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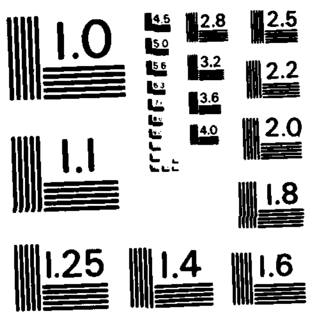

MICROCOPY RESOLUTION TEST CHART
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PHYSICAL MODELING TECHNIQUES FOR MISSILE
AND OTHER
PROTECTIVE STRUCTURES

Papers Submitted for Presentation During the
American Society of Civil Engineers
National Spring Convention
Las Vegas, April 1982

Sponsored By the ASCE Engineering Mechanics Division
Committee on Experimental Analysis and Instrumentation

Edited By: T. Krauthammer and C. D. Sutton

DEPARTMENT OF THE AIR FORCE
HEADQUARTERS BALLISTIC MISSILE OFFICE (AFSC)
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29 Jun 83

SUBJECT: Review of Material for Public Release

TO: Mr. James Shafer
Defense Technical Information Center
DDAC
Cameron Station
Alexandria, VA 22314

The following technical papers have been reviewed by our office and are approved for public release. This headquarters has no objection to their public release and authorizes publication.

1. (BMO 81-296) "Protective Vertical Shelters" by Ian Narain, A.M. ASCE, Jerry Stepheno, A.M. ASCE, and Gary Landon, A.M. ASCE.

2. (BMO 82-020) "Dynamic Cylinder Test Program" by Jerry Stephens, A.M. ASCE.

3. (AFCMD/82-018) "Blast and Shock Field Test Management" by Michael Noble.

4. (AFCMD/82-014) "A Comparison of Nuclear Simulation Techniques on Generic MX Structures" by John Bet-.

5. (AFCMD/82-013) "Finite Element Dynamic Analysis of the DCT-2 Models" by Barry Bingham.

6. (AFCMD/82-017) "MX Basing Development Derived From H. E. Testing" by Donald Cole.

7. (BMO 82-017) "Testing of Reduced-Scale Concrete MX-Shelters-Experimental Program" by J. I. Daniel and D. M. Schultz.

8. (BMO 82-017) "Testing of Reduced-Scale Concrete MX-Shelters-Specimen Construction" by A. T. Ciolko.

9. (BMO 82-017) "Testing of Reduced-Scale Concrete MX-Shelters-Instrumentation and Load Control" by N. W. Hanson and J. T. Julien.

10. (BMO 82-003) "Laboratory Investigation of Expansion, Venting, and Shock Attenuation in the MX Trench" by J. K. Gran, J. R. Bruce, and J. D. Colton.

11. (BMO 82-003) "Small-Scale Tests of MX Vertical Shelter Structures" by J. K. Gran, J. R. Bruce, and J. D. Colton.

12. (BMO 82-001) "Determination of Soil Properties Through Ground Motion Analysis" by John Frye and Norman Lipner.

13. (BMO 82-062) "Instrumentation for Protective Structures Testing" by Joe Quintana.

14. (BMO 82-105) "1/5 Size VHS Series Blast and Shock Simulations" by Michael Noble.

15. (BMO 82-126) "The Use of Physical Models in Development of the MX Protective Shelter" by Eugene Sevin.

*16. REJECTED: (BMO 82-029) "Survey of Experimental Work on the Dynamic Behavior of Concrete Structures in the USSR" by Leonid Millstein and Gajanen Sabnis.

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DYNAMIC CYLINDER TEST PROGRAM

by

Jerry E. Stephens, A.M. ASCE[1]

INTRODUCTION

The Dynamic Cylinder Test (DCT) program consists of three tests on models of the tube section of the generic, horizontal Missile-X (MX) shelter (see Table 1). The objective cf the program is to analytically and experimentally determine the loads on and response of the shelter and adjacent soil media subjected to nuclear airblast and airblast-induced ground shock loadings. The first two tests in the program, the DCT-1 and DCT-2 tests, have been completed. The particular areas of concern in these tests were,

1. the effects of structural detail (SALT ports, breakout joints, mass simulator support (MSS) beams, floor, and thickness-to-radius (t/r) ratio of the tube) on shelter response,

2. the character of the loadings across the structure/soil interfaces, and

3. the development/refinement of nuclear blast simulation techniques.

The DCT-1 and DCT-2 tests were performed by the New Mexico Engineering Research Institute (NMERI) at the Civil Engineering Research Facility (CERF) on Kirtland Air Force Base (KAFB), Albuquerque, New Mexico. In the DCT-1 test, three shelter models were subjected to a side-on airblast

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TABLE 1. DCT TEST MATRIX

Test Event	Scale	Model	Structural Features		Airblast Environment
			Details	t/r*	
1	1/5	A	Floor		3 MPa, 24 kt
		B	SALT Ports, Breakout Joints, Floor	0.22	Sideon; Simulate
		C	SALT Ports, Floor	0.22	1/10 Slope Berm
2	1/4.22	D	SALT Ports, Egress Beams	0.28	4 MPa, 40 kt
		E	SALT Ports, Egress Beams	0.19	Transverse; 18 MPa
					Axial; 50 deg
					Attack Angle
3	1/4	F	SALT Ports, Egress Beams (Precast)	0.24	4 MPa, Transverse;
		G	SALT Ports, Egress Beams (Cast-in-Place)	0.24	18 MPa, Axial;
					50 deg Attack Angle

* Cylinder wall thickness to inside radius ratio

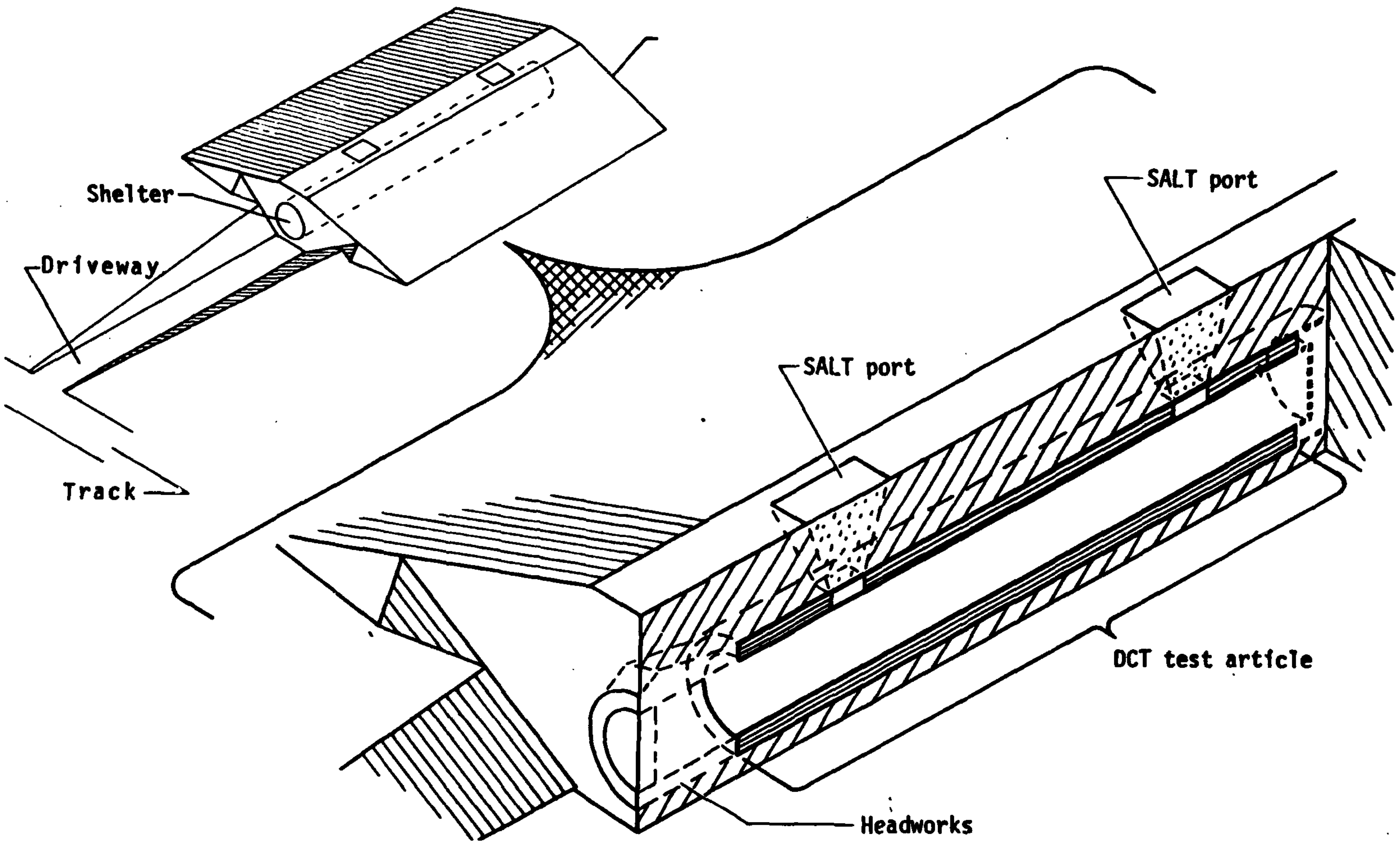
loading. In the DCT-2 test, two shelter models were subjected to a combined axial and transverse airblast load. The simulated nuclear airblast loadings were generated using a High Explosive Simulation Technique (HEST). The instrumentation in the tests consisted of steel strain, relative displacement, acceleration, structure/media interaction (SMI), and normal stress gages in the models; and blast pressure and soil stress and acceleration gages in the adjacent soil (freefield).

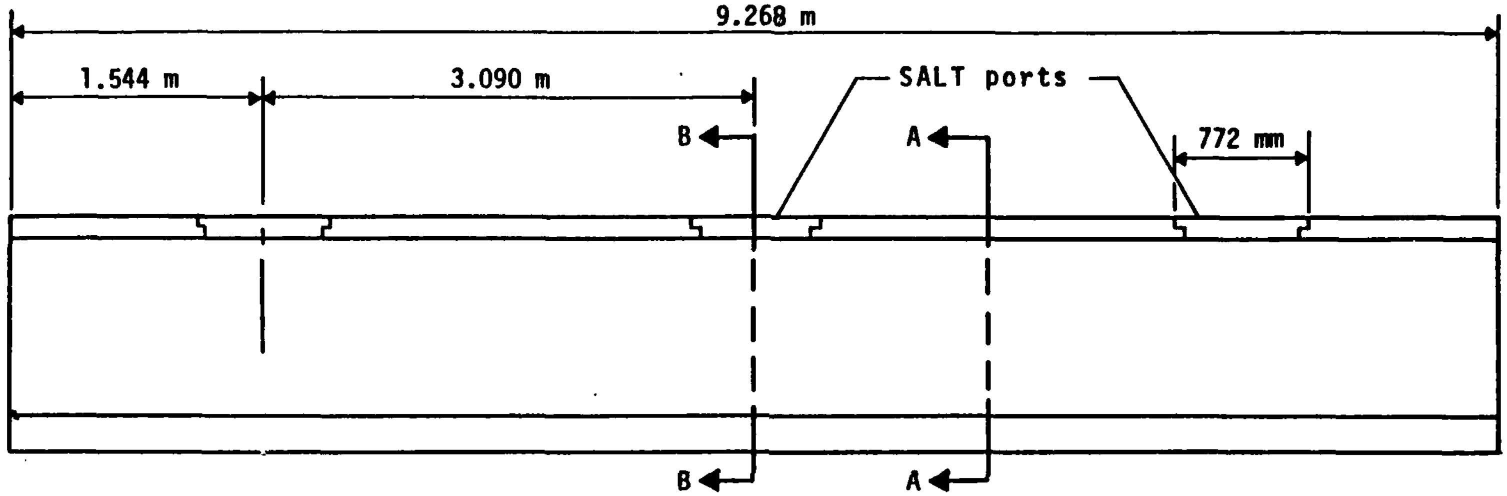
The behavior of the test structures was modeled analytically prior to the tests. The effectiveness of the modeling techniques was evaluated by comparing the calculated results with the test data.

TEST ARTICLE

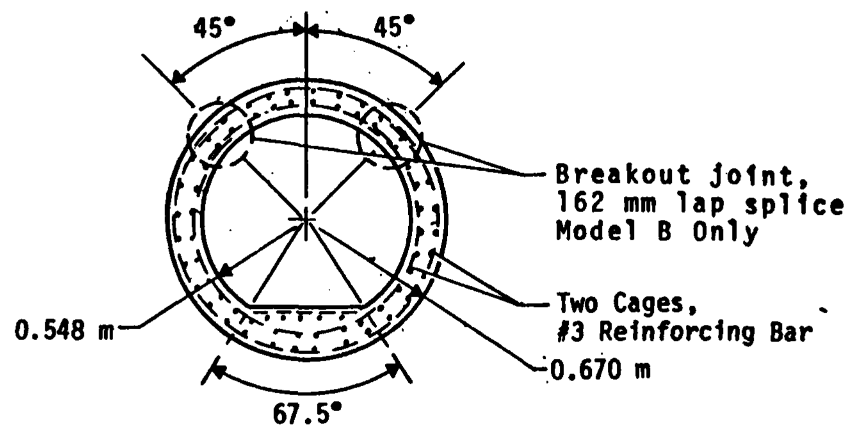
Description

The DCT-1 and DCT-2 test structures were 1/5-size and 1/4.22 size models, respectively, of the cylinder (tube) section of the generic MX horizontal shelter, as shown in Figure 1. The DCT-1 structures, designated the A, B, and C models, were open reinforced concrete cylinders with a common outside diameter of 1.341 m and a cylinder t/r ratio of 0.22 (Figure 2). Model A was a monolithic cylinder without SALT ports or breakout joints. Model B had both SALT ports and breakout joints. Model C had only SALT ports. The DCT-2 structures were reinforced concrete canisters capped with removeable closures. These structures, designated the D and E models, had a common outside diameter of 1.341 m and cylinder t/r ratios of 0.28 and 0.19, respectively (Figure 3). The inside surface of the DCT-2 models was lined with sheet steel. These models also had SALT ports and mass simulator support beams.

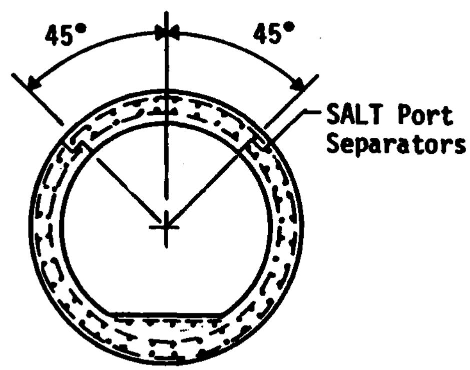

Shelter
Driveway
Track
SALT port
SALT port
DCT test article
Headworks



Longitudinal Section

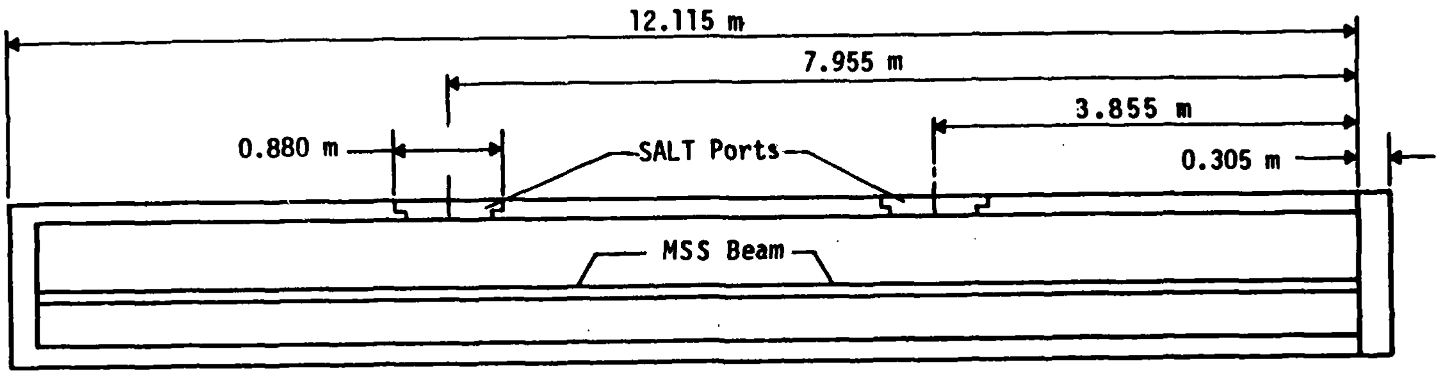


Section A-A

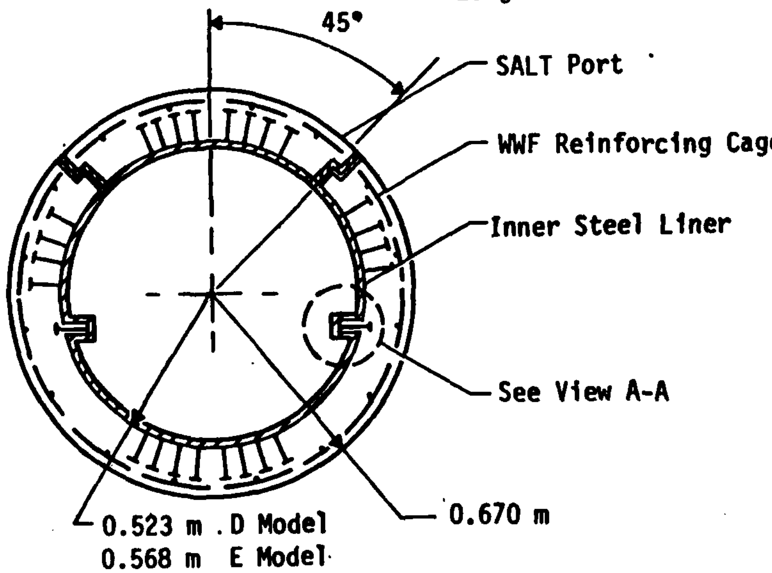


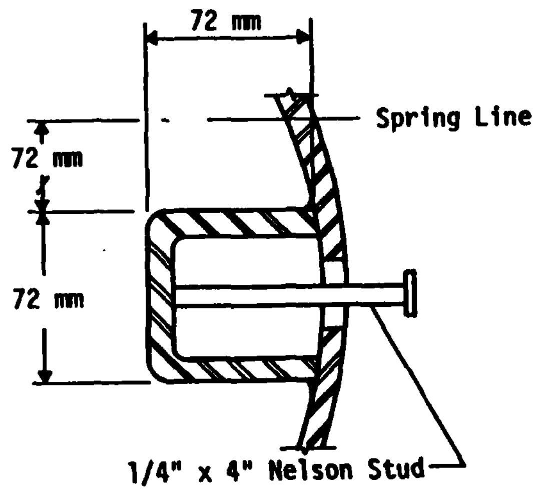
Section B-B

Models B&C Only



Longitudinal Section





Egress Beam
View A-A

The concrete in the DCT-1 and DCT-2 models had a design 28-day unconfined compression strength of 59 MPa. The mix proportions for the concrete are shown in Table 2. The location, percentage, and strength of the reinforcing steels used in the models are indicated in Table 3.

The SALT ports in the DCT-1 and DCT-2 models were removeable panels spaced along the crown of the structure. The DCT-1 models each had three ports; the DCT-2 models, two ports. These ports modeled the missile-presence verification inspection panels planned for the actual shelter (such ports will possibly be required by future Strategic Arms Limitation Talks (SALT) agreement). Each port consisted of a steel lined opening and mating lid, as shown in Figure 4a. The ports were reinforced consistent with the reinforcing in the main structure, with the addition of shear ties encircling both the lids and the openings.

The breakout joints in the DCT-1 B model consisted of lap splices in the circumferential reinforcing bars located 45 deg on either side of the crown of the cylinder, as shown in Figure 4b. These splices were purposely underdesigned to facilitate breakout of the missile through the crown of the cylinder pursuant to launch.

Each DCT-2 model contained two MSS beams cast integrally on the model walls immediately below the springlines, as shown in Figure 4c. These beams, running the full length of the cylinders, act as support rails for a missile mass simulator deception device planned for the MX system.

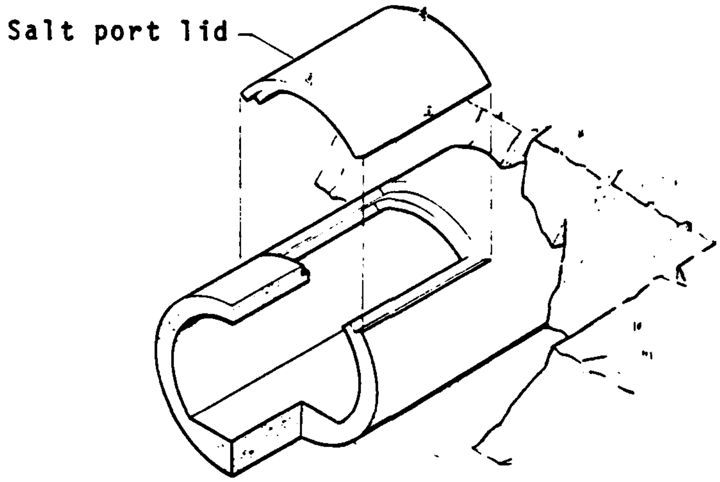
The closures and end walls on the DCT-2 models, constructed of reinforced concrete, were purposely overdesigned to insure their survival dur"ng the tes .

TABLE 2. CONCRETE MIX PROPORTIONS FOR THE DCT-1 AND DCT-2 MODELS

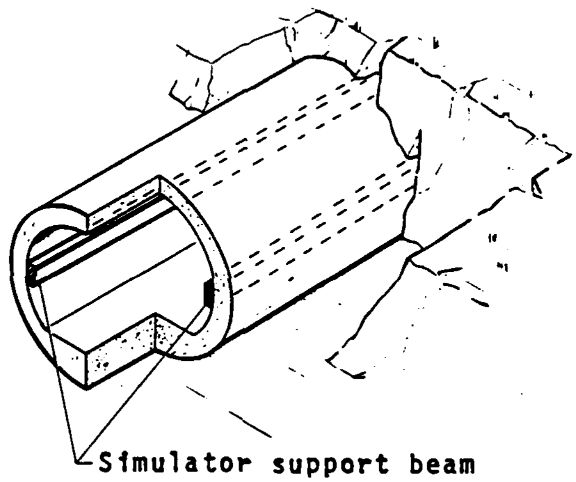
Material	Quantity	
	DCT-1	DCT-2
Cement (Type I)	474 kg	595 kg
Fly ash	84 kg	----
Fine aggregate (washed sand)	605 kg	648 kg
Coarse aggregate (9.5 mm crushed stone)	949 kg	943 kg
Water	193 kg	191 kg
Pozzolith (Master Builders 300R)	1820 ml	3312 ml
High range water reducer (Master Builders LA-8)	7278 ml	11325 ml
Yield	1 m^3	1 m^3
Slump	222 mm	222 mm
Water/Cement ratio	0.35	0.32

TABLE 3. SUMMARY OF THE REINFORCING IN THE DCT-1 AND DCT-2 MODELS

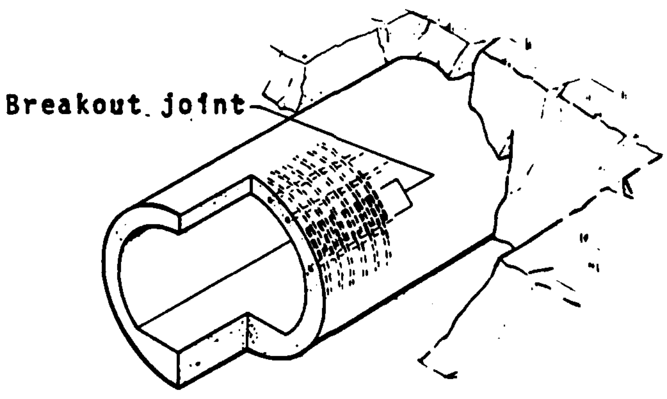
Model	Reinforcement			
	Description	Type	Percent by Volume	
			Long.	Circum.
DCT-1				
A,B,C	Inner Cage	#3 Grade 60 Bars	0.5	0.5
	Outer Cage	#3 Grade 60 Bars	0.5	0.5
DCT-2				
D	Inner Liner	2.7 mm A36 Plate	1.6	1.8
	Outer Cage	#3 Grade 60 Bars	0.2	0.5
E	Inner Liner	2.7 mm A36 Plate	2.4	2.6
	Outer Cage	#3 Grade 60 Bars	0.2	0.5



a. SALT port detail



b. MSS beam detail



c. Breakout joint detail.

Fabrication

The DCT-1 and DCT-2 models were cast in a vertical orientation. The inside of the DCT-1 models was formed using reuseable segmented steel cylinders; the inside of the DCT-2 models, using the models permanent inner steel lining. The requisite reinforcing cages were fabricated around the inner forms. The outside forms, consisting of reuseable segmented steel cylinders, slipped over the completed inner form/reinforcing cage assembly. A uniform wall thickness was maintained in the models by placing steel spacer rods between the inner and outer forms.

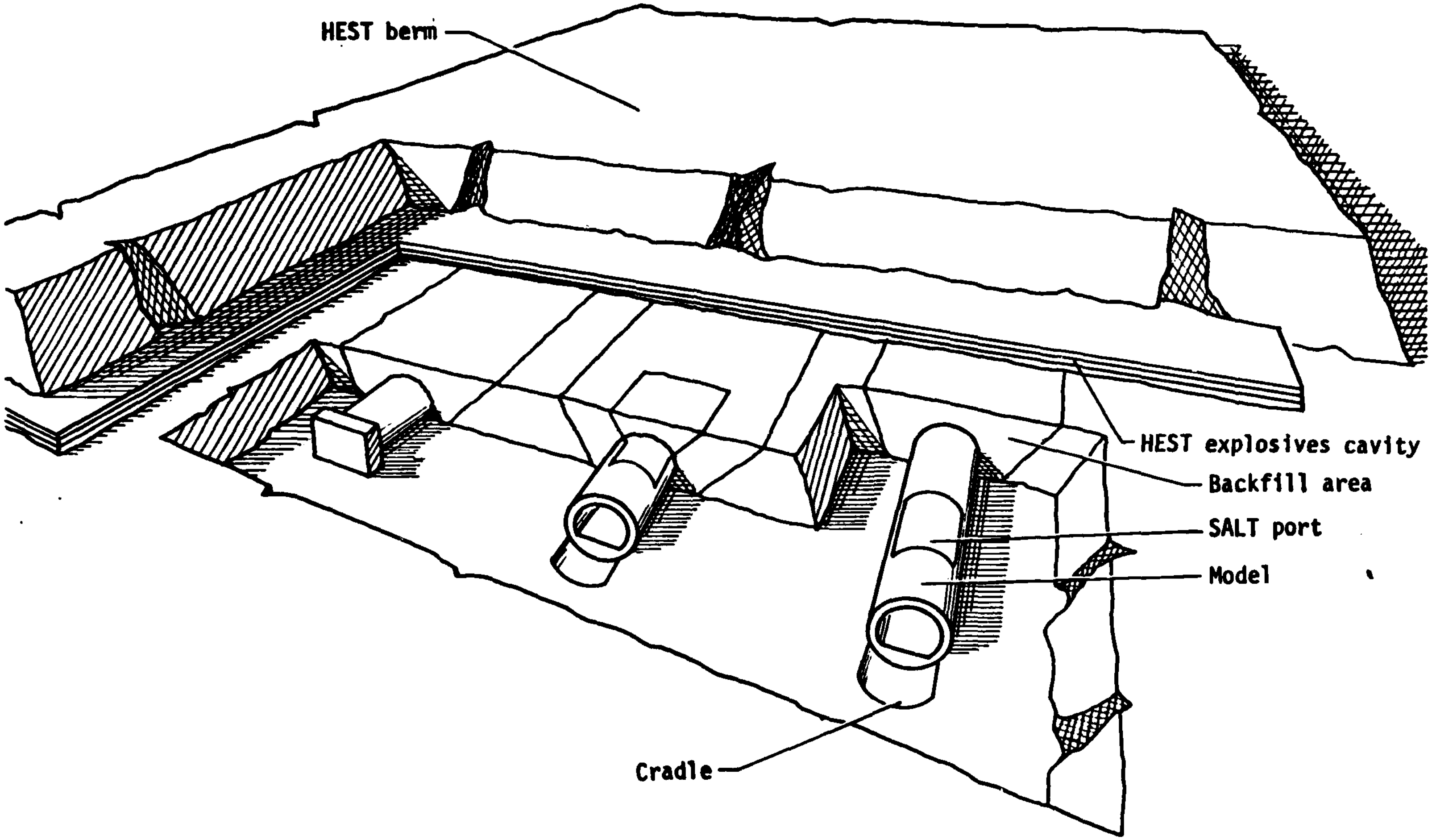
The models were cast using two vertical steel pipes placed between the inner and outer form walls. The pipes were placed in the models during form assembly. The pipes were gradually withdrawn as the level of concrete rose in the forms. Inspection holes were drilled in the lower wall of each SALT port frame and an inspection panel cut in the outside form to permit observation of the consolidation of the concrete under the frame. During casting, the concrete was consolidated using both external and internal vibration. The SALT port lids were cast separately from the models using the same basic concrete used in the models but with a lower slump (less water reducing agent was added to the mix).

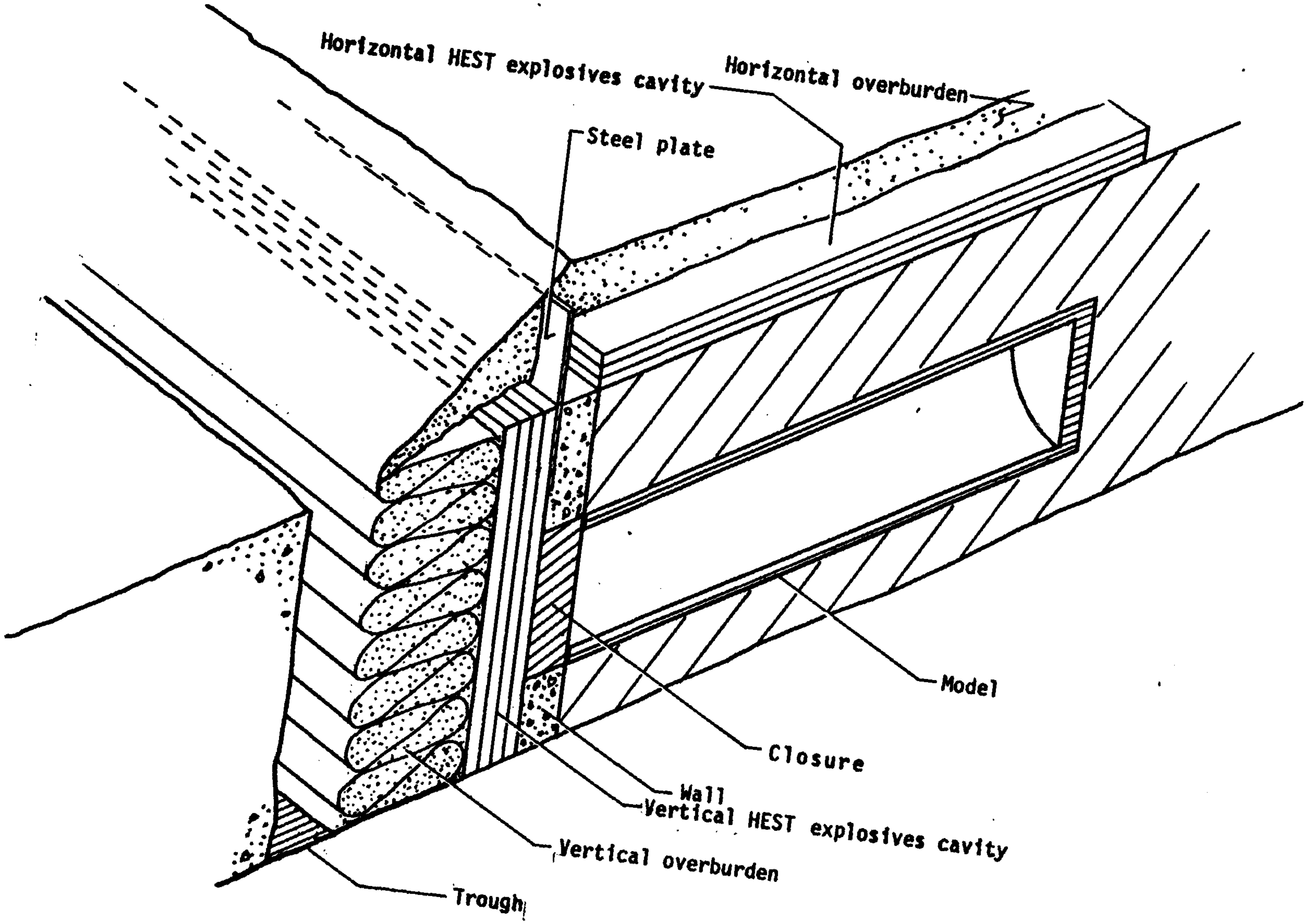
The models were allowed to cure in the forms undisturbed for a minimum of seven days. The forms were subsequently stripped, the exposed concrete surfaces sprayed with curing compound, and the models turned to their normal horizontal orientation. Turning of the models was accomplished using a special lifting fixture fabricated for this purpose.

During model fabrication, specimens were cast from each batch of concrete for material strength and response testing. All sampling and testing was performed in accordance with the applicable American Society for Testing and Materials (ASTM) standards.

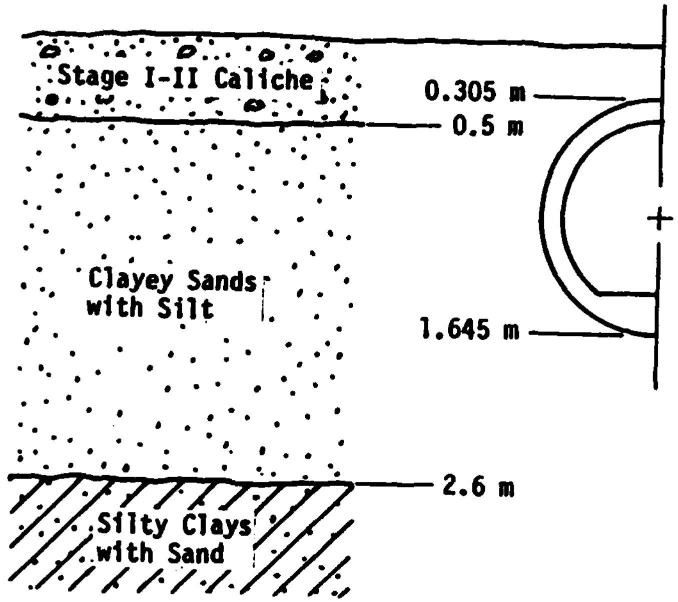
TEST FACILITY

The DCT-1 and DCT-2 tests were conducted at the CERF McCormick Ranch test site. The layout of the DCT-1 and DCT-2 testbeds is shown in Figures 5 and 6, respectively. The soil profiles at the two testbed locations are shown in Figure 7. In the DCT-1 test, the models were situated parallel in the testbed, perpendicular to the direction of propagation of the airblast load. In the DCT-2 test, the models were placed parallel in the testbed, parallel to the direction of propagation of the airblast load. The DCT-1 models were buried 305 mm below the ground surface; the DCT-2 models, 361 mm. In both tests the models were placed in 120 deg cradles cut in situ McCormick Ranch soil. The DCT-1 models rested on a thin layer of soil matching grout poured in the cradles. The DCT-2 models were seated in the cradles on a 25 mm layer of moist sand. On either side of the cradles was a 356 mm wide horizontal bench. The sides of the trenches around the models sloped at 45 deg from the edge of the bench to the ground surface. The trenches were backfilled with native McCormick Ranch soil compacted to a target unit weight of 1760 kg/m^3. The density of the recompacted material was checked at 200 mm intervals using a Troxler nuclear density meter. At the SALT ports, a sheet of plastic was placed in the backfill isolating the fill material over the ports from the rest of the backfill. The backfill over the SALT ports in the DCT-1 B model was compacted to a target unit weight of 1602 kg/m^3. The backfill over the rest of the SALT ports was compacted to a target unit weight of 1760 kg/m^3.

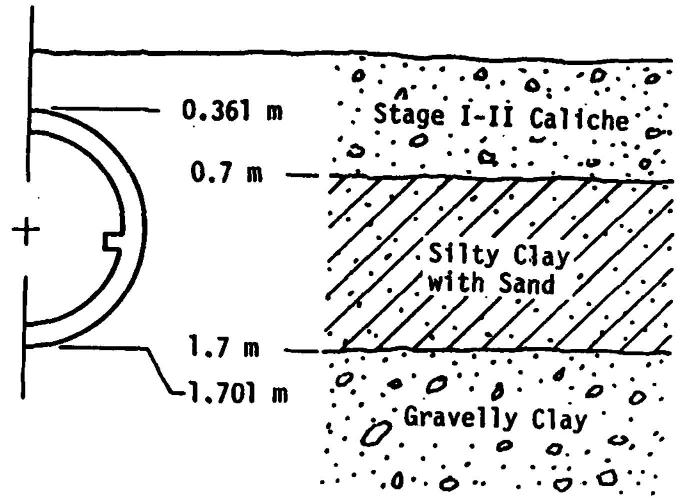

HEST berm
HEST explosives cavity
Backfill area
SALT port
Model
Cradle



Horizontal HEST explosives cavity
Horizontal overburden
Steel plate
Model
Closure
Wall
Vertical HEST explosives cavity
Vertical overburden
Trough



a) DCT-1 in situ soil profile



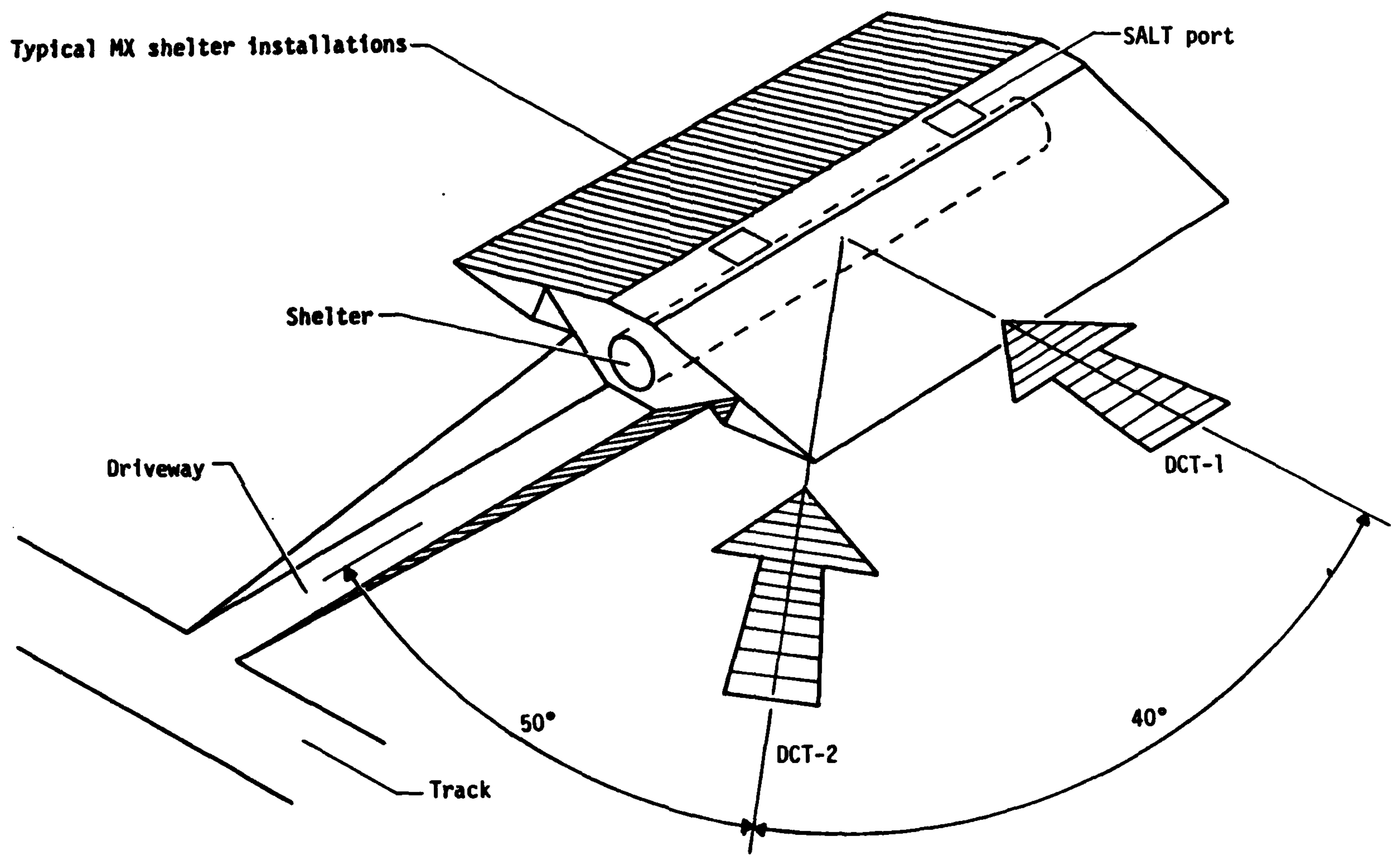
b) DCT-2 in situ soil profile

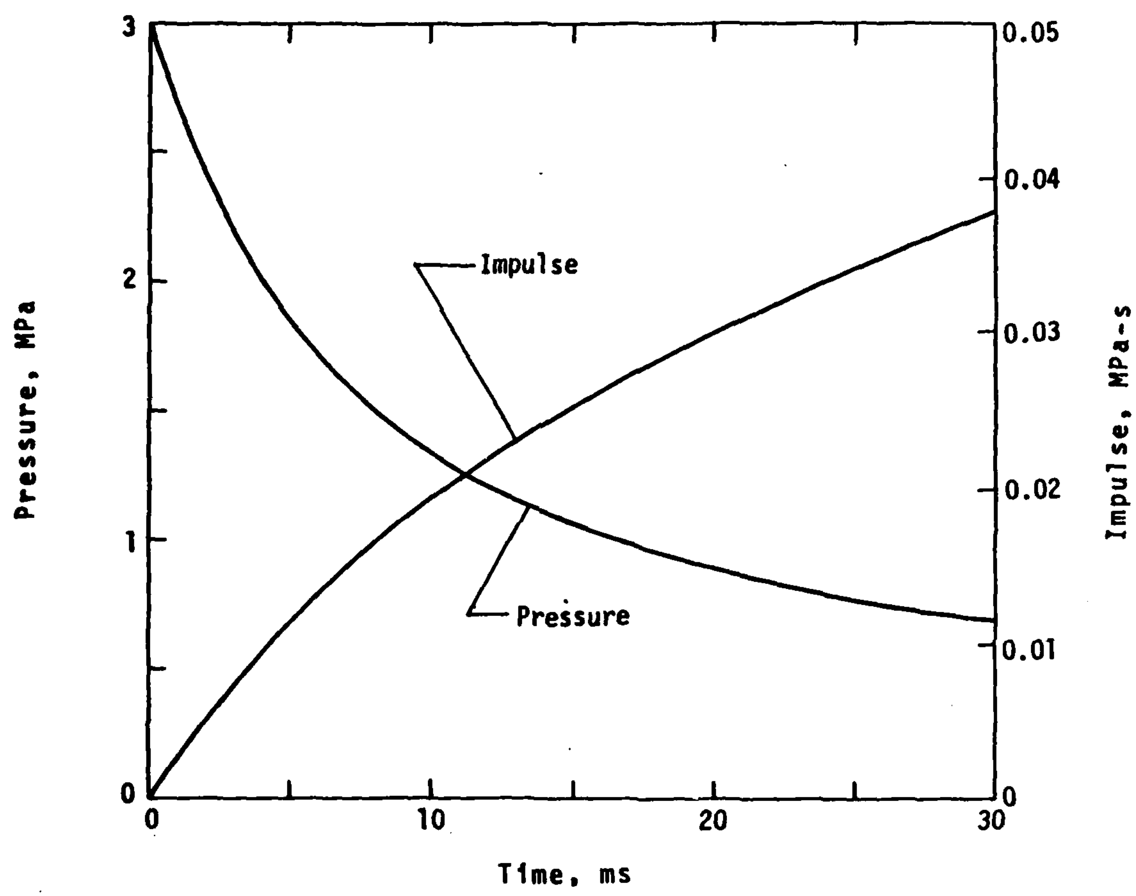
In the DCT-2 test, at the closure end of the models, a concrete headwall was constructed transverse to the models. The models extended through this wall, with the surface of their closures flush with the surface of the wall. The wall, 229 mm thick, was constructed of concrete with a design 28-day unconfined compression strength of 34 MPa. The wall was reinforced 0.5 percent by volume. This headwall functioned as part of the environment simulator and was not intended to accurately model any portion of the actual shelter system.

TEST ENVIRONMENT

The DCT-1 and DCT-2 test environments were generated using HEST's. A HEST is a method for simulating the incident airblast overpressure and airblast-induced ground shock motions resulting from a nuclear explosion; it consists of an explosion cavity confined by an earthen overburden placed over a testbed. The desired peak overpressure and impulse time history are produced by varying the charge and overburden densities and the cavity and overburden dimensions. The proposed HESTs for the DCT-1 and DCT-2 tests were designed using the Air Force Weapons Laboratory (AFWL) Lock-up Impulse Code (Reference 1).

The required environment for the DCT-1 test consisted of a traveling airblast at the 3.0 MPa peak overpressure range from the near surface detonation of a 24 kt (scaled) yield nuclear weapon (Figure 8). The airblast had to sweep the testbed side-on to the structures at a rate simulating a nuclear airblast traversing a berm with slope of 1/10. The airblast pressure and impulse time histories for this environment are shown in Figure 9. The HEST designed to generate this environment

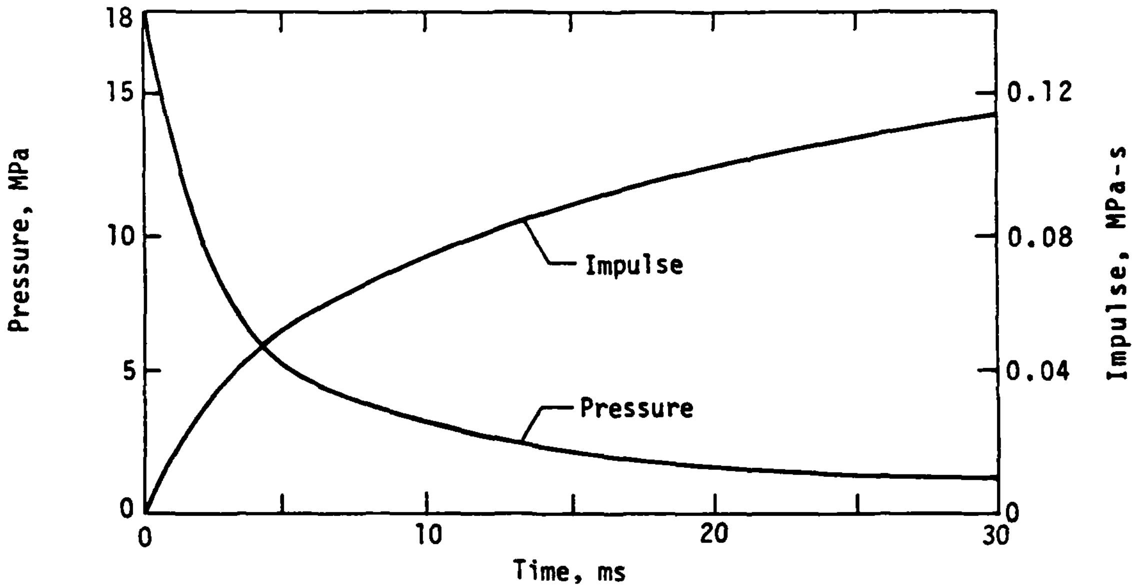

Typical MX shelter installations
SALT port
Shelter
Driveway
Track
DCT-1
DCT-2
50°
40°



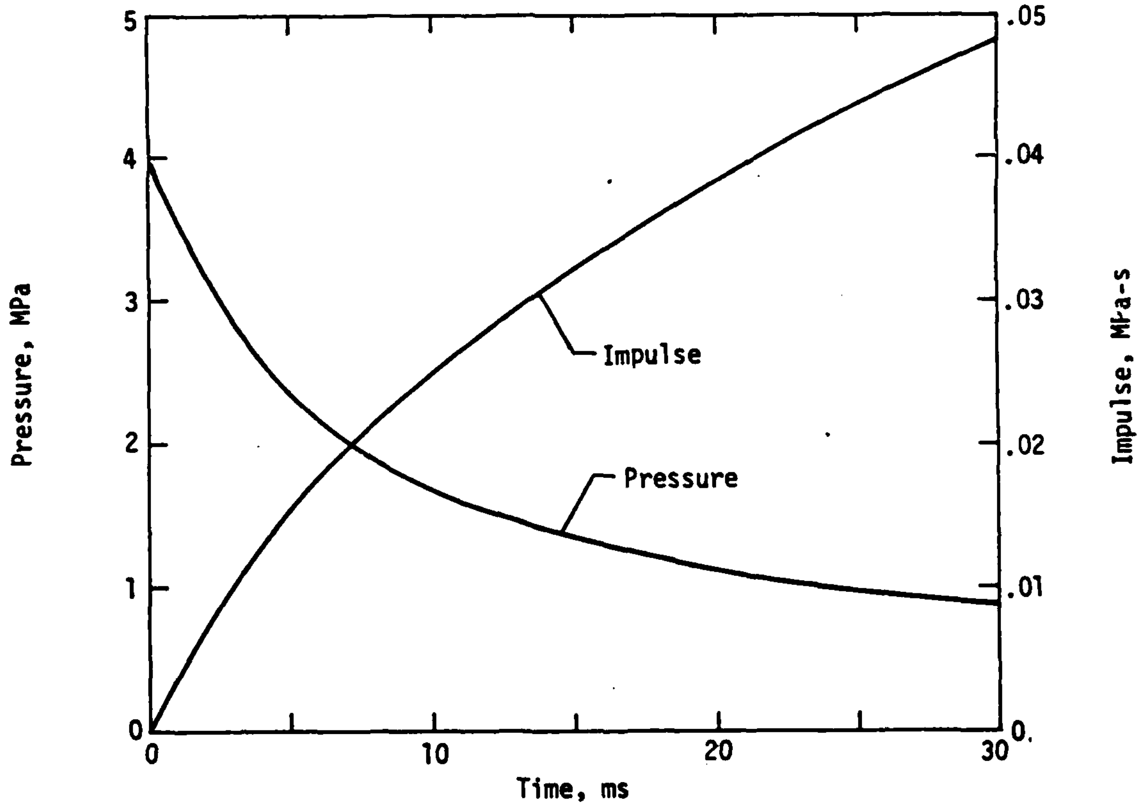
Pressure, MPa
Impulse, MPa-s
Time, ms
Impulse
Pressure
0
1
2
3
0
0.01
0.02
0.03
0.04
0.05
0
10
20
30

consisted of a 100 percent foam filled explosion cavity, 333 mm high, covered with 1.22 m of overburden, as shown in Figure 5. The charge density of the cavity was 6.25 kg/m^3. The cavity contained four layers of 0.085 kg/m detonation cord. The cord was placed in skewed parallel arrays to produce the desired airblast propagation rate. The sweep rate of the airblast was adjusted to a value of 1653 m/s so that the angle of incidence of the shock wave induced in the soil matched that which would be induced for an airblast sweeping a 1/10 slope. The overburden on the explosion cavity consisted of uncemented, uncompacted McCormick Ranch soil placed at a unit weight of 1442 kg/m^3.

The required environment for the DCT-2 test consisted of a traveling nuclear airblast with a 4.0 MPa peak overpressure and scaled 40 kt yield. The airblast had to sweep across the models at an attack angle of 50 deg (Figure 8). This environment was modeled by applying a combined axial and transverse load to the structures using a vertical and a horizontal HEST, respectively. The airblast pressure and impulse curves associated with these environments are shown in Figure 10. The vertical HEST, generating a design 18.0 MPa peak overpressure, consisted of a 100 percent foam filled explosion cavity, 457 mm wide, bermed with 1.83 m of soil placed at 1441 kg/m^3 (Figure 6). The HEST was constructed directly against the headwall and model closures. The charge density in the HEST cavity was 16.66 kg/m^3. The cavity contained six layers of 0.085 kg/m detonation cord. The HEST was fired vertically from top to bottom at a shock propagation rate of 6400 m/s (maximum burn rate for the detonation cord used). The horizontal HEST, generating the transverse load, consisted of a 100 percent foam filled cavity 318 mm high, covered with



a. Design axial airblast environment.



b. Design transverse airblast environment.

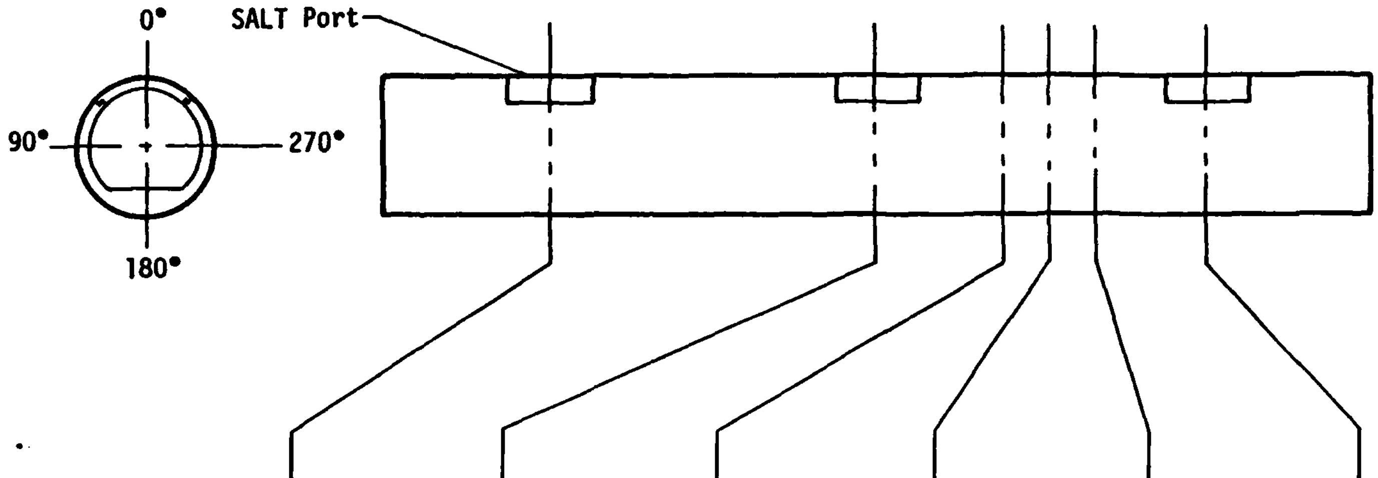
1.83 m of overburden placed at a unit weight of 1441 kg/m (Figure 6). The charge density in the cavity was 8.01 kg/m . The cavity contained four layers of 0.085 kg/m detonation cord. The cord was placed in skewed parallel arrays to produce an airblast propagation rate parallel to the models of 3005 m/s. Detonation of the vertical and horizontal HESTs was staggered so as to simulate the smooth sweep of an airblast across the testbed.

Prior to each of the main test events, two calibration tests were conducted using the proposed HEST designs to check the adequacy of the generated simulations.

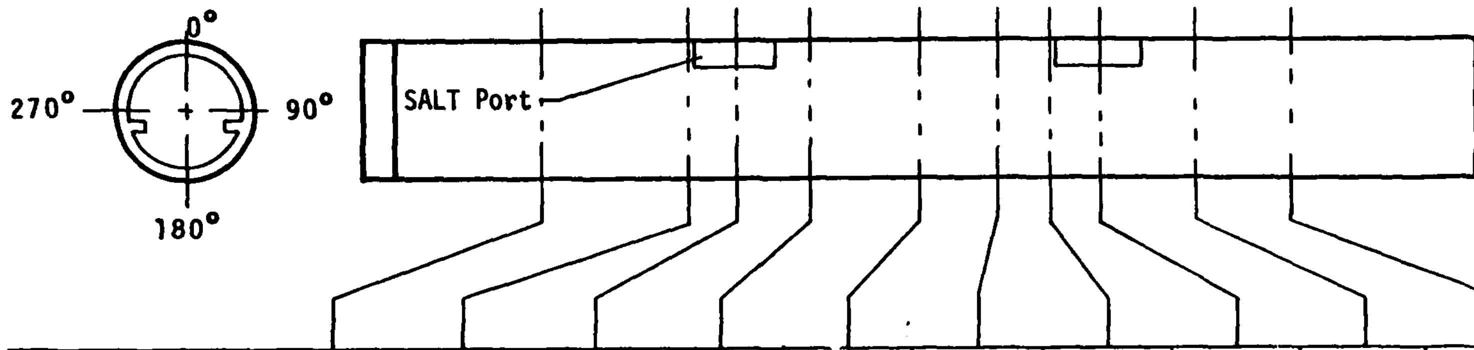
INSTRUMENTATION

The instrumentation layouts for the DCT-1 and DCT-2 tests are shown in Figures 11 and 12, respectively. The structural instrumentation in the models consisted of strain, relative displacement, acceleration, and SMI gages. Stress and acceleration gages were also placed in the recompacted soil immediately adjacent to the models and in situ soil. The airblast loading generated by the HESTs was measured using blast pressure gages. The number and type of transducer employed for each kind of measurement are indicated in Table 4. The instrumentation in the DCT-1 test was positioned primarily to monitor ovaling response of the cylinders. In the DCT-2 test, the instrumentation was positioned to monitor both the ovaling and axial response of the models.

Hoop strain was measured at several locations on the circumferential reinforcing bars in the DCT-1 models and on the circumferential reinforcing bars and liner steel in the DCT-2 models. Axial strain measurements were



Hoop Strain	0, 90, 147, 214, 270	0, 90, 180, 270	—	0, 45, 90, 180, 270	—	—
Relative Displacement	—	—	—	—	0-180 90-270	0-180 90-270
Radial Acceleration	0, 90, 180	—	0, 90, 180	—	—	—
SMI	0, 90, 180, 270	0, 56, 90, 135, 180, 225, 270, 304	—	—	—	0, 90, 180, 270
	Azimuth					



	1	2	3	4	5	6	7	8	9	10
Hoop Strain	—	0, 180, 270, 304	0, 180 225,270 304	0, 180 225,270 304	—	—	—	0, 180 270,304	—	—
Longitudinal Strain	0, 180, 270	0, 180 270,304	0, 180 225,270 304	0, 180, 270	0, 180 225,270 304	—	—	0, 180 270,304	—	0, 180, 270
Relative Displacement	—	—	0-180, 90-270	—	—	0-180, 90-270	—	—	0-180, 90-270	—
Radial Acceleration	—	—	—	—	0, 180, 270	—	0	0, 180, 270	—	—
Longitudinal Acceleration	270	—	270	—	270	—	270	270	270	—
SMI	—	—	0, 56, 90, 135 180	—	0, 56, 90, 135 180	—	—	0, 56, 90, 135 180	—	—

Azimuth

also taken on the longitudinal reinforcing bars in the DCT-2 models. Epoxy bonded gages were used at all strain gage locations. At each reinforcing bar installation, two gages were mounted on the bar. These gages were wired so that local bending effects cancelled.

Crown-to-invert and springline-to-springline relative displacements were measured at several locations in each model using linear potentiometers. The potentiometers were mounted across passive relative displacement gages.

Radial structural accelerations were measured at the crown, invert, and springlines of all models. At the springlines of the DCT-2 models, longitudinal accelerations were also measured. The accelerometers were mounted on the interior wall of the models.

Force interactions at the soil/structure interface were measured in both tests using NMERI built SMI gages. The SMI transducer provides a measurement of three mutually orthogonal dynamic stress vector histories, normal stress, circumferential shear stress, and longitudinal shear stress, at the structure/media interface (Reference 2). The SMI gages were mounted in canisters cast in the models during construction. In both the DCT-1 and DCT-2 tests, normal and circumferential shear stress were measured at several locations around the models' circumference. In the DCT-2 test, longitudinal structure/soil shear stresses were also monitored.

High speed motion picture documentation of the response of the interior of the DCT-2 models was performed. Emphasis was placed on observing the behavior of the SALT ports.

All power and signal wires to the model instrumentation were routed on the inside of the models. The wires were collectively exited through cable access pipes at the ends of the models.

Soil stress and motion were measured in the DCT-1 and DCT-2 tests with soil-stress gages (WES type) and accelerometers, respectively. The soil stress gages, mounted in aluminum paddles, were positioned to measure radial soil stress at the crown, invert, and springlines of the models. Soil accelerations were measured with accelerometers mounted in epoxy canisters. Measurements were taken at the soil stress gage locations and at locations between the models in situ material.

The airblast loading generated by the HESTs were measured with blast pressure gages mounted on the surface of the explosion cavities. The gages in the horizontal HESTs were mounted in concrete cylinders placed in the soil flush with the surface of the testbed. The gages in the vertical HEST (DCT-2 only) were mounted in steel canisters cast in the headwall and model closures.

The instrumentation signals were recorded in vans located 600 m from the testbeds. Conditioning and amplification of the electrical signals from the strain, acceleration, and blast pressure measurements were provided by downhole mini-conditioners located in a splice bunker 30 m from the testbeds. The signals from the relative displacement, SMI, and soil stress gages were amplified and conditioned in the vans. The signals were recorded using 28 tract Ampex recorders.

PRETEST ANALYSIS

DCT-1 Test

The DCT-1 pretest calculations were performed using the finite element computer code SAMSON and the finite difference code DEPROSS.

SAMSON is a two-dimensional (2-D) dynamic finite element computer code originally developed by the Illinois Institute of Technology Research Institute; it has been modified and expanded by AFWL (Reference 3). The code is particularly suited for handling problems involving nonlinear material properties and a large number of degrees of freedom. The SAMSON code was used in the DCT-1 test to predict ovaling related velocity, displacement, and strain in the structures and stress at the soil/structure interfaces. DEPROSS is a dynamic finite difference code developed at the Massachusetts Institute of Technology (Reference 4). The DEPROSS code can accomodate both geometric and material nonlinearities in a structure. The DEPROSS code was used to investigate the response of the breakout joints in the B model.

The 2-D model used for the DCT-1 SAMSON prediction consisted of the test structure, the McCormick Ranch backfill, and a section of the in situ McCormick Ranch soil. Roller boundary conditions were applied at both the vertical boundaries and the bottom nodes of the structure/soil-island grid. Sliding separating boundaries were assumed at the contact surface between the structure and soils, and between the SALT ports and the main portion of the structure. The sliding phenomenon is characterized in the SAMSON code by the Coulomb friction law and is limited to small displacement behavior. The reinforced concrete, in situ soil, and backfill soils in the model were treated as piecewise linear elastic-plastic materials. The surface of the structure/soil-island was loaded with a piecewise linear approximation of the design airblast pressure time history.

In the DCT-1 DEPROSS calculations only half of the cylinder was modeled since the structure and loading were assumed symmetric. The model of the structure was divided into circumferential segments, with the segments divided into discrete concrete and steel layers. The concrete and steel were modeled as piecewise linear elastic-plastic materials. The model was loaded by forces applied through the displacement of springs representing the soil adjacent to the structure. The outside ends of the springs were driven by soil motions derived from the motions of the boundary of a void in a soil medium under a surface airblast load.

Based on the SAMSON and DEPROSS calculations, the following predictions were made for the DCT-1 test.

1. The principal structural response would be ovaling, with the long axis of the elliptical deflected shape horizontal. Tensile strains would develop sufficient to cause cracking in the models on the inner surfaces at the crown and invert and outer surfaces at the springlines.

2. The strains at the breakout joints in model B would be significantly below yield values.

3. The peak reflected interface normal stresses at the crown of the models would be approximately twice the level of the incident peak overpressure. The largest reflected peak overpressures would occur over the SALT ports with loose backfill (model B).

4. The peak interface normal stresses at the springlines and invert of the models would be, respectively, 80 and 50 percent lower than the peak normal stress at the crown.

DCT-2 Test

The DCT-2 pretest predictions were performed using three simplified computational techniques. A computer or minicomputer is required for these techniques. They are, however, fairly inexpensive and offer a detailed treatment of the dynamics of the response of the test structures. The three techniques employed were,

1. A Two-Degree-of-Freedom (TDOF) Program to investigate the ovaling response and to determine an average normal load around the circumference of the structure.

2. A Multi-Degree-of-Freedom Elastic-Plastic Spring Mass Program (MDFSMI) to model the axial response.

3. A Multi-Degree-of-Freedom Beam-Column (BEAMCO) Model to investigate the beam-column action.

These simplified procedures assume that the effects of ovaling and axial/beam bending can be decoupled and solved separately.

The ovaling of the cylinders was predicted by a program that models the cylinder as two masses lumped at the crown and invert. The masses are connected by a spring which represents the stiffness of the cylinder in flexure and includes the stiffness resulting from the soil adjacent to the springlines. This system is driven by forces applied through the displacement of springs representing the soil adjacent to the crown and invert. The forced displacements on the outside ends of the soil springs are derived from the displacements of the boundaries of a void in an elastic medium under a pressure load. The calculated displacements of the crown and invert of the cylinder are used to determine a change in curvature and thus bending strains and stresses in the cylinder (Reference 5).

The dynamic axial response of the structures was calculated using a computer code called SPRING (Reference 6). It is a one-dimensional (axial only) multi-degree-of-freedom spring-mass code that models the bending distress. A sketch of the damage observed on the exterior surface of the DCT-2 D model is presented in Figure 14. The damage sustained by the thinner walled E model was similar in nature to, but more severe in degree than, the damage sustained by the D model. Longitudinal tension cracks were observed in the exterior surfaces of the models at the springlines, indicating ovaling of the models occurred under the transverse load. Circumferential tension cracks were observed at the invert of the models opposite the SALT ports. At the first SALT port, these tension cracks were accompanied by compression buckling of the interior steel liner in the upper (crown) portion of the models. In the E model, major compression cracks were observed in the exterior wall paralleling the compression buckles in the interior steel liner. This distress pattern (tension at the invert, compression at the crown) is consistent with that produced by longitudinally bending the structure in a "smile" mode. The test data, presently under examination, supports these observed distress patterns.

SUMMARY AND CONCLUSIONS

The objective of the Dynamic Cylinder Test (DCT) program was to analytically and experimentally determine the response of a buried MX horizontal shelter subjected to a nuclear airblast. The first two tests in the program, the DCT-1 and DCT-2 tests, have been completed. These tests were concerned with the effect of structural detail on shelter response and the character of the structure/soil interaction loadings on the shelter. Pretest predictions were performed for each test. The prediction techniques were evaluated using the test data.

structure as a series of lumped masses joined by springs and dashpots. The computer code SPRING has a subroutine, MATCON, that is used to calculate the forces generated by the springs that represent the concrete. The material model used by MATCON is a strain softening model that unloads along the slope of the initial elastic modulus. The material model also contains a tension cut off. In addition to the concrete, the structures also contained steel liners and reinforcing bars, each of different strength. The steel springs were modeled by an elastic plastic material that allows cyclic loading and tensile or compressive failure. One set of SPRING calculations was performed including shear force interactions at the structure/soil interface.

The beam column response of the structures was modeled using BEAMCO. BEAMCO, a modified version of the code DEPROSS, is a multi-degree-of-freedom spring-lumped-mass program that treats the cylindrical shelter as an equivalent (equal area and moment of inertia) rectangular beam resting on an elastic foundation (Reference 6). The applied loading used in the BEAMCO calculations consisted of a time dependent axial load and an end moment applied at the front of the model. An end moment was applied to the model purely for investigative purposes and did not represent any expected load condition. Axial shear forces were also applied to the BEAMCO model to simulate the shear at the soil/structure interface resulting from axial displacements of the shelter relative to the soil. In the BEAMCO analysis, the structure was represented by 80 mass nodes, the first three simulating the headworks and door region; the remaining ones, the tube. Each node was divided into eight equal flanges. The foundations soils were treated as elastic material represented by springs applied perpendicular to the axis of the cylinder (beam).

Based on the simplified calculations performed, the following predictions were made for the DCT-2 test,

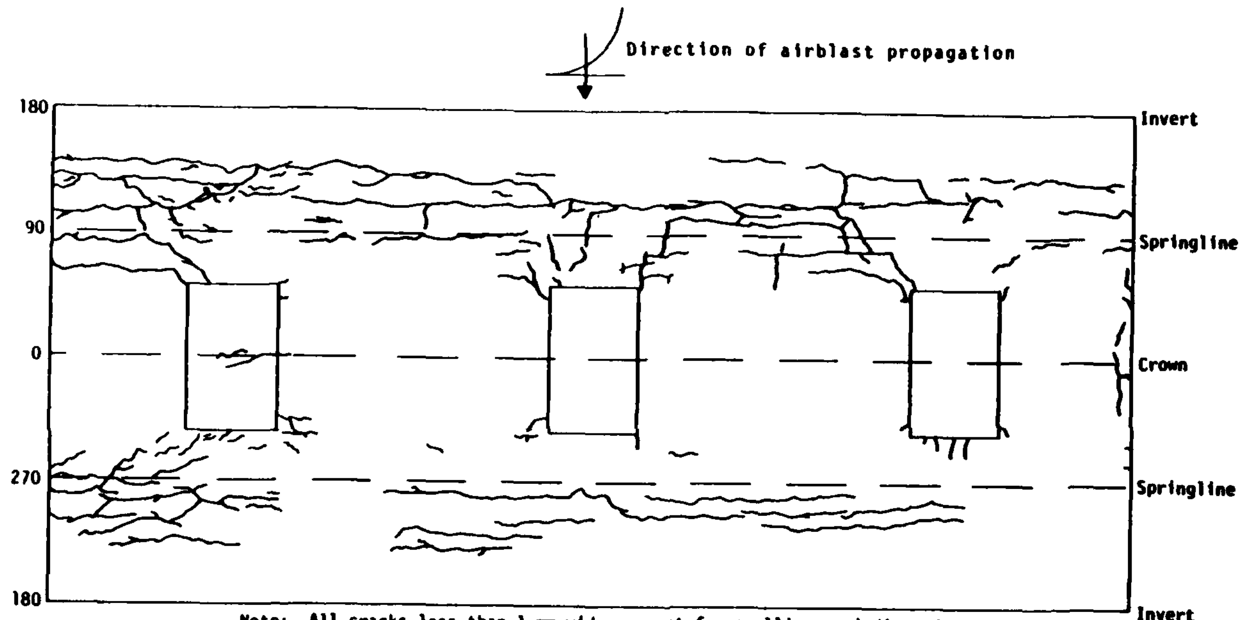
1. The cylinders would not fail in the ovaling mode.

2. The cylinders would not fail under the axial load, unless the axial load acted eccentrically.

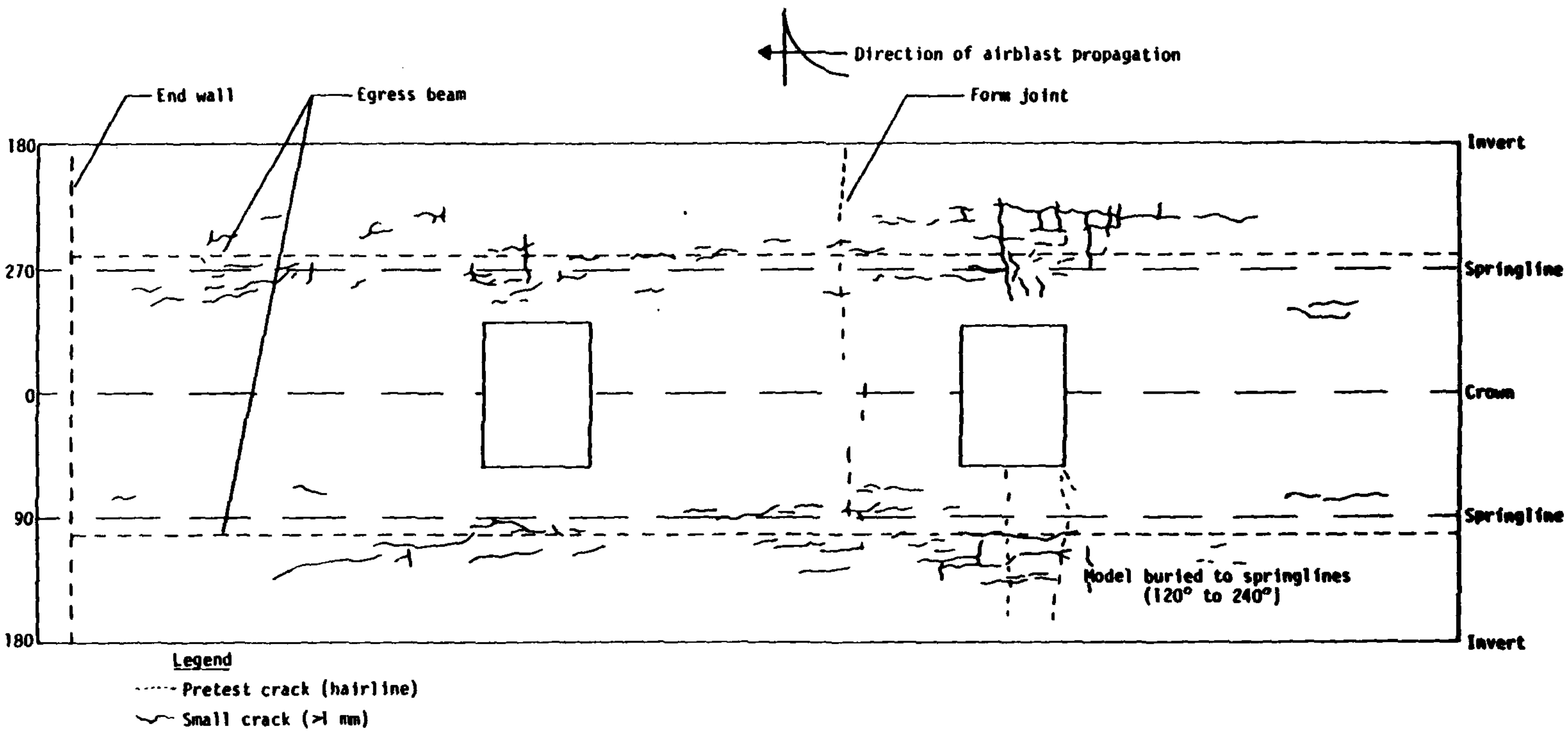
TEST RESULTS

The DCT-1 models sustained minimal damage during the test. All the models ovaled under the applied load, with the long axis of the elliptical deflected shape horizontal. The ovaling deformation caused longitudinal tension cracks in the model walls on the inside surface at the crown and invert and outside surface at the springlines. A sketch of the typical damage observed in a DCT-1 model is presented in Figure 13. Similar patterns and degrees of distress were observed in all the models. The structural response data obtained from the test was similar for all models and supported the distress patterns observed. The level of damage of the SALT ports was consistent with the damage observed in the main structure, with the exception of a longitudinal compression crack seen on the outside surface of the SALT ports in the B model. The effect on shelter response of varying structural details (breakout joint, floor, and SALT port) and SALT port backfill densities was minimal. The SMI data from the test indicated the structures moved vertically downward relative to the soil and translated horizontally in the direction of propagation of the airblast.

In the DCT-2 test, the models exhibited both ovaling and axial/beam



Note: All cracks less than 1 mm wide, except for spalling as indicated.


Direction of airblast propagation
End wall
Egress beam
Form joint
180
270
0
90
180
Invert
Springline
Crown
Springline
Invert
Model buried to springlines
(120° to 240°)
Legend
Pretest crack (hairline)
Small crack (>1 mm)

In the DCT-1 test, three 1/5-size models of the cylinder (tube) section of the shelter were loaded sideon with a simulated nuclear air-blast. The test articles, constructed of reinforced concrete, consisted of a monolithic tube, a tube with inspection panels, and a tube with inspection panels and missile breakout joints. In the DCT-2 test, two 1/4.22-size models of the shelter tube were subjected to a combined axial and transverse load. The two models had different wall thicknesses. The structural instrumentation in both tests consisted of strain, acceleration, relative displacement, and structure/media interaction gages. The free-field instrumentation in the tests consisted of blast pressure gages and soil stress and acceleration gages. The DCT-2 test also included high speed photographic documentation of the interior of the models during the test.

The DCT-1 structures ovaled under the sideon load. The observed distress patterns, similar in all the models, consisted of longitudinal tension cracks on the inside wall at the crown and invert, and on the outside wall at the springlines. The presence of inspection panels and breakout joints in the models had minimal effect on response. The DCT-2 structures ovaled in a similar fashion to the DCT-1 models under the transverse load applied in the DCT-2 test. In the DCT-2 test, axial/beam bending distress was also observed in the models. A significant axial/beam bending failure occurred in the thin walled model at the first SALT port.

The behavior of the DCT-1 structures was modeled analytically prior to the test using a finite element and a finite difference computer code. A comparison of the test and predicted response indicated both codes correctly predicted the overall behavior of the models. Problems were encountered in both calculations with the parameters input in the soil material models and the techniques selected to model behavior at the soil/structure interface. The pretest predictions for the DCT-2 test were performed using a spring-mass, a two-degree-of-freedom, and a beam on elastic foundation code to determine axial, ovaling, and longitudinal bending response of the structures, respectively. These codes, general by nature, adequately predicted the gross response of the structures.

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KEY WORDS: <u>dynamics</u>; <u>missile</u>; Missile-X (MX); <u>nuclear explosions</u>; <u>reinforced concrete</u>; structural analysis; structure/media interaction

ABSTRACT: The response of buried horizontal MX missile shelters to simulated nuclear airblast and airblast induced ground shock loadings is investigated. Two tests were conducted on scaled reinforced concrete models to examine the effect of structural variations on shelter response and to characterize the loadings across the shelter/soil interface. Pretest calculations were performed for each test. The effectiveness of the calculation techniques was evaluated through comparison of the test and predicted results.

SUMMARY: Dynamic Cylinder Test Program, by Jerry E. Stephens. In the Dynamic Cylinder Test Program the response of horizontal Missile-X (MX) shelters to nuclear airblast loadings was investigated both experimentally and analytically. The program emphasized the effect of structural variations on response and load characterization across structure/soil interfaces.

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