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OPERATION
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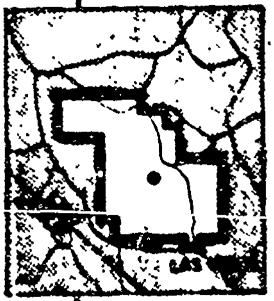

NEVADA TEST SITE
MAY-SEPTEMBER 1957

Project 3.2

EVALUATION of BURIED CONDUITS as PERSONNEL SHELTERS

Issuance Date: July 14, 1960

HEADQUARTERS FIELD COMMAND
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OPERATION PLUMBBOB—PROJECT 3.2

EVALUATION of BURIED CONDUITS as PERSONNEL SHELTERS

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FOREWORD

This report presents the final results of one of the 46 projects comprising the military-effect program of Operation Plumbbob, which included 24 test detonations at the Nevada Test Site in 1957.

For overall Plumbbob military-effects information, the reader is referred to the "Summary Report of the Director, DOD Test Group (Programs 1–9)," ITR–1445, which includes: (1) a description of each detonation, including yield, zero-point location and environment, type of device, ambient atmospheric conditions, etc.; (2) a discussion of project results; (3) a summary of the objectives and results of each project; and (4) a listing of project reports for the military-effect program.

ABSTRACT

(Supersedes ITR-1421)

Twelve large-diameter buried conduit sections of various shapes were tested at different ~~in the 60- to 140-psi~~ overpressure field ~~region of Shot Priscilla~~ blast to make an empirical determination of the degree of personnel protection afforded by commercially available steel and concrete conduits at depths of burial of 5, 7.5, and 10 feet below grade. Essentially, it was desired to assure that Department of Defense Class I (100-psi and comparable radiations) and Class II (50-psi and comparable ~~radiations) protection is~~ afforded by use of such conduits of various configurations.

Measurements were made of free-field overpressure at the ground surface above the structure; pressure inside the structures; acceleration of each structure; deflection of each structure; dust inside each structure; fragmentary missiles inside the concrete structures; and gamma and neutron radiation dose inside each structure.

All buried conduit sections tested provided adequate Class I protection (100-psi overpressure and comparable radiation protection) for the conditions under which the conduits were tested. Standard 8-foot concrete sewer pipe withstood 126-psi overpressure without significant damage (minor tension cracks observed); standard 10-gage corrugated-steel 8-foot circular conduit sections withstood 126-psi overpressure without significant damage; and standard 10-gage corrugated-steel cattle-pass conduits withstood 149-psi overpressure without significant damage. Durations of positive pressure were from 206 to 333 milliseconds.

PREFACE

The pretest planning, field test, and completion of the interim test report was accomplished by the Bureau of Yards and Docks (BUDOCKS) with assistance in the field by the research staff of the U.S. Naval Civil Engineering Laboratory (NCEL). The project was conceived, planned, and executed under the guidance of CAPT A.B. Chilton, Jr., CEC, USN, who was then Manager of the Atomic Energy Branch of BUDOCKS. LTJG G.H. Albright, CEC, USNR, was Project Officer and writer of the interim test report. P.J. Rush was Project Engineer for the NCEL participation at the test site.

This weapons test report was prepared by the research staff of NCEL. The following agencies and projects made essential contributions to the total success of this project:

Chemical Warfare Laboratory, Project 2.4, Radiation Shielding
Ballistic Research Laboratories, Project 3.7, Structural Instrumentation
Waterways Experiment Station, Project 3.8, Soils Survey
Lookout Mountain Laboratory, Project 9.1, Photography
Lovelace Foundation, Project 33.2, Missile Traps, Project 33.5, Dust Investigation.

CONTENTS

FIGURES

TABLES

Chapter 1
INTRODUCTION

1.1 OBJECTIVES

The general purpose of this project was to obtain the necessary information from which to develop criteria for the economical and practical selection of standard, commercially available conduit sections for use as shelters to protect personnel from the effects of air blast and nuclear radiation.

The specific objectives were: (1) to make an empirical determination of the degree of protection to personnel afforded by steel and concrete conduits at various depths of burial, when loaded in the high pressure region; (2) to assure that Department of Defense (DOD) Classes I and II protection (100 psi and 50 psi, respectively) are afforded by the use of buried conduits of various configurations.

1.2 BACKGROUND

The use of standard, commercially available conduit sections, placed in relatively long lengths in a multiple-tube shelter arrangement such as indicated in Figure 1.1, is considered to be an inexpensive and adequate method of providing personnel protection at high overpressure levels (100 psi). Also, the use of commercially available conduit sections for emergency field protection had been proposed by the Bureau of Yards and Docks as a rapid and inexpensive means of providing protection at high overpressure levels.

There was little information available on the behavior of closed-end buried conduits when subjected to blast from air bursts. Corrugated-steel and precast-concrete circular pipe sections had been used as entrance passages in various semi-buried shelters in Operation Upshot-Knothole and Operation Teapot; however, no attempt had been made to record deformations in such passages. Tests of steel and concrete circular pipe sections had been conducted (Reference 1) in the lower overpressure regions (9 to 25); however, the ends of the pipe sections had not been closed, and in many cases peak internal pressures had exceeded the peak overpressures at the earth surface. Therefore, the information obtained at that time could not be used to estimate structural behavior or nuclear radiation protection afforded by closed-end buried conduit sections.

It has been indicated (Reference 2) that some of the principal ways in which the earth cover over buried structures can act include (1) changing the pattern of distribution of the forces on the structure by changing the effective shape of the structure or (2) permitting the transfer of forces around, but not through, the structure. It has also been stated (Reference 3) that when deflections become large, as in many cases of flexible structures, arching begins to be effective after the deflections have reached values corresponding to about 5 percent of the span.

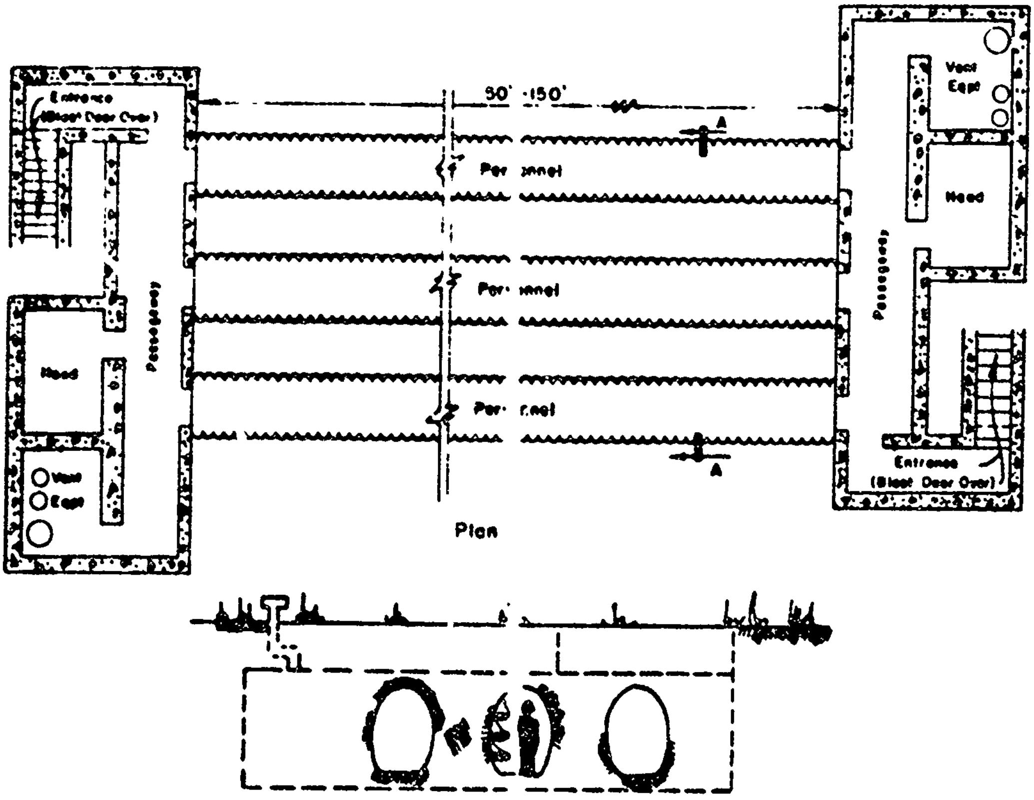
Reference 4 indicates that the design of buried structures (conduits) based on stress analysis is not possible because of the great uncertainty in the pattern of forces on the conduits. The change in shape of flexible structures and the arching action of the soil cannot be presently evaluated to permit a rational analysis for dynamic loads.

Reference 5 reports the development of empirical design theories by means of field tests over a period of years at a large number of varied installations.

For Operation Plumbbob, test sections, typical of portions of a multiple-tube (Figure 1.1), or emergency shelter, were selected by means of modified static design procedures and on the basis of standard commercially available material. The soil used for backfill consisted of a gravelly-silty-sand mixture from borrow pits, more nearly representing a typical backfill material such as may be found at continental U. S. and oversea base locations, rather than the dry-lake bed material found in Frenchman Flat.

Inasmuch as DOD Classes I and II protection assumes protection against comparable effects (thermal radiation, nuclear radiation, etc.) it was desired to obtain an index of radiation shielding afforded by conduits arranged with various depths of earth cover.

It was planned that an evaluation of the various sections for use as typical sections of personnel shelters would be made from (1) maximum and residual changes in vertical diameter, (2) residual change in horizontal diameter, (3) internal peak pressures, (4) vertical acceleration of conduits, (5) gamma and neutron-radiation levels, (6) missile and dust hazards, and (7) general examination.



Section A-A

Figure 1.1 Possible arrangement of conduits as personnel shelters.

It was anticipated that the conduits located to receive 100-psi or greater overpressure would possibly provide adequate Class I protection and that the conduits located to receive 50-psi or greater overpressure would provide Class II protection, including effects from radiations.

Chapter 2
PROCEDURE

2.1 DESCRIPTION OF CONDUITS

Twelve 20-foot long closed-end conduit sections, completely buried, with 5 to 10 feet of earth cover, were subjected to Shot Priscilla of Operation Plumbbob. They were arranged as indicated in Tables 2.1 and 2.2 and Figure 2.1. Each structure was so arranged and was of such length as to preclude the action of end restraint from interfering with its response.

To permit installation and adjustment of instrumentation after burial of test sections, access passages of fabricated corrugated-steel sections were provided as a simple, economical test configuration. These were closed with a steel plate and sandbags to prevent blast pressures from entering the conduit and to permit valid nuclear radiation measurement to be made in the actual test sections. Inasmuch as the objectives of this project include evaluation of test sections of conduits only, such an entrance was definitely not designed for operational use as a part of a shelter.

The general arrangement of the access passage (test operation purposes only) for all conduits is shown in Figure 2.2.

Both ends of each test section were provided with a closure (designed solely for the purpose of this experiment) consisting of 10-by-12 inch wood timbers assembled into a diaphragm by means of 2-by-4 inch wood members and steel angles. Strips of ½-inch thick asphaltic impregnated composition board were nailed to the wood diaphragms, on the side adjacent to the conduits, to insure a tight seal and to correct any surface irregularities. At one end of each conduit, an access passage was attached, and an opening reinforced with steel angles was provided in the wood bulkheads. Typical end bulkhead arrangements are shown in Figures 2.3 and 2.4.

A 1-inch steel plate was used as a hatch. This was covered with 4 feet of sandbags inside a 5-foot-square plywood box without top or bottom. The wood box is shown in Figure 2.5.

The bedding and backfill operations were performed in a manner typical to conventional construction practices. The backfill was carefully placed in nominally 6-inch lifts, and compacted with hand-operated pneumatic tampers and other mechanical equipment, as explained in Appendix A. In general, the backfill material used was a gravelly-silty-sand material similar to that utilized over the Operation Teapot 3.6 corrugated-metal structure (Reference 4). This backfill material, rather than the dry-lake bed material found in Frenchman Flat, was used to more nearly represent backfill material typical of continental and oversea base locations. Thus, the data obtained would be more pertinent to the proposed use of conduits as personnel shelters, and possibly more easily correlated with previous data collected on the Operation Teapot Project 3.6 structures (Reference 4).

During backfilling operations, density and water-content data were obtained by the Waterways Experiment Station (WES, Project 3.8). Also, mechanical analyses of the soil were performed by WES, and chemical and spectrographic analyses were performed by the U.S. Naval Civil Engineering Laboratory (NCEL). Analyses of the soil used, compaction data, and details of backfilling operations are included in Appendix A, Section A.3.

2.1.1 Corrugated-Steel Cattle-Pass Conduits. Conduits designated as 3.2a, 3.2b, 3.2c, 3.2f, 3.2g, 3.2k, and 3.2m in Table 2.2 consisted of curved and flat 10-gage corrugated-steel sections assembled into cattle-pass shapes, 20 feet long, arranged as indicated in Figures 2.6 and 2.7. The properties of the corrugated plate sections (Reference 6) are given in Table 2.3. Typical interior and exterior views of a test section are shown as Figures 2.8, 2.9, and 2.10.

TABLE 2.1 ARRANGEMENT OF CONDUITS AT TEST SITE, SHOT PRISCILLA

37 kt yield, 700 feet height of burst.

Station Number	Conduit	Range from Ground Zero to center of Structure	Slant Range	Angle of Sight	Topographic Coordinates		Predicted Theoretical Overpressure at Earth Surface
					North	East	
		ft	yds	deg			psi
9016.01	3.2a	970	399	36	746,889.76	715,271.52	125
9016.02	3.2f	1,040	418	34	746,819.76	715,130.58	100
9016.03	3.2c	1,040	418	34	746,868.75	715,164.33	100
9016.04	3.2b	1,040	418	34	746,915.74	715,201.66	100
9016.05	3.2g	1,150	449	31	746,525.82	714,884.17	75
9016.06	3.2m	1,360	510	27	746,686.76	714,712.71	50
9016.07	3.2k	1,360	510	27	746,957.70	714,839.35	50
9017.01	3.2e	1,040	418	34	747,003.73	715,284.11	100
9017.02	3.2j	1,150	449	31	746,677.78	714,933.14	75
9017.03	3.2l	1,360	510	27	747,007.69	714,871.34	50
9018.01	3.2d	1,040	418	34	746,961.73	715,242.36	100
9018.02	3.2h	1,150	449	31	746,602.80	714,906.06	75

TABLE 2.2 DESCRIPTION OF TEST CONDUITS

Conduit	Nominal Depth of Earth Cover	Type of Structure	Material	Size			
				Internal Width		Internal Height	
	ft			ft	in	ft	in
3.2a	7.5	Steel Cattle Pass	Corrugated Steel	5	10	7	8
3.2b	10.0	Steel Cattle Pass	Corrugated Steel	5	10	7	8
3.2c	7.5	Steel Cattle Pass	Corrugated Steel	5	10	7	8
3.2d	7.5	Steel Circular	Corrugated Steel	8	—	8	—
3.2e	7.5	Concrete Circular	Precast Concrete	8	—	8	—
3.2f	5.0	Steel Cattle Pass	Corrugated Steel	5	10	7	8
3.2g	7.5	Steel Cattle Pass	Corrugated Steel	5	10	7	8
3.2h	7.5	Steel Circular	Corrugated Steel	8	—	8	—
3.2j	7.5	Concrete Circular	Precast Concrete	8	—	8	—
3.2k	7.5	Steel Cattle Pass	Corrugated Steel	5	10	7	8
3.2l	7.5	Concrete Circular	Precast Concrete	8	—	8	—
3.2m	5.0	Steel Cattle Pass	Corrugated Steel	5	10	7	8

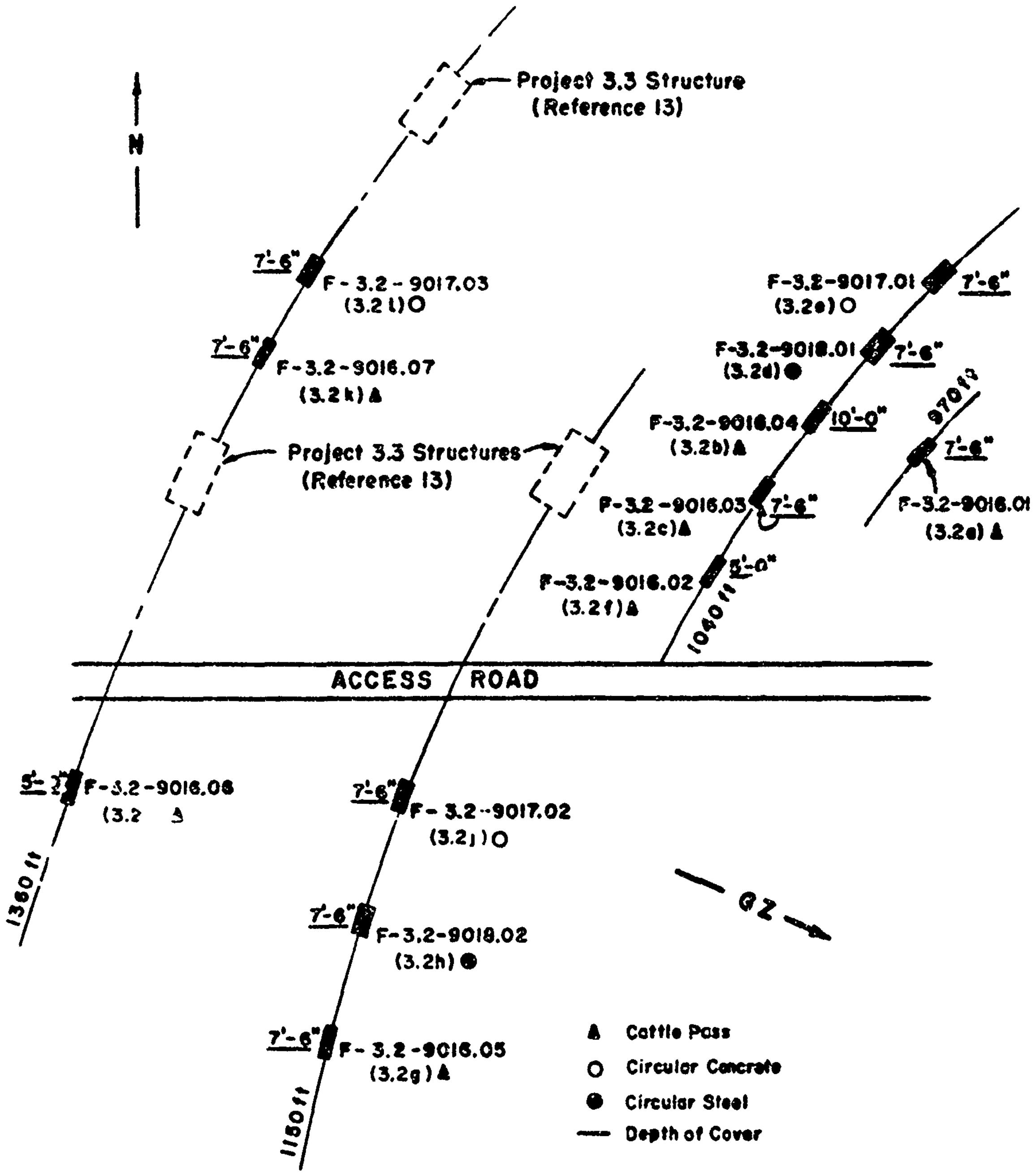


Figure 2.1 Plot plan, Project 3.2

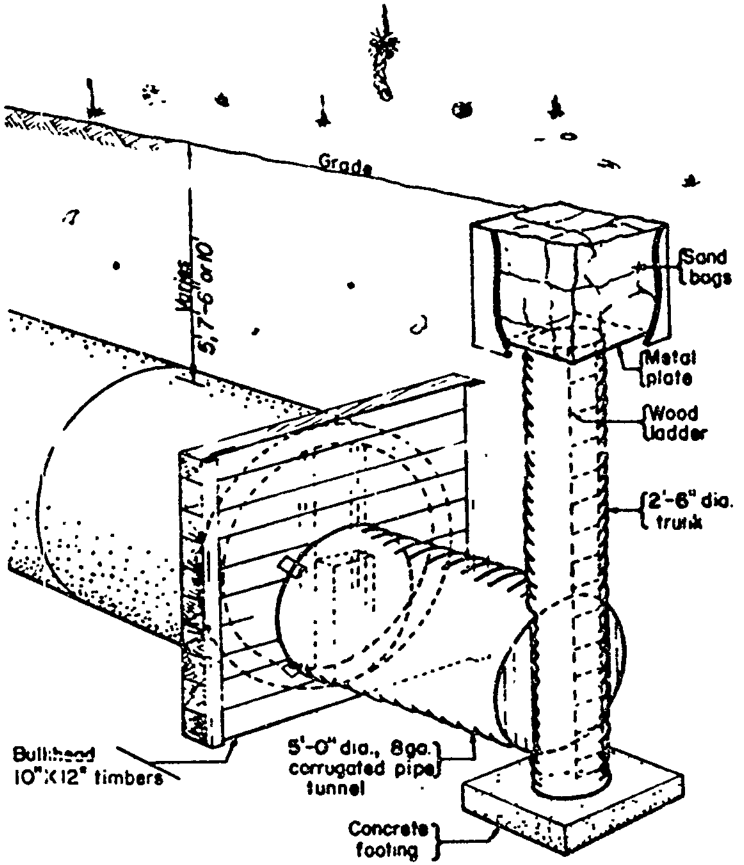


Figure 2.2 Access passage used for test operations.

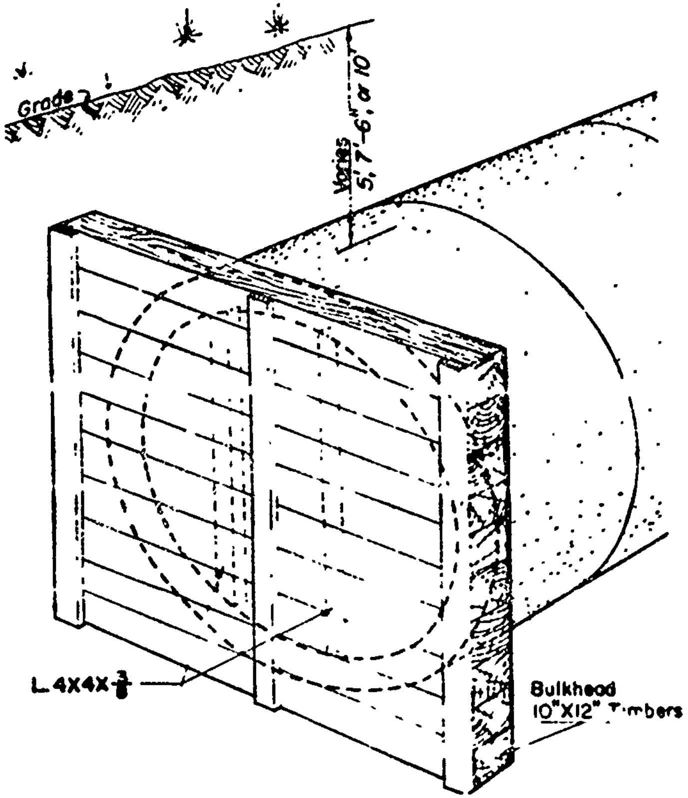


Figure 2.3 Closed-end timber bulkhead.

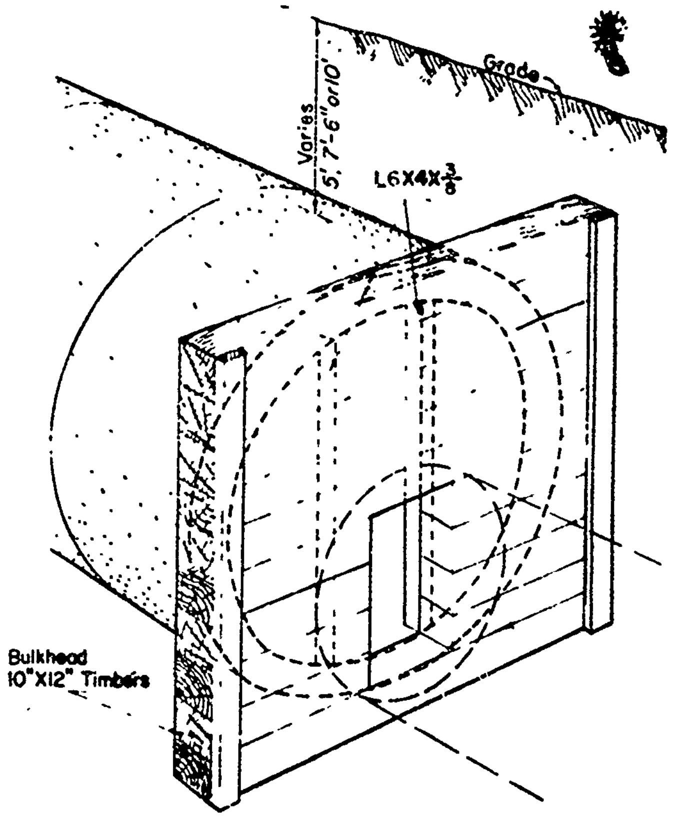


Figure 2.4 Access-end timber bulkhead.

Figure 2.5 Entrance to test conduits.

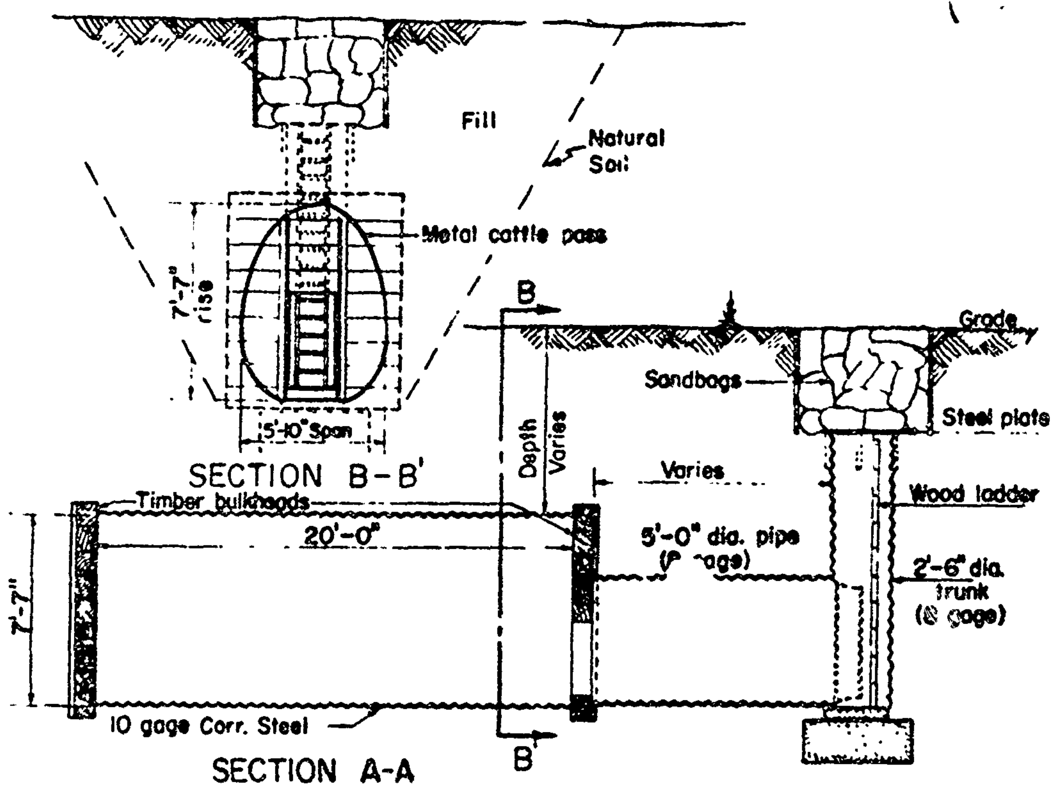


Figure 2.6 Cattle-pass test section and access passage.

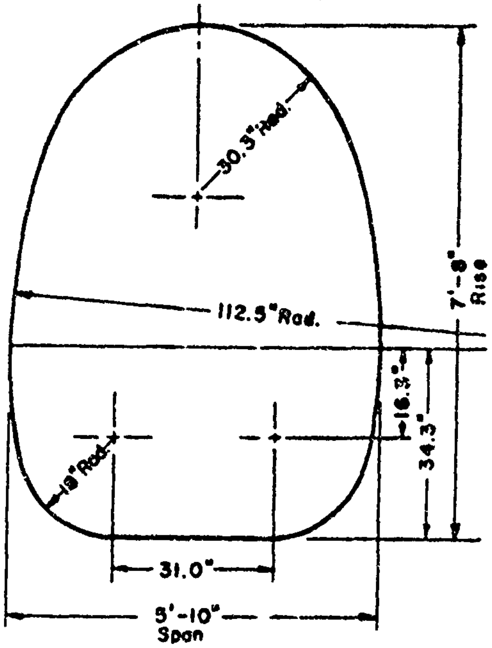
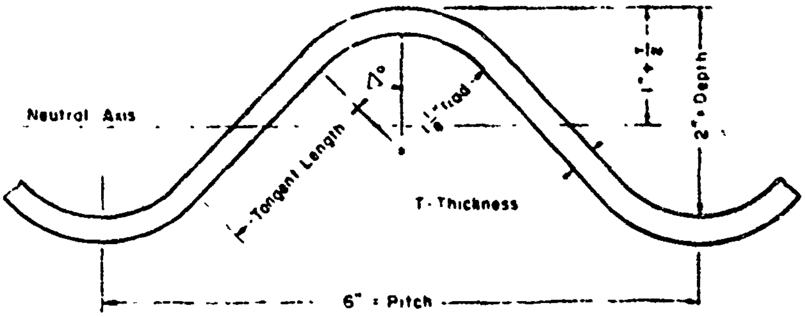


Figure 2.7 Assembled shape of cattle-pass section.

TABLE 2.3 PROPERTIES OF 10-GAGE CORRUGATED STEEL PLATE



Thickness (inch)	0.1345
Tangent Length (inch)	1.8606
Angle in Degrees and Minutes	44° 00'
Moment of Inertia (inch^4)*	0.9372
Area of Section (inch^2)*	2.003
Section Modulus (inch^3)*	0.8784
Radius of Gyration (inch)	0.684

* Per foot of horizontal length of conduit.

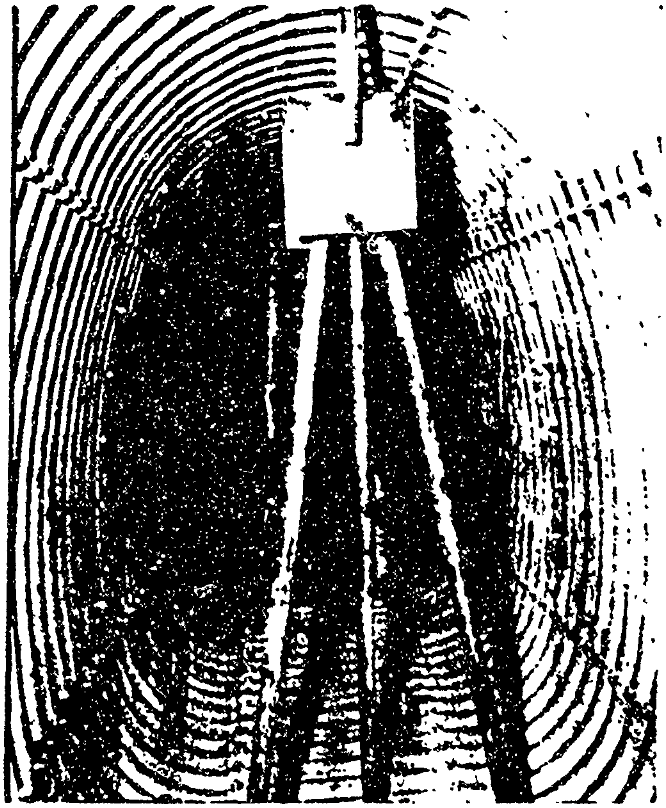


Figure 2.8 Interior view of typical cattle-pass conduit, showing scratch deflection gage at mid-length.

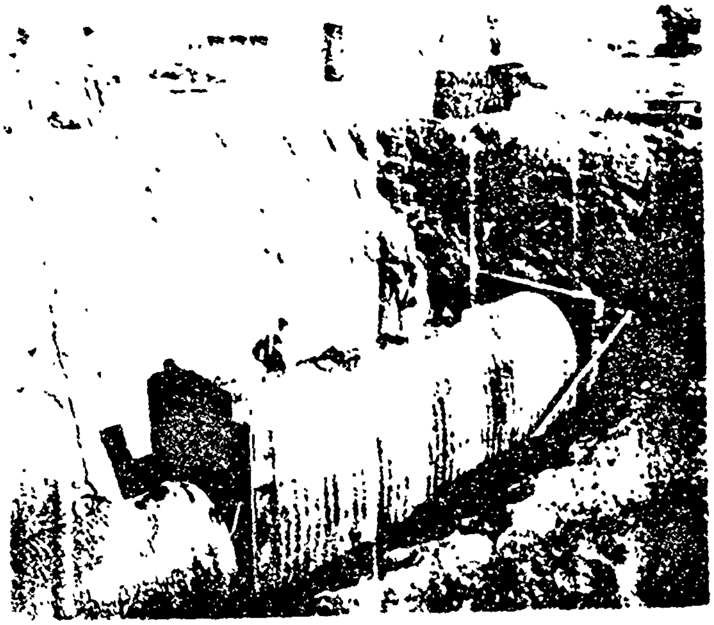


Figure 2.9 Exterior view of cattle-pass section prior to backfilling.

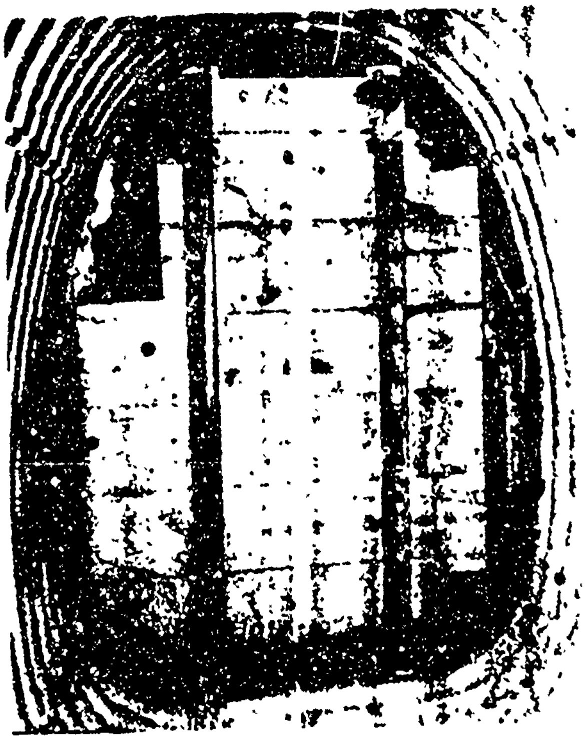


Figure 2.10 Interior view of cattle-pass section showing timber end closure.

2.1.2 Corrugated-Steel Circular Structures. Structures designated as 3.2d and 3.2h in Table 2.2 were standard 10-gage corrugated-steel sections of 8-foot diameter. The properties of the steel plate sections were identical to those given for the cattle-pass sections in Table 2.3. Each 20-foot long test section consisted of three basic plate lengths assembled as indicated in Figures 2.11, 2.12, 2.13, and 2.14.

2.1.3 Reinforced-Concrete Circular Conduits. Conduits designated as 3.2e, 3.2j, and 3.2l, in Table 2.2 were standard concrete sewer pipe (Reference 7) having the properties indicated in Table 2.4.

Each 20-foot long test section consisted of two 8-foot and one 4-foot sections grouted at the time of assembly. The conduit sections were assembled as indicated in Figures 2.15, 2.16, 2.17, and 2.18.

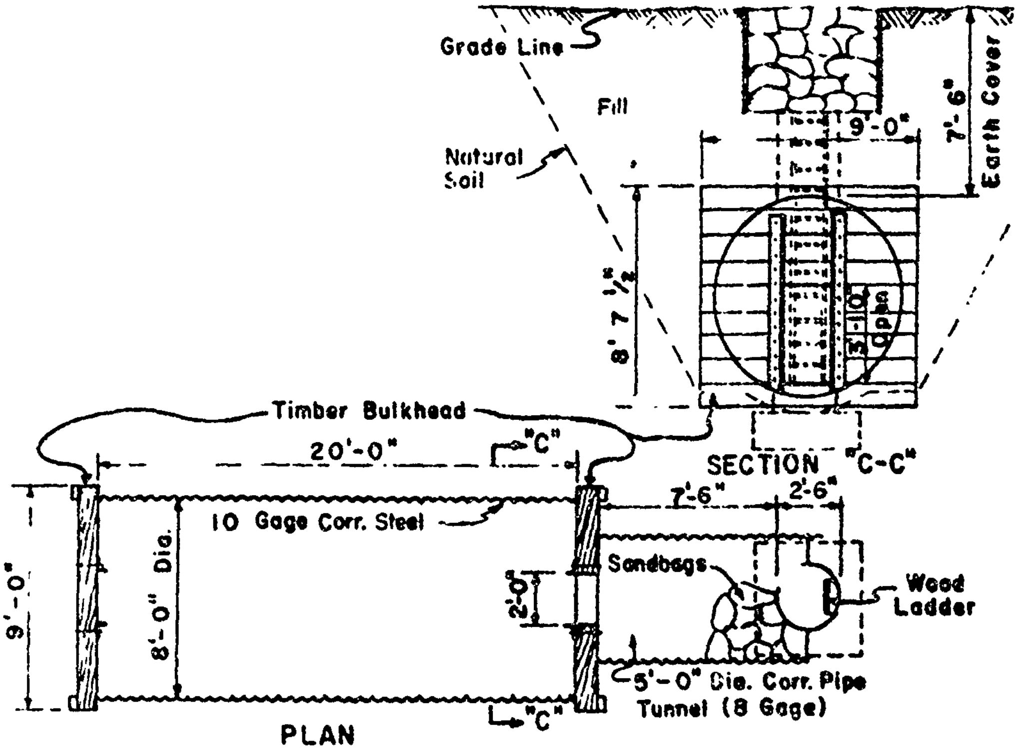


Figure 2.11 Circular steel test section and access passage.

2.2 DATA REQUIREMENTS

2.2.1 Structural Measurements. The structural instrumentation for this project consisted of instruments to measure the transient air overpressures at ground surface, peak internal pressures, peak and dynamic acceleration of bottom of conduits (all by Ballistic Research Laboratories, BRL Project 3.7) and the change in vertical diameters by NCEL. Four electronic channels were utilized for the dynamic-acceleration measurements. A summary of structural instrumentation is shown in Table 2.5. The specific locations of the instruments in the conduits are shown in Figure 2.19.

Data reliability, description of instruments, and conclusions regarding instrumentation are presented in Appendix B.

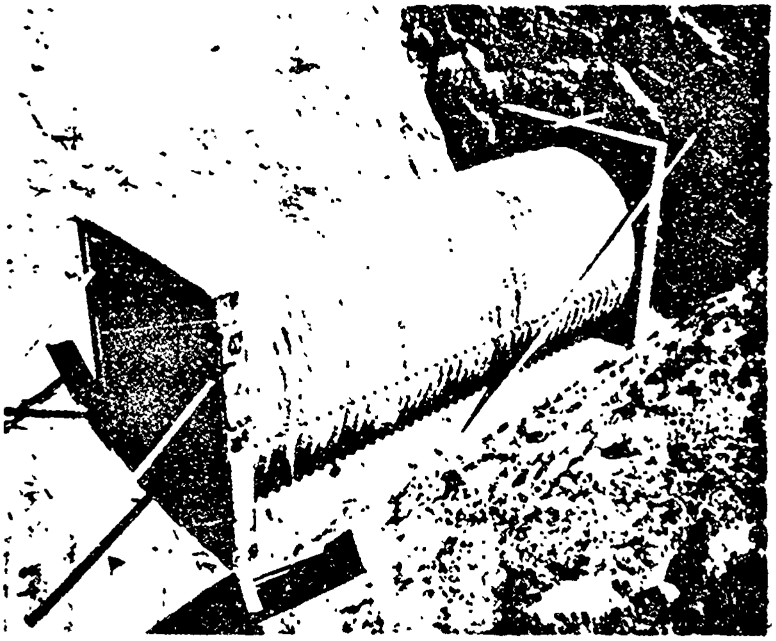


Figure 2.12 Exterior view of circular steel conduit prior to installation of access passage.

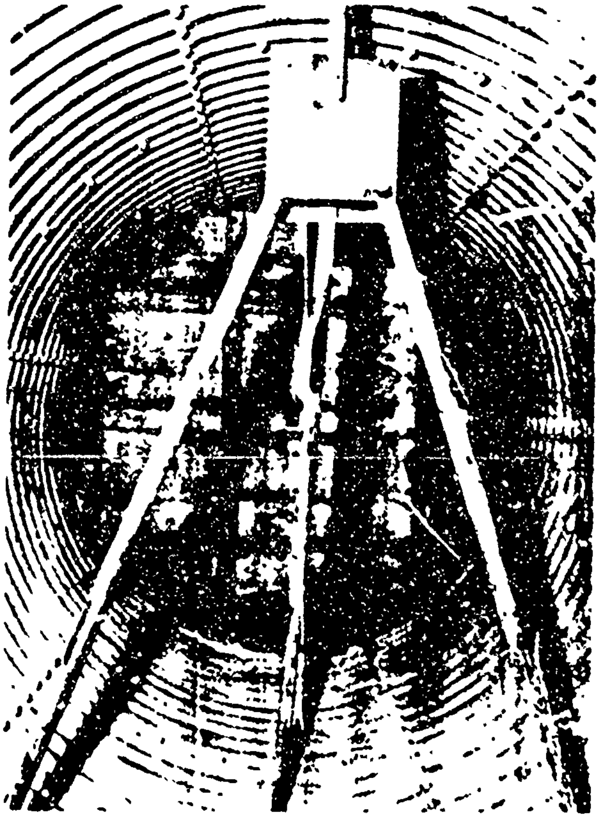


Figure 2.13 Interior view of typical circular steel conduit.

In order to aid in the evaluation of the effectiveness of test sections for use as shelters, critical dimensions were determined by surveys made approximately 18 days before the shot, 9 days after the shot, and again 113 days after the shot. Measurements included cross section shape, and absolute location below an established mark at the entrance tunnel section. The specific locations and magnitudes of such measurements are indicated in Section 3.1 and Appendix B, Section B.1. A series of preshot and postshot photographs were made to aid in evaluation of postshot conditions.

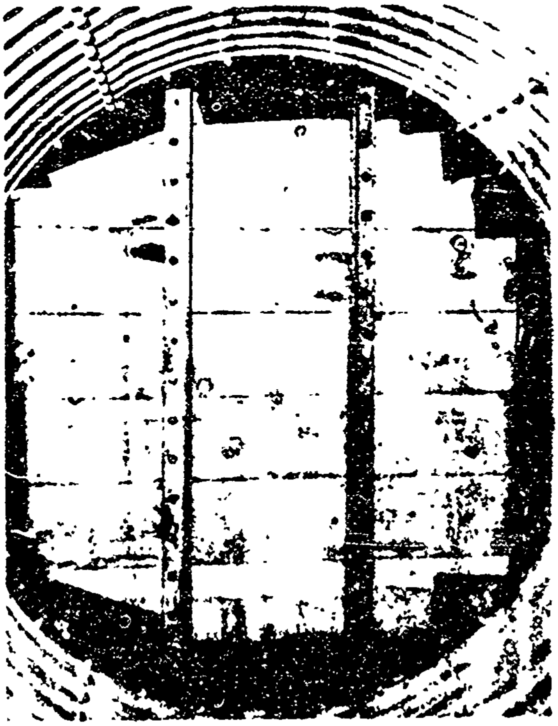


Figure 2.14 Interior view of circular steel section showing timber closure.

2.2.2 Environmental Hazards. For this test particular attention was given to those effects defined as personnel environmental hazards inside closed underground conduits, specifically: acceleration effects, internal pressure effects, missile hazards, and dust hazards (in concrete conduits).

TABLE 2.4 PROPERTIES OF CONCRETE TEST SECTION

Standard Specification	ASTM 75-55
Internal Diameter	96 inches
Shell Thickness	9 inches
Concrete Strength (minimum)	3,000 psi
Total Steel Area:	
Circumferential	2 lines totaling 0.57-inch^2 per linear foot
Elliptical	None, steel placed concentrically only

Accelerometers were mounted on the bottom of the conduits to provide acceleration measurements. Peak-pressure gages were installed inside each structure to serve not only as a

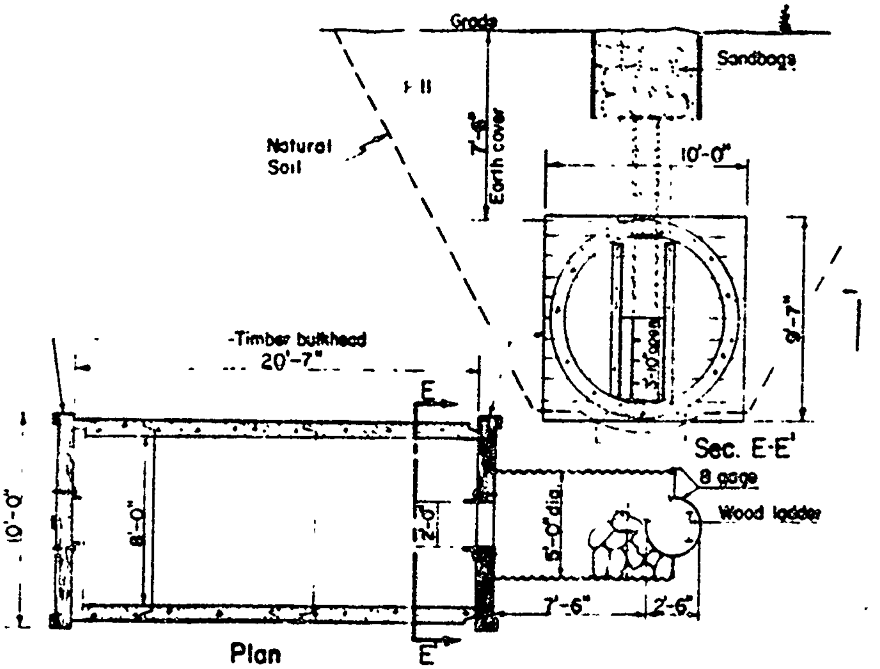


Figure 2.15 Concrete conduit section and access passage.

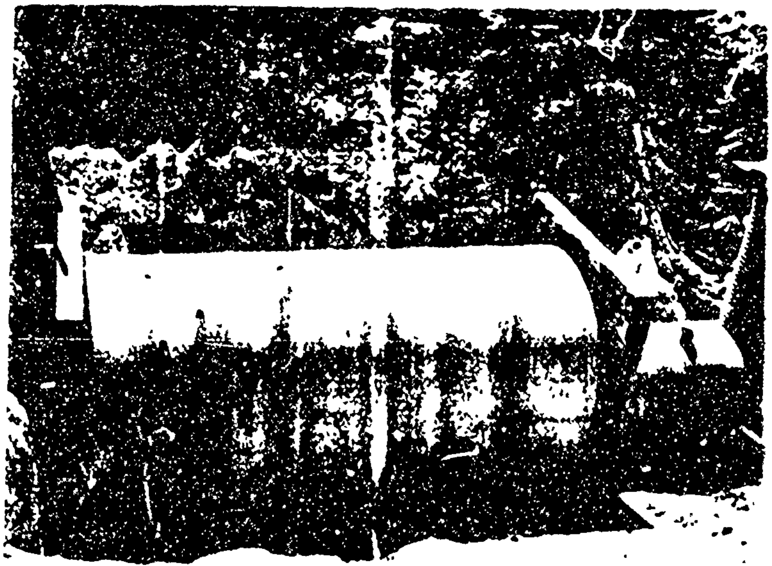


Figure 2.16 Exterior view of typical circular concrete conduit prior to backfilling.

Figure 2.17 Interior view of typical circular concrete conduit.

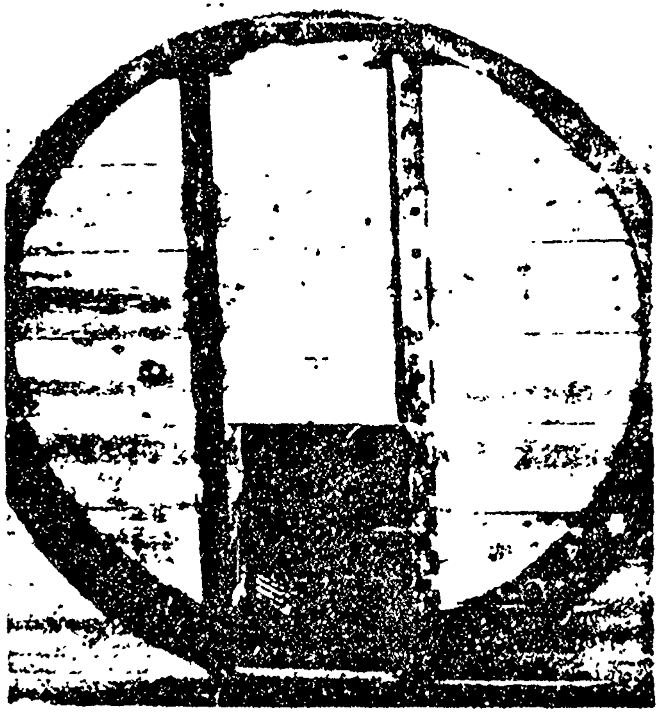


Figure 2.18 Interior view of circular conduit section showing timber closure at access end.

check for structural behavior due to leakage but also as a check for pressure hazards to personnel. Photographs served also as documentation in connection with potential missile hazards (bolts, connecting angles, etc).

Inasmuch as dust is a known environmental personnel hazard and because no data exist referable to closed underground structures subjected to shock from atomic weapons, the Lovelace Foundation (Project 33.5, Reference 8) conducted a field investigation which included three concrete conduits of this project. The objectives for this study were to (1) document the particle sizes of preshot and postshot dust and (2) differentiate, if possible, the sources of the postshot dust; whether or not particles after the detonation arose from existing dirt on the floor of conduits or actually spalled from the conduits or bulkheads as a result of the shock. Two types of dust collectors were installed in 3.2e, 3.2j, and 3.2l. Results are indicated in Section 3.2, and a detailed explanation of the dust collectors is included in Appendix B.

TABLE. 2.5 STRUCTURAL INSTRUMENTATION SCHEDULE

Number	Type	Location
12	Deflection Gages (Scratch)	One in each of 12 conduits (at top)
4	Self-recording Pressure-Time Gages (on earth surface)	Conduit 3.2a (125 psi) Conduit 3.2b-c (100 psi) Conduit 3.2h-g (75 psi) Conduit 3.2l (50 psi)
12	Peak Internal Pressure Gage	One in each of 12 conduits
12	Peak Accelerometers (Vertical Component)	One in each of 12 conduits
4	Electronic Dynamic Accelerometer (Vertical Component)	One in Conduit 3.2a (125 psi) One in Conduit 3.2f (100 psi) One in Conduit 3.2g (75 psi) One in Conduit 3.2l (50 psi)

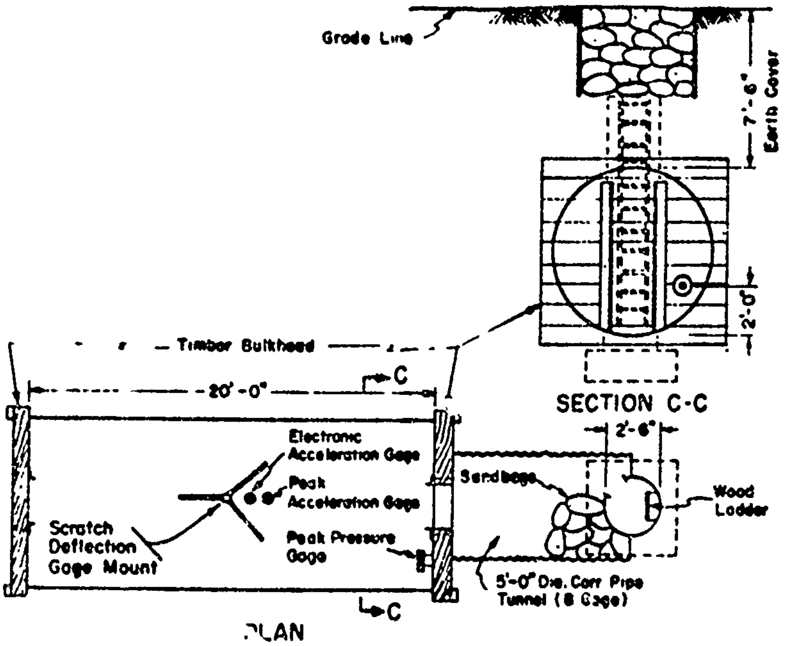


Figure 2.19 Typical gage location inside test section.

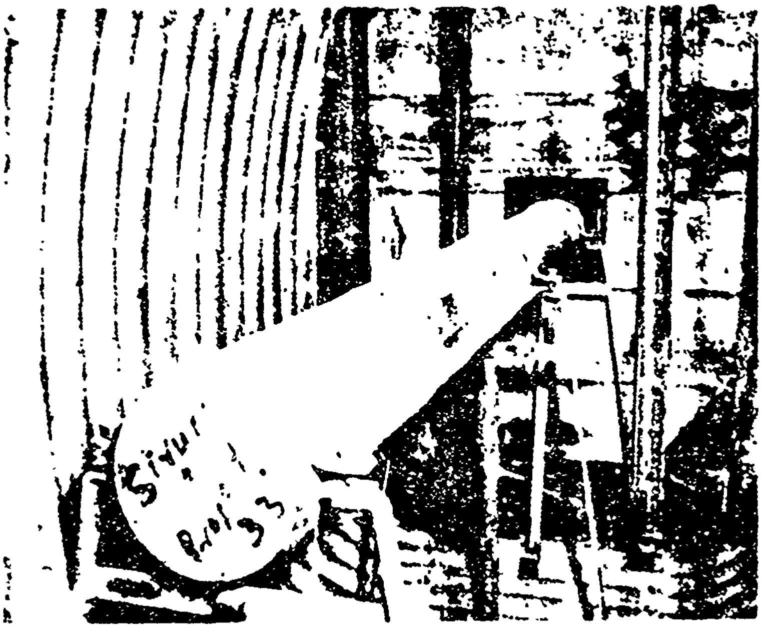


Figure 2.20 Interior view of cattle-pass section showing aluminum tube used to house neutron-threshold device.

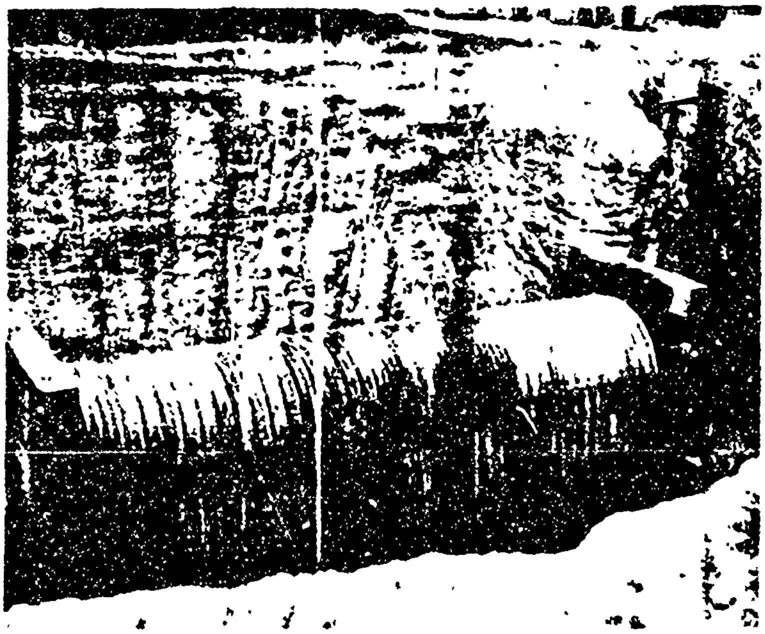


Figure 2.21 Exterior view of Conduit 3.2f prior to backfilling. Note 8-inch steel pipe used as recovery tube for neutron-threshold device.

As a part of the investigation of possible spalling effects of large missiles, missile traps were installed also in Conduits 3.2e, 3.2j, and 3.2l by the Lovelace Foundation (Project 33.2, Reference 9). Styrofoam was used as missile receivers.

Results are discussed in Section 3.2, and additional details are included in Appendix B.

2.2.3 Nuclear Radiation Instrumentation. The nuclear radiation shielding measurements were provided by the Chemical Warfare Laboratory (Project 2.4, Reference 10) and consisted of the following:

Gamma film packets	All 12 conduits
Chemical neutron dosimeters	All 12 conduits
Neutron threshold devices	Conduit 3.2f

The specific location of the nuclear radiation measuring devices within the various conduits is indicated in Section 3.3, and details of the specific measuring devices are furnished in Appendix C, Section C.2. The neutron-threshold devices, attached to a $^3/_8$-inch steel cable, rested in a 4-foot-length aluminum pipe section inside the conduit. The cable passed from the aluminum section through an 8-inch steel pipe extending from the end of the conduit, making a 45-degree turn toward the surface to approximately one foot below the ground level. The $^3/_8$-inch cable terminated in a cap covering the end of the steel pipe. To the opposite end of the cap was attached a $^3/_4$-inch steel cable, which in turn was attached to the Project 2.4 master cable. The recovery tube for the neutron-threshold measuring device was provided to permit extraction at H + 45 minutes of those particular radiation shielding measuring devices for which early time of recovery was essential. The recovery tube is shown inside the structure in Figure 2.20; an exterior view prior to backfilling is shown in Figure 2.21.

In order to completely define the shielding material, an elemental analysis of the soil used for backfill was made by NCEL and is included in the Appendix, Section A.3.1. Results of the shielding measurements of the conduits are included in Section 3.3 and the Appendix, Section C.4.

Chapter 3

RESULTS

3.1 STRUCTURAL MEASUREMENTS

Structural measurements are tabulated in Tables 3.1 and 3.2. Details of the instrumentation used are included in Appendix B.

Measured peak overpressures were somewhat greater than predicted. Overpressures were measured directly over or adjacent to only six of the conduits. The overpressures thus obtained are indicated in Table 3.1, as being applicable also to the other six conduits at the corresponding ranges from ground zero.

Recorded peak internal pressures range from 1.0 to 3.7 psi but the reliability of these data is questionable.

All recorded downward accelerations of conduit bottoms were less than 10g. The values of 8 and 5 g's at conduits 3.2a, 3.2f, and 3.2g are considered good records. The other acceleration records are questionable but fall within about the same range. In comparison, Reference 11 reports free-field peak downward accelerations of 7.0 and 4.2 g's followed by peak upward accelerations of 4.1 and 3.5 g's respectively at 10 feet below ground surface and at a range of 1,350 feet. In making such a comparison it must be remembered that a soil different from the native Frenchman Flat soil was used as backfill around the conduits. Measured durations of downward acceleration were 50, 48 and 45 milliseconds at Structures 3.2a, 3.2f, and 3.2g, respectively.

Preshot measurements of conduit dimensions were made on D−18 days and postshot measurements were made on D + 9 days and D + 113 days. Recorded conduit dimensions from the first two surveys are given in Table 3.2. Changes in conduit dimensions as indicated by the two postshot surveys are given in Table 3.1. Full scale scratch gage deflection traces are included in the Appendix, Section B.1. The fact that some of the survey measurements do not agree with corresponding scratch gage records indicates a definite experimental error in one or the other. Nevertheless, a close examination of these data reveals several interesting tendencies.

Scratch gage records indicate that the crown of two of the cattle-pass type conduits sprang back to a relative residual position higher than their initial position. The other cattle-pass conduits had residual relative vertical deflections at the crown of from 29 to 53 percent of their maximum vertical deflection. In comparison the circular concrete conduits and the circular steel conduits had residual relative vertical deflections of from 20 to 50 percent of maximum and from 57 to 67 percent of maximum, respectively.

Except for one conduit, the change in internal height of conduit as measured by a D + 9 days survey is consistently greater than indicated by the scratch gage records. No explanation is offered for this discrepancy.

The D + 9 days survey indicated that the width of the cattle-pass conduits decreased (net) during the period from D−18 days to D + 9 days. During the same period the net change in the width of the circular conduits was either an increase or zero.

The D + 113 survey indicated no significant change in conduit height.

In all flexible metal conduits there was a tendency for the circumferential dimension to reduce because of slipping of corrugated plates at the seams. In no case was a sheared bolt observed. The cattle-pass sections in general appeared to experience greater slippage than the circular sections. The slippage of any one joint was not greater than $\frac{1}{4}$ inch.

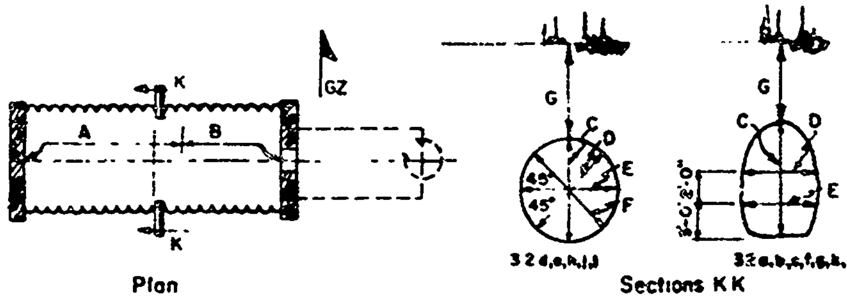
TABLE 3.1 STRUCTURAL MEASUREMENTS

+ = upward deflection, or increase in height or width. − = downward deflection, or reduction in height or width.

Conduit	Station Number	Nominal Depth of Earth Cover	Peak Over-pressure at Earth Surface	Positive Duration of Pressure Pulse	Peak Internal Pressure	Peak Downward Acceleration of Bottom Conduit	Maximum Vertical Deflection from Scratch Gages	Residual Vertical Deflection from Scratch Gages	Change in Internal Height from D + 9 Days Survey	Change in Internal Height from D + 113 Days Survey	Change in Internal Width from D + 9 Days Survey	Gross Movement of Conduit Bottom Relative to Reference Point from D + 9 Days Survey
		ft	psi	sec	psi	g	in	in	in	in	in	in
3.2a †	9016.01	7.5	140	0.232	3.7	8.0	−18/16*	−6/16	−16/16	−20/16	−7/16	−5/8
3.2b †	9016.04	10.0	136	0.206	no record	< 8	−17/16	−9/16	−19/16	−12/16	−5/16	+7/8
3.2c †	9016.03	7.5	126	0.206	2.0	< 5	−14/16*	−4/16	−3/16	−2/16	−9/16	−1 1/2
3.2d ‡	9018.01	7.5	140	—	3.0	no record	−14/16*	−9/16	−20/16	−10/16	0	−3/8
3.2e §	9017.01	7.5	126	—	3.0	< 5	−10/16	−5/16	−20/16	−20/16	+9/16	−1 1/2
3.2f †	9016.02	5.0	136	—	3.0	5.0	−13/16	−9/16	−10/16	−10/16	−6/16	+1/8
3.2g †	9016.05	7.5	100	0.333	2.0	5.0	−10/16	−3/16	−4/16	−4/16	0	−3/4
3.2h ‡	9018.02	7.5	100	0.333	1.3	< 5	−14/16	−9/16	−10/16	−10/16	+4/16	0
3.2j §	9017.03	7.5	100	—	3.0	< 5	−3/16	−3/16	−12/16	−12/16	0	−1 1/4
3.2k †	9016.07	7.5	60	—	1.0	< 10	−6/16	+1/16	−2/16	−2/16	−3/16	−1
3.2l §	9017.03	7.5	60	0.361	2.5	< 10	−5/16	−1/16	−10/16	−12/16	+2/16	−1 1/8
3.2m †	9016.06	5.0	60	—	1.7	< 5	−6/16	−1/16	−14/16	−2/16	−1/16	−1 1/4

*Incomplete record, see Appendix B. † Type: Steel cattle pass. ‡ Type: Steel circular. § Type: Concrete circular.

TABLE 3.2 SURVEY MEASUREMENTS



Conduit	Time*	Dimensions						
		A	B	C	D	E	F	G
		ft. & in.	ft. & in.	in.	in.	in.	in.	ft. & in.
3.2a	Pre	11 7⅝	8 8⅝	92⅞	63⅝	68⅞	—	6 10⅜
	Post	11 7⅜	8 8⅝	91⅞	63⅛	68½	—	7 0⅜
3.2b	Pre	11 8	8 8¼	92⅝	63¼	68⅜	—	9 9⅞
	Post	11 7¾	8 8⅜	92	62¾	68½	—	9 9¼
3.2c	Pre	11 1⅞	9 2⅛	92⅜	63⅜	69½	—	7 3⅝
	Post	11 2⅛	9 1⅞	92¼	63	69⅛	—	7 8⅝
3.2d	Pre	11 8¼	8 8½	95⅜	96⅝	96¼	95⅛	7 7¾
	Post	11 7⅞	8 8⅞	95¼	96⅝	96¼	95	7 7⅝
3.2e	Pre	9 0⅝	11 5⅜	96	96⅜	96	96¼	7 8
	Post	9 0¾	11 4⅞	96¼	96½	96½	96½	7 6⅝
3.2f	Pre	11 8	8 8⅜	92⅝	63⅜	69	—	4 10⅛
	Post	11 7⅞	8 8⅜	92	63¼	68⅝	—	4 11⅝
3.2g	Pre	10 1¼	10 2⅜	92⅜	63¼	69½	—	7 3⅝
	Post	10 1⅝	10 2⅛	92⅞	63¼	69½	—	7 3⅝
3.2h	Pre	11 8¼	8 8	96½	95½	94½	96½	7 2⅜
	Post	11 8	8 8	95⅞	95¼	94¾	96¼	6 8
3.2j	Pre	9 1¼	11 4½	96⅜	96	96⅜	96¼	7 4¼
	Post	9 1⅛	11 4½	96⅛	96	96⅜	96½	7 3⅜
3.2k	Pre	11 7⅝	8 8⅝	92⅛	63⅝	69¼	—	6 11⅛
	Post	11 7¾	8 8¼	92	63½	69½	—	7 2⅜
3.2l	Pre	9 1⅛	11 4⅝	96	96	96¼	96	7 2
	Post	9 1	11 4¾	95⅞	96	96⅜	96	7 5¼
3.2m	Pre	11 8⅜	8 7⅝	92⅝	63⅜	69¾	—	4 10½
	Post	11 8¼	8 7¾	92½	63¼	69¾	—	4 6⅞

* Preshot measurements on D – 18; Postshot measurements on D + 9.

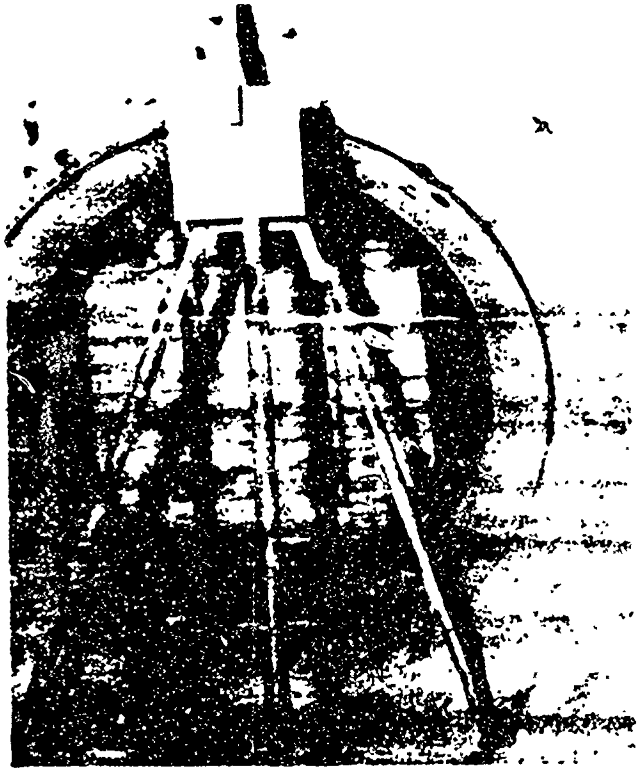


Figure 3.1 Interior view of concrete Conduit 3.2e, preshot.

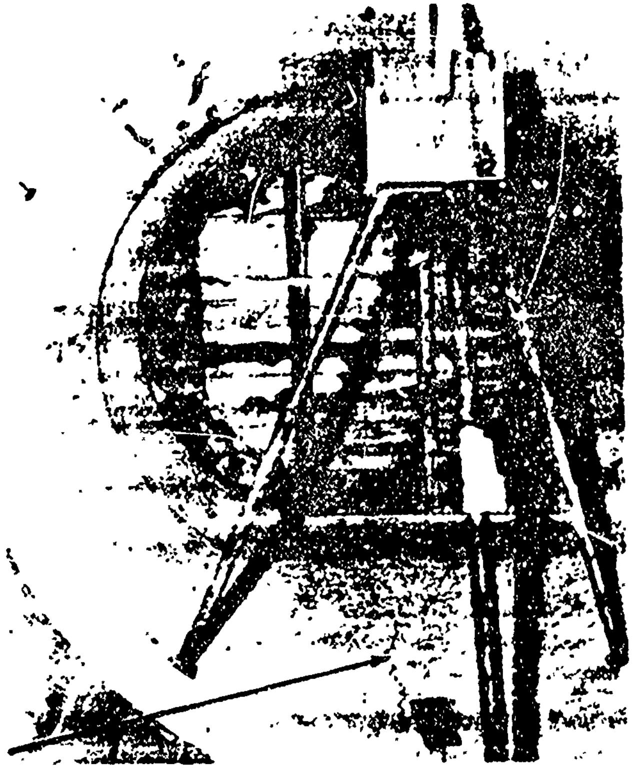


Figure 3.2 Interior view of concrete Conduit 3.2e, postshot. Note 1/4-inch tension crack at bottom of conduit.

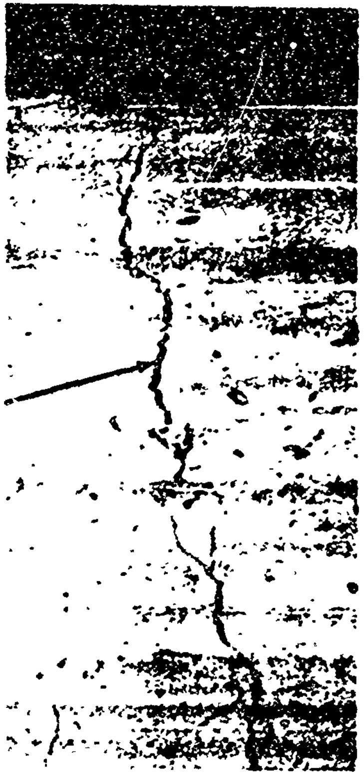


Figure 3.3 Close-up of $^1/_4$-inch crack in bottom of Conduit 3.2e, postshot.

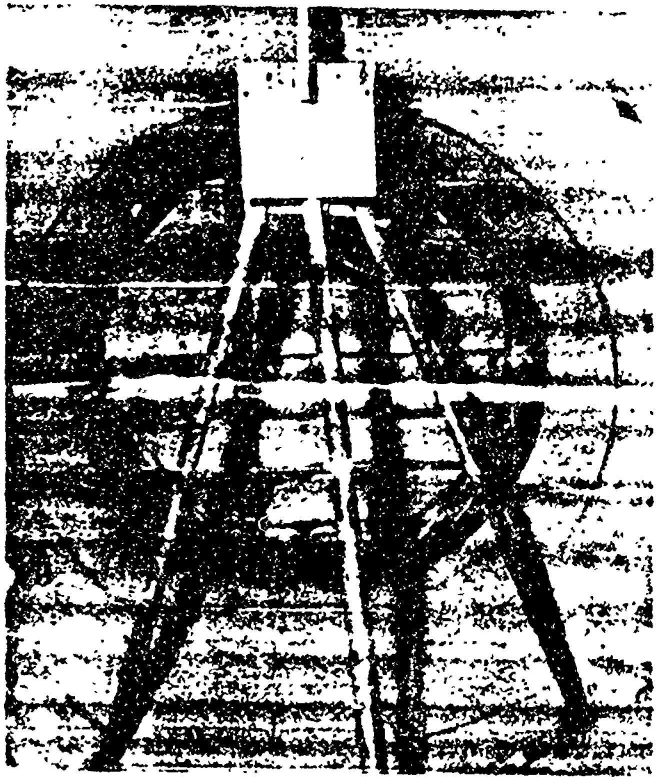


Figure 3.4 Interior view of concrete Conduit 3.2j, postshot.

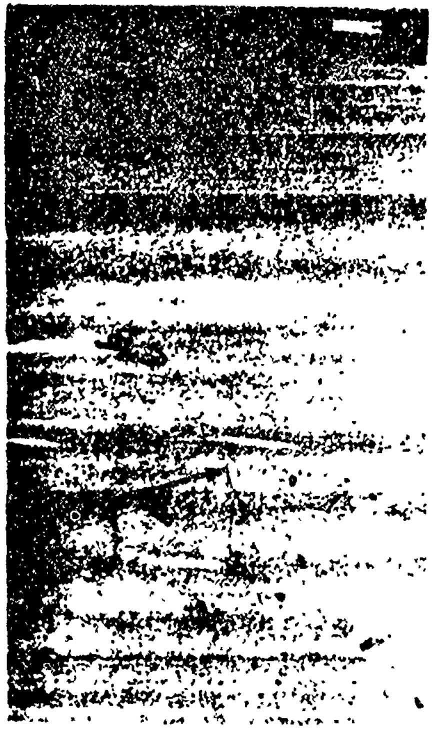
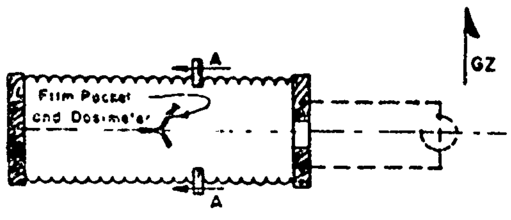


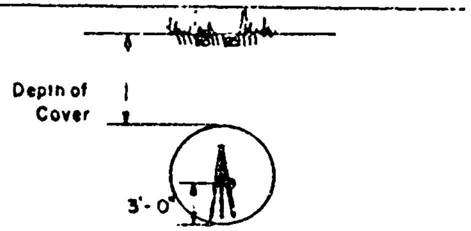
Figure 3.5 Close-up of $^1/_{32}$-inch crack in bottom of Conduit 3.2j, postshot.

NOT REPRODUCIBLE

TABLE 3.3 NUCLEAR RADIATION MEASUREMENTS



Plan



Section AA

Conduit	Depth of Earth Cover	Free Field Measurements		Measurements Inside Conduits			
		Gamma Dose	Neutron Dose	Gamma Dose		Neutron Dose	
				Film Packet	Chemical Dosimeter	Foil Method	Chemical Dosimeter
	feet	r	rep	r	r	rep	rep
3.2a	7.5	2.35×10^5	1.42×10^5	0.2	<5	N.I.†	<10
3.2b	10.0	1.89×10^5	1.62×10^5	0	<5	N.I.†	<10
3.2c	7.5	1.89×10^5	1.62×10^5	0	<5	N.I.†	<10
3.2d	7.5	1.89×10^5	1.62×10^5	0	<5	N.I.†	<10
3.2e	7.5	1.89×10^5	1.62×10^5	0	<5	N.I.†	<10
3.2f	5.0	1.89×10^5	1.62×10^5	7.7	<5	<25	<10
3.2g	7.5	1.35×10^5	1.24×10^5	0	<50‡	N.I.†	<50‡
3.2h	7.5	1.35×10^5	1.24×10^5	0	<5	N.I.†	<10
3.2j	7.5	1.35×10^5	1.24×10^5	0	<5	N.I.†	<10
3.2k	7.5	1.02×10^5	7.65×10^4	0	<5	N.I.†	<10
3.2l	7.5	1.02×10^5	7.65×10^4	0	<5	N.I.†	<10
3.2m	5.0	1.02×10^5	7.65×10^4	1.3	<5	N.I.†	<10

† Not instrumented.

‡ High ranges dosimeter accidently installed.

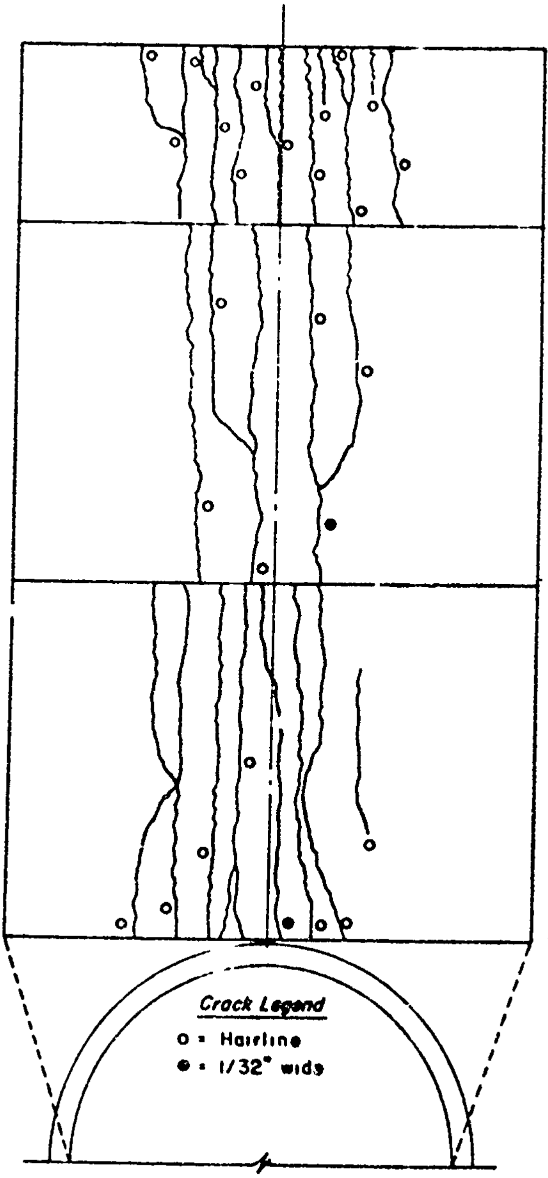


Figure 3.6 Crack survey of top half, developed; concrete Conduit 3.2e.

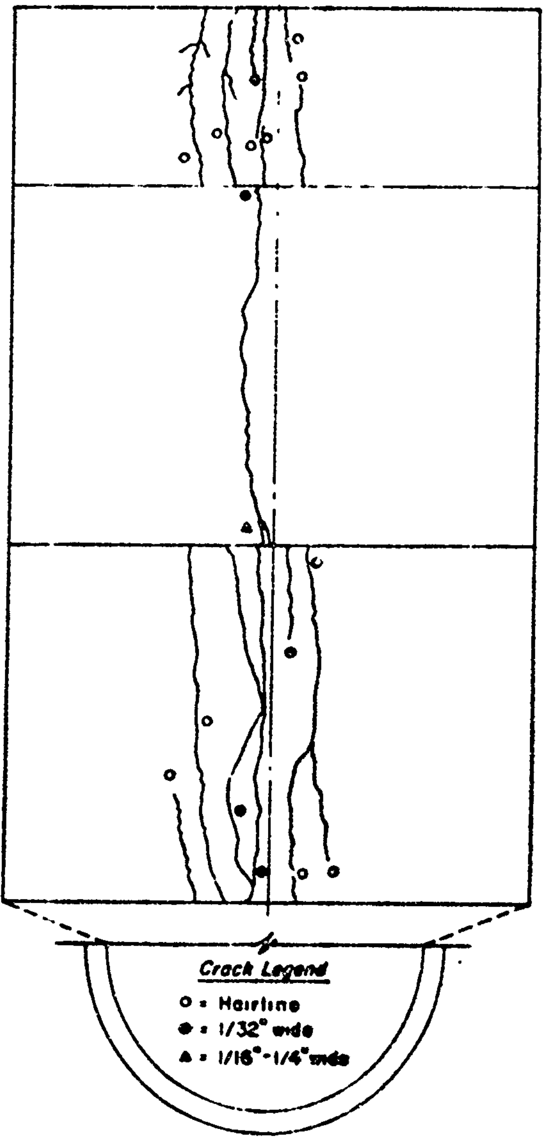


Figure 3.7 Crack survey of bottom half, developed; concrete Conduit 3.2e.

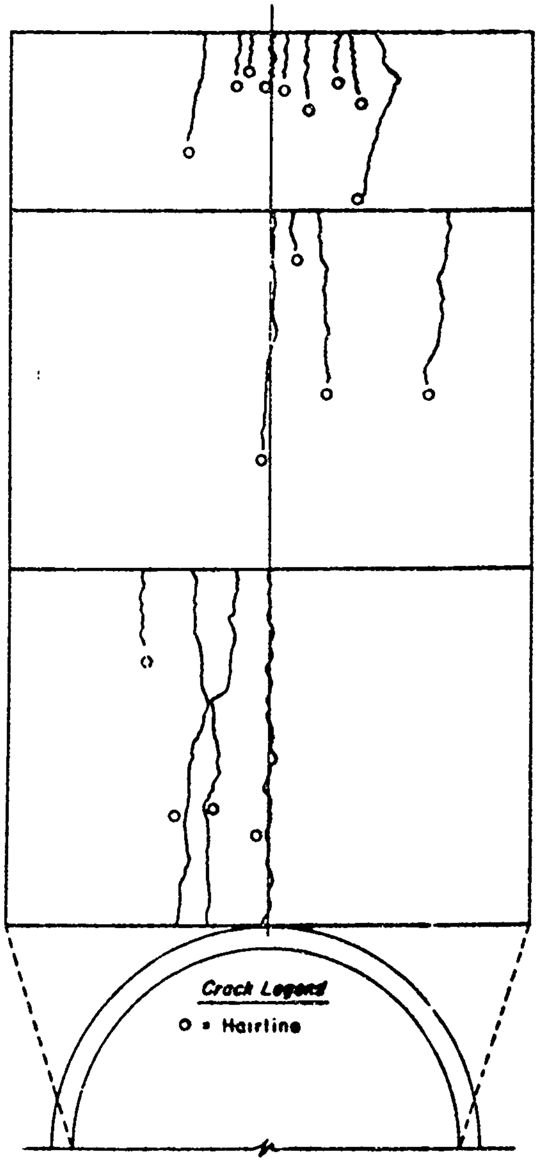


Figure 3.8 Crack survey of top half, developed; concrete Conduit 3.2j.

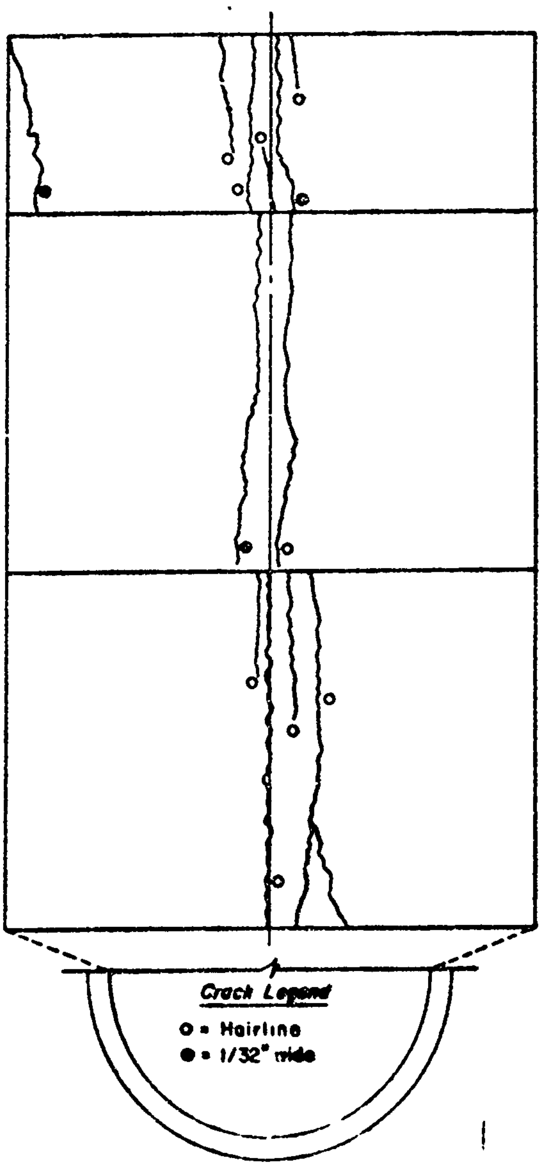


Figure 3.9 Crack survey of bottom half, developed; concrete conduit 3.2j.

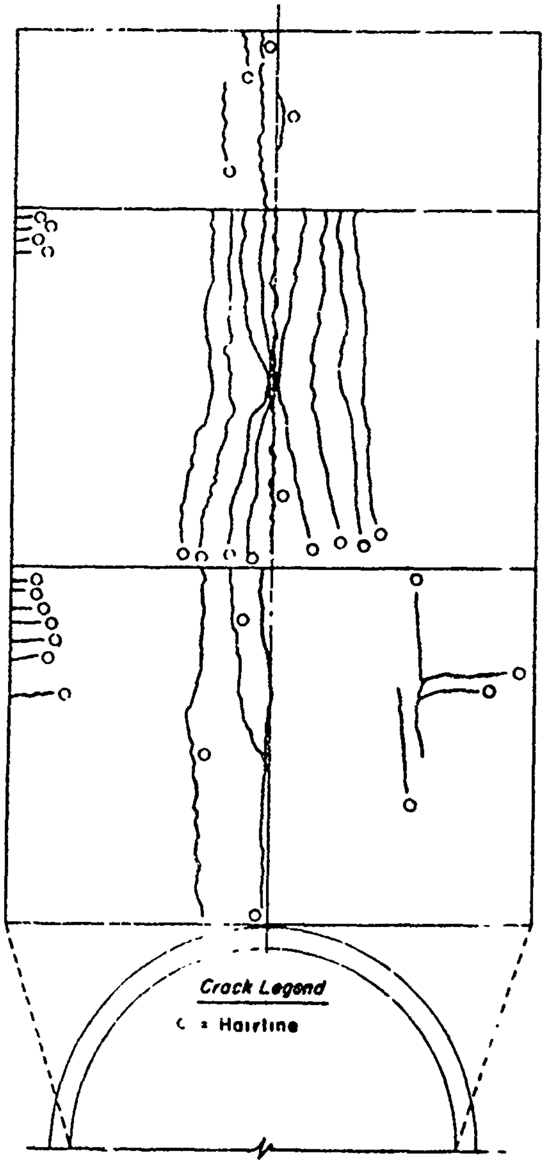


Figure 3.10 Crack survey of top half, developed; concrete Conduit 3.21.

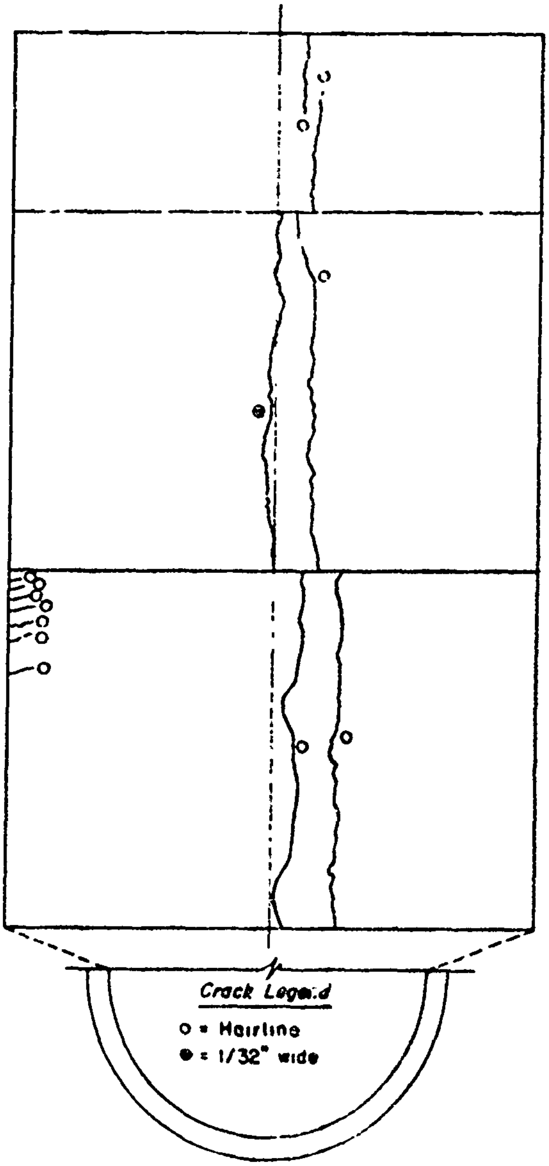


Figure 3.11 Crack survey of bottom half, developed; concrete Conduit 3.21.

Preshot and postshot photographs of the interior of two of the concrete conduits are shown in Figures 3.1 through 3.5. Significant cracks occurred in one concrete conduit (3.2e). The cracking in the other two concrete sections was barely noticeable and is hardly detectable on photographs, consequently crack pattern drawings for all concrete conduits are included in the form of developed sections as Figures 3.6 through 3.11.

The entrances to all test sections and all timber bulkheads were in excellent postshot condition.

3.2 ENVIRONMENTAL HAZARDS

A small amount of dust and wood splinters accumulated on the fallout trays and microscopic slides placed in the concrete conduits. No missiles, such as spalled concrete or mortar, were observed in any of the missile traps placed inside the concrete conduits. The dust and wood splinter samples obtained will be analyzed and significant findings will be reported in the Operation Plumbbob Project 33.5 final report.

Those structural measurements which contribute to environmental hazards (accelerations and internal pressures) are presented in Section 3.1.

3.3 RADIATION MEASUREMENTS

On this project, neither direct thermal radiation nor nuclear radiation from fallout were of significance, consequently, the radiation of interest consisted of initial gamma and neutron radiation. Results are presented in detail in Appendix C. The gamma and neutron doses are summarized in Table 3.3. Free-field neutron-flux data are included in Reference 12.

Chapter 4
DISCUSSION

Complete scratch deflection records were obtained in nine conduits, partial scratch deflection records were obtained in three conduits, and eleven of a total of twelve internal-pressure gages recorded. All dynamic accelerometers functioned, however, self-recording accelerometers used as backup for electronic measurements produced somewhat questionable values.

It was not possible to recover the neutron threshold device from Conduits 3.2C at D+45 minutes as planned; however, radiation measurements from a chemical dosimeter in this conduit provided a valid reading. The neutron-threshold device was lodged in the recovery tube because of excess sand entering the capped end of the tube. An identical recovery-tube arrangement, however, worked very satisfactorily in adjacent structures of Operation Plumbbob Project 3.3 (Reference 13).

Photographs and survey measurements provided sufficient documentation of general postshot condition and residual deformation of the conduits respectively.

4.1 STRUCTURAL ADEQUACY OF CONDUITS

The structural measurements have been presented in Chapter 3. The criterion for structural adequacy in this case is that the structure maintain its general form and stability, that is, that the structure does not collapse, and that deflections are not great enough to preclude the successful performance of the structure as a protective shelter. None of the conduits collapsed and maximum changes in conduit height were about one inch. Thus, the test results indicate the structural suitability of the conduits for use as personnel shelters, if used under conditions identical to those of this test.

If present knowledge will permit, it is very desirable to make general conclusions that are applicable to other conditions. To do this, it is necessary to have an understanding of the reaction of the various soils to air-blast loading, the reaction of the structure to the resultant soil loading, and the interaction of the structure response and the soil reaction. The remaining paragraphs of this section discuss this in more detail.

4.1.1 Loads Acting. An air-blast load induces a ground shock wave which is propagated through the soil to the structure. This ground shock wave interacts with the buried structure causing the structure to deform. The deformation of the structure has a major effect on the contact pressure at the soil-structure interface.

For this test, measured free-field overpressures ranged from 60 to 149 psi and durations were from 206 to 361 msec. The air pressure wave form was characterized by a sharp rise of pressure to a first low peak followed by a plateau or a slight decay, then a second much-higher peak, followed by a decay to zero pressure (Reference 14). The time interval between initial arrival of the air blast and peak overpressure was of the order of 50 to 100 msec. Thus, the loads acting at the ground surface are known to test accuracy but the earth stresses acting on the structures were not measured and are not known.

If a semi-infinite homogeneous elastic medium is subjected to an air blast, the maximum vertical stress at any depth is the same as the applied air blast, the vertical strain is proportional to the stress, and the instantaneous particle velocity is proportional to the instantaneous stress (Reference 15). But the assumption of a truly elastic medium implies no energy loss in the transmission of a stress wave. Reference 15 states, "It is known that the dynamic stress-strain curve in earth presents a considerable hysteresis loop, representing a dissipation of energy. This loss probably results largely in the eating away of the shock front, increasing the rise time with increasing depth."

If a semi-infinite homogeneous soil mass is subjected to a step function load of infinite duration, the ultimate vertical stress at any depth is the same as the applied load. But, as stated by Reference 16, "In the real case, the finite velocity and duration of the blast wave cause an attenuation of peak stress with depth. This attenuation is obviously a function of duration and should be less with longer durations, but the nature and magnitude of this function are not evident from presently available data. The peaked form of the input also permits reflections from layers of different acoustic impedance to effect the shape and magnitude of the stress wave".

We know from atomic field tests that for relatively short duration blasts over silty Frenchman Flat soil, there is some attenuation of free-field peak acceleration with increases in soil depth (References 11 and 15). For the same conditions other investigators have observed an attenuation with depth of pressure acting on a buried stress gage or structure (References 3, 17, 18, and 19). The amount of reduction of pressure depends on the flexibility of the structure (References 3 and 19).

The field test data do not agree as to the rate of attenuation with depth, particularly in the first few feet. Measurements made by Operation Upshot-Knothole Project 1.4 (Reference 17), using Carlson-Wiancko earth stress gages at 1-, 5-, and 15-foot depths, suggest a logarithmic or an inverse power attenuation of vertical earth stress as a function of depth. Some 1- and 5-foot deep gages indicated an apparent earth stress greater than the surface air overpressure. But, according to Reference 17, the near surface data was erratic and less dependable than the data from the 15-foot deep gages. In contrast, measurements made by Operation Plumbbob Project 1.7 (Reference 19), using a calibrated 2-foot diameter diaphragm as a gage, suggest that the rate of stress attenuation is greatest in the first few feet below ground surface.

For quite different conditions at Eniwetok Proving Ground (EPG) the observed results were somewhat different. The two EPG detonations were at the ground surface; one produced a relatively long duration blast, the other a relatively short duration blast; and the soil at EPG is predominately coral sand with the water table only a few feet below ground surface.

Free-field data taken at EPG indicates greater attenuation with depth of local air-induced acceleration than at NTS (Reference 16). The same investigators observed that air-induced ground shock waves were refracted through the earth, from remote locations nearer ground zero, to contribute significantly to earth acceleration readings. Beyond a certain range the earth transmitted wave front outran the air blast wave, thus masking locally air-induced effects.

Preliminary data obtained by another project prompted the following conclusions quoted from Reference 20: "The data suggests that there exists a considerable effect of structure flexibility on the pressures on structures buried both above and below the water table in this soil." and, "The data also suggests that a large-magnitude surface burst can produce very-large horizontal water-transmitted pressures, which will be greater than the air-induced pressures below the water table."

Operation Hardtack Project 3.2 tested two earth covered 25-foot span corrugated steel 180-degree arch structures, one subjected to 90-psi overpressure from a kiloton-range detonation and the other subjected to 78-psi from a megaton-range detonation. Reference 21 reports "Since the two arch shells were identical and the confining earthworks were almost identical, the fact that Structure 3.2b suffered complete collapse at 78 psi (long-duration loading), and Structure 3.2a sustained extensive localized damage without complete collapse at 90 psi (short-duration loading) is significant."

With the exception of References 3 and 17 the references cited above are preliminary test reports subject to further analysis, development, and possible revision. These preliminary reports do, however, point out some of the many variables that may effect the air-induced ground load acting on a buried structure, for certain limited test conditions. But a quantitative understanding of the effect of all significant variables is required before the test data can be used to predict pressures resulting under other conditions.

4.1.2 Response of Structures. A buried conduit type structure has a certain inherent strength due to its form and material characteristics. But if it is a relatively flexible structure as were the steel conduits tested, it must depend on the surrounding soil for a large part of its strength. Reinforced concrete circular conduits are relatively less flexible than steel conduits and therefore depend upon the surrounding soil to a lesser degree.

A buried circular flexible conduit subjected to blast load tends first to deform into an elliptical shape. Both the passive earth pressure and the air-blast induced ground pressure resist this deformation. It is possible for higher forms of deflection with more stress reversals to take place, depending upon the loading, the characteristics of the structure, and the deformation characteristics of the surrounding soil. Scratch-gage records indicate a maximum transient reduction in internal height of the circular steel conduit of 0.8 and 0.9 percent. Survey measurements indicate that this type conduit became more elliptical shaped during the period from D-18 days to D+9 days. Some of the change in vertical dimension is no doubt due to joint slippage.

Scratch-gage records indicate a maximum transient reduction in internal height of the circular concrete conduits of 0.3 and 0.6 percent. Survey measurements indicate that this type conduit also became more elliptical shaped during the period from D-18 days to D+9 days. Note that the peak transient reduction in height is somewhat less than that for the circular steel conduits. But an examination of the survey data given in Table 3.1 will show changes in shape of the concrete conduit as great as those for the steel conduit. It is reasonable to believe that the concrete conduits tested gained some strength from the passive soil resistance although it was probably considerably less than did the more flexible steel conduits.

Scratch-gage records indicate maximum transient reductions in internal height of the steel cattle-pass type structure of from 0.3 to 1.1 percent. Survey data indicates a decrease in width of this type conduit during the period from D-18 days to D+9 days. This suggests the possibility that this type conduit assumed a high form of deflection shape characterized by several stress reversals around its periphery.

Unfortunately, transient measurements of change in width of any of the conduits were not taken.

4.1.3 Extrapolation of Results. Present knowledge is not sufficient to permit direct extrapolation of these test data to other conditions. The loads acting on the ground surface during the test are known to a reasonable accuracy. But the loads acting at the soil-structure interface are definitely not know. Since a gravelly-silty-sand material, rather than the natural Frenchman Flat soil, was used for backfill, the attenuation data obtained by other Operation Plumbbob projects is not valid for this project. References 16, 20, and 21 indicate some of the great differences in loading and response to be expected for conditions differing from those existing during Operation Plumbbob.

4.2 INTERNAL ENVIRONMENT CONSIDERATIONS

4.2.1 Acceleration. Peak downward accelerations of 5g and 8g with durations of about 50 msec were measured at the conduit floor. An upward acceleration of smaller peak magnitude followed the initial downward acceleration. For different soil and detonation conditions a completely different magnitude, duration, direction, and sequence of acceleration loading is possible (Reference 16).

Reference 22 states that for human beings the tolerable limit of acceleration depends to a great extent upon the manner in which the forces arising act on the body. This reference reports studies made to determine the tolerable limits of acceleration on a human strapped into an aircraft-type seat. The investigator reports that a person so supported can tolerate 20g's deceleration of a forward moving seat for a duration of a few hundred milliseconds without injury. The same studies report that a man so supported can withstand an upward acceleration of the seat of up to about 20g s for 100 msec without injury. But it cannot be assumed that shelter occupants will be so well supported. Obviously, no general statement can be made regarding acceleration effects on personnel without considering the manner in which the resulting forces act on the personnel.

If the accelerations measured in this test are thought to be excessive for certain shelter uses, their effect could be reduced by installing the necessary shock isolation mechanisms inside the structure.

4.2.2 Pressure. Peak-pressure gages indicated overpressures of up to 3.7 psi inside the conduit sections but the reliability of these data is questionable.

Reference 23 reports that the atomic explosions in Japan during World War II resulted in "no cases of direct damage to internal organs by the blast among the survivors although there were some ruptured eardrums." This reference also states, "The air blast overpressure required to cause rupture of eardrums appears to be highly dependent upon circumstances. Several observations indicate that the minimum overpressure is in the range from 10 to 15 pounds per square inch, but both lower and higher values have been reported." Even if overpressures were as high as 3.7 psi in the test conduits, it is very unlikely that such a condition would be hazardous to personnel.

A possible explanation for the internal pressures is that they were caused by a leakage between the individual wood members of the bulkhead used. The endwalls were not intended to serve as endwalls of an actual shelter; they were included only to provide an economical end closure for the test section. An impregnated joint filler strip was used between the test sections of the conduits and the bulkheads to avoid pressure infiltration at those points. A similar impregnated joint filler was placed between the vertical entrance trunk end steel cover plate to similarly avoid pressure infiltration at these points. In any case, the internal pressures were of magnitudes such that the structural behavior was probably not appreciably affected. To repeat, the endwalls and entrances were not intended to be satisfactory for an actual shelter. A final shelter design could certainly provide adequate sealing to prevent harmful internal pressures.

4.2.3 Missiles and Dust. In all three concrete conduits in which missile traps were installed, no evidence of a missile was observed. In all three concrete conduits in which a dust investigation was made, debris varying from microscopic particles of dust to discrete pieces of mortar, wood, and small aggregates of dirt were observed. According to Reference 8, it is believed that under the conditions of shelter exposure occupants of the conduit shelters would have suffered no harm. The dust might have been annoying to personnel and might have interfered with certain operations.

4.3 NUCLEAR RADIATION SHIELDING EFFECTIVENESS

Since the maximum nuclear radiation dose that may be measured with a film pack is 70,000 r, no experimental method was available for direct measurement of the high dose received at the free-field stations close to ground zero. The free-field gamma measurements listed in Table C.1 of Appendix C were obtained by extrapolation from data obtained for Project 2.4. It is recognized that the validity of the linear extrapolation to close ranges is open to question but no other procedure presented itself. Free-field neutron dosimeter readings are also listed in Table C.1.

The maximum dose inside any conduit was received in 3.2f having 5 feet of earth cover. The gamma dose was 7.7 r and neutron dose <10 rep. According to Reference 24 the probability is that this dose would produce no significant medical effects on human beings. Thus, it is evident that all conduits provided adequate protection against nuclear radiation under the test conditions.

Chapter 5
CONCLUSIONS and RECOMMENDATIONS

5.1 CONCLUSIONS

Based on the field test results, it is concluded that all types of conduits tested, corrugated steel circular, corrugated steel cattle-pass, and concrete circular, will provide adequate Class I (100-psi overpressure and comparable radiations) protection for the same conditions (loading, soil, dimensions, etc.) as those of this test.

In addition, for the particular conditions of this test and within the accuracy of the overpressure measurements, it was observed that:

(1) The corrugated steel cattle-pass conduit with 7.5 feet of earth cover withstood a peak overpressure of 149 psi.

(2) The corrugated steel cattle-pass conduit with 5 feet of earth cover withstood a peak overpressure of 126 psi.

(3) The corrugated steel circular conduit with 7.5 feet of earth cover withstood a peak overpressure of 126 psi.

(4) The precast concrete circular conduit with 7.5 feet of earth cover withstood a peak overpressure of 126 psi.

(5) All conduits tested provided adequate protection against nuclear radiation.

Present knowledge does not justify making more general conclusions.

5.2 RECOMMENDATIONS

If future tests are made on similar structures it is recommended that the structures be instrumented to obtain the following data:

(1) Soil pressure versus time at the soil-structure interface at several points around the structure periphery.

(2) Soil pressure versus time at points in the soil cover between the earth surface and the structure.

(3) The relative motion of the structure with respect to an undisturbed point in the earth as a function of time.

(4) The change in shape of the structure as a function of time.

(5) Air pressure versus time inside the structure.

(6) All time records should have a common zero reference.

There is a need for further study into the nature of shock propagation through soil. Many questions are as yet unanswered regarding the attenuation, reflection, and refraction of shock energy; regarding the partition of energy when a shock wave meets an air-soil boundary, a water-soil boundary, an unsaturated soil-saturated soil boundary, or a structure-soil boundary; and regarding similitude. It is recommended that these questions be thoroughly studied, both analytically and experimentally, if we are to obtain a rational solution to the underground structure problem.

Appendix A
CONSTRUCTION

A.1 RESPONSIBILITIES

Construction for this project was accomplished by means of a cost-plus-fee contract administered by the Armed Forces Special Weapons Project and the Atomic Energy Commission. Excavation survey for this project commenced at Frenchman Flat of the Nevada Test Site on 5 March 1957; actual construction started on 11 March 1957, backfill commenced on 23 April 1957, and had been completed on the final structure on 4 June 1957. Construction of all structures was performed by Reynolds Electric and Engineering Company (REECO) with Holmes and Narver (H&N) serving as general construction inspector. The Bureau of Yards and Docks project officer served as technical inspector at the site in connection with critical construction details. A soil-survey program was conducted by the Waterways Experiment Station (Project 3.8).

A.2 CONSTRUCTION DETAILS

Schematic drawings of all conduits are included in Chapter 2 of the principal text. A detail drawing of the neutron-threshold-device recovery tube is included in Figure A.1. In order to provide additional details of procedures used for construction of the test structures, construction photographs are included as Figures A.2 through A.5.

Selected portions of the construction specifications are given on Page 45.

A.3 SOIL SURVEY PROGRAM

A.3.1 Soil Data. The soil survey program (project 3.8) consisted of: (1) compaction control (sand density method) during backfill, (2) record samples, (3) soil tests in WES laboratories, (4) soil tests at NCEL, and (5) determination of water content of backfill before shot. Specifications for backfill are included in Appendix A 2.

Sieve analysis, classification, and compaction test data of the soil used for backfill are included in Figure A.6. Density and moisture content measurements utilized for compaction control during backfilling operations are included in Table A.1.

Triaxial shear tests were performed by NCEL on one sample each from fill over conduits 3.2f and 3.2l. The tests were performed, using 2.8-inch diameter specimens, on -½-inch fraction (93.8 percent of total and 94 percent of total for 3.2f and 3.2l, respectively); the rate of strain was 0.1 in/min. The results are given in Table A.2.

The results of chemical and spectrographic analyses which have been performed at NCEL, and the density and moisture-content measurements taken at the site (Project 3.8) are included in Table A.3. Additional data on the natural soil at Frenchmen Flat and on the gravelly silty sand used for backfill is included in Reference 25.

A.3.2 Excavation and Backfill Operations. The earth was excavated so that the test conduit sections would be completely surrounded by a gravelly-silty-sand backfill. The earth excavation lines are shown in Figures 2.6, 2.11, and 2.15. Compaction of backfill for this project was performed in a manner as nearly similar to standard construction practices as practicable. The entire fill was completed in order to simulate an actual installation, whereby natural consolidation would compact the material within a period of several months. The backfill material was excavated from a preselected area to an approximate depth of 5 feet. The soil was removed from the pit using self-propelled scrapers, together with loading pusher Cats, hauled to the site of backfilling in the scrapers, and stockpiled at each structure excavation. During the digging of the backfilling material, water trucks kept the surface of the soil well saturated. An effort was made to keep each scraper load as uniform as possible by scooping soil at angles so that material from the surface, as well as material from a 5-foot depth was included in each scraper load.

The backfill stockpiles were not processed further except for wetting the surface of each stockpile with a water truck prior to the start of backfilling operations each day to prevent excessive surface drying. By placing the backfill material in 6-to-8 inch lifts with a clamshell, the utilizing compaction methods described in the next paragraph, compaction requirements (90-percent maximum density at optimum moisture content) were satisfied.

Up to a point approximately 6 feet above the base of the conduits, the 6-inch pneumatic tampers shown in Figure A.7 were used in a pattern illustrated in Figure A.8. From the 6-foot level to a level 3 feet above each conduit section, gasoline-driven vibrating rollers were used. Four passes over each area provided ample compaction effort. The operation of the

EXCERPTS from CONSTRUCTION SPECIFICATIONS

Earthwork. Earth for backfill and fill material will be furnished by the Government to the contractor for transportation by him from borrow pits located within 1 miles of the site of the work. Borrow pits shall be graded in a manner to drain properly so that the existing surface drainage will be maintained. Any surplus earth not required for filling or backfilling shall be removed and deposited within 2,000 feet of the site of the work as directed. Soil pits shall be graded in a manner to drain properly so that the existing surface drainage will be maintained.

Excavations shall be carried to the contours, dimensions and depths indicated or necessary. Excavations carried below the depths indicated without specific directions shall be refilled to the proper grade with thoroughly compacted suitable fill, except that in excavations for footings, or for buried concrete members the concrete shall be extended to the bottom of the excavation, all additional work of this nature shall be done at no additional cost to the Government. All excavations may be made by means of machines, except that the last six inches of earth and the trimming of the excavations shall be done by hand in a careful accurate manner to the exact grades and slopes indicated or directed. Extreme care shall be exercised to shape the bottoms of excavations for circular and irregular shaped members to the contour necessary to provide continuous solid bearing for the members. Prior to backfill operations, all debris, muck, and other loose silt shall be removed from the excavations.

Backfill shall be taken from a sand and gravel pit (selected by the project officer) excavated uniformly to a depth of [illegible] feet and shall be placed in 6-inch lifts in a manner that will not cause segregation of the backfill material. All backfill and fill shall be compacted to at least 90 per cent maximum density at optimum moisture content by means of pneumatic or other mechanical compaction equipment. All backfill placed within 2 feet of the structure shall be free from rocks, boulders, and clods larger than 2 inches at the greatest dimension, and vegetable matter and other debris, otherwise the backfill material may be used as obtained from the pit. The backfill shall be placed in alternate layers from both sides of the structures maintaining as nearly as practicable a uniform height of backfill at all times. In no case should the backfill on one side be carried more than 1[illegible] inches higher than on the opposite side. The moisture content and density of the soil will be determined by Project [illegible]. If it is determined that moisture must be added to the existing stock piled material, the methods proposed to be used by the contractor for adding the water, mixing, etc., shall be approved by the project officer prior to the start of backfilling operations. In any case, all processing required to obtain the specified water content shall be accomplished before the material is placed around or over the structures. The earth fill shall be maintained within a tolerance of plus or minus $^{1}/_{10}$ of a foot on the cover. Prior to backfilling, the contractor shall ascertain that end bulkheads are plumb and are not separated from the conduit sections. Backfilling shall not be started until the contractor is certain that once started a day-to-day sequence of backfilling operations can be effected.

Earth moving equipment may be used according to standard practice, except that no heavy equipment will be permitted to operate over the crown of the structures until at least [illegible] feet of earth have been compacted over the top of the structures. In no case should equipment used for compaction exceed a surface pressure of 10 psi. Pneumatic hand tampers may be used for compacting the backfill immediately adjacent to the surfaces of the structures.

Concrete Construction. Concrete may be ready mixed. All concrete shall be class [illegible] (3000 psi).

Setting miscellaneous material. When practicable, all anchors and bolts in connection with concrete shall be placed and secured in position when the concrete is placed. Anchors and anchor bolts shall be plumbed carefully and set accurately and shall be held in position rigidly to prevent displacement during the placing of the concrete.

Concrete pipe (indicated as conduit) shall be 3,000 psi standard strength reinforced concrete sewer pipe conforming to ASTM Specification C75-55, the pipe shall have tongue-and groove joints. The concrete pipe shall be laid on a solid bed of earth, all joints shall be buttered with a 1-to-3 cement mortar prior to assembly of sections. After assembly, joints shall be filled to the level of the adjacent surfaces of the pipe.

Prefabricated Structures. The ingress tunnel and pipe shall be of corrugated steel culvert pipe conforming to the applicable requirements for Type 1, Class 2 of Federal Specification QQ-C-806a, except that zinc-coating will not be required. Metal shall weigh not less than 6.875 psf (nominal 8-gage) before corrugating. Openings shall be cut accurately and fitted neatly.

Corrugated culvert pipe shall be of metal weighing not less than 5.625 psf before corrugating (nominal 10-gage) and shall conform to the applicable requirements of Federal Specification QQ-C-806a, except that it may be black or zinc-coated steel. Types for the various uses shall be as follows:

a. Circular Conduits 'd and h' shall be Type I, Class II

b. Cattle pass Conduits 'a,b,c,f,g,k, and m' shall be Type II, Class I

Pipe tripods. Tripod legs shall be of $1\frac{1}{2}$ inch standard weight black pipe, legs shall be welded to a $\frac{1}{4}$ inch thick steel base plate approximately as indicated. A steel angle shall be welded to the base plate to form a seat, the angles shall be drilled as necessary to allow for the attachment of the government instrumentation. Tripods shall be anchored to floor slabs at locations specified by the Project Officer.

Steel plate covers with handles shall be provided for the tops of ingress shafts to conduits '[illegible] through m'. They shall be of black steel not less than 1 inch thick and shall be held in position with sand bags placed over them approximately as indicated.

Carpentry. Grading of materials shall be in accordance with the rules of the association governing the species used. All material subject to stress shall have a minimum fiber stress in bending of 1,450 psi.

Wood ladders shall be provided in lieu of the metal ladders indicated on Drawing Number 771098. They shall have uprights of 2-by-4-inch material and rungs of 1-by-4-inch material. Uprights shall be spaced 16 inches apart, spacing of rungs shall be 12 inches from top to top. Ladders shall be secured to the corrugated pipe with metal clips, clips shall be welded to the pipe and bolted to the uprights. Metal for clips shall weigh not less than 6.875 psf before forming.

TABLE A.1 SAND DENSITY TESTS

Date of Sample	Structure and Station	Depth above (Depth below (Ground Sur	Location	Water Contents	Dry Density
		feet		pct	pcf
15 May 1957	3.2a (9016.01)	−8	Leeward	10.7	112.0
16 May 1957		−4	Blast Side	10.3	110.0
17 May 1957		−4	Leeward	13.3	121.1
			Average	11.4	114.4
25 May 1957	3.2f (9016.02)	−12	Leeward	10.4	118.8
28 May 1957		−4	Leeward	7.9	106.5
28 May 1957		−3	Over Center	7.1	114.4
3 June 1957		−0.5	Over Center	7.8	117.5
			Average	8.3	114.3
2 May 1957	3.2g (9016.05)	−11.5	Leeward	9.5	114.0
2 May 1957		−11.5	Blast Side	9.4	112.2
3 May 1957		−4.6	Blast Side	9.7	113.1
3 May 1957		−4.6	Leeward	8.7	117.9
			Average	9.3	114.3
31 May 1957	3.2l (9017.03)	−12	Leeward	10.6	117.1
3 June 1957		−4	Leeward	13.3	115.6
3 June 1957		−4	Over Center	9.1	120.0
4 June 1957		−0.5	Over Center	8.0	119.0
			Average	10.3	117.9

TABLE A.2 RESULTS OF TRIAXIAL SHEAR TESTS

Sample	Depth	Position	Water Content	Dry Density	Angle of Internal Friction, ϕ	Cohesion
			pct	lb/ft^3	deg	psi
3.2f	−3.0	over center	7.1	114.4	32.5	7.8
3.2l	−4.0	over center	9.1	120.0	39.7	4.4

TABLE A.3 CHEMICAL AND SPECTROGRAPHIC ANALYSES

Structure	Depth Below Grade †	Density	Water Content, pct			Elemental Composition, pct									
			At Backfill*	D−7 5/17	D−3 6/21	Si	Al	Mg	Fe	Ti	Na	Ca	Mn	Cu	B
	feet	pcf													
3.2f	−3.0	114.4	7.1	8.1	8.2	12.0	13.4	3.0	4.6	0.8	A	A	B	C	C
3.2f	−0.5	117.5	7.1	7.1	7.8	12.0	11.8	10.0	4.2	0.8	A	A	B	C	C
3.2l	−4.0	120.0	9.1	9.3	9.4	14.5	14.8	5.5	5.4	0.8	A	A	B	C	C
3.2l	−0.5	119.0	8.0	7.3	7.1	14.5	10.6	5.5	3.2	0.5	A	A	B	C	C
		Accuracy ± 1.0 percent	Quantities shown are accurate to nearest 0.1 percent			Accuracy ± 10 percent for Si, Al, Mg, Fe, and Ti					A • 1 – 10 percent B = 0.01 – 0.1 percent C 0.001 – 0.1 percent				

* Dates of samples at time of backfilling are included in Table A.1.

† Position over center.

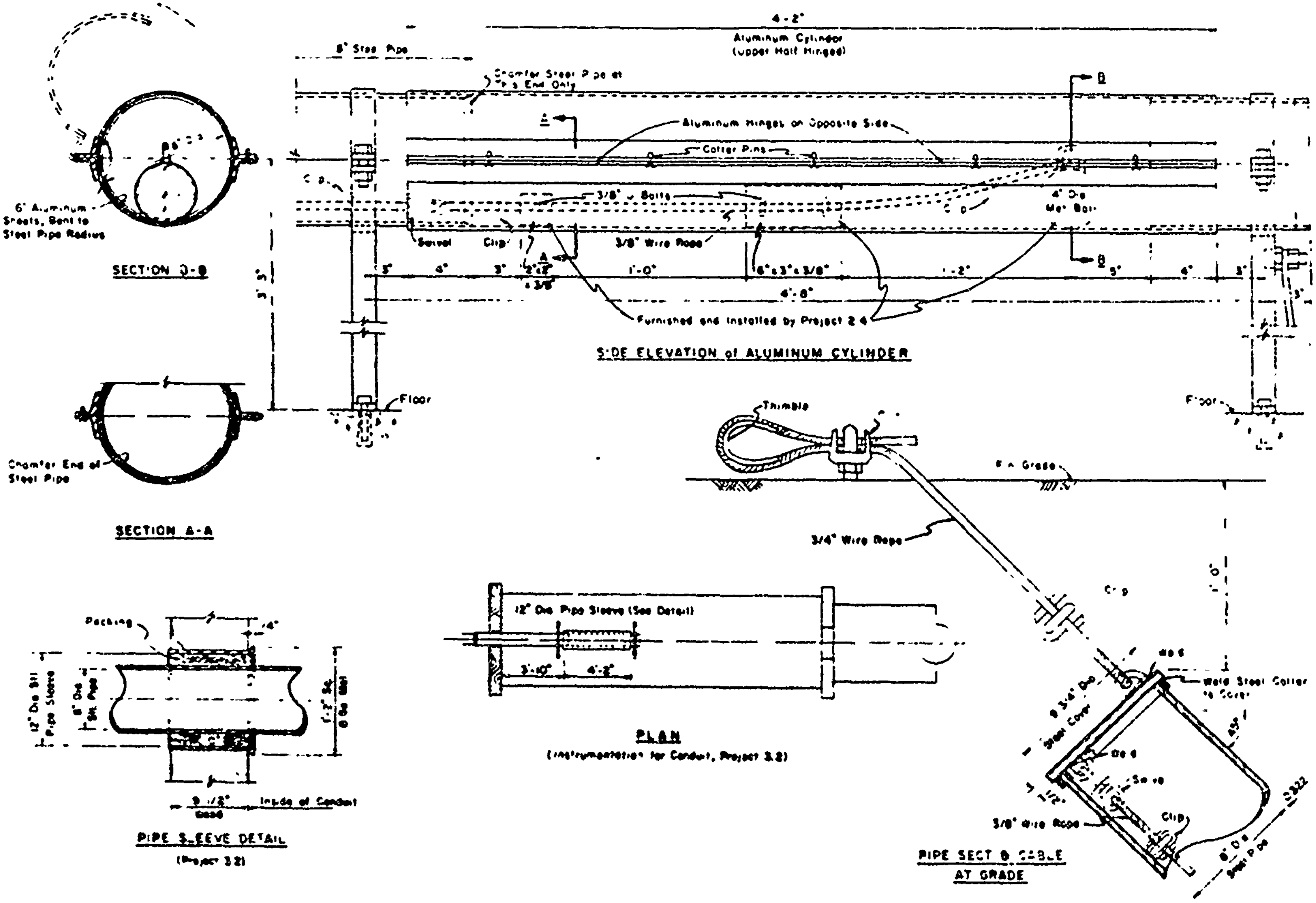


Figure A.1 Details of recovery tube for neutron threshold device.

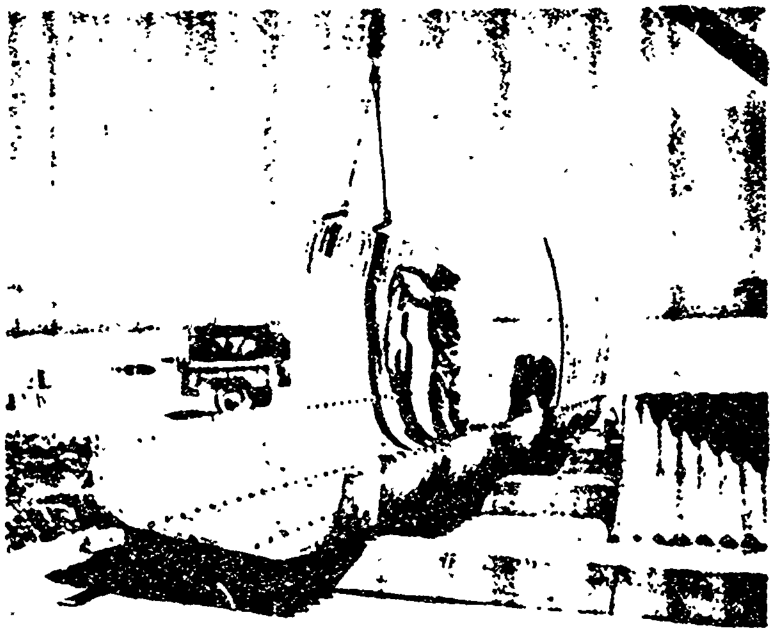


Figure A.2 Assembly of typical cattle-pass conduit.

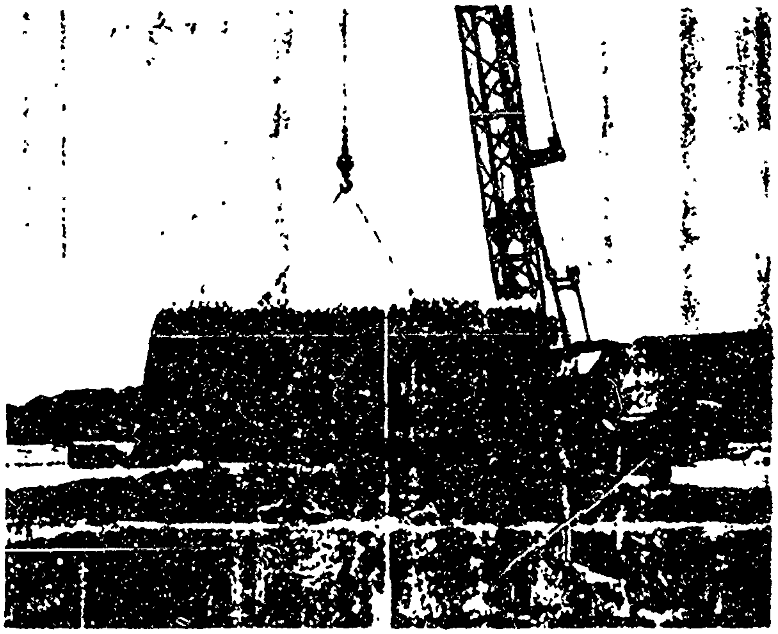


Figure A.3 Lowering assembled cattle-pass conduit into excavation.

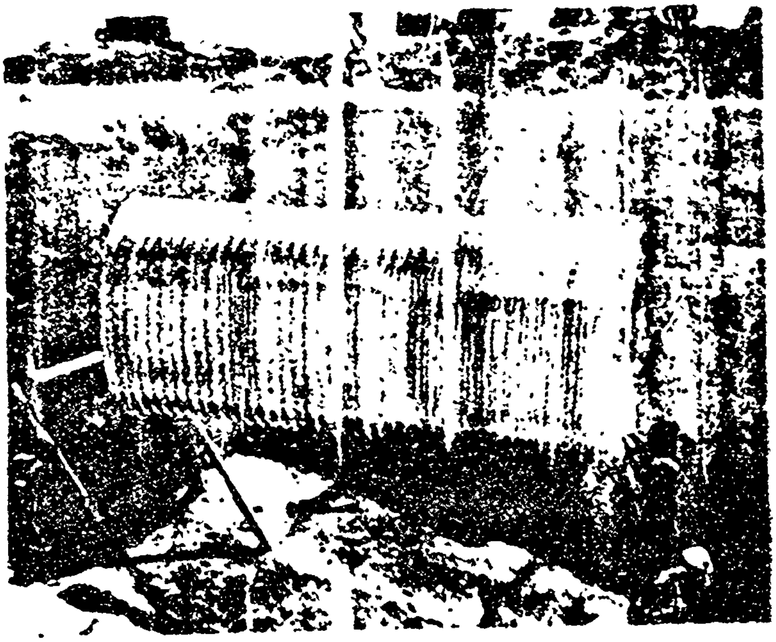


Figure A.4 Positioning cattle-pass conduit in excavation.

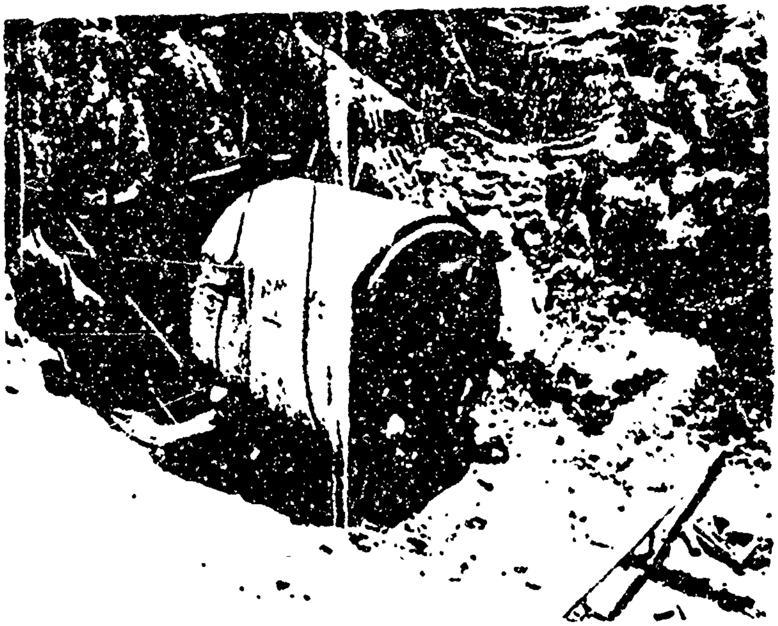
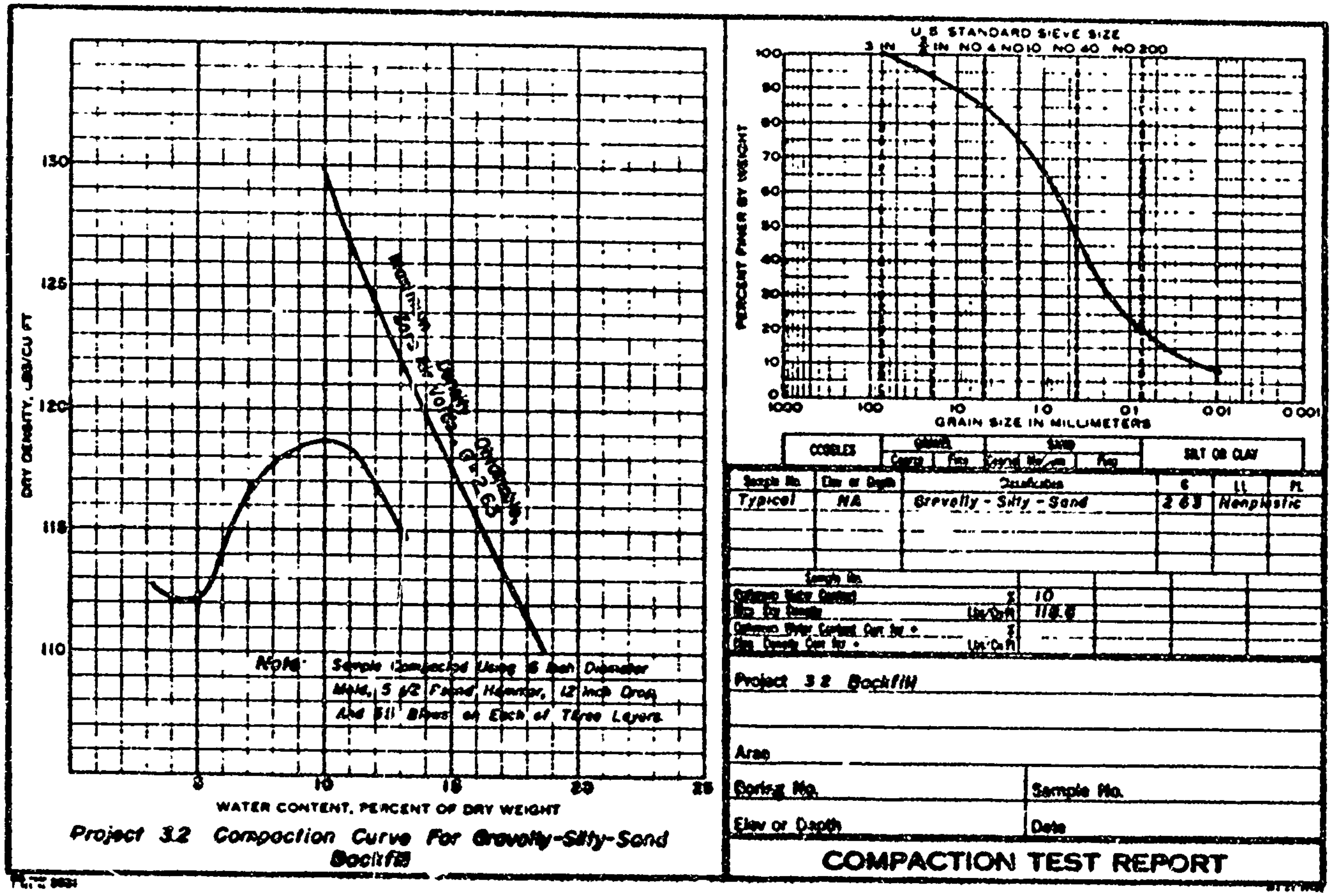


Figure A.5 24,000-pound concrete conduit section being positioned.



Note: Sample Compacted Using 6 Inch Diameter Mold, 5 1/2 Pound Hammer, 12 Inch Drop And 56 Blows on Each of Three Layers.

Project 3.2 Compaction Curve For Gravelly-Silty-Sand Backfill

Sample No.	Elev or Depth	Classification	G	LL	PL
Typical	NA	Gravelly - Silty - Sand	2.63	Nonplastic	

Sample No.					
Optimum Water Content	%	10			
Max Dry Density	Lbs/Cu Ft	118.6			
Optimum Water Content Corr for +	%	--			
Max Density Corr for +	Lbs/Cu Ft				

Project 3.2 Backfill

Area

Boring No.

Sample No.

Elev or Depth

Date

COMPACTION TEST REPORT

Figure A.6 Soil survey compaction test report.

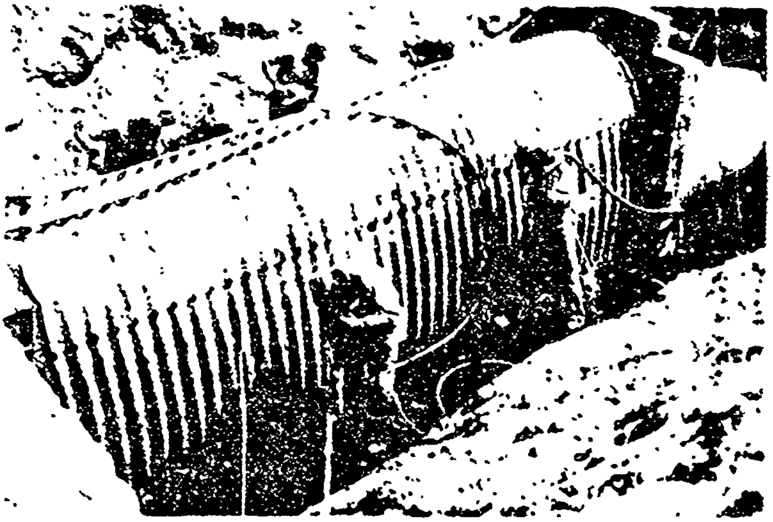


Figure A.7 Tamping backfill with pneumatic tamper.

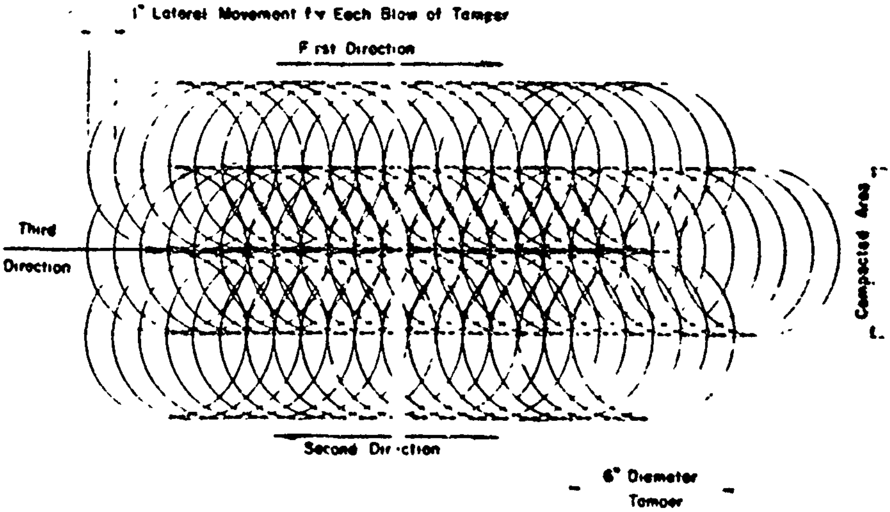


Figure A.8 Tamper compaction pattern.

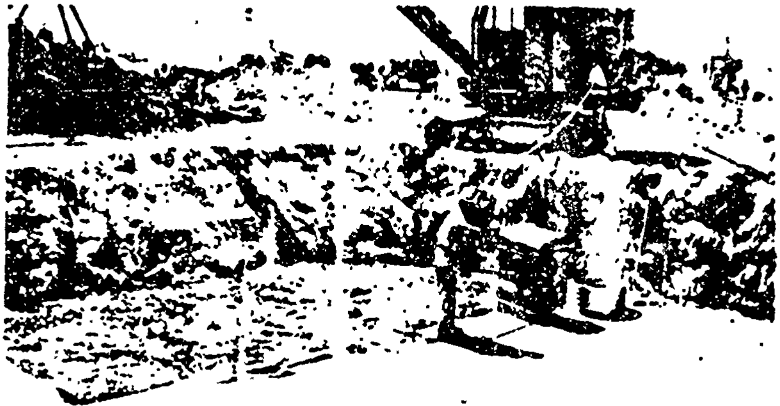


Figure A.9 Compacting backfill with gasoline driven vibrating roller compactor is indicated in Figure A.9. From a level 3 feet above each conduit to the level of the original surface a D-8 Cat crawler tractor (bearing pressures approximately 10 psi) was used for compaction by making four passes over each area

Appendix B
STRUCTURE INSTRUMENTATION

B.1 DEFLECTION GAGES

Scratch-type deflection gages, utilized to determine maximum and residual deflections were fabricated and installed by NCEL. The scratch gage (Model P-3.2) illustrated in Figures B.1 and B.2 consisted of a scribing assembly, two scratch plates, and attaching hardware. The scribing assembly was attached to the top of the conduit sections by bolts. The scratch plates were 16-gage aluminum sheets, 12 by 13 inches, with ½-inch flanges turned on their sides to act as stiffeners. The scratch plates were coated with conventional machinist's bluing compound, thus, the scratches showed as aluminum colored. The scratch plates were attached with machine screws to opposite flanges of a ¼-inch steel channel, 10 by 12 inches; this in turn was welded to a steel tripod having 1½-inch pipe legs. The complete assembly is shown in Figure B.3.

Full-scale scratch gage records are included as Figures B.12 through B.15. It is considered that the Model P-3.2 scratch deflection gage performed satisfactorily except for measurements in Conduits 3.2a, 3.2c, and 3.2d. In these three cases the scribing stylus jumped from the scratch plate before recording a maximum dynamic deflection. The shock imparted to the tripod legs evidently caused the scratch plate to move away from the scribe. A spring tension of 16 pounds had been used; however, by increasing the spring tension, the pressure on the plate could be increased thereby avoiding a future similar situation.

B 2 SELF-RECORDING PRESSURE VERSUS TIME (p_t) GAGES INSTALLED BY BRL, PROJECT 3.7.

The recording mechanism for the pressure-time gages was enclosed in a heavy airtight case, the top of which acted as a baffle plate. Holes in the baffle plate allowed initiation and pressure intake.

The sensing element was basically a chamber formed by welding together two diaphragms at their edges, each of which was impressed with a series of connective corrugations. A stylus, consisting of an osmium-tipped phonograph needle mounted on a spring arm, was attached to the element. When pressure was transmitted inside the element, the element expanded. This expansion, which is proportional to the amount of pressure, was scratched on a silvered glass disk by the stylus. The glass disk was mounted on a turntable and was driven by a carefully governed motor in order to record the scratch of the stylus versus time.

Calibration of the pressure capsules was performed by the manufacturer. The calibrations were plotted using a Leeds-Northrup X-Y recorder. The output of a Statham strain-gage-type pressure transducer was fed through amplifiers to the pen (X-axis) of the recorder. Capsule deflection was measured by a micrometer head equipped with a null detector and servo system operating a slide-wire potentiometer which, in turn, controlled the chart drive (or Y-axis). The resulting presentation gave a plot of capsule deflection as a function of applied pressure.

The p_t gage is shown in Figure B.4. Actual installation of the gage is shown in concrete base for overpressure measurements in Figure B.5.

The self-recording measurements observed on the ground surface are included in Table B.1.

The values shown in Table B.1 are used in Table 3.1. In all cases the overpressures are within 10 percent of the preliminary composite overpressure curve for Shot Priscilla.

B.3 PEAK PRESSURE GAGES (INSTALLED BY BRL PROJECT 3.7)

The peak-pressure gage utilized a pressure capsule like that used in the pressure-time gage; however, in this gage, the recording blank was held stationary. The recording blank, a silvered glass rectangle, was put in place under the capsule stylus. The stylus, when activated by pressure, reported the maximum positive and negative deflections of the pressure capsule.

This capsule was calibrated by the manufacturer similarly to the p_t gage. Figure B.6 shows the installation of a peak pressure gage on the access end of the timber bulkhead.

The peak internal pressure measurements observed are shown in Table B.2. The reliability of the peak pressure values is questionable and it is concluded that a self-recording pressure-time gage would have provided a more accurate and reliable record.

B.4 DYNAMIC ACCELEROMETERS (INSTALLED BY BRL PROJECT 3.7)

B.4.1 Electronic Accelerometers. Electronic-dynamic-accelerometer-versus-time measurements

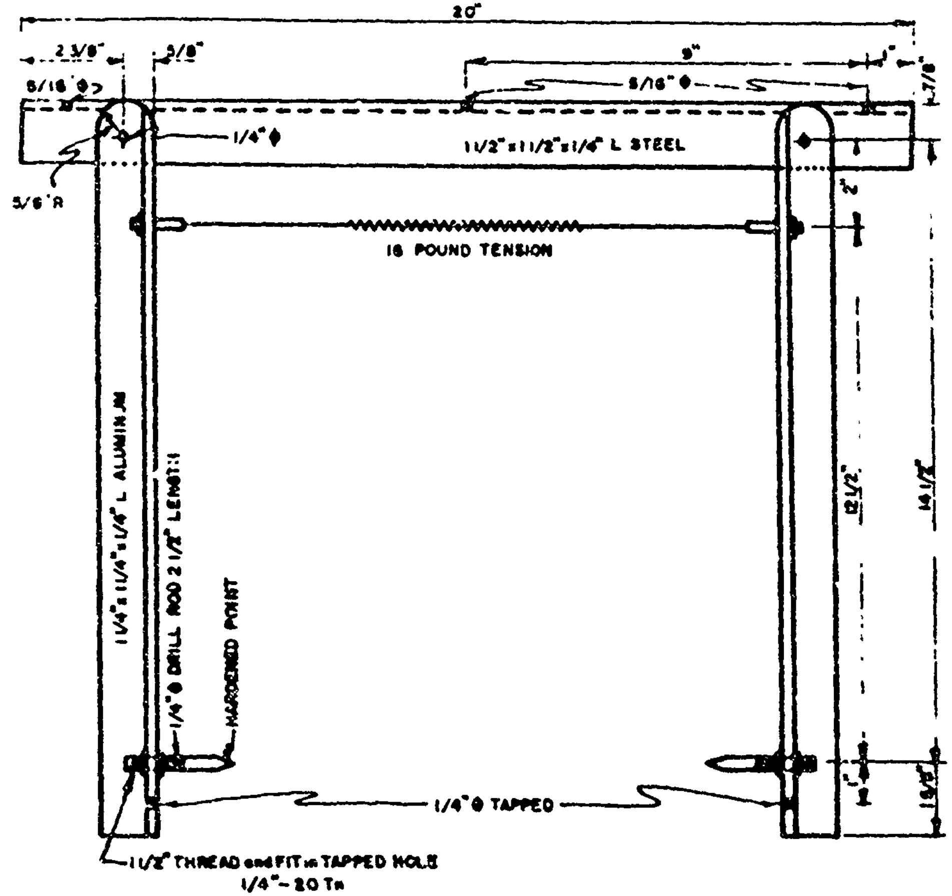


Figure B.1 Deflection gage scribing assembly.

Figure B.2 Scratch deflection gage installed inside conduit

NOT REPRODUCIBLE

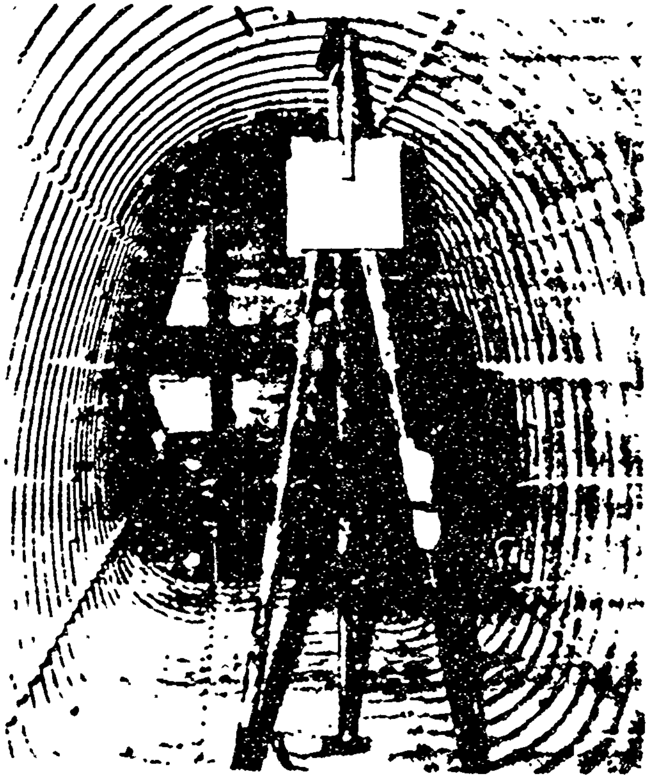


Figure B 3 Typical scratch gage installation. Note chemical dosimeter and gamma film badge taped to tripod leg.

Figure B.4 Self-recording pressure-time gage

NOT REPRODUCIBLE

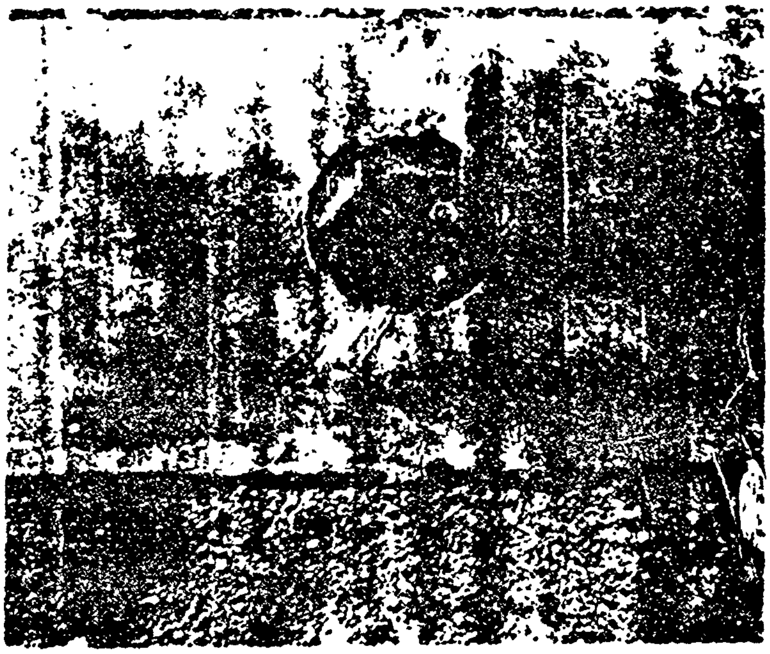


Figure B.5 Self-recording pressure-time gage mounted in concrete base.

Figure B.6 Peak pressure gage installed on timber bulkhead at access-end of conduit.

were made with Wiancko Type 3AAT accelerometers. The sensing element consisted of an armature bonded at its center to the vertex of a V-shaped spring member and held in close proximity to an E-coil. A weight was attached to one end of the armature so that an acceleration in a direction normal to the armature caused it to rotate about the vertex of the spring.

The E-coil consisted of two windings wound on the extreme legs of an E-shaped magnetic core. As the armature rotated, it decreased the reluctance of the magnetic path composed of the armature, the center leg, and one extreme leg of the E, and increased the reluctance of the other, similar path. The electronic accelerometers were given static calibration on a spin-table accelerometer before their installation (Figure B.7).

The spin table was a disk which was rotated at a speed determined accurately by an electronic tachometer. The accelerometer was mounted on the disk with its sensitive direction parallel to the radius of the disk. Connections to the recorder cable were made through slip rings. An accurate knowledge of the distance of the accelerometer sensing element from the center of the disk and the rotational velocity of the disk were used to find the radial acceleration produced in the sensing element. The installation of the gage in the concrete conduit is shown in Figure B.8 (left).

The results of the electronic dynamic acceleration measurements of the conduits are shown in Table B.3.

B.4.2 Self-Recording Accelerometers. The self-recording accelerometer utilized an element similar to that used in the peak accelerometer. To obtain acceleration versus time, the recording disk was rotated. The installation of the gage is shown in Figure B.8 (right).

One self-recording accelerometer had been installed in 3.2l in lieu of a peak accelerometer. The resulting (< 10g negative) is questionable. Because the electronic records were considered good and the self-recording and peak values (Section B.5) were somewhat questionable, the electronic values have been considered more valid and consequently have been utilized for discussion.

B.5 PEAK ACCELEROMETERS (INSTALLED BY BRL PROJECT 3.7)

The peak accelerometer was basically the same as the peak-pressure gage (Section B.3). Instead of a pressure-sensing capsule, an accelerometer element was utilized. The element consisted of a cantilever beam with a weight attached to its free end. A spring arm attached to the weight held a stylus which scratched a record on the recording blank when the element was activated. The cantilever beam was shaped to prevent oscillations in any direction except that desired.

The accelerometer elements were calibrated by clamping them in a support similar to the one in the gage. This support was then placed on a calibrated drop table to be subjected to transient acceleration. The drop table consisted of a heavy metal plate which was raised to a predetermined height and then allowed to fall freely. The fall was terminated by a box of sand into which the plate falls flat. The accelerations produced when the plate is stopped were accurately reproducible and by means of a standard accelerometer, have been related to the height from which the plate was released. A peak accelerometer, attached to the bottom of the concrete conduit section, is shown in Figure B.9.

Results of the peak accelerometer readings observed are shown in Table B.4. It has been concluded that the electronic dynamic accelerometer would have provided a more valid measurement.

B.6 MISSILE TRAPS (INSTALLED BY LOVELACE FOUNDATION PROJECT 33.2)

Inasmuch as low-velocity missiles secondary to large-scale explosions have been a significant cause of casualties, missile traps were installed in all the concrete conduits of this project to determine (1) if concrete conduits were a source of missiles and (2) to examine the ballistic properties of low-velocity missiles which might be produced by compression failure of the concrete or by spalling of concrete as the result of a tension crack.

Styrofoam was used for the missile traps. The relatively low shear properties of the material and its non-fibrous structure result in localization of compressive deformations. Styrofoam's resistance to deformation is low enough so that relatively slow missiles penetrate sufficiently to be measured accurately.

The missile trap consisted of 2-inch sheets of styrofoam 6 inches by 36 inches, covered with aluminum foil, and attached to the interior surface of the concrete with asphaltic cement in a manner indicated in Figure B.10. Additional data on missiles secondary to nuclear blast are included in Reference 9.

In all three concrete conduits in which missile traps were installed, 3.2e, 3.2j, and 3.2l, no evidence of a missile had been observed. It is concluded that for the magnitude of deformation experienced by the concrete conduit sections of the project a missile hazard does not exist.

B.7 DUST COLLECTORS (PROJECT 33.5, REFERENCE 8)

Two somewhat similar types of dust collectors were utilized. The first, which was taped to the floor of each shelter, consisted of an ordinary glass microscopic slide, one inch of which was covered with transparent sticky tape, sticky side up. The second was a

TABLE B.1 SELF-RECORDING .GE MEAS. IEMENTS OBSERVED ON GROUND SURFACE

Structure		Peak Overpressure	Arrival Time	Positive Duration	Quality of Record
		psi	sec	sec	
3.2a	9016 01	149	—	0.232	Good
3 2c-d	9016 04	126	0.105	0.206	Good
3.2g-h	9016.05	100	0.176	0.333	Good
3.2l*	9017 03*	60	0.121	0.361	Poor

*This gage, adjacent to both 3.2l and 3.3b (Reference 13) was considered to be a part of Plumbbob Project 3.3.

TABLE B.2 PEAK INTERNAL-PRESSURE MEASUREMENTS

Structure	Station	Peak Internal Pressure
		psi
3.2a	9016.01	3.7
3.2b	9016.04	*
3.2c	9016.03	2 0
3.2d	9018.01	3.0
3.2e	9017.01	3.0
3.2f	9016.02	3.0
3.2g	9016.05	2.0
3.2h	9018.02	1.3
3.2j	9017.02	3.0
3.2k	9016.07	1.0
3.2l	9017.03	1.5
3.2m	9016.06	1.7

*Not Recorded.

TABLE B.3 RESULTS OF ELECTRONIC DYNAMIC ACCELERATION MEASUREMENTS

Structure	Station	Peak Value	Duration	Remarks
		g	sec	
3.2a	9016.01	8.0	0.050	Good Record
3.2f	9016.02	5.0	0.048	Good Record
3.2g	9016.05	5.0	0.045	Good Record
3.2l	9017.03	<10.0	No Record	

TABLE B.4 RESULTS OF PEAK ACCELEROMETER READINGS

Structure	Station	Negative Acceleration	Remarks
		g	
3 2a	9016.01	<5	Questionable record
3.2b	9016.04	<5	Questionable record
3.2c	9016.03	<5	Questionable record
3.2d	9018.01	—	Gage failed to record
3.2e	9017.01	<5	Questionable record
3.2f	9016.02	<5	Questionable record
3.2g	9016.05	<5	Questionable record
3.2h	9018.02	<5	Questionable record
3.2j	9017.02	<5	Questionable record
3.2k	9016.07	<10	Questionable record
3.2m	9016.06	<5	Questionable record

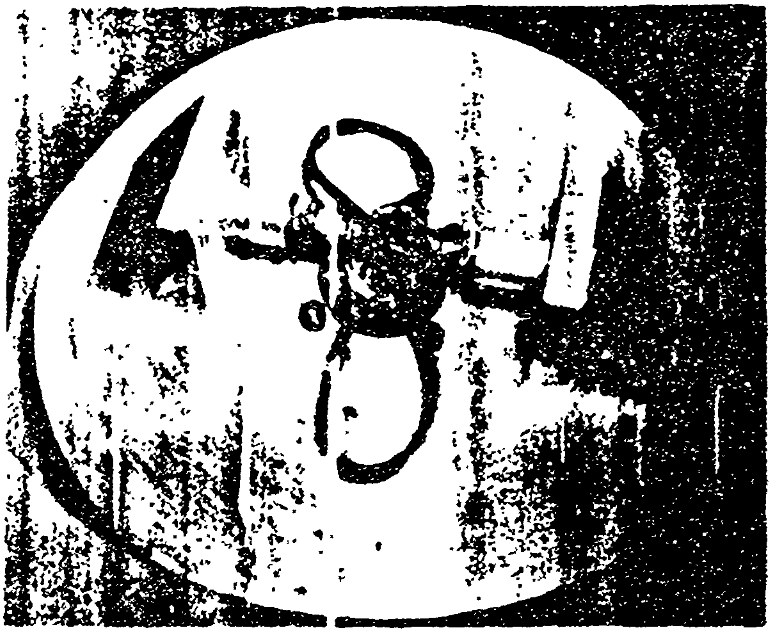


Figure B.7 Calibration of electronic accelerometer.

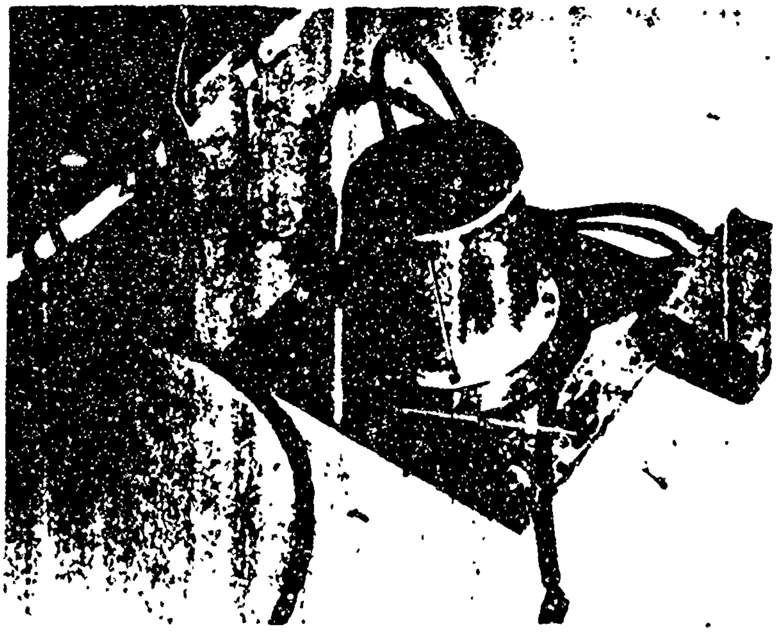


Figure B.8 Electronic accelerometer (left) and self-recording accelerometer (right) installed in concrete. Conduit 3.21

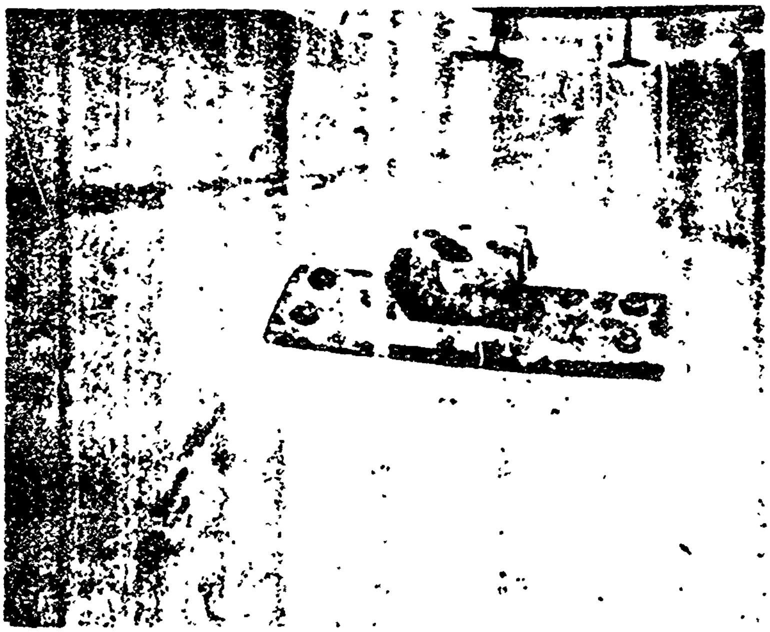


Figure B.9 Self-recording peak accelerometer installed on bottom of concrete conduit.

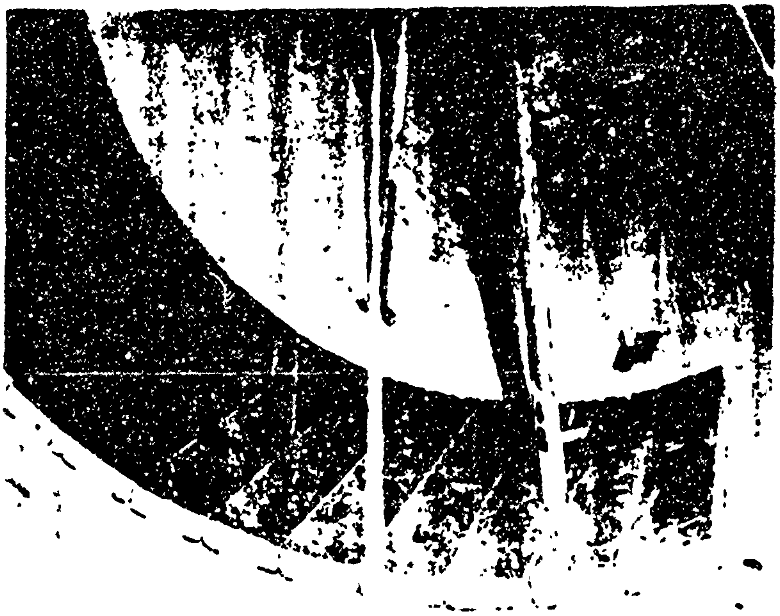


Figure B.10 Styrofoam missile trap inside concrete conduit.

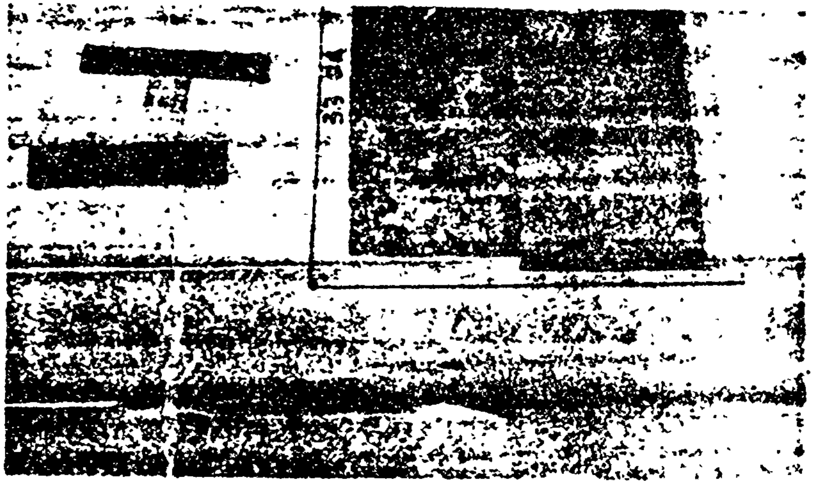


Figure B.11 Dust collectors installed inside concrete conduit.

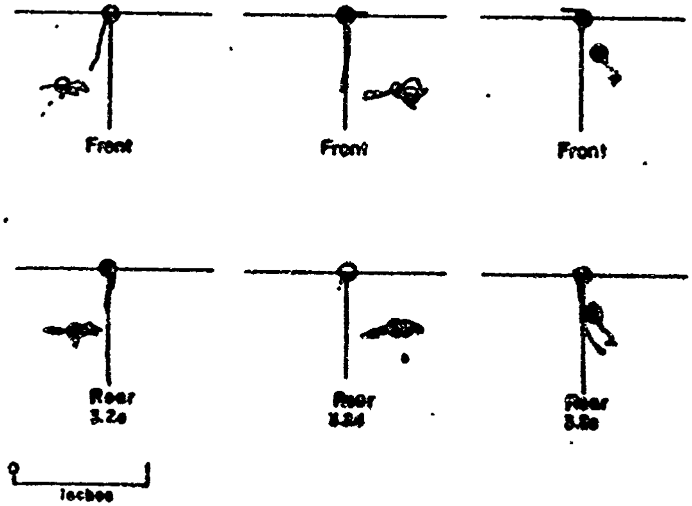


Figure B.12 Deflection records, Conduits 3.2a, 3.2d, and 3.2e.

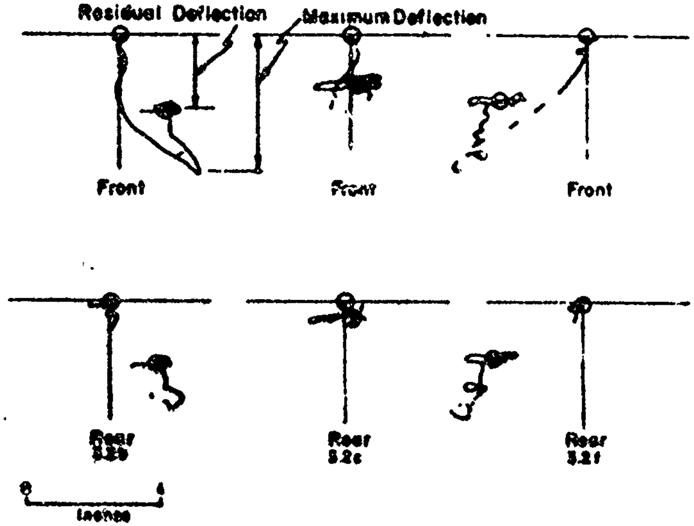


Figure B.13 Deflection records, Conduits 3.2b, 3.2c, and 3.2f.

sticky-tray fallout collector; to provide rigidity, a $\frac{1}{16}$-inch thick plate of galvanized sheet metal ($9\frac{1}{2}$ by $10\frac{1}{2}$ inches) was employed on top of which a transparent, but sticky, paper was fixed with masking tape.

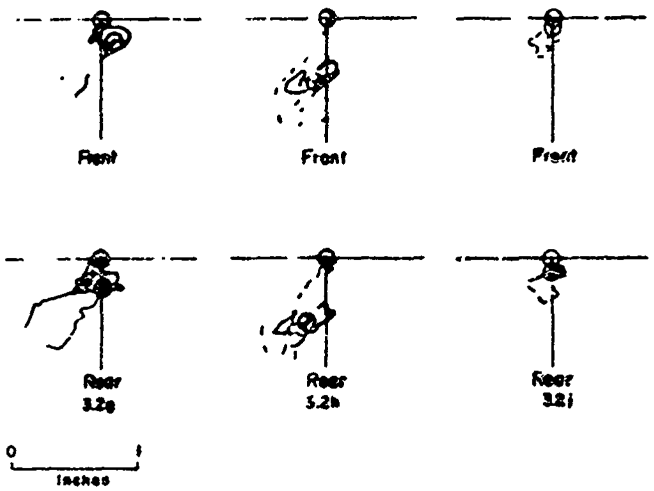


Figure B.14 Deflection records, Conduits 3.2g, 3.2h, and 3.2j.

The top of the sticky tray (8 by 9 inches) was protected by two rectangular pieces of paper which ordinarily are stripped off just before exposure to the collector. Upon installation of each plate, one of the protective papers was removed and the uncovered side of the collector was marked C for control. Upon Button-up of the structure prior to the test, (D – 3 days) the other protective paper was removed, thus exposing the other side of the collector marked E for experiment. The two types of dust collectors which were installed in Conduits 3.2g, 3.2j, and 3.2l are shown in Figure B.11.

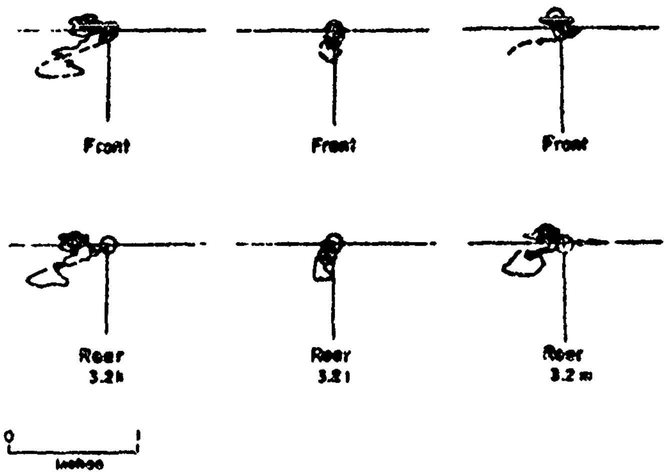


Figure B.15 Deflection records, Conduits 3.2k, 3.2l, and 3.2m.

Recovery of trays and slides was accomplished upon initial postshot entry of the structure (D + 8). The top of the microscopic slides were covered with a piece of transparent scotch tape, and the fallout trays, after being pried loose from the floor, were placed face to face, care being taken to oppose the control side of one collector to the control side of the other taken from the same shelter. These measures served to protect each of the dust collectors from contamination after removal from the several structures.

After recovery, the two opposing sheets of the transparent, sticky paper were stripped from the fallout trays. The sticky paper was successful in trapping debris varying from microscopic particles of dust to discrete pieces of mortar, wood and small aggregates of dirt. A few slivers of wood measured $^3/_8$ inch wide. (It should be noted that the wood bulkheads on the structures of this project are not a part of the actual shelter design but have been used as an economical method to provide closure to the conduits for the purpose of this test).

Each microscopic slide was contaminated with dirt and will be usable for subsequent microscopic studies.

The data obtained will be subjected to laboratory analysis by Project 33.5, using microscopic, photographic, and chemical methods. As much as possible of the trapped debris will be identified. It is anticipated that dust collected preshot from the bottom of the conduits will be most helpful in aiding the observations calculated to establish the origin of postshot material collected on the experimental side of the fallout trays.

Appendix C
NUCLEAR RADIATION INSTRUMENTATION

Prepared by Project 2.4, Radiological Division,
U.S. Army Chemical Warfare Laboratories;
Robert C. Tompkins, Project Officer

C.1 BACKGROUND AND THEORY

Tests prior to Operation Teapot have shown that below-grade shelters give 75 percent better gamma shielding than those shelters which are partially above grade (Reference 26). Operation Teapot data illustrated that completely below-grade shelters with four feet of radial earth cover gave an inside-to-outside gamma dose ratio, to be designated herein as a gamma transmission factor, as low as 1.2 by 10^{-4} and a neutron transmission factor of 1.5 by 10^{-7} for the high energy neutron flux which would be detected by sulfur-threshold detectors (Reference 27). Detector stations nearer to the entranceways of the structures indicated much higher transmission factors, and therefore received higher radiation dosages.

The shelters to be instrumented for radiation measurements at Operation Plumbbob were all underground. For this reason, the Operation Teapot results in below-grade structures UK-3.8a, UK-3.8b, UK-3.8c, and UK-3.7 were particularly useful in predicting expected shielding by the shelters at Operation Plumbbob (Reference 27). These results were augmented by empirical relations for neutron and gamma radiation passing through hollow cylinders as given in the "Reactor Shielding Design Manual" for evaluating the effect of various openings and baffles (Reference 28). In the case of the Operation Plumbbob 3.2 structures, the predictions indicated that they should provide considerably greater radiation protection than that provided by the below-grade Operation Teapot structures, since none of them would have any entrance ways or ventilation system openings at shot time. Moreover, the levels of protection should be about equal throughout the main portions of the test section.

C.2 DESCRIPTION OF INSTRUMENTATION

C.2.1 Gamma Film Packets. Gamma dose was measured with the National Bureau of Standards—Evans Signal Laboratory (NBS-ESL) film packets (References 29, 30, and 31). In the exposure range from 1 to 50,000 r and in the energy range from 115 kev to 10 Mev the accuracy of the dosimeter is considered to be within ± 20 percent. The net photographic response is expected to be approximately energy independent. This is achieved by modifying the bare-emulsion energy response, which has peaks near the K-shell photoelectric absorption edges, absorber and brown..., by placing the entire emulsion in a 0.25-mm-thick bakelite case covered with 1.07 mm of tin and 0.3 mm of lead and surrounded by a $\frac{1}{32}$-inch lead strip over the open edges. The entire arrangement is placed in a plastic cigarette case.

Although the angular dependence of the gamma film packet when it is exposed to high energy radiation is negligible, for lower energies it is important. An interpretation of the results obtained by Ehrlich (Reference 30) indicates that, for radiation isotropically incident on the packet, the dose value is about 5.5 percent lower for 1.2-Mev radiation than that obtained by an instrument having no angular dependence, about 32 percent low for 0.20-Mev radiation, and about 45 percent low for 0.11-Mev radiation. Although the film packets may show only ± 20 percent error in normal radiation fields, some consideration should be given to the fact that in a relatively isotropic and degraded energy field, such as might exist in structures with many feet of earth cover, the film packets may indicate low values.

C.2.2 Chemical Dosimeters. The chemical dosimeters utilized for instrumenting the structures were supplied by the United States Air Force School of Aviation Medicine (SAM).

The SAM chemical dosimeters include two main types of chemical systems. One system is hydrogen free, while the other system has a high hydrogen content. The latter system is essentially water-equivalent in its response. The high-hydrogen-content dosimeters respond to all the gamma rays, fast neutrons, and thermal neutrons; whereas the hydrogen-free dosimeters respond only to the coexistent gamma rays and thermal neutrons (Reference 31). Both systems are based on the same principle: acid formed from the radiation of a chlorinated hydrocarbon is a linear function of radiation dose throughout a broad range (25 to 100,000 r) (see References 31, 32, 33 and 34). Neutron calibration of these systems was made by G. S. Hurst and P. E. Harris (Reference 35).

The hydrogen-free dosimeters utilized were furnished by SAM in the following prepared ranges: 0.5 to 5, 2 to 20, 5 to 200, 100 to 500, 400 to 2,000, 1,600 to 3,000, and 2,000 to 18,000 rep. The high-hydrogen dosimeters utilized were furnished in the following prepared ranges: 10 to 200, 50 to 500, and 100 to 1,000 rep.

All of the dosimeters if exposed within their prepared ranges were evaluated spectrophotometrically or visually by observation of the color changes in the indicator dye from red (pH 6.0 or above) to yellow (pH 5.6 or below). Since these color changes are a function of the dose, exposure doses were estimated by color comparison with irradiated controls. The amount of acid formed, hence the amount of absorbed dose, in over-exposed dosimeters (pH 5.6 or below) was evaluated by titration with standardized 0.001 N sodium hydroxide. Division of the amount of acid produced in an unknown exposure by the calibration data for the sensitivity of the system to Co^{60} gamma radiation (namely the amount of acid produced per milliliter of chlorinated hydrocarbon for each roentgen absorbed) yielded the gamma dose in roentgens.

The measurement of the neutron dose with the high-hydrogen-content dosimeter was accomplished by evaluation of the amount of stable acid produced in a mixed radiation field by one of the above techniques. Since the water-equivalent, high-hydrogen-content dosimeter is X- and gamma-ray energy-dependent and has a known neutron response, the total acid production can be considered as a combined function of the neutron and gamma radiations. Subtraction of the gamma-produced acids as measured by the fast neutron insensitive chemical dosimeter systems (Reference 32) left a given quantity of acid produced by the neutrons. Division of this neutron-produced acid by the acid yield per rep yielded a neutron dose in terms of rep.

Gamma measurements in the presence of neutrons were accomplished by using the hydrogen-free dosimeters. Since all chemical dosimeters are sensitive to thermal neutrons the thermal neutron dose was calculated independently from cadmium-gold difference measurements. The data were then corrected by subtraction of 6.7 roentgen equivalents per thermal neutron rep (Reference 34).

C.2.3 Neutron Threshold Devices. A complete description of the neutron system used for instrumenting the structures can be found in Reference 12. Thermal and epithermal neutron flux was measured with gold foils by the cadmium difference method. This technique yields the flux of neutrons below the cadmium cutoff of about 0.3 electron-volt. Intermediate energy neutrons were measured with a series of three boron-shielded fission-threshold-detectors; Pu^{239} (~3.7 kev), Np^{237} (~0.7 Mev), and U^{238} (~1.5 Mev). High energy neutrons were measured with sulfur detectors having an effective threshold of [illegible] Mev. The cadmium cutoff and the various energy thresholds are not clearly defined points. For this reason neutron fluxes in this report will be identified with detectors rather than with energy ranges.

The accuracy of these detectors is approximately ±15 percent for doses greater than 25 rep. Measurements are unreliable below 25 rep and cannot be made below 5 rep. The detectors were calibrated and read by Project 2.3.

C.3 INSTRUMENTATION LAYOUT

The objective of nuclear radiation instrumentation was to determine the effectiveness of the buried structures for providing radiation protection. Accordingly, the structures were instrumented to measure the gamma and neutron dose that would be received at a nominal height of three feet above the floor of the structure.

Since the activities produced in the threshold detectors are relatively short-lived, structure 3.2f, which was to be instrumented with these detectors, was equipped with an aluminum tube from which the threshold devices could be withdrawn by means of a cable system within a few minutes after shot time. The structural details of the cable system are given in Appendix A.

Since none of the other dose detection systems require early recovery, their locations were controlled only by the data that were desired. A film packet, a chemical dosimeter, and in some cases a thermal-neutron detector were installed in each of the structures. The detectors were taped to the tripod of the scratch-type deflection gages at a height of three feet above the floor level of the structure. In this method of location each detector was approximately at the center of the 20-foot sections and at the center of the width of the structure.

In order to calculate transmission factors it was necessary to obtain free-field readings. Neutron spectral data were obtained from the line of stations established by Project 2.3 at 100-yard intervals west from ground zero. In addition [illegible] dosimeter and film packet free-field stations were located at the ranges of the structures tested.

C.4 RESULTS AND DISCUSSION

Most of the free-field NBS-[illegible] film packets, which cannot measure dosages greater than 70,000 r, were overexposed, and the rest were either neutron activated or lost in processing. Therefore, the free-field film packet data obtained for Project 2.4 were plotted as a function of distance and extrapolated to the ranges of interest (Reference [illegible]). It is recognized that the validity of the linear extrapolation to close ranges is open to question, but no other procedure presented itself. The doses resulting from this curve are given in Table C.1 along with the other free-field dose measurements. The chemical dosimeter data were obtained from a smoothed curve through the

TABLE C.1 FREE-FIELD GAMMA AND NEUTRON MEASUREMENTS

Structure	Gamma Dose Film	Neutron Dose Foil Method
	r	rep
3.2a	2.35×10^{5}	1.92×10^{5}
3.2b, c, d, e, f	1.89×10^{5}	1.62×10^{5}
3.2g, h, j	1.35×10^{5}	1.24×10^{5}
3.2k, l, m	1.02×10^{5}	7.65×10^{4}

ABLE C.2 GAMMA-SHIELDING CHARACTERISTICS OF PROJECT 3.2 STRUCTURES: SHOT PRISCILLA, FRENCHMAN FLAT

Structure	Earth Cover, ft	Dose, r		Transmission Factor, Di/Do	
		Film Badge	Chemical Dosimeter	Film Badge	Chemical Dosimeter
3.2a	7.5	0.2	<5	1×10^{-6}	$<2 \times 10^{-5}$
3.2b	10.0	0.0	<5		$<3 \times 10^{-5}$
3.2c	7.5	0.0	<5		$<3 \times 10^{-5}$
3.2d	7.5	0.0	<5		$<3 \times 10^{-5}$
3.2e	7.5	0.0	<5		$<3 \times 10^{-5}$
3.2f	5.0	7.7	<5	3.8×10^{-5}	$<3 \times 10^{-5}$
3.2g	7.5	0.0	<50*		$<4 \times 10^{-4}$
3.2h	7.5	0.0	<5		$<4 \times 10^{-5}$
3.2j	7.5	0.0	<5		$<4 \times 10^{-5}$
3.2k	7.5	0.0	<5		$<5 \times 10^{-5}$
3.2l	7.5	0.0	<5		$<5 \times 10^{-5}$
3.2m	5.0	1.3	<5	1.2×10^{-5}	$<5 \times 10^{-5}$

* High range dosimeter accidentally installed.

TABLE C.3 NEUTRON-SHIELDING CHARACTERISTICS OF PROJECT 3.2 STRUCTURES: SHOT PRISCILLA, FRENCHMAN FLAT

Structure	Earth Cover, ft	Dose, rep		Transmission Factor, Di/Do	
		Film Badge	Chemical Dosimeter	Film Badge	Chemical Dosimeter
3.2a	7.5	†	<10	†	$<5 \times 10^{-5}$
3.2b	10.0	†	<10	†	$<6 \times 10^{-5}$
3.2c	7.5	†	<10	†	$<6 \times 10^{-5}$
3.2d	7.5	†	<10	†	$<6 \times 10^{-5}$
3.2e	7.5	†	<10	†	$<6 \times 10^{-5}$
3.2f	5.0	<25	<10	$<1.3 \times 10^{-4}$	$<6 \times 10^{-5}$
3.2g	7.5	†	<50*	†	$<4 \times 10^{-4}$
3.2h	7.5	†	<10	†	$<8 \times 10^{-5}$
3.2j	7.5	†	<10	†	$<8 \times 10^{-5}$
3.2k	7.5	†	<10	†	$<2 \times 10^{-4}$
3.2l	7.5	†	<10	†	$<2 \times 10^{-4}$
3.2m	5.0	†	<10	†	$<2 \times 10^{-4}$

* High range dosimeter accidentally installed.

† Not instrumented.

measured values. The threshold detector dose figures were obtained from Project 2.3 (Reference 12).

Gamma and neutron doses inside the shelters are listed in Tables C.2 and C.3, respectively. Results shown as less than a given figure indicate the lower limit of detector sensitivity in cases where the detector gave no reading. Although the early recovery of the threshold detector system in structure 3.2f was unsuccessful, as pointed out in Chapter 4, it was nevertheless possible to set an upper limit to the dosage received, based on the sulfur detector. It was evident that these shelters provided adequate protection against initial nuclear radiations under the test conditions, in agreement with predictions made by Project 2.4 (Reference 10).

C.5 CONCLUSIONS

The underground shelters constructed by Project 3.2 provided adequate protection against the initial gamma and neutron radiation from the Shot Priscilla device for the slant ranges of the test.

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Ardith Jarrett
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