072

Fig. 32. Test installation viewed from south end after collapse of wall panel; Ring No. 1 buried under debris.

of one wall indicated that the sandbox was failing. Two studs were splitting, and four studs had sprung away from the 1-by-6 sheathing (Figs. 27 and 28). Several jury braces were erected to sustain the wall panel to resist further lateral pressure. Indications were that failure of the wall panel would occur with the addition of another increment of the test load. Such was not the case; before the last 1,000 pounds of the 2-ton increment (13½-ton level) could be placed, the wall panel abruptly gave way (Figs. 29 through 32). As each 1,000-pound weight was applied, a hurried observation was made of the ring deflections. At the 13½-ton level, it was not noted that the rate of deformation was any greater than observed in previous examinations. In fact, approximately 10 minutes elapsed after the last weight had been applied before the wall failed. Another lead weight was being applied when failure of the sandbox took place.

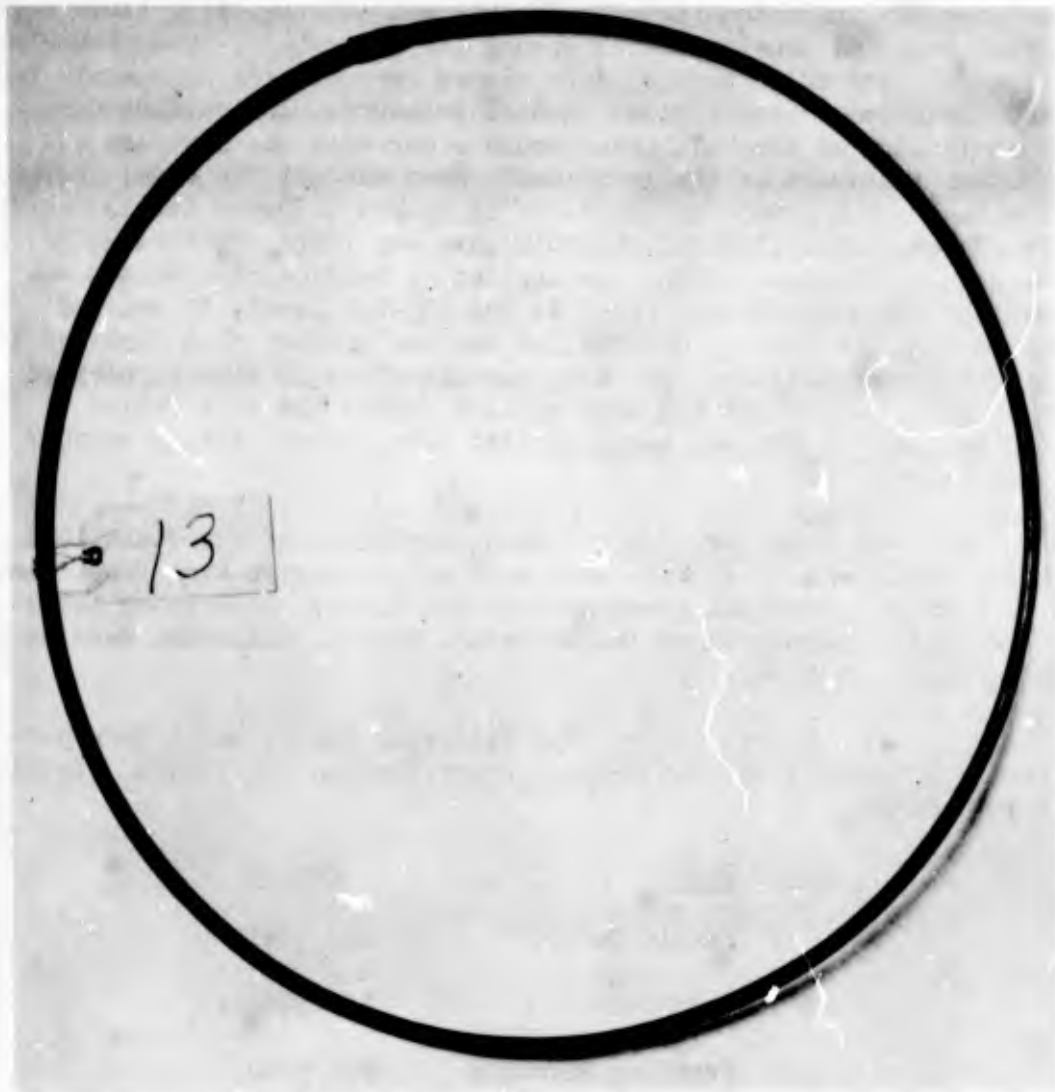
9. Supplementary Tests. Upon completion of the field load test, supplementary studies were made of the cotton duck fabric and steel rings, principal components of the liner. Laboratory tests were made by personnel of the Materials Branch, Technical Service Department, USAERDL.

a. Fabric Tests. The following fabric tests were performed in accordance with Federal Specification CCC-T-191b, "Textile Test Methods."

<u>Test</u>	<u>Method</u>
(1) Fabric Weight	No. 5041
(2) Yarn Count	No. 5050.1
(3) Breaking Strength	No. 5100
(4) Ultimate Elongation	No. 5100
(5) Bursting Strength	No. 5122
(6) Tear Strength	No. 5134

Fabric submitted for testing was taken from the same roll from which material to fabricate the field-tested liner was taken.

b. Compressive Ring Test. A compressive ring test was made of Ring No. 13 (Fig. 33). This particular ring was salvaged after failure of the sandbox. The near perfect condition of the ring was attributed to the function it performed as an anchorage ring. Ring No. 13 was more representative of the type of ring used in the liner.



G3491

Fig. 33. Near-perfect condition of Ring No. 13 used for supplementary testing.

The ring test was performed on a 300,000-pound-capacity Universal Testing Machine. With the connecting joint oriented on the horizontal diameter, the ring was loaded progressively in increments of 20 pounds until the vertical diameter was reduced by 90 percent. The vertical and horizontal deflections were to be measured at each successive load increment; however, due to an oversight the horizontal deflection measurements were not taken. The horizontal measurements were, therefore, computed by Data Processing and Statistical Services Branch, Technical Service Department, USAERDL.

### III. TEST RESULTS AND OBSERVATIONS

10. Vertical and Horizontal Deflections. Test data concerning the field load test is found in Tables I, II, and III. Tables IV, V, and VI (based on data from Tables II and III) provide a ready comparison of the effects of the test load on liner performance. The inside vertical diameter of ring alone was 30 inches, but when the ring was encased in web pocket this measurement was reduced to 29-3/4 inches. Since the ring joints were oriented on the horizontal axis, the web flap covering the joint and the wall thickness of the rod ring coupling reduced the pipe ring horizontal diameter to 29-5/8 inches and the rod ring horizontal diameter to 29-1/2 inches.

Test results of the ring compression test performed in the laboratory appear in Table VII. The portion of data pertaining to vertical deflections has been used to construct a deflection versus load graph (Fig. 34). Since the increase in horizontal diameter is nearly the same as the decrease in vertical diameter, the graph of this function is not shown.

11. Condition of Duck Covering. Constant surveillance was maintained throughout the test to observe the effect of loading on the duck covering of the liner. Bulges about 3 inches deep developed between the rings, but until the sandbox failed the cotton duck did not burst or tear and no stitching or seams gave way.

Results of all textile tests are listed in Table VIII. All values recorded are the average of at least five specimens. Columns two and three of Table VIII contain the minimum requirements for No. 4 and No. 6, type I, numbered duck in accordance with Table 1 of Federal Specification CCC-C-419, Cloth, Cotton, Duck, Unbleached, Plied Yarns (Army and Numbered). Column four contains the USAERDL test results of the fabric.

Table I. Load Equivalents

Total Load (Lb)	Fill Height (Ft)	Surcharge (Tons)
16,120	4	0
20,125	5	0
24,125	6	2
28,125	7	4
32,125	8	6
36,125	9	8
40,125	10	10
44,125	11	12
47,125	12	13½

Table II. Vertical Diameter Measurements (Inches)<sup>(a)</sup>

Ring No.	Total Load (Lb) <sup>(b)</sup>						
	16,120	20,125	24,125	28,125	32,125	36,125	40,125
1	30	29-5/8	29-5/8	29-5/8	29-5/8	29-5/8	29-5/8
2	29-1/2	29	28-7/8	29	28-1/2	28-1/4	28
3	29	28-1/4	28-1/8	28	27-1/2	27-1/2	26-5/8
4	29	28-1/4	28-1/4	27-7/8	27-5/8	27-3/8	26-3/4
5	29-1/8	29-1/8	27-3/8	27-3/4	27-1/2	27-1/4	26-3/8
6	29	--	28-1/8	27-3/4	28	27-1/2	26-1/2
7	29-3/8	29	28-1/2	28	27-1/2	27-3/4	26-7/8
8	29-1/8	28-1/8	30	28	27-3/4	27	26-3/4
9	29-1/4	28-1/4	28-1/4	28	27-1/2	27-1/2	26-3/4
10	29	28-1/4	28-1/8	28	27-1/2	27-1/4	26-1/4
11	29	28-1/2	28-1/8	28-1/8	27-5/8	27-5/8	26-3/4
12	29-3/8	29	28-7/8	28-3/4	28-1/2	28-3/8	28-1/8
13	29-7/8	29-7/8	29-7/8	29-3/4	29-3/4	29-3/4	29-3/4

(a) Measurements not taken at 44,125-lb and 47,125-lb loads.

(b) Load equivalents included in Table I.

Table III. Horizontal Diameter Measurements (Inches)<sup>(a)</sup>

Ring No.	Total Load (Lb) <sup>(b)</sup>						
	16,120	20,125	24,125	28,125	32,125	36,125	40,125
1	29-1/2	29-1/2	30-1/8	29-3/8	29-1/2	29-1/2	29-3/4
2	29-1/8	29-1/8	30-3/4	30-1/4	30-1/2	30-1/8	30-1/8
3	30	30-3/4	30-3/4	31-1/8	31-1/4	31-1/2	32
4	29-1/2	30-1/8	30-1/8	30-1/4	31	31-5/8	31-5/8
5	29-3/8	29-3/4	30-3/8	30-1/4	31-1/2	31-3/4	31
6	29-1/4	--	30-1/2	30-3/4	31-1/2	31-1/4	31
7	29-1/8	29-5/8	29-1/2	29-3/4	30-1/2	29-3/4	31-1/2
8	29-3/8	30-1/2	30-1/2	30-1/2	31-1/4	31-3/4	31-1/2
9	29-1/8	29-5/8	30-1/4	30-1/4	31-3/8	31-1/4	32-1/8
10	29-3/8	30-1/4	30-1/4	30-1/4	31	31-1/2	32
11	29-3/8	30-1/8	30	30-1/8	30-1/2	30-1/8	31-1/8
12	29-3/8	29-1/2	29-1/2	29-3/4	29-5/8	29-5/8	30
13	29-5/8	29-1/8	29-3/8	29-1/4	29-3/8	29-1/4	29-1/8

(a) Measurements not taken at 44,125-lb and 47,125-lb loads.

(b) Load equivalents included in Table I.

Table IV. Vertical Deflection (Inches)<sup>(a)</sup>

Ring No.	Total Load (Lb) <sup>(b)</sup>						
	16,120	20,125	24,125	28,125	32,125	36,125	40,125
1	+ 1/4	- 1/8	- 1/8	- 1/8	- 1/8	- 1/8	- 1/8
2	- 1/4	- 3/4	- 7/8	- 3/4	-1-1/4	-1-1/2	-1-3/4
3	- 3/4	-1-1/2	-1-5/8	-1-3/4	-2-1/4	-2-1/4	-3-1/8
4	- 3/4	-1-1/2	-1-1/2	-1-7/8	-2-1/8	-2-3/8	-3
5	- 5/8	- 5/8	-2-3/8	-2	-2-1/4	-2-1/2	-3-3/8
6	- 3/4	0	-1-5/8	-2	-1-3/4	-2-1/4	-3-1/4
7	- 3/8	- 3/4	-1-1/4	-1-3/4	-2-1/4	-2	-2-7/8
8	- 5/8	-1-5/8	+ 1/4	-1-3/4	-2	-2-3/4	-3
9	- 1/2	-1-1/2	-1-1/2	-1-3/4	-2-1/4	-2-1/4	-3
10	- 3/4	-1-1/2	-1-5/8	-1-3/4	-2-1/4	-2-1/2	-3-1/2
11	- 3/4	-1-1/4	-1-5/8	-1-5/8	-2-1/8	-2-1/8	-3
12	- 3/8	- 3/4	- 7/8	-1	-1-1/4	-1-3/8	-1-5/8
13	+ 1/8	+ 1/8	+ 1/8	0	0	0	0

(a) Measurements not taken at 44,125-lb and 47,125-lb loads.

(b) Load equivalents included in Table I.

Table V. Horizontal Deflections (Inches)<sup>(a)</sup>

Ring No.	Total Load (Lb) <sup>(b)</sup>						
	16,120	20,125	24,125	28,125	32,125	36,125	40,125
1	0	0	+ 5/8	- 1/8	0	0	+ 1/4
2	- 3/8	- 3/8	+1-1/4	+ 3/4	+1	+ 5/8	+ 5/8
3	+ 1/2	+1-1/4	+1-1/4	+1-5/8	+1-3/4	+2	+2-1/2
4	0	+ 5/8	+ 5/8	+ 3/4	+1-1/2	+2-1/8	+2-1/8
5	- 1/8	+ 1/4	+ 7/8	+ 3/4	+2	+2-1/4	+1-1/2
6	- 1/4	--	+1	+1-1/4	+2	+1-3/4	+1-1/2
7	- 3/8	+ 1/8	0	+ 1/4	+1	+ 1/4	+2
8	- 1/8	+1	+1	+1	+1-3/4	+2-1/4	+2
9	- 3/8	+ 1/8	+ 3/4	+ 3/4	+1-7/8	+1-3/4	+2-5/8
10	- 1/8	+ 3/4	+ 3/4	+ 3/4	+1-1/2	+2	+2-1/2
11	- 1/8	+ 5/8	+ 1/2	+ 5/8	+1	+ 5/8	+1-5/8
12	- 1/4	- 1/8	- 1/8	+ 1/8	0	0	+ 3/8
13	0	- 1/2	- 1/4	- 3/8	- 1/4	- 3/8	- 1/2

(a) Measurements not taken at 44,125-lb and 47,125-lb loads.

(b) Load equivalents included in Table I.

Table VI. Percent Change in Diameter

Fill Height (Feet)	Original Vertical Diameter (Inches)	Computed Vertical Deflection (Inches)	Vertical Diameter Change (%)	Original Horizontal Diameter (Inches)	Computed Horizontal Deflection (Inches)	Horizontal Diameter Change (%)
<u>a. Ring No. 1</u>						
4	29-3/4	+ 1/4	+ 0.84	29-5/8	0	0.00
5		- 1/8	- 0.42		0	0.00
6		- 1/8	- 0.42		+ 5/8	+2.11
7		- 1/8	- 0.42		- 1/8	-0.42
8		- 1/8	- 0.42		0	0.00
9		- 1/8	- 0.42		0	0.00
10		- 1/8	- 0.42		+ 1/4	+0.84
<u>b. Ring No. 2</u>						
4	29-3/4	- 1/4	- 0.84	29-5/8	- 3/8	-1.27
5		- 3/4	- 2.52		- 3/8	-1.27
6		- 7/8	- 2.94		+1-1/4	+4.22
7		- 3/4	- 2.52		+ 3/4	+2.53
8		-1-1/4	- 4.20		+1	+3.38
9		-1-1/2	- 5.04		+ 5/8	+2.11
10		-1-3/4	- 5.88		+ 5/8	+2.11
<u>c. Ring No. 3</u>						
4	29-3/4	- 3/4	- 2.52	29-1/2	+ 1/2	+1.69
5		-1-1/2	- 5.04		+1-1/4	+4.24
6		-1-5/8	- 5.46		+1-1/4	+4.24
7		-1-3/4	- 5.88		+1-5/8	+5.51
8		-2-1/4	- 7.56		+1-3/4	+5.93
9		-2-1/4	- 7.56		+2	+6.78
10		-3-1/8	-10.50		+2-1/2	+8.47
<u>d. Ring No. 4</u>						
4	29-3/4	- 3/4	- 2.52	29-1/2	0	0.00
5		-1-1/2	- 5.04		+ 5/8	+2.12
6		-1-1/2	- 5.04		+ 5/8	+2.12
7		-1-7/8	- 6.30		+ 3/4	+2.54
8		-2-1/8	- 7.14		+1-1/2	+5.08
9		-2-3/8	- 7.98		+2-1/8	+7.14
10		-3	-10.08		+2-1/8	+7.14

Table VI (cont'd)

Fill Height (Feet)	Original Vertical Diameter (Inches)	Computed Vertical Deflection (Inches)	Vertical Diameter Change (%)	Original Horizontal Diameter (Inches)	Computed Horizontal Deflection (Inches)	Horizontal Diameter Change (%)
<u>e. Ring No. 5</u>						
4	29-3/4	- 5/8	- 2.10	29-1/2	- 1/8	-0.42
5		- 5/8	- 2.10		+ 1/4	+0.85
6		-2-3/8	- 7.98		+ 7/8	+2.97
7		-2	- 6.72		+ 3/4	+2.54
8		-2-1/4	- 7.56		+2	+6.78
9		-2-1/2	- 8.40		+2-1/4	+7.63
10		-3-3/8	-11.01		+1-1/2	+5.08
<u>f. Ring No. 6</u>						
4	29-3/4	- 3/4	- 2.52	29-1/2	- 1/4	-0.85
5		0	0.00		0	0.00
6		-1-5/8	- 5.46		+1	+3.39
7		-2	- 6.72		+1-1/4	+4.24
8		-1-3/4	- 5.88		+2	+6.78
9		-2-1/4	- 7.56		+1-3/4	+5.93
10		-3-1/4	-10.92		+1-1/2	+5.08
<u>g. Ring No. 7</u>						
4	29-3/4	- 3/8	- 1.26	29-1/2	- 3/8	-1.27
5		- 3/4	- 2.52		+ 1/8	+0.42
6		-1-1/4	- 4.20		0	0.00
7		-1-3/4	- 5.88		+ 1/4	+0.85
8		-2-1/4	- 7.56		+1	+3.39
9		-2	- 6.72		+ 1/4	+0.85
10		-2-7/8	- 9.66		+2	+6.78
<u>h. Ring No. 8</u>						
4	29-3/4	- 5/8	- 2.10	29-1/2	- 1/8	-0.42
5		-1-5/8	- 5.46		+1	+3.39
6		+ 1/4	+ 0.84		+1	+3.39
7		-1-3/4	- 5.88		+1	+3.39
8		-2	- 6.72		+1-3/4	+5.93
9		-2-3/4	- 9.24		+2-1/4	+7.63
10		-3	-10.08		+2	+6.78

Table VI (cont'd)

Fill Height (Feet)	Original Vertical Diameter (Inches)	Computed Vertical Deflection (Inches)	Vertical Diameter Change (%)	Original Horizontal Diameter (Inches)	Computed Horizontal Deflection (Inches)	Horizontal Diameter Change (%)
<u>i. Ring No. 9</u>						
4	29-3/4	- 1/2	- 1.68	29-1/2	- 3/8	-1.27
5		-1-1/2	- 5.04		+ 1/8	+0.42
6		-1-1/2	- 5.04		+ 3/4	+2.54
7		-1-3/4	- 5.88		+ 3/4	+2.54
8		-2-1/4	- 7.56		+1-7/8	+6.36
9		-2-1/4	- 7.56		+1-3/4	+5.93
10		-3	-10.08		+2-5/8	+8.90
<u>j. Ring No. 10</u>						
4	29-3/4	- 3/4	- 2.52	29-1/2	- 1/8	-0.42
5		-1-1/2	- 5.04		+ 3/4	+2.54
6		-1-5/8	- 5.46		+ 3/4	+2.54
7		-1-3/4	- 5.88		+ 3/4	+2.54
8		-2-1/4	- 7.56		+1-1/2	+5.08
9		-2-1/2	- 8.40		+2	+6.78
10		-3-1/2	-11.76		+2-1/2	+8.47
<u>k. Ring No. 11</u>						
4	29-3/4	- 3/4	- 2.52	29-1/2	- 1/8	-0.42
5		-1-1/4	- 4.20		+ 5/8	+2.12
6		-1-5/8	- 5.46		+ 1/2	+1.69
7		-1-5/8	- 5.46		+ 5/8	+2.12
8		-2-1/8	- 7.14		+1	+3.39
9		-2-1/8	- 7.14		+ 5/8	+2.12
10		-3	-10.08		+1-5/8	+5.51
<u>l. Ring No. 12</u>						
4	29-3/4	- 3/8	- 1.26	29-1/2	- 1/4	-0.85
5		- 3/4	- 2.52		- 1/8	-0.42
6		- 7/8	- 2.94		- 1/8	-0.42
7		-1	- 3.36		+ 1/8	+0.42
8		-1-1/4	- 4.20		0	0.00
9		-1-3/8	- 4.62		0	0.00
10		-1-5/8	- 5.46		+ 3/8	+1.27

Table VI (cont'd)

Fill Height (Feet)	Original Vertical Diameter (Inches)	Computed Vertical Deflection (Inches)	Vertical Diameter Change (%)	Original Horizontal Diameter (Inches)	Computed Horizontal Deflection (Inches)	Horizontal Diameter Change (%)
<u>m. Ring No. 13</u>						
4	29-3/4	+ 1/8	+ 0.42	29-1/2	0	0.00
5		+ 1/8	+ 0.42		- 1/2	-1.69
6		+ 1/8	+ 0.42		- 1/4	-0.85
7		0	0.00		- 3/8	-1.27
8		0	0.00		- 1/4	-0.85
9		0	0.00		- 3/8	-1.27
10		0	0.00		- 1/2	-1.69

Table VII. Ring Deflections in Compression Test

Total Head (Lb)	Measured Vertical Deflection (1/16 Inch)	Resultant Vertical Axis (Inches)	Computed Horizontal Deflection* (1/16 Inch)	Resultant Horizontal Axis (Inches)
0	0	30	0	30
20	1	29-15/16	1	30-1/16
40	3	29-13/16	3	30-3/16
60	5	29-11/16	5	30-5/16
80	6	29-5/8	6	30-3/8
100	8	29-1/2	8	30-1/2
120	20	28-3/4	19	31-3/16
140	24	28-1/2	22	31-3/8
160	29	28-3/16	26	31-5/8
180	36	27-3/4	32	32
200	42	27-3/8	36	32-1/4
220	64	26	52	33-1/4
240	90	24-3/8	67	34-3/16
260	156	20-1/4	100	36-1/4
280	196	17-3/4	115	37-3/16
300	228	15-3/4	125	37-13/16
320	258	13-7/8	134	38-3/8
340	280	12-1/2	139	38-11/16
360	304	11	144	39
380	316	10-1/4	146	39-1/8
400	340	8-3/4	150	39-3/8
420	358	7-5/8	153	39-9/16
440	382	6-1/8	156	39-3/4
460	398	5-1/8	157	39-13/16
480	406	4-5/8	158	39-7/8
500	412	4-1/4	158	39-7/8
520	418	3-7/8	159	39-15/16
540	422	3-5/8	159	39-15/16
560	426	3-3/8	159	39-15/16
580	432	3	160	40
600	436	2-3/4	160	40
620	438	2-5/8	160	40
640	442	2-3/8	160	40
660	448	2	160	40

\* Computed by Data Processing & Statistical Services Branch by approximate formula for perimeter of an ellipse;

$$p = \pi/2a (3a^2 + b^2)$$

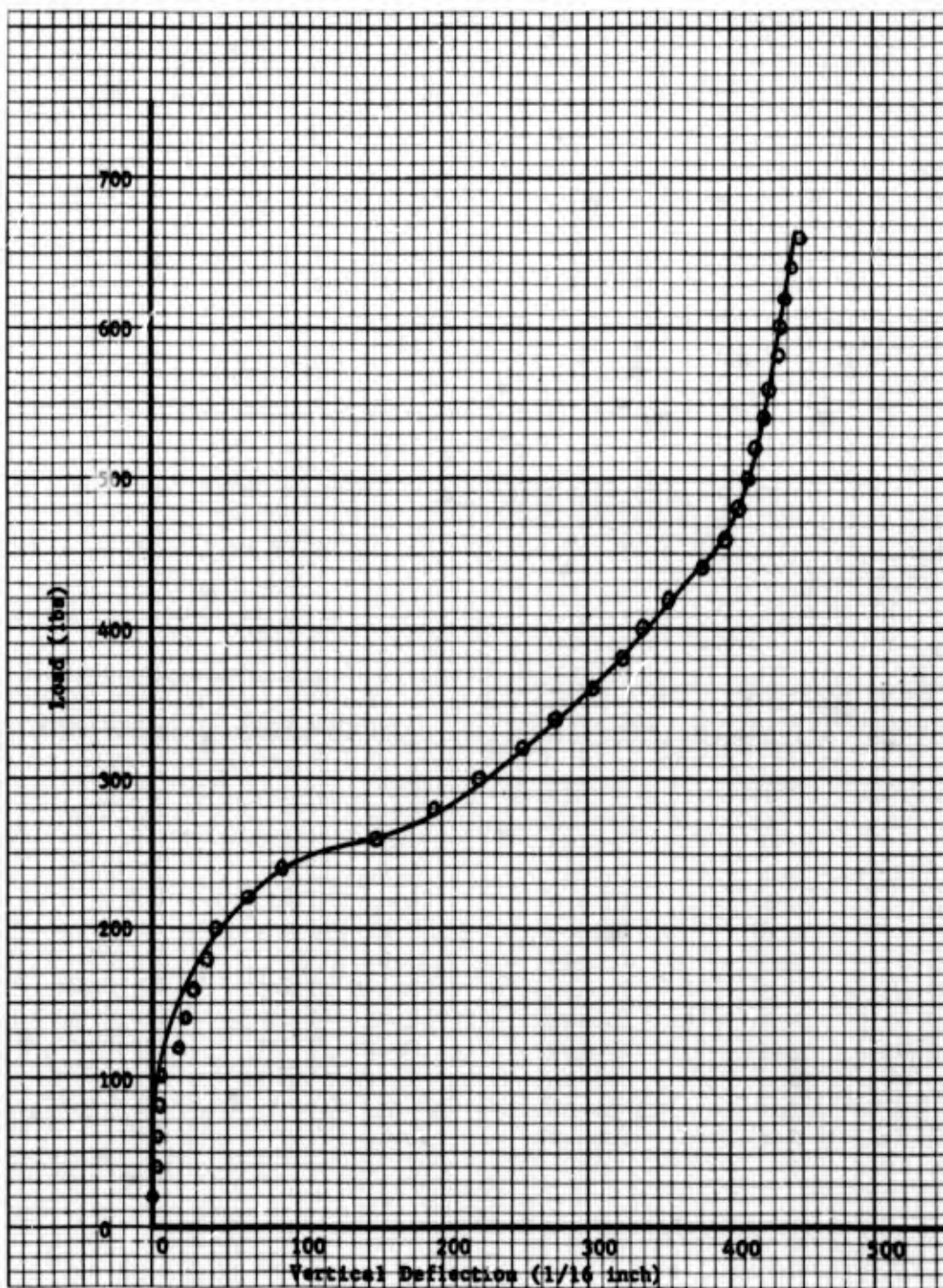


Fig. 34. Vertical deflections vs load as measured in ring compression test.

Table VIII. Textile Test Results Vs CCC-C-419 Requirements

Characteristic	CCC-C-419 No. 4	CCC-C-419 No. 6	USAERDL Results
Weight of fabric, oz. per sq. yd	23.93	20.74	21.3
Yarn count, warp, No. per in.	31	35	36
Yarn count, fill, No. per in.	22	25	26
Breaking strength, warp, lb	375	335	325
Breaking strength, fill, lb	300	250	200
Ultimate elongation, warp, %	---	---	30
Ultimate elongation, fill, %	---	---	13
Tear strength, warp, lb	---	---	18
Tear strength, fill, lb	---	---	13
Burst strength, lb per sq in.	---	---	382

12. Types of Ring Joint Failure. Table IX summarizes the ring joint data gathered in field load test. Figures 33 and 35 through 39 illustrate the effect of the two types of joints on ring performance.

Table IX. Summary of Ring Joint Data

Ring Number	Type Ring	Joint Condition End of Test	Type of Coupling Weld	Allen Screw Condition
1	Pipe	Broken	NA	Out
2	Pipe	Broken	NA	In place
3	Rod	Broken	Short fillet	Out
4	Rod	Intact	Long fillet	In place
5	Rod	Intact	Long fillet	Out
6	Rod	Intact	Long fillet	In place
7	Rod	Intact	Long fillet	In place
8	Rod	Broken	Short fillet	In place
9	Rod	Intact	Short fillet	In place
10	Rod	Broken	Short fillet	In place
11	Rod	Broken	Short fillet	In place
12	Rod	Intact	Long fillet	In place
13	Rod	Intact	Long fillet	Out

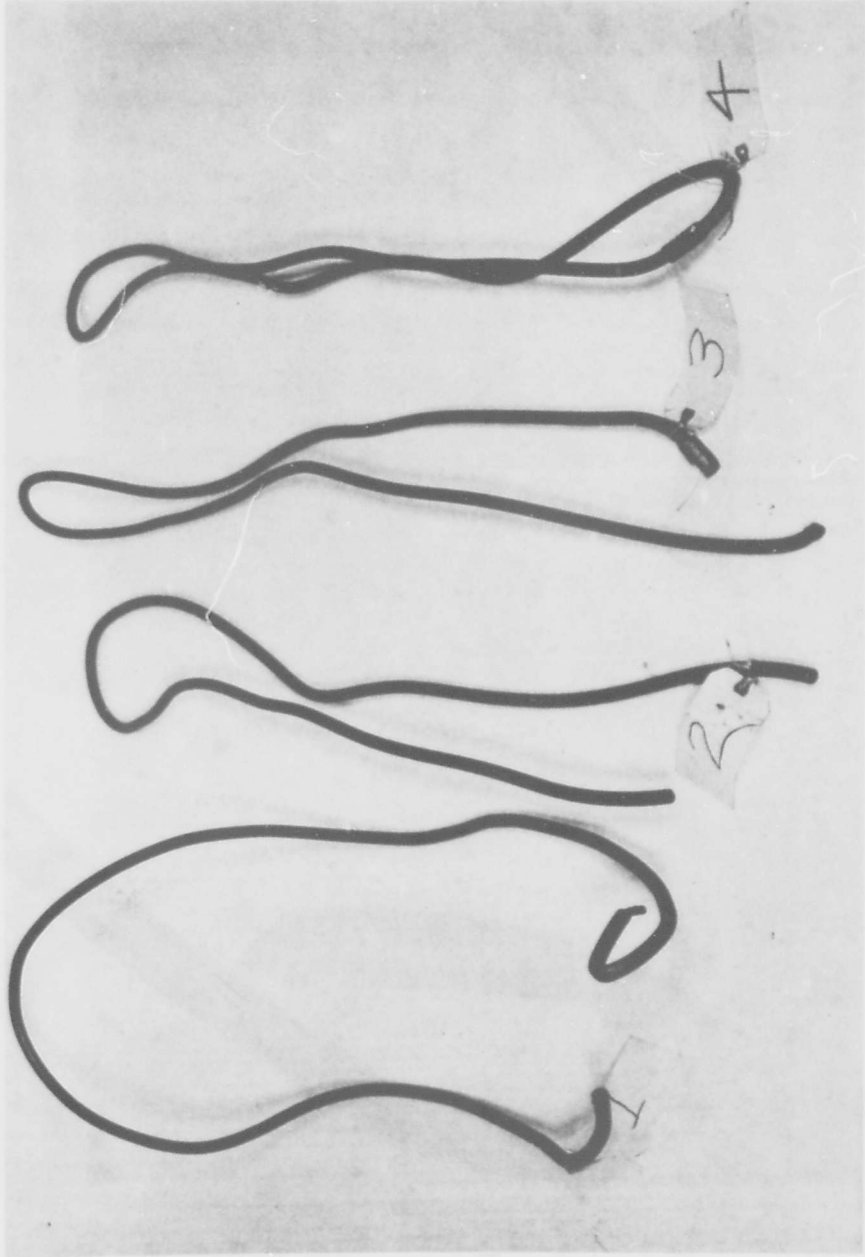


Fig. 35. Representative failures of rings and joints.

G3492

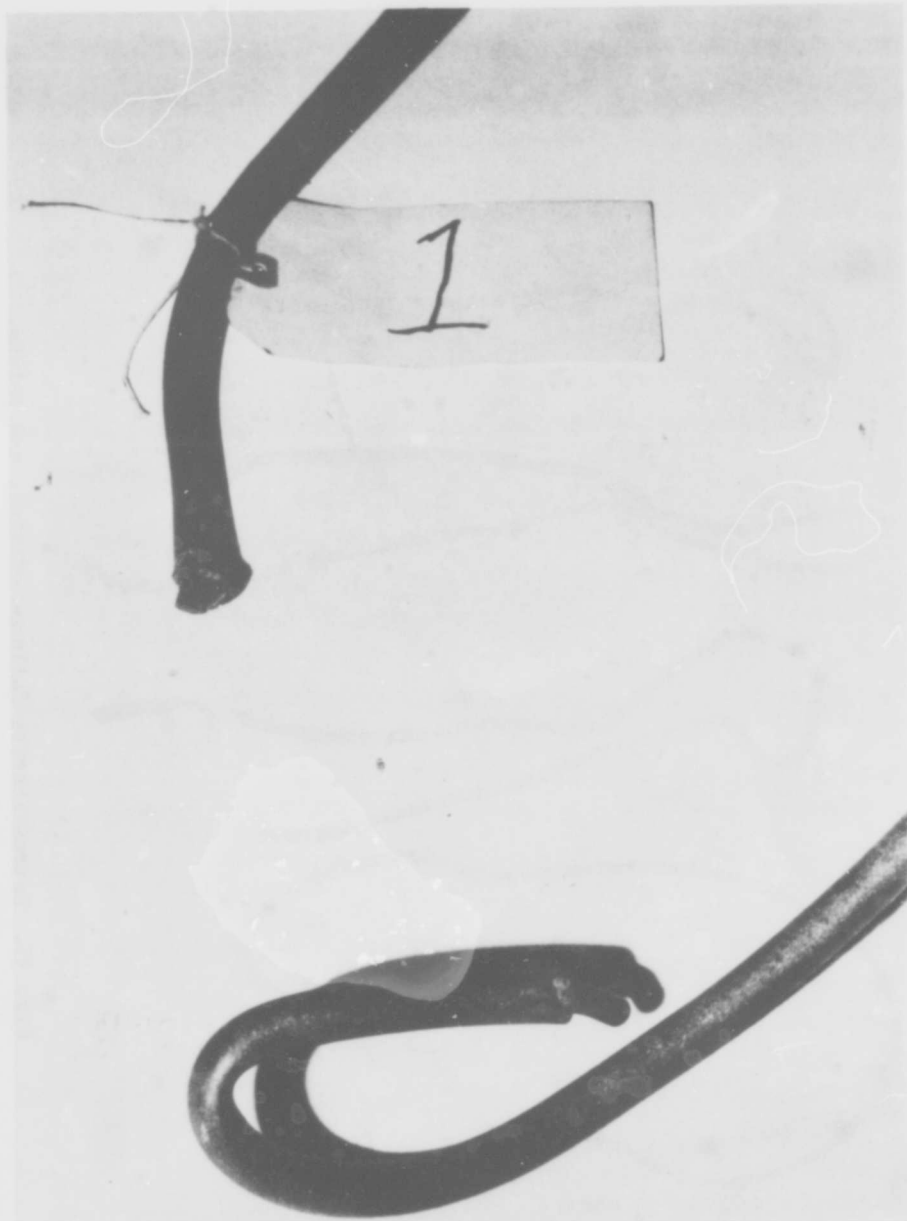


Fig. 36. Ring No. 1 joint failure caused by inadequate edge distance and thickness of pipe wall. G3494



Fig. 37. Ring No. 2 joint failure caused by excess bending stress in pipe insert.

G3495

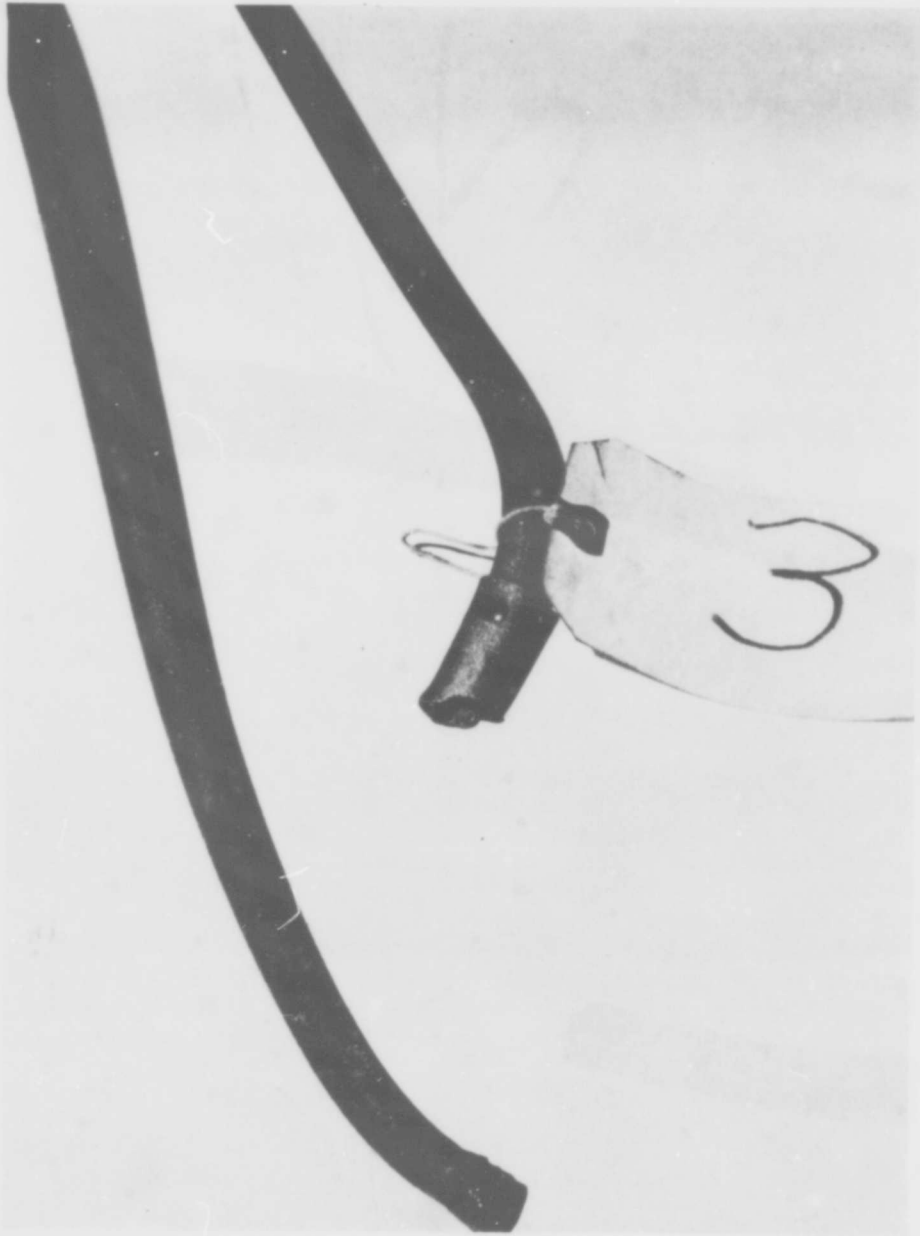


Fig. 38. Ring No. 3 joint failure caused by inadequate thickness of rod coupling wall (note short fillet weld). G3493

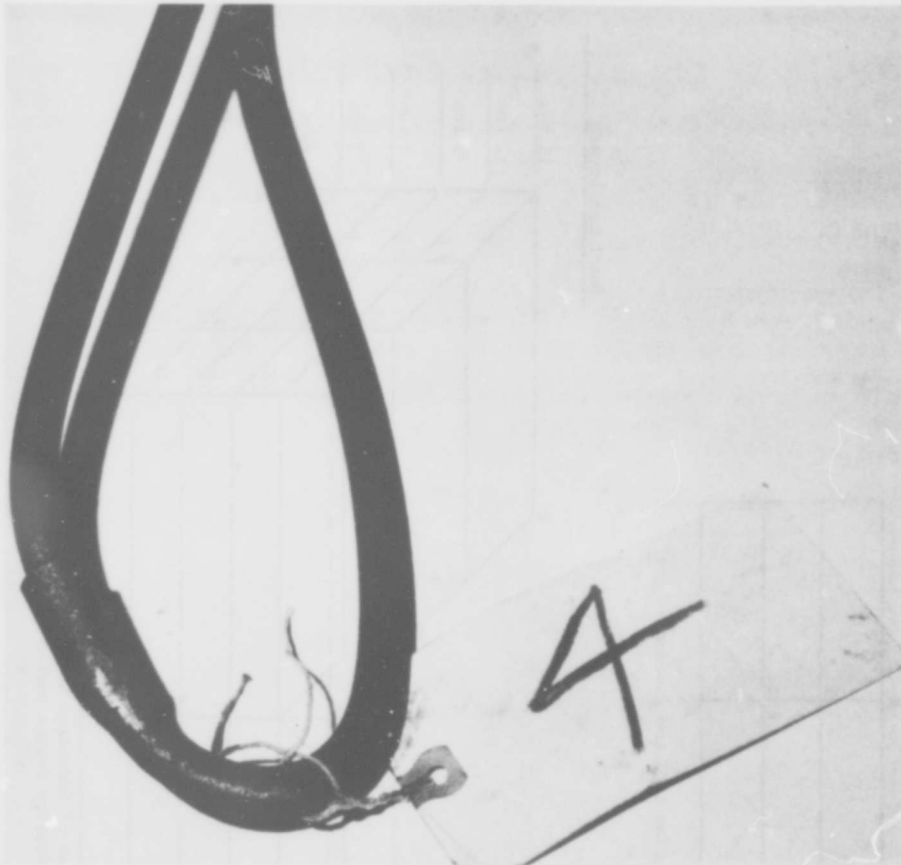
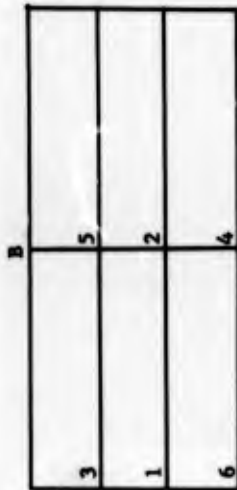


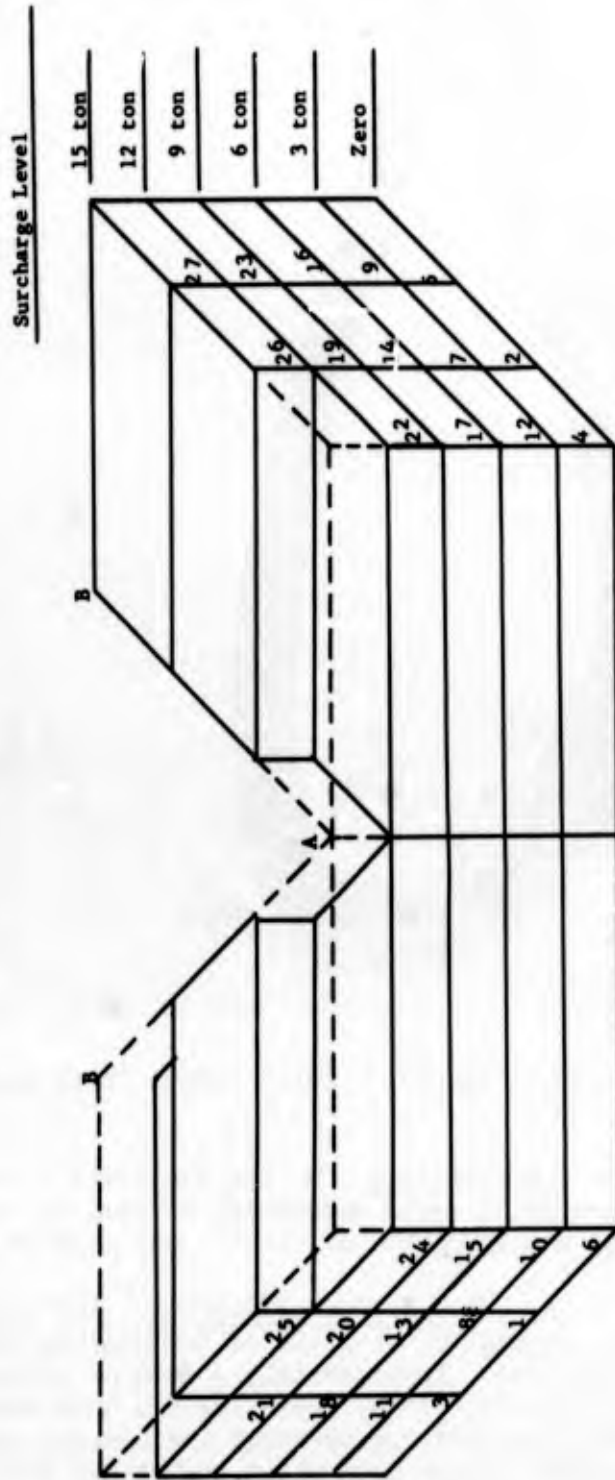
Fig. 39. Ring No. 4 joint intact (note long fillet weld). G3496

13. Observations. During the field load test, observations were made relative to foundation of sandbox, method of loading sandbox, and configuration of rings under loading.

a. Foundation of Sandbox. The subgrade upon which was laid the foundation or sills of the sandbox was not a thoroughly consolidated base. Approximately 3 feet of loose, uncompacted soil overlaid the test area. Leveling and hand tamping of the immediate test site improved considerably the bearing capacity of the soil. However, the ground into which the stakes that held the wall braces were driven offered little resistance to the lateral force eventually applied. The load subsequently placed on the sills also caused



a. Plan of 3 ton Surcharge Level



b. Isometric view of Surcharge Loading with rotation about "A". Numbers denote number of 1000 lb weights.

Fig. 40. Surcharge loading diagram.

small differential settlement of these members. Re-examination of Figs. 22, 26, and 27 indicates the extent of this settlement.

b. Method of Loading Sandbox. Attention to acceptable construction practice resulted in relative even distribution of the sand loading of the liner. When the sand supply was depleted and loading had to be applied by lead weights, an eccentricity of load application was developed. The bearing area of a single weight was about one-sixth of the top surface area of the sandbox to be covered. The loading method devised to minimize this eccentricity is shown in Fig. 40. Indications were that this method together with the rigid bearing plate atop the sand load permitted no significant unevenness of the load. This is illustrated in Fig. 23 which shows the 10-ton surcharge level. When the 12-ton surcharge level was reached, however, greater settlement of the sand took place on one

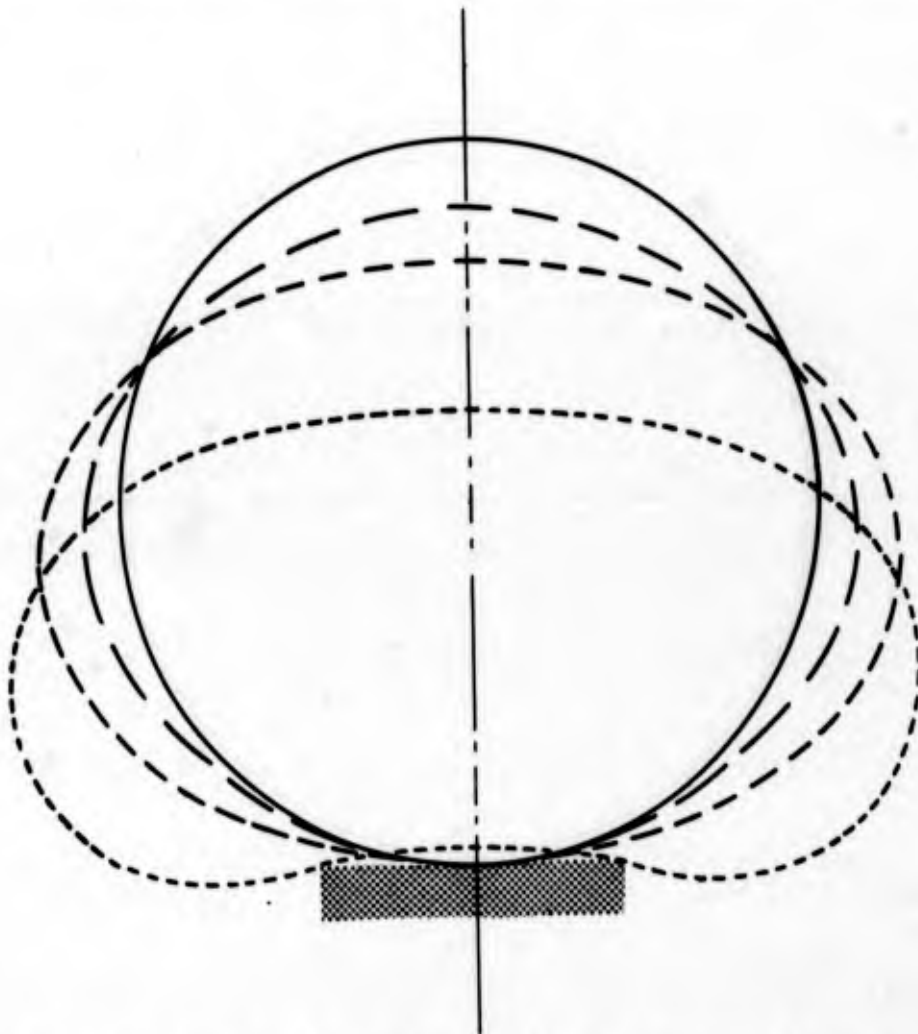


Fig. 41. Stages of ring deformation in compression test.

end of the sandbox. This is shown in Fig. 25; the right side is lower than the left.

c. Configuration of Rings under Loading. One point of interest noted in the field load test was the manner of deformation taken by the steel rings. Prior to the field test, it was thought that the rings would take a shape similar to those taken by Ring No. 13 (Fig. 41) in the laboratory test, flatter and flatter ellipses. This did not occur; instead, the rings took the shape illustrated in Fig. 42 (attested by Figs. 12, 20, 22, 24, and 26). Indications were that most of the deformation of the rings took place above the horizontal axis. Ring deformations in these figures are greatly exaggerated by the bulges encountered between rings. These bulges greatly restricted the vertical clearance and seriously hampered passage through the liner.

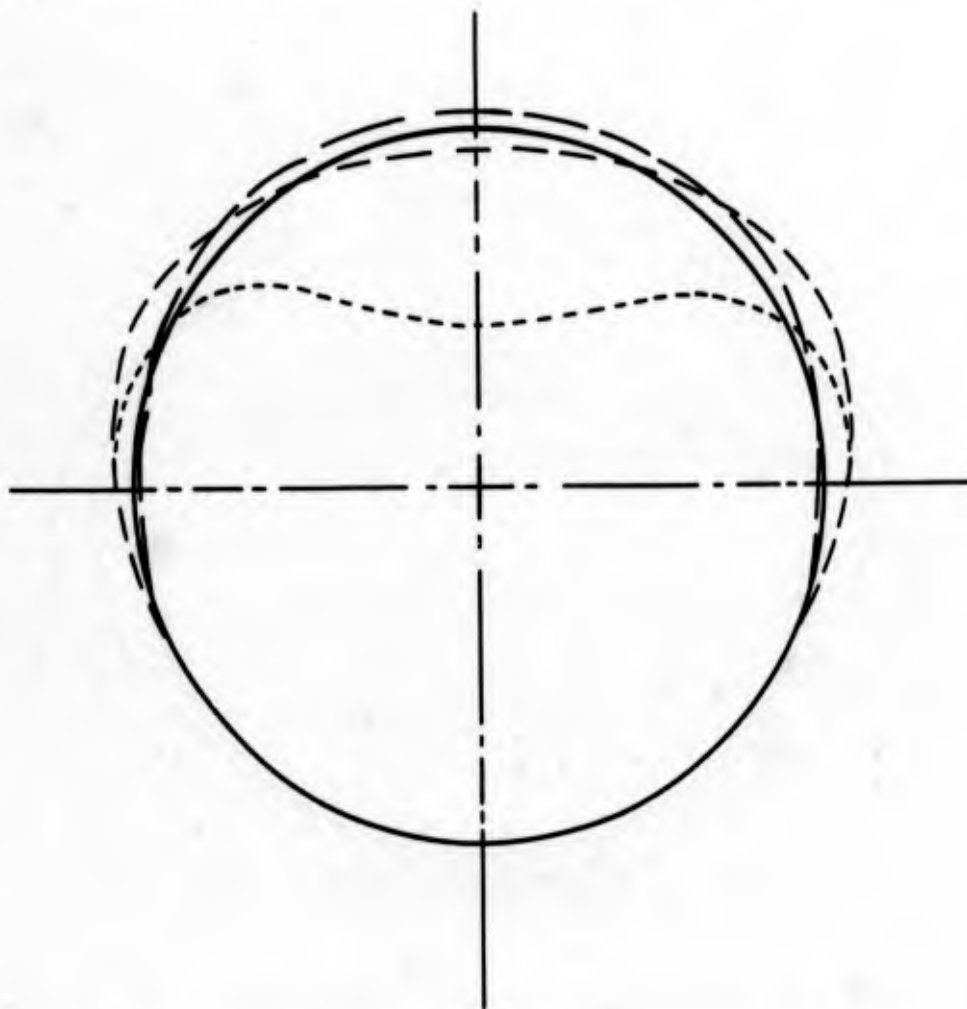


Fig. 42. Stages of ring deformation in field load test.

## IV. DISCUSSION

14. Examination of Test Method. The method of test evolved to evaluate the liner seems to have been satisfactory. The sandbox method has been used before in determination of the crushing strength of corrugated metal pipe. The standard sand-bearing method was developed for rigid conduit such as concrete, cast iron, and clay pipe. For thin, corrugated-metal, flexible pipe, there exists a method for determination of beam strength with third-point loading. The third-point loading method was entirely out of question since the liner has little, if any, longitudinal beam strength. An individual laboratory ring compression test would serve as well but a single ring does not truly represent the entire liner. The sand-bearing method for rigid pipe could not be used in its entirety because of the flexible fabric covering of the liner. The sides of the top bearing frame would rest on the rings, and sand would escape through the space between the rings. Any attempt to place scalloped sides in the top bearing frame to fit the bulges would not suffice since the size of the bulges is dependent upon the loading and the elongation of the cotton duck. Adaptation of the sand-bearing method with retaining side frames offered a ready solution.

Many factors were considered in the determination of the size of the sandbox and the manner in which the canvas liner was installed. The liner could not be construed as a rigid structure, but it had many features of a flexible one. Underground structures derive their capacity to support vertical loads from two sources, either through the inherent strength of the structure itself to resist external pressures or through side support developed in the enveloping soil as passive pressure due to the outward deformation of the sides of the structure. These are the criteria for rigid and flexible conduit, respectively. Another difference between these types of structures is that while rigid conduit fails by rupture of the walls, flexible conduit generally fails by change in shape or excessive deformation. One distinct advantage of a flexible structure when it is used for human occupancy or passage is that it does not fail rapidly when the material is stressed beyond the elastic limits, but continues to function structurally until the deflections result in a change in shape to such an extent that the curvatures in the top and bottom of the structure are reversed.

Selection of the sandbox method established the class of installation condition as being a trench or ditch conduit. In this class, a conduit is completely buried in a narrow trench in relatively passive or undisturbed soil. For most trench installations, the load on a rigid conduit with relatively compressible side fills increases approximately with the square of the width of the trench. From the standpoint of rigid conduits, trenches should be as narrow as possible from the bottom to the top of the conduit. This is

reasonably true for flexible conduit also with one major exception. The strength of flexible conduit depends to a large extent upon the inherent capacity to flex under loading. For this reason, the width of a trench for a flexible conduit is dependent upon the permissible horizontal deflections. With the canvas liner considered as a flexible conduit, a 3-inch deflection on each side was felt to be the maximum deflection to be sustained and still permit the liner to be a useful structure. On this basis alone and allowing for 3-inch-thick sidefills, a 42-inch width was chosen for the sandbox.

Another aspect considered in the manner of liner installation was the bedding condition. (Definitions of bedding classifications are found in appropriate literature.) For purposes of the field load test, it was felt that the "ordinary" bedding method would be the more likely one to be used by the military. In many situations, the lesser method of "impermissible" bedding may have to be used. Extreme conditions were not used to test the liner since no useful information could be gathered if early failure occurred.

Two obvious criticisms must be made of the test program. The load-carrying capacity of the liner was underestimated and precluded construction of a sufficiently strong sandbox. Better lumber and fasteners together with appropriate exterior wales would have prevented collapse of the sandbox. Secondly, no provisions were made to measure the vertical clearance between rings where bulges of the cotton fabric developed. These bulges greatly reduced passage through the liner and prevented the taking of ring deflection data under increased loading.

15. Analysis of Results. There is no doubt that had the sandbox not failed, the liner could have sustained a greater height of fill. Indications were evident that the box was failing at the 12-ton surcharge level; likewise, reversal of the curvature of the rings was occurring. However, similar to flexible conduit failure, the buckling of the rings still did not prevent the liner from being serviceable with accompanying hazards. On the basis of criterion set for liner failure, Table VI indicates that the maximum vertical diameter change for most of the rings was between 10 and 11 percent. At the 13 $\frac{1}{2}$ -ton surcharge level, the liner deformed and the rings deflected as before but failure of the liner did not occur until the wall of the sandbox collapsed. A relative period of time elapsed between application of the load and collapse of the sandbox.

A conservative estimate of the crushing strength of the liner is the load at which the sandbox failed; that is, a total load of 47,125 pounds or 4,713 pounds per lineal foot. This value was obtained by assuming that the weight of the entire prism of sand (3.5 by 10 by 5 ft; unit weight of sand equals 115 lb per cu ft)

above the crown plus the  $13\frac{1}{2}$ -ton surcharge load was carried by the liner.

This assumption gives the probable maximum load on the liner. The practice is customary in trench conduits to disregard the cohesion between the backfill material and the trench walls since the maximum load may develop at any time due to numerous causes which may eliminate the cohesion. Furthermore, considerable time is required before effective cohesion is developed between backfill material and trench walls. In the field load test, the liner was not allowed to stand under each load longer than was required to apply the next load and observe and record the effect. Because of the cohesionless granular nature of the sand load and the dressed sides of the sandbox, no significant cohesion was evident even after the two-day interval between sand loading and surcharge loading.

The laboratory test data on ring deformation and the load versus deflection values in the field test indicate that the total load was not entirely supported by the liner. The major portion of the load was carried by the side fills adjacent to the liner. This fact is logical when the theoretical analysis of fill loads on trench conduit is considered.

A load on a trench conduit is greatly affected by the differential settlement of the soil over the conduit to the settlement of side fills. When a conduit is placed in a trench, the fill material will settle downward. This downward movement of the fill material will produce vertical frictional forces or shearing stresses along the boundaries of the various prisms of soil fill. The interior prism is that soil that lies between the vertical planes tangent to the outside of the conduit barrel; the remaining soil fill makes up the exterior prisms. The net dead load on the conduit is the weight of the interior prism of soil plus or minus an amount dependent on the direction of the generated shearing stresses between soil prisms. This stress transfer is greatly influenced by the flexibility and foundation or bedding condition of the conduit. If either the conduit is sufficiently flexible or the foundation is yieldable or if both conditions prevail, the interior prism of soil will settle downward a greater amount than the exterior prism. When this situation occurs, the induced shearing stresses act upward and the stresses are subtractive from the weight of the interior prism. This settlement phenomenon has been the basis for development of the "imperfect ditch" method of construction to gain such an objective.

In the case of the liner, indications are that to some degree this objective was achieved. The liner was extremely flexible, and the 6-inch bed of sand beneath the liner was relatively compressible. The side fills were thoroughly tamped, and their stiffness greatly exceeded that of the liner. This permitted them to

reduce considerably the load over the liner. The bulges in the cotton fabric, the negative horizontal deflection recorded in Table V, and the ring configurations attained as shown in Fig. 42 are indications of the stiffness or compactiveness of the side fills. Measurements of the horizontal diameter of the liner taken during placement of the side fills would have shown more vividly this pinching-in of the rings which was not neutralized until considerable sand load caused resumption of original horizontal diameter. This occurred slightly above the fill height of 4 feet. The configuration of the rings in the field load test did not correspond to the laboratory ring test because of the restraining force of the side fills to the flexing of the rings. Since this transverse flexing action was limited, the liner could only draw minimal support from the surrounding side fills in distributing the stresses peripherally. Instead, the external pressures were concentrated through the vertical axis causing premature buckling of the top of the rings. Deformation upward of the bottom of the rings, below the horizontal axis, was of little consequence.

In general, ring deflections followed the identical pattern for each level of surcharge loading. The manner in which the surcharge loading was applied (Fig. 40) is similar to the application of two equal, concentrated loads symmetrically placed on a beam which is fixed at both ends. If the resultant vertical diameters were plotted in profile, a line joining their tops would form a catenarian type of curve with a slight rise at the center (at Ring No. 7). The low points of the curve indicate that the surcharge was concentrated over Rings 4 and 5 and over Rings 9 and 10. These rings carried a disproportionate share of the load. This reveals the importance of balanced backfill practice. To a lesser degree, this behavior is exhibited in complementary changes in horizontal diameters.

The greater diameters of the rings at the ends of the liner illustrate that the anchorage effect on the load-carrying capacity of the liner is of considerable magnitude. As a result of the bedding condition and the taut effect of the anchorage system, little, if any, bulging of the canvas covering took place at the bottom of the liner over that which was originally attained in initial installation. The tension placed in the upper portion of the canvas covering by the anchorage system reduced to some extent the vertical compressive forces applied by the loading. The load on the canvas covering, based on a loading of 4,713 pounds per lineal foot, was less than 10 pounds per square inch. This is far less than the bursting strength. A bulge of about 3 inches between rings shows that the fabric was stretched approximately 24 percent of its ultimate warp elongation. The major portion of elongation had taken place, and subsequent loading would not increase the depth of bulges further than about  $3/8$  inch. The importance of yarn direction was

not fully appreciated when the liner was fabricated but it was pointed out in the textile test. If the filling yarns had been oriented parallel to the longitudinal axis of the liner, the depth of bulges would have been about 50 percent less during the field load test.

During the field load test, the solid rings showed very little, if any, advantage over the pipe rings. Examination of deflections of Ring No. 2 and Ring No. 12 revealed that the hollow pipe rings deformed slightly less than the solid rings. A pipe ring laboratory test would have presented a better comparison. A graph of the vertical deflection versus load as measured in the laboratory compression test for the solid ring is given in Fig. 34. From the curve, it can be seen that the ring began to yield between 200 and 250 pounds of load. During the test, the configuration was observed and there was no evidence of any reversing of the curvature of the ring until the load reached 450 pounds. At this load level, the bottom began to reverse but the top continued to flatten as before (Fig. 41). Because the horizontal axis of the ring at load level was greater than the width of the testing machine base, an edge effect was introduced. This was believed to be the cause of the reversal of curvature at the bottom of the ring.

Throughout the entire laboratory test of Ring No. 13, the connecting joint showed no signs of failure. Figures 35 through 39 illustrate typical joint failures; this data is summarized in Table IX. It was believed that the failure of the Allen screws to stay in place in the ring joints was due to the inability of such thin material to retain screws and to the variation in workmanship of the handmade rings. With one exception, Ring No. 9, all the short fillet joints were intact. It is apparent that the length and angle of edge fillet welds are critical. A better joint connection is indicated for pipe rings.

## V. CONCLUSIONS

### 16. Conclusions. It is concluded:

a. Based on the criterion for liner failure, a conservative estimate of the load-carrying capacity of the liner is 4,713 pounds per lineal foot or a fill height of 12 feet of sand fill. (The ultimate crushing strength was never ascertained.)

b. The bedding condition significantly affects settlement and, therefore, affects the supporting strength of the liner.

c. The "imperfect trench" method of installation would materially increase the liner's load-carrying capacity.

d. It is desirable to have the liner fabric yarn with the least ultimate elongation oriented parallel to the longitudinal axis of the liner. (Lack of knowledge of textile properties resulted in greater deformation of the canvas covering than anticipated.)

e. Of the two types of ring joints tested, the steel insert and the pipe coupling, the latter appears to be the better.

f. Method of welding of the pipe coupling appears critical and should be given proper consideration.

g. The hollow pipe rings seem to have only a minimal advantage over the solid rod rings, but on the basis of military logistics a greater weight reduction can be achieved by the use of the pipe rings.

## APPENDIX

## AUTHORITY

Item No. 2158  
CETC Mtr. No. 252

SUB R & D/ PROJECT CARD		TYPE OF REPORT PROGRESS		REPORT CONTROL SYMBOL CSCRD-1 (R1)	
1. PROJECT TITLE SUBPROJECT TITLE FIELD FORTIFICATIONS AND OBSTACLES (U)		2. SECURITY OF PROJECT U		3. PROJECT NO. 8-07-10-000	
		4. INDEX NUMBER 8-07-10-420		5. REPORT DATE 31 Dec 59	
6. BASIC FIELD OR SUBJECT Mines and Obstacles		7. SUB FIELD OR SUBJECT SUB GROUP Fortifications, Obstacles & Demolitions		7A. TECH. OBJ. LC-13	
8. COGNIZANT AGENCY C of E		12. CONTRACTOR AND/OR LABORATORY Engr Res & Dev Lab DeBell & Richardson, Inc. Harvey Machine Co. DeBell & Richardson, Inc.		CONTRACT/W. O. NO. DA-44-009 eng-2608 DA-44-009 eng-2906 DA-44-009 eng-4002	
9. DIRECTING AGENCY Res & Dev Div, OCE					
10. REQUESTING AGENCY OCE					
11. PARTICIPATION AND/OR COORDINATION CONARC USMC (C) ORD (C) N BU ORD (C)		13. RELATED PROJECTS		17. EST. COMPLETION DATES	
				RES. Cont	
				DEV. Cont	
				TEST Cont	
				OP. EVAL. Cont	
		14. DATE APPROVED 2 Apr 54 by GSUSA as amended		18. FY. FISCAL ESTIMATES	
				60 68M	
				61 180M	
		15. PRIORITY 1-B		16. MAJOR CATEGORY 5600	
19. REPLACED PROJECT CARD AND PROJECT STATUS Supersedes project card dated 31 Dec 58				P/A 140M	
20. REQUIREMENT AND/OR JUSTIFICATION This project is expected to provide new or improved items of materiel, equipment, and techniques for increasing the efficiency and ease of handling and construction of field fortifications and obstacles, to facilitate the movement and defense of field forces in the theater of operation, assist in the attainment of their military objective, more adequately meet the threat of increased firepower and destructive potentialities of present weapons and modes of warfare, including atomic, and provide increased defense against massed infantry attacks. The improved or developed items will decrease losses of					
21. <del>REQUIREMENT AND/OR JUSTIFICATION</del> materiel and personnel, and warrant the assignment of a 1-C priority.					
21. BRIEF OF PROJECT AND OBJECTIVE					
a. Brief:					
(1) Objective:					
This project is expected to improve present types and develop new types of field fortifications and obstacles, as well as equipment that will assist in the construction and erection of such items, and to provide additional protection and security to field forces in the theater of operations.					
(2) Military Characteristics: See 31 Dec 57 Project Card.					
22. CARD (R & D)		DN.	CN.	C.	X. I. C.
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REPLACES DD FORM 613, 1 JAN 55.					

SUB  
R&D PROJECT CARD  
CONTINUATION SHEET

1. <del>PROJECT NO.</del> SUBPROJECT TITLE	2. SECURITY OF PROJECT U	2158/252 3. PROJECT NO. 8-07-10-000
FIELD FORTIFICATIONS AND OBSTACLES (U)	4. INDEX NUMBER 8-07-10-420	5. REPORT DATE 31 Dec 59
<p>BLOCK 21 Continued</p> <p>b. Approach:</p> <p>(1) Based on tactical assumptions, efforts will be made to improve the characteristics of field fortifications to increase the efficiency and ease of their usage, i.e., in their transportation, handling, and construction. Special attention will be given to the use of prefabricated sections of stable and light material designed to facilitate transporting, handling, and erecting. Development of obstacles will be based on: (1) their independent use as a means to delay and embarrass the enemy and (2) as an auxiliary means of defense of field fortifications. Special consideration will be given to the development of prefabricated sections of steel obstacles such as hedgehogs and barbed wire. The potentialities of flame as an obstacle will be fully investigated, as also will be obstacles against amphibious assault and obstacles against airborne assaults. Coordination with employment of mine warfare will be considered.</p> <p>(2) The accomplishment of the mission of this project shall be effected through six specific and successive phases:</p> <ol style="list-style-type: none"> <li>1. Confirmation of requirements by the using agency (CONARC).</li> <li>2. Investigation and evaluation by the developing agency, to determine the merits of possible approaches towards the solution of confirmed requirements.</li> <li>3. Preparation of specific military characteristics.</li> <li>4. Approval of the military characteristics by the using agency (CONARC).</li> <li>5. Approval of the military characteristics by appropriate amendment and/or revision to this project through action of the Corps of Engineers Technical Committee.</li> <li>6. Research and development in accordance with approved military characteristics.</li> </ol> <p>c. Subtasks: None.</p> <p>d. Other Information:</p> <p>(1) Scientific Research: No scientific research done during 1957. Research previously done during 1955 and 1956 under Contract 2608.</p> <p>(2) References:</p> <ol style="list-style-type: none"> <li>(a) Field Fortifications Manual, FM 5-15.</li> <li>(b) Obstacle Techniques Manual, FM 5-30.</li> <li>(c) Various Engineer Technical Intelligence Reports of field experiments use by both friendly and enemy forces in Korea, relative to the field of Fortifications and Obstacles.</li> <li>(d) Item 1263, CETC Meeting No. 238, closing Project No. 8-07-06-001.</li> </ol> <p>(3) Discussion: None.</p>		
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