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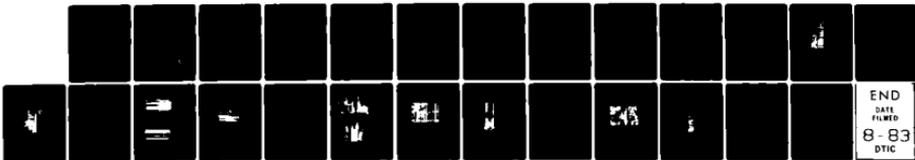
TESTING OF REDUCED-SCALE CONCRETE MX-SHELTERS SPECIMEN
CONSTRUCTION(U) BALLISTIC MISSILE OFFICE NORTON AFB CA
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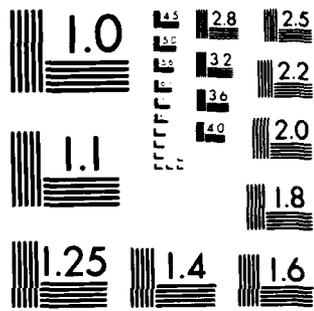
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PHYSICAL MODELING TECHNIQUES FOR MISSILE
AND OTHER
PROTECTIVE STRUCTURES

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Papers Submitted for Presentation During the
American Society of Civil Engineers
National Spring Convention
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Sponsored By the ASCE Engineering Mechanics Division
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SUBJECT Review of Material for Public Release

TO
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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 Betz.
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. ~~X~~
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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TESTING OF REDUCED-SCALE CONCRETE MX-SHELTERS

SPECIMEN CONSTRUCTION

KEY WORDS: Breakout joint; Construction; liner thickness; Missile; Models; Plain concrete; Reinforced concrete; Reinforcement; SAL panel; Shelter; Structural engineering; Stud spacing; Tolerances; Variables; Wall thickness

ABSTRACT: An experimental program involving construction and testing of reduced-scale concrete Horizontal MX-Shelters was conducted. This paper describes the construction of 43 reduced-scale cement models of the Shelters. Twenty-two different prototypes were constructed. All specimens had a 2-ft (0.61 m) inside diameter with plain or reinforced concrete walls 1.8 (46 mm) or 2.4-in. (61 mm) thick. Specimen test length was 4 ft (1.22 m) with 1 ft (0.30 m) at each end for load transfer.

Variables in specimen construction included wall thickness, amount of reinforcing, breakout joint details, liner thickness, spacing of studs, and Z-insert gap of the SAL inspection panel. Sensitivity of test results to variations in specimen dimensions required unusually rigid tolerances. In spite of manufacturing complexities, specimens were manufactured at a rate of three per week.

DMD 82-017

TESTING OF REDUCED-SCALE CONCRETE MX-SHELTERS

SPECIMEN CONSTRUCTION

by

Adrian T. Ciolko*

INTRODUCTION

An experimental program involving construction and testing of reduced-scale concrete Horizontal MX-Shelters was conducted by Construction Technology Laboratories, a Division of the Portland Cement Association. The program included 43 specimens tested under static loading conditions. Each specimen represented a "candidate design" being considered for prototype construction.

One deployment concept involved MX missiles stored in underground horizontal shelters. One purpose of the shelter was to protect the missiles from nearby nuclear weapon attack such that the missiles could be successfully launched after an attack. In the testing program, loads modeling combinations of forces that might occur from an attack were applied to the specimens. Loads consisted of axial thrust and non-uniform radial surface pressure. Data obtained from this test program were used to analyze shelter behavior under "known" loading conditions.

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This is the second of three individual papers describing the test program. Other papers describe the Experimental Program⁽¹⁾ and Instrumentation and Load Control.⁽²⁾

OBJECTIVE

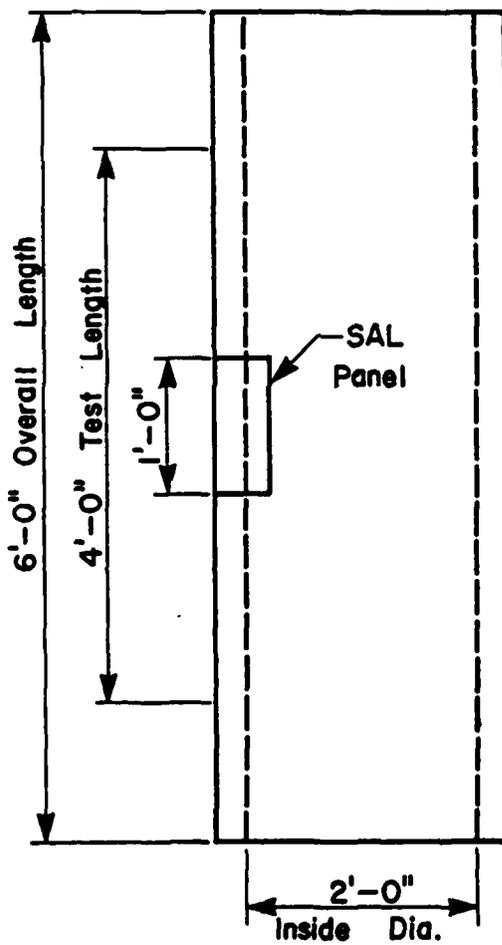
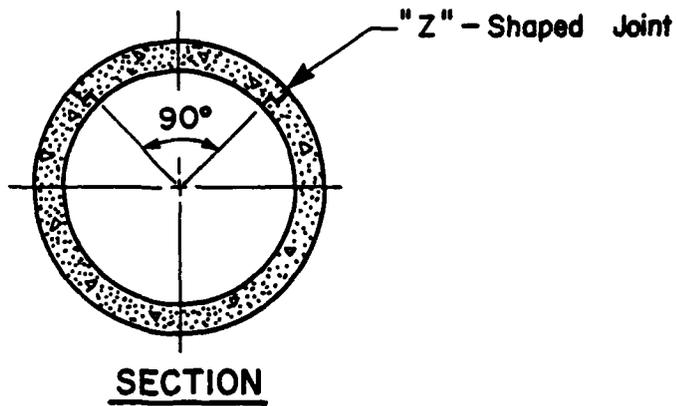
The objective of the Specimen Construction program was to fabricate 43 reduced-scale concrete models of MX-Horizontal shelters for testing in the Experimental Program.⁽¹⁾ Following sections of this paper describe the test specimens, materials, and construction.

TEST SPECIMENS

All specimens had a 2-ft (0.61 m) inside diameter with either plain or reinforced concrete walls 1.8 (46 mm) or 2.4-in. (61 mm) thick. As shown in Fig. 1, specimen test length was 4 ft (1.22 m) with an additional 1 ft (0.30 m) at each end for load transfer. Overall specimen length was 6 ft (1.83 m). At specimen mid-length, there was a 90° wide removable segment 1-ft (0.31 m) long representing the MX-Shelter Strategic Arms Limitation (SAL) panel. This panel was fitted into the specimen with "Z"-shaped joints. Weakened plane joints, when required, were simulated at $\pm 45^\circ$ from the crown in the remaining specimen length.

Design Configurations

Twenty-two different prototypes were constructed. Each design was modeled at approximately 1/7-th scale. There were seven "basic" wall design configurations. They were designated



METRIC EQUIVALENT
1ft. = 12in. = 0.30m.

Fig. 1 Horizontal MX Shelter Model

as follows:

- A1 - plain concrete, no SAL panel
- A2 - double layer reinforcement, no SAL panel
- A3 - plain concrete, with SAL panel
- B1 - double layer reinforcement, with SAL panel
- B2 - single layer reinforcement, with SAL panel
- C1 - steel liner with stud anchors, plain concrete, with
SAL panel
- C2 - steel liner with stud anchors, single layer
reinforcement, with SAL panel

Additional variables within the basic design configurations included wall thickness, amount of reinforcing, breakout joint details, thickness of liner, spacing of studs, and gap between inner and outer Z-insert. Variable matrix and quantities are given in Table 1.

Acceptance Criteria and Tolerances

Because of the sensitivity of test results to variations in specimen dimensions, unusually rigid tolerances were required. A construction specification was written⁽³⁾ which included procedures for fabrication of specimens as well as materials specifications and tolerances.

Acceptance of shelters was based on tolerances intended to prevent unintentional eccentricity of loading during tests. In addition, physical dimensions and properties had to accurately model the full-size shelter. Tolerances of ± 0.10 in. (2.5 mm) were required for specimen wall thickness and outside diameter. Specimen length was required to be 6 ft. (1.83 m) ± 0.125 in.

TABLE 1 - MX-HORIZONTAL SHELTERS SPECIMEN DESCRIPTION

Construction Phase	Specimen Identification Number	Reinforcing	Liner, Studs	SAL Gap (in.)	Breakout Joint	Thickness (in.)	Total Quantity
I	A1	None	None	No SAL	Yes	1.8	2
	A2	2 layer, 1/20 ewef	None	No SAL	Yes	1.8	3
	A3	None	None	0.025	Yes	1.8	3
	B1	2 layer, 1/20 ewef	None	0.025	Yes	1.8	6
	B2	1 layer, 10 ew	None	0.025	Yes	1.8	3
	C1	None	16 Ga, 3-1/2 in. OC	0.025	Yes	1.8	6
	C2	1 layer, 1/30 ew	16 Ga, 3-1/2 in. OC	0.025	Yes	1.8	3
II	B1.2	2 layer, 1/40 ewef	None	0.025	No	1.8	2
	B1.3	2 layer, 10 ewef	None	0.025	No	1.8	2
	C1.2	None	20 Ga, 4 in. OC	0.025	No	1.8	2
	C1.3	None	16 Ga, 4 in. OC	0.025	No	1.8	2
	C1.4	None	16 Ga, 3 in. OC	0.025	No	1.8	2
III	C2.2	1 layer, 1/30 ew	20 Ga, 3 in. OC	0.025	No	1.8	1
	C2.3	1 layer, 1/30 ew	20 Ga, 3 in. OC	0.025	No	2.4	4
	C2.4	1 layer, 1/30 ew	20 Ga, 3 in. OC	0.05	No	2.4	1
	C2.5	1 layer, 1/30 ew	20 Ga, 3 in. OC	0.10	No	2.4	1

Notes: Metric Equivalent:

ew = each way
 ewef = each way, each face
 Ga = gage
 OC = on center

1 in. = 25.4 mm

(3.2 mm). Similar requirements were placed on steel reinforcement. Steel cages were tied at tolerances of ± 0.05 in. (1.3 mm) on the clear distance to formed surfaces, and ± 0.125 in. (3.2 mm) on the spacing between bars.

MATERIALS

To meet stringent construction specifications, innovative materials were developed for modeling concrete shelters. The following sections describe concrete and steel reinforcement for the specimens.

Concrete

A micro-concrete was developed to satisfy modeling requirements as well as demands for casting and consolidation. All cement was purchased from one manufacturing burn. Type III cement was used. Maximum aggregate size was $3/8$ in. (9.5 mm). A short program of placement tests was performed to evaluate consolidation techniques for the micro-concrete. Specimen mock-ups including reinforcing and simulated SAL panels were used as shown in Fig. 2.

A 28-day compressive strength of concrete of 6000 psi (41 MPa) was required for the 4-ft (1.22 m) middle portion of the specimens. The proportion of ingredients for the mix were 1.0 part Portland Cement to 4.75 parts aggregate to 0.50 parts water. In addition, an 8000 psi (55 MPa) 28-day compressive strength micro-concrete was designed for the 1-ft (0.30 m) long load transfer portions at the specimen ends.

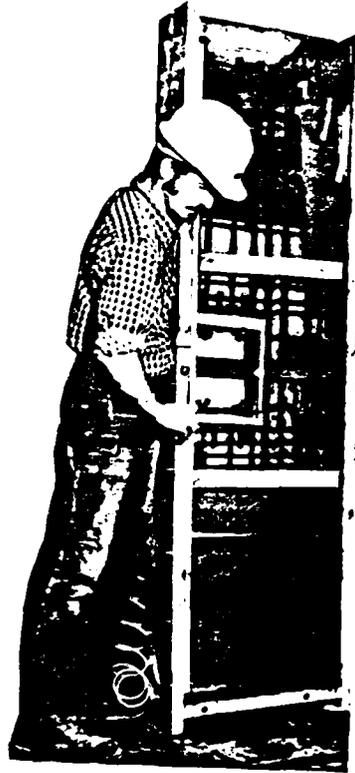


Fig. 2 Specimen Mock-up During Placement Test

Reinforcing

to satisfy modeling requirements, reinforcing steel was used. Size D3 cold worked deformed steel wire, annealed to the properties of Grade 60 reinforcement, was used as longitudinal bars. No. 2 Grade 60 plain steel reinforcing bars were used for dowels in weakened plane joints. Cold drawn wire, size No. W1, was used for fabricating stirrups. For specimens requiring liner plates, various thicknesses of 1/4-in. to 1/2-in. cold rolled sheet steel were used. This material was used to fabricate the Z-inserts for SAL panels. 1/2-in. diameter threaded 1-5/8-in. (41 mm) long studs with nuts were used as shear connectors for liner plates. They were welded to the plates using drawn arc capacitor discharge stud welders. Figure 1 shows a liner plate with attached studs.

FORMWORK AND EQUIPMENT

In the use of strict acceptance criteria on shelter models, the forms for casting were manufactured with tolerances less than 0.01 in. (0.3 mm). Forms consisted of a base ring, an inner form, and an outer form. The precisely machined base ring and inner and outer forms were placed in place. The inner form was made and machined from 0.50-in. (12 mm) thick steel plate. It contained a 4-in. (101 mm) wide removable gate along its length. Removal of the gate permitted collapsing the form. The entire inner form could then be removed from the interior of the specimen after hardening of the concrete.



Fig. 3 Liner Plate with Studs

The outer form consisted of 180° wide halves. They were connected using heavy pins and bolts. Joints in all forms were sealed to prevent leakage of mortar using O-ring gaskets. Figs. 4 and 5 show the shelter form.

A separate form was manufactured for casting SAL panels. It was a horizontal form which matched the tolerances of shelter forms. It permitted casting of three SAL panels simultaneously. The Z-inserts were bolted to the outside of the form. The form was filled with concrete and carefully finished so that the completed SAL panels would fit inside the shelter form. Figure 6 shows the form with two Z-inserts in place before casting.

Other equipment required for casting included two external form vibrators attached opposite each other to the outer form. Vibrators were selected based on placement tests of mock-up specimens and discussion with manufacturers. Vibration was transmitted to the entire length of the form through channel sections welded to the outer form wall. Vibrators were rated for 1650-lb (7.3 kN) centrifugal force at approximately 3600 vibrations per minute.

CONSTRUCTION

Complete construction of a shelter model consisted of many important tasks to meet strict specifications. Although casting of the concrete took only about 45 minutes, numerous hours were spent preparing each specimen.

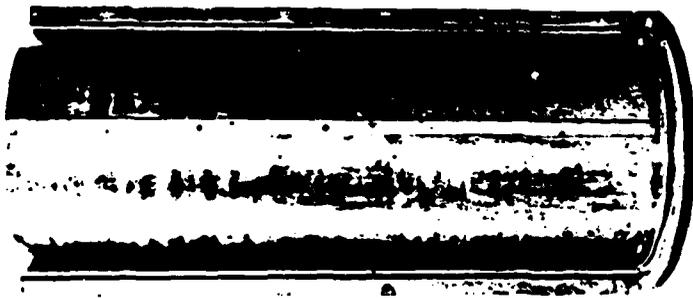


Fig. 4 Inner Form and Rear
Outer Form Attached
to Base Ring

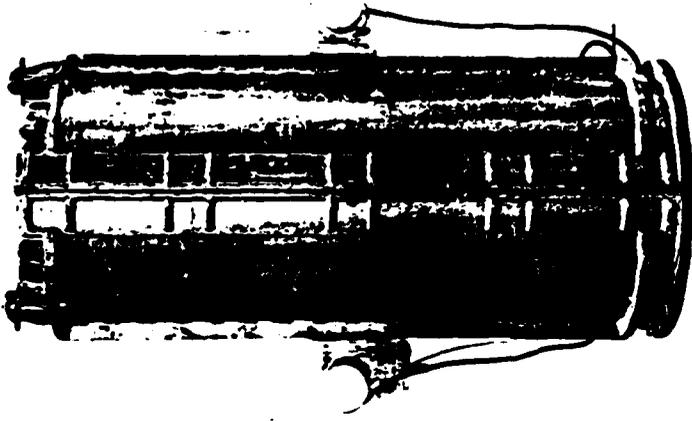


Fig. 5 Completely Assembled
Form Vibrators Attached



Fig. 6 SAL Panel Form

Fabrication and Placing of Reinforcement

The most difficult type of reinforcement to fabricate prior to casting was the double layer reinforcing cage. A portion of the steel cage was tied as shown in Fig. 7. It was then positioned over the inner shelter form. Tying of steel continued as shown in Fig. 8. After the longitudinal and circumferential steel was in place, stirrups were attached. Strain gages and inserts for attaching displacement transducers to the specimen were also positioned at this time. Figure 9 shows strain gages attached to the reinforcement. Figure 10 shows a complete cage with precast SAL panel in place.

For specimens requiring liner plates, steel fabrication procedures were similar. A liner plate was positioned over the inner form, and studs, if required, were welded to it. If required, a steel cage was then assembled and instrumentation was attached.

After fabrication of reinforcing steel and placing of instrumentation, the outer shelter form was attached to the base ring and preparations were begun for concrete casting.

Concrete Production

Concrete for shelter models was batched and mixed in the Batch Plant of Construction Technology Laboratories. Prior to batching, weights of aggregate and water were adjusted for moisture conditions of the aggregate. Mixing of concrete took place in a 6-cu ft (0.17 m³) drum-type mixer. Two concrete mixes were

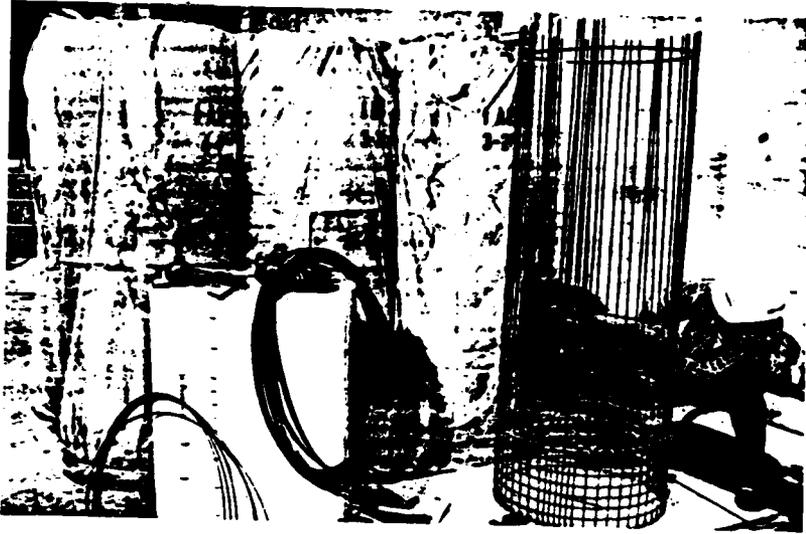


Fig. 7 Tying Bottom Portion of Steel Cage



Fig. 8 Tying Top Portion of Steel Cage



Fig. 9 Closeup of Reinforcement with Strain Gages

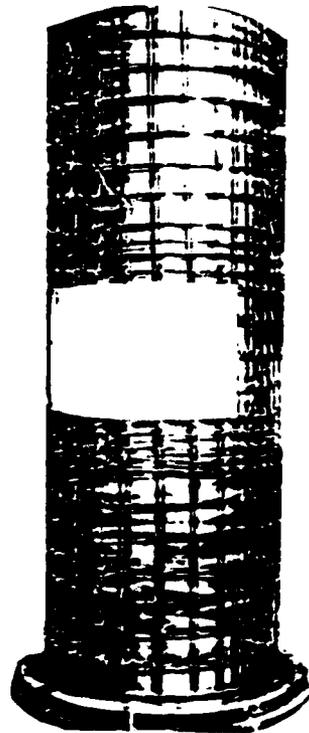


Fig. 10 Complete Reinforcing Steel Cage

used for each specimen. Higher strength concrete was used in the first and last foot of each specimen.

Concrete Placement, Handling and Curing

Before starting concrete placement, forms were checked for roundness and embedded items were checked to verify location. Specimens were cast by depositing concrete between the inner and outer forms. The first and last foot of the specimen was cast using the high-strength mix. The remainder of the specimen was cast using the 6000 psi (41 MPa) compressive strength micro-concrete. Figure 11 shows casting of a specimen. External form vibrators operated continuously during placement.

Forms were removed within 24 hrs after casting. Specimens were cured in large plastic bags until needed for testing. Figure 12 shows a specimen awaiting testing. Immediately after forms were removed, preparations were begun for casting the next specimen.

Quality Control

Concrete materials were tested during manufacture of the shelters. During mixing, slump was determined using applicable procedures outlined in the Construction Specification.⁽³⁾ Also, six-6x12-in. (152x305 mm) cylinders were cast to represent concrete in each shelter. Two cylinders were tested for compressive strength at 7 and 28 days, and two were tested for modulus of elasticity and compressive strength at an age representing testing of the shelter. Quality control charts were

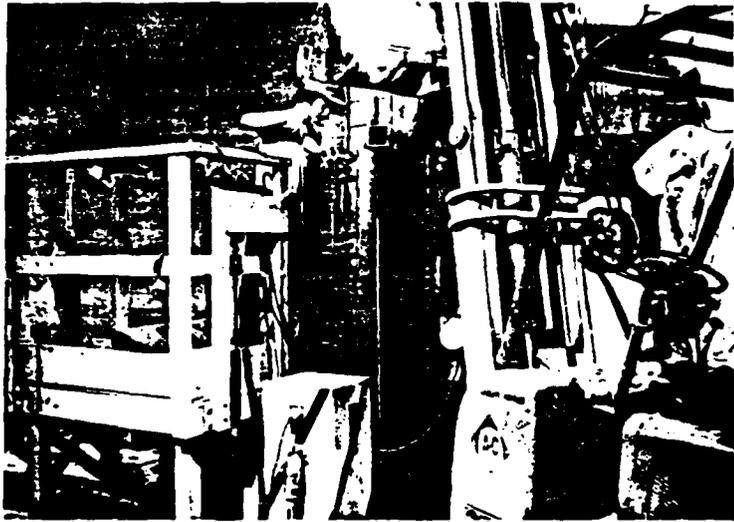


Fig. 11 Specimen Casting



Fig. 12 Specimen Prior to Testing

established to monitor performance of the micro-concrete mix with respect to specifications.

RESULTS

Although the nature of the manufacturing process was complex and delicate, specimens were constructed at a rate of three per week, with no rejections based on either material properties or workmanship.

ACKNOWLEDGMENTS

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3. Ciolko, A.T. and Schultz, D.M., "Specification for Construction of MX-Horizontal Shelters with Inspection Panels," Report submitted to Karagozian and Case, Structural Engineers, April 1980.

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