Operation PLUMBBOB Preliminary Report

Project 30.3

# EVALUATION OF FCDA FAMILY SHELTER, MARK I, FOR PROTECTION AGAINST NUCLEAR WEAPONS

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Federal Civil Defense Administration

August 1957



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ABSTRACT

An underground reinforced-concrete family shelter designed for six persons was tested at three anticipated nuclear blast overpressures: 30, 48, and 65 psi. Assuming static-load equivalents and following the procedures recommended in the appendix to ACI-56, "Ultimate Strength Design," the structures were calculated to sustain a 30-psi long-duration overpressure. Postshot examination of all shelters indicated there was little or no deflection in the reinforced-concrete members. Although the actual blast load was of short duration, the natural period for the structures was also short; therefore it is felt that the structures would withstand similar overpressures from long-duration blast loadings.

The average attenuation factor for gamma radiation varied from 3000 to 4500.

Permanent damage was confined to the exposed portions of the ventilation pipes, which were bent to a nearly horizontal position. The steel-plate door at the 65-psi level was dished inward about 1¼ in., but it opened and closed easily.



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Chapter 1

# INTRODUCTION

The test covered by this report was prepared by the Engineering Office of the Federal Civil Defense Administration (FCDA) with the assistance of other offices of the Technical Advisory Services. Preparation included the engineering designs and drawings and construction supervision through the Nevada Test Site Architect-Engineer. Instrumentation was planned by FCDA personnel, and installed and calibrated by the field group of the Ballistics Research Laboratory (BRL) of the Aberdeen Proving Ground, Ordnance Corps, U. S. Army.

## 1.1 OBJECTIVES

The two primary objectives of Project 30.3 were to test the most recent shelter designs and to collect engineering data to aid in establishing criteria for future designs.

## 1.2 BACKGROUND

Prior to the development of megaton-range weapons, family type shelters were developed to protect occupants from peak incident overpressures of 15 psi and fallout radiation (cover equivalent of about 3 ft of earth). As the destructive capabilities of a single nuclear weapon were increased, studies indicated that the level of protection offered by the family shelter should be raised if it was to be effective in, or adjacent to, potential target areas.

Project 30.3 test structures were prototypes for an inexpensive underground shelter designed to accommodate six persons. It was designed to protect its occupants from a peak incident overpressure of 30 psi or more, initial and fallout radiation, and other hazards created by nuclear explosions. Space was provided for storing supplies to sustain the group for seven days (see Fig. 1.1).



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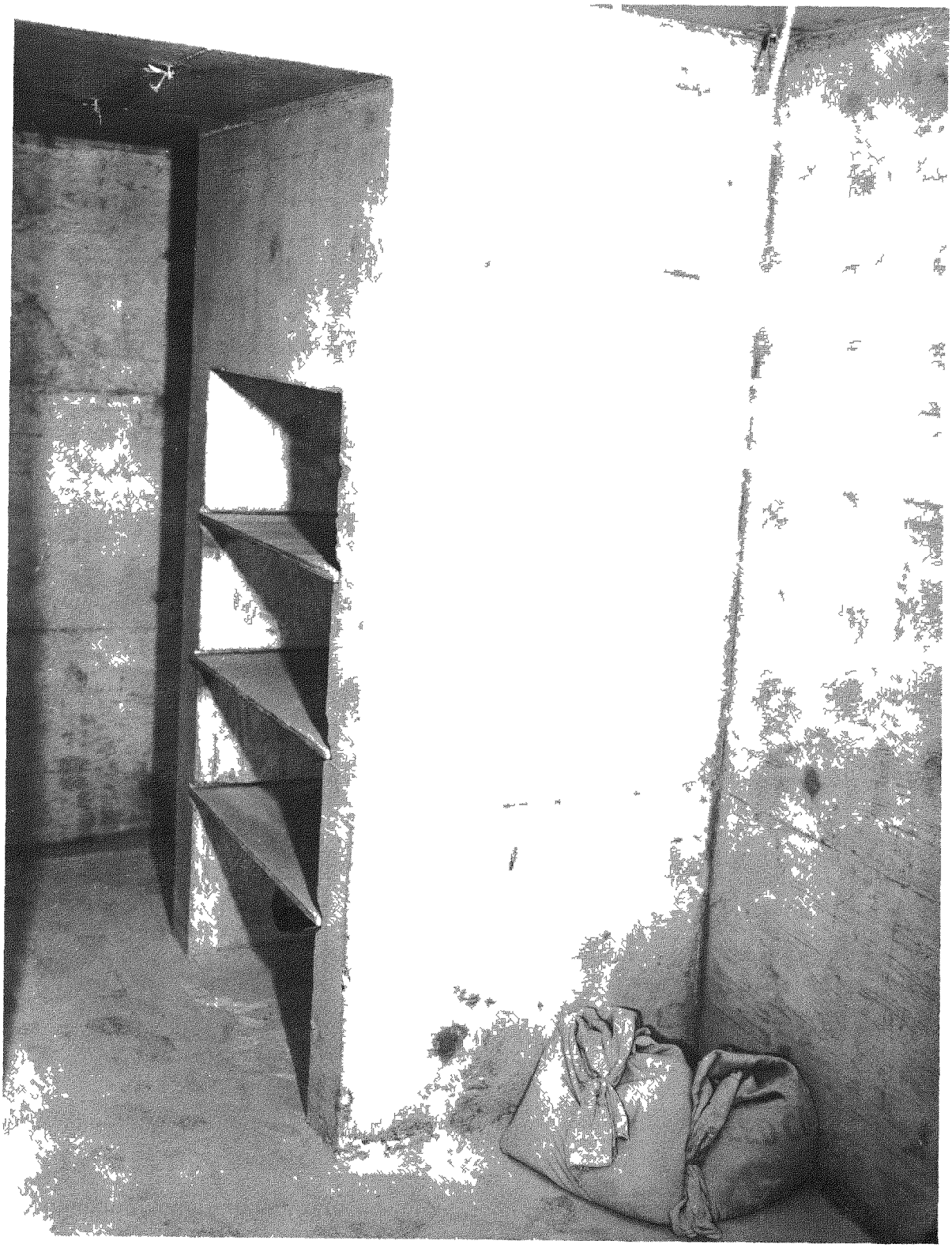

Fig. 1.1 - Storage shelves facing entrance from main room.

In the fall of 1956, preliminary designs were prepared by the Engineering Office of the FCDA for a four-person shelter. Later the six-person shelter was selected because the small increase in cost was more than compensated for by its extended range of application.

## 1.3 DESIGN

Three aspects of protective construction were considered in designing the shelter.

These were structural stability of the shelter and its components, the architectural problems of space and ventilation, and protection from initial and fallout radiation independent of angular distribution.

### 1.3.1 Structural Design

Design criteria for the roof, floor slabs, and side walls of the main chamber are summarized in Appendix A.

Alternate designs of the main chamber were made: one was a flat-slab type with pipe columns and the other, a two-way slab. The two-way slab design was selected because the main chamber, free of columns, was more adaptable to individual needs and presented a more pleasing appearance. The two-way slab design required a roof and floor slab thickness 5 in. greater than the flat-slab type, but the cost of this was compensated for by eliminating the pipe columns.

The design procedures followed were those recommended in the appendix to ACI 318-56, "Ultimate Strength Design." Allowable stresses were those proposed by N. M. Newmark of the University of Illinois. The use of static-load equivalents equal to the peak incident overpressure on the roof and floor slabs and the assumption that the vertical walls were subjected to lateral static-load equivalents of 0.25 of peak incident pressure were recommendations made by N. M. Newmark.

In an effort to simplify the construction problems, only straight bars or those with $90^{\circ}$ hooks were used. This was the reason for selecting the relatively low concrete compressive strength of 3000 psi.

Only a cursory analysis was made for shear failure of the soil and for soil settlement. The depth of foundation and the relatively low bearing loads were the two main factors which indicated that the chances of a foundation failure were remote.

The steel-plate door was intentionally overdesigned using conventional elastic design methods for an applied normal pressure of about 45 psi. If future designs take advantage of the dynamic properties of the door, a reduction of plate thickness to ½ in. or less can be

expected. The method used to seal the door was effective and inexpensive. It consisted of a peripheral bar channel seal-welded to the plate. A strip of neoprene was cemented inside this channel.

The door design permitted it to be bolted from the inside against negative pressures but also allowed it to be opened from the outside. This is an important feature because it would allow rescue teams access if the occupants of the shelter were too badly injured to open the door from the inside.

### 1.3.2 Architectural Details

The over-all dimensions of the main chamber were determined by living space allowance and ventilation.

The minimum allowance for living space in shelters was established at about 10 sq ft per person. This is a net figure and does not include a prorating of areas allocated for common use, such as corridors and storage. The family shelter contains almost 11 sq ft per person in the main chamber based on an occupancy of six people.

There were three separate aspects of the ventilation problem. First, the ventilation of the shelter during the long preattack period had to be sufficient to ensure the continuous removal of vitiated air so that, when the shelter was sealed off, it would contain relatively fresh air. This was accomplished by attaching an air-driven ventilator to the exhaust pipe as shown in Fig. 1.2.

Between the time the shelter is occupied and the end of the attack, the ports to both vents will be closed. The allowable sealed-off period is the second aspect of the ventilation problem. Calculations relating to this are summarized in Appendix B.

During the postattack period when high ambient radiation or other factors make occupancy of the shelter necessary, the ventilation system must change the air frequently. Any one of several commercially available hand-operated blowers attached to the intake pipe would be adequate for this.

### 1.3.3 Radiation Attenuation Details

The two criteria established by FCDA for protection against radiation for the family shelter are:

(1) An earth-cover equivalent of 6 ft 8 in. over the entire shelter as shown in Fig. 1.3.

(2) An entrance corridor with a minimum of two $90^{\circ}$ bends as shown in Fig. 1.4.



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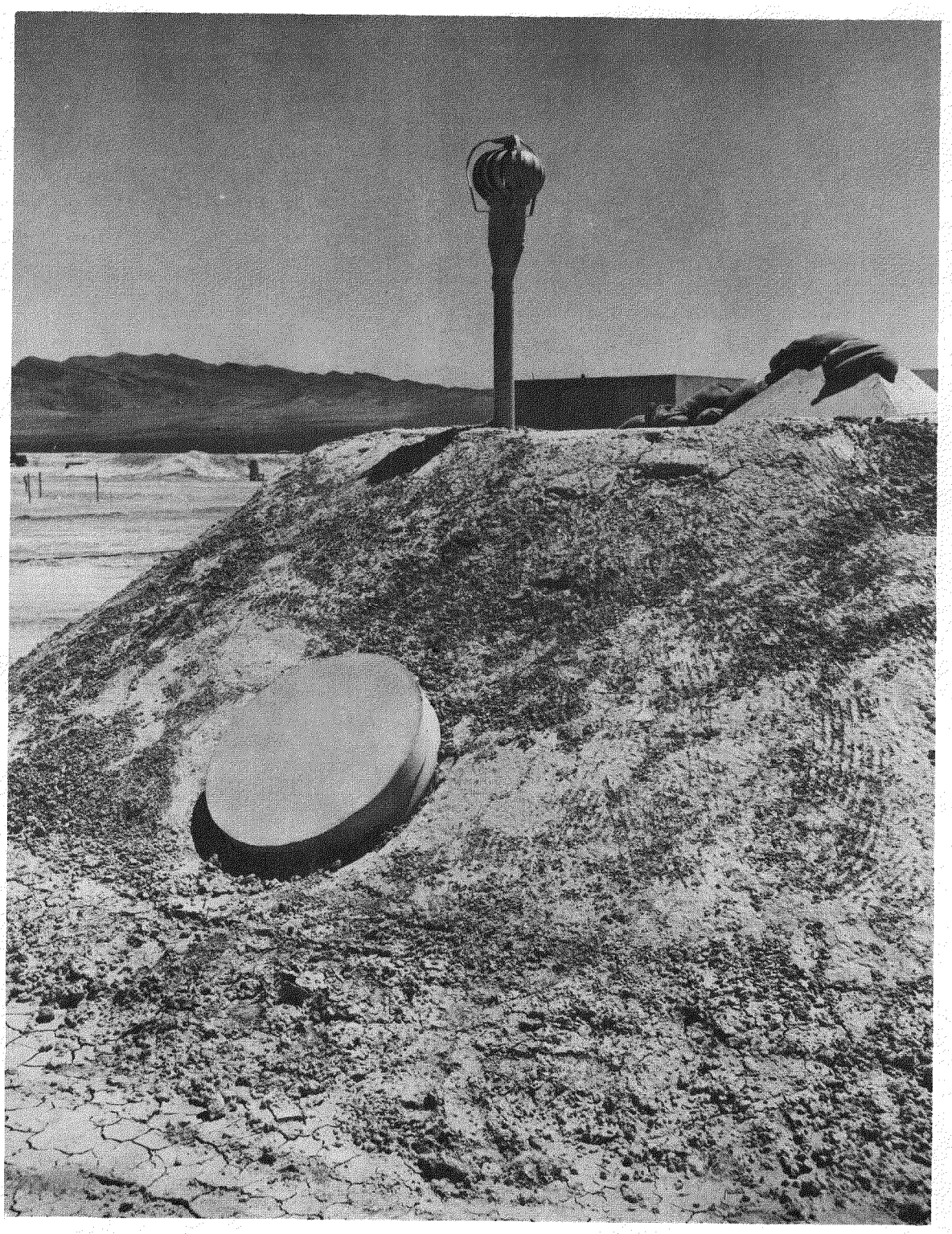

Fig. 1.2 - Exhaust pipe with air-driven ventilation, escape hatch with cover in foreground.



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Fig. 1.3 - Earth mounded over family shelter.

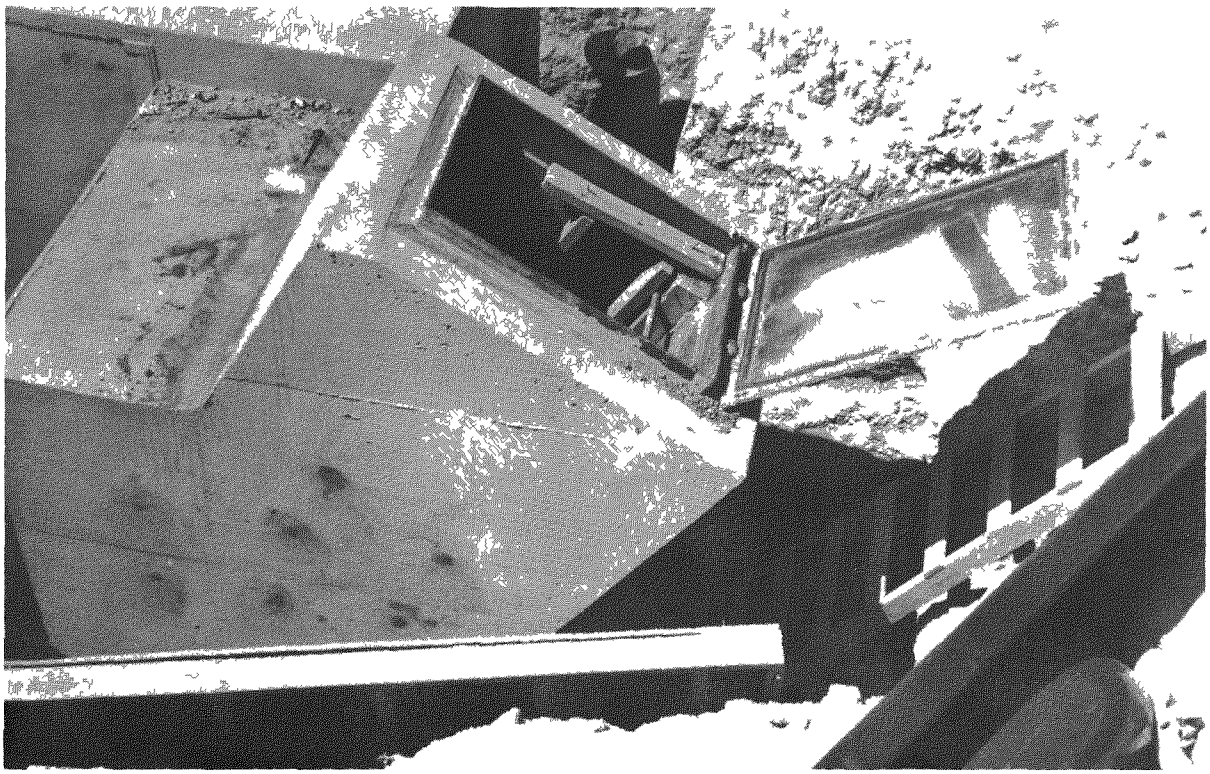

Fig. 1.4 - Shelter entrance corridor before backfill.

The possibility of noxious quantities of radioactive particles entering the ventilation pipes was considered, but it was decided that the amount leaking into the shelter would be too small to be considered.

Chapter 2

# PRELIMINARY WORK

Preshot work included fabrication of the shelter doors and other metal work, the construction of the shelters, and the installation and calibration of the instruments.

## 2.1 CONSTRUCTION AT THE NEVADA TEST SITE

Three family shelters were built in Frenchman Flat. The doors were shop fabricated and the steel reinforcement was cut and bent in Las Vegas, but all other work was done on-site.

### 2.1.1 Earth Work

Excavation for the three shelters was performed by a backhoe. The soil removed was a dessicated brown clayey silt (ML-CL). The earth walls of the 9-ft-deep excavation stood vertically without sheeting. A base course of concrete sand about 4 in. deep was placed under the floor slab. Both backfill and embankment over the shelter consisted of the excavated soil. Mechanical tamping of the dampened soil was done in both cases. The embankments were further stabilized by treatment with a solution of calcium chloride.

### 2.1.2 Concrete Work

Type II portland cement was used. A 5½-sack concrete mix was used throughout all the structures. Results of 28-day cast cylinders given in Fig. 2.1 indicate the strength of the concrete was greater than the specification requirement. The average strength of the concrete on shot day as estimated in Fig. 2.2 was about 4600 psi.

The floor slabs were placed first, and the remaining portions of



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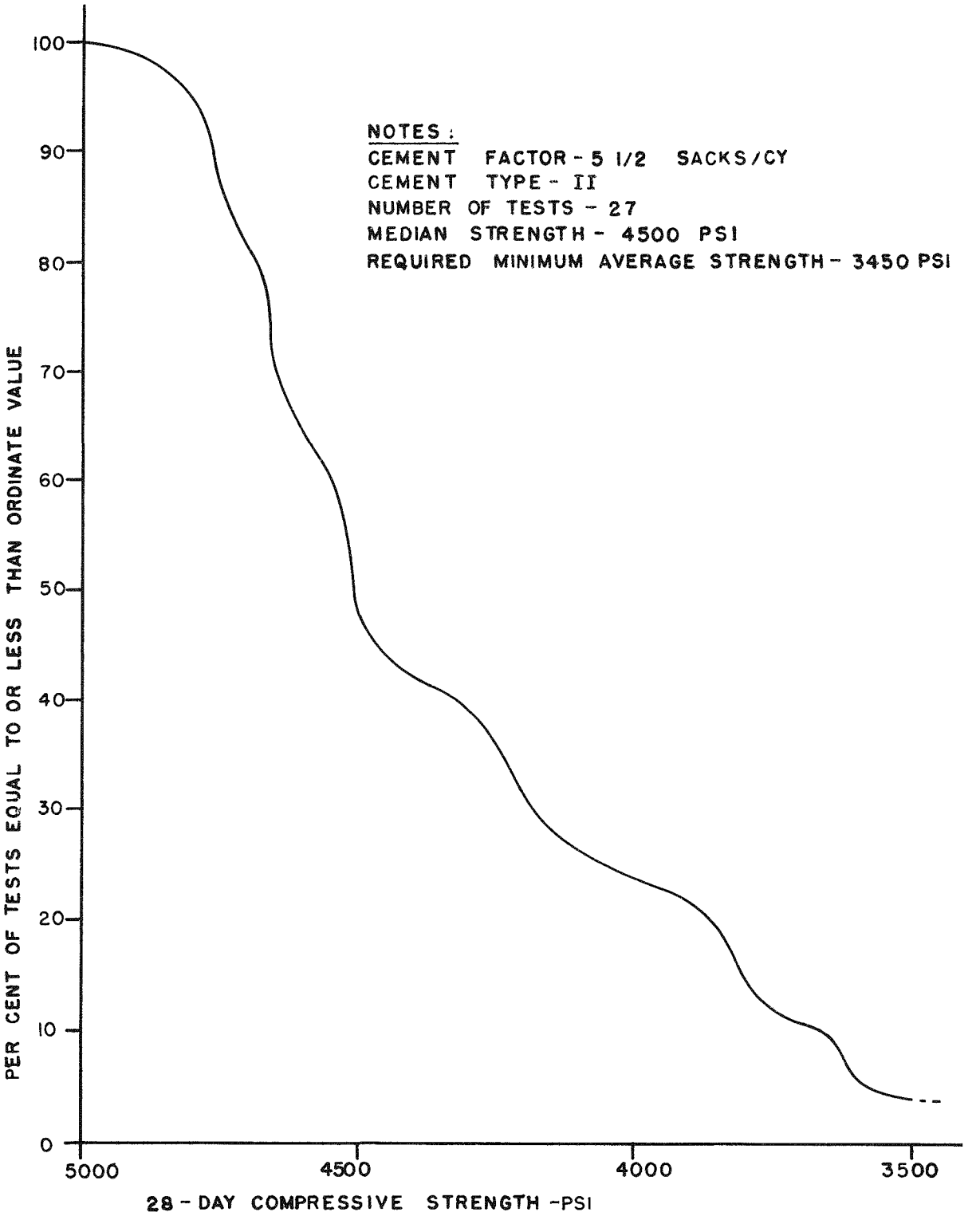


Fig. 2.1 - Ogive Curve - 28-day compressive strength of concrete.



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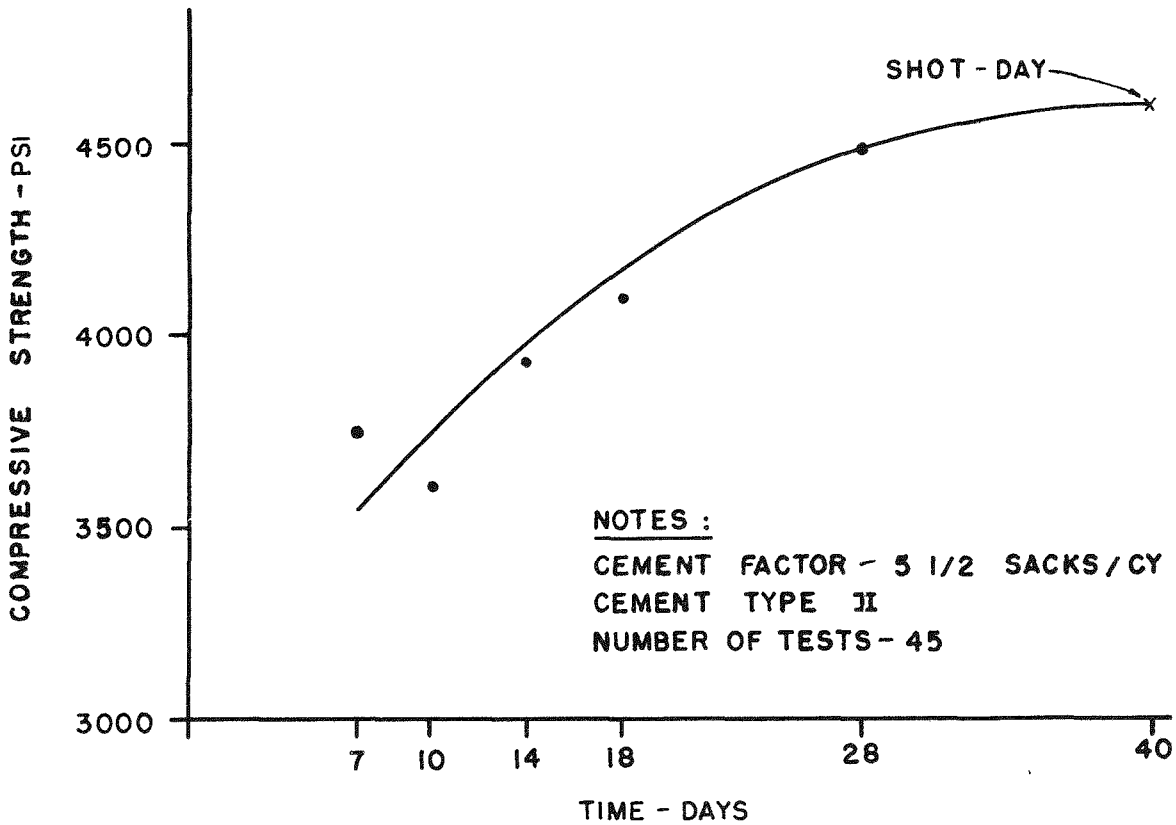


Fig. 2.2 - Strength Gain Curve - concrete compressive strength.

the shelters were cast monolithically. The concrete placement operations, which used a 3-in. slump, were without incident. Inspection of the completed structures revealed a few small isolated and insignificant sections with honeycomb.

Hunt's membrane process was used in curing exposed surfaces, and a close examination of the completed structures did not disclose any evidence of shrinkage cracks.

Including waste, the amount of concrete delivered to each shelter for placement was from 27 to 30 cu yd.

### 2.1.3 Steel Work

About 1½ tons of reinforcement were required for each family shelter. Bars with ASTM-A305 deformations were used, and the 90° hooks were used for lap splices only and not for anchorage. No problems were encountered in any of the steel placement. The horizontal portions of the corrugated-metal escape tube were cast into the end-wall concrete. The inclined section was welded to this several days later after the concrete had cured (see Fig. 2.3).

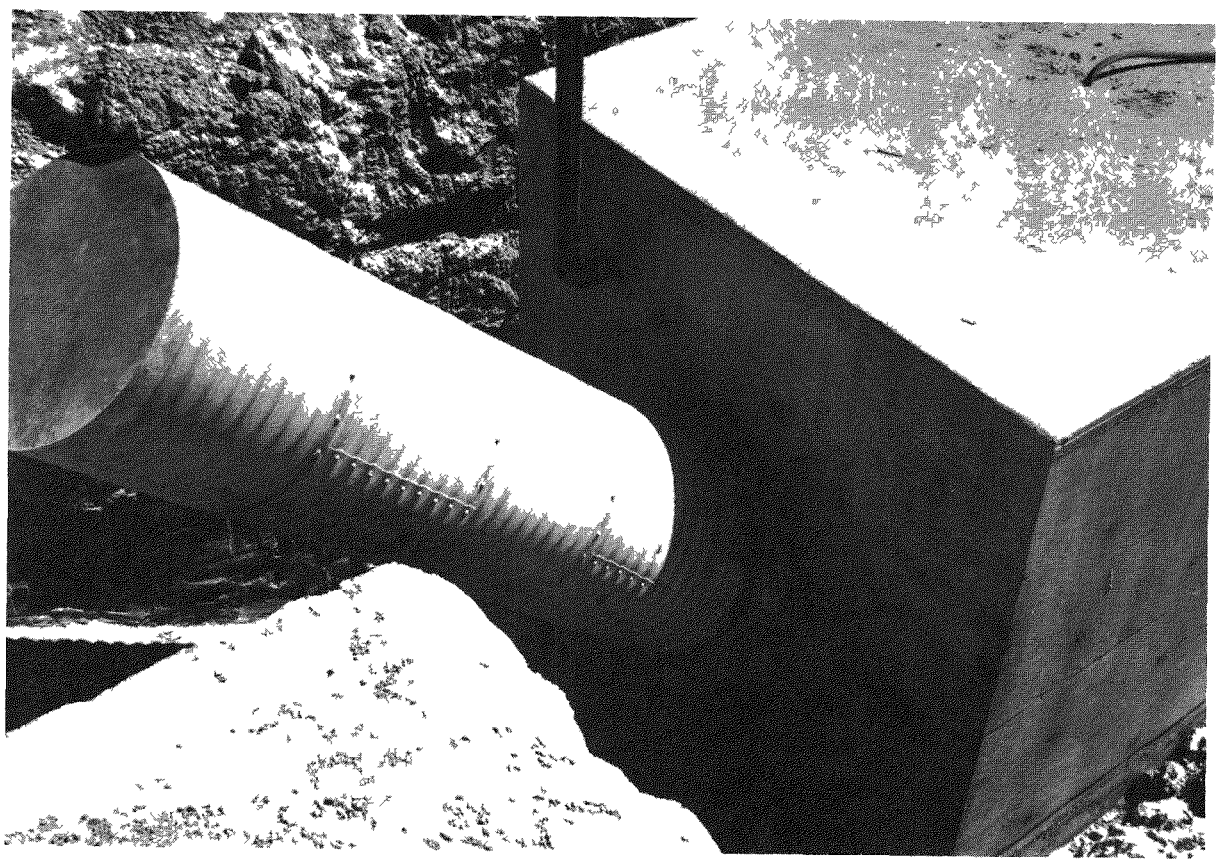

Fig. 2.3 - Corrugated escape tube at rear of shelter before backfill.

There was one field modification to the steel-plate door. Instead of the four closure bolts shown on the drawings, it was decided to stub the two lower ones and fix the door in the closed position with the two upper ones. This change was necessary because the lower bolts bend during the operation of the door.

### 2.1.4 Miscellaneous Work

The installation of the ferrite rod antenna in the antenna block presented a problem because the antenna could be easily damaged by the aggregate in the concrete. To prevent this, the antenna rod was first cast in a small mortar block, which was then placed in the main antenna frustum.

## 2.2 INSTRUMENTATION

Exterior selfrecording pressure-time (SR/PT) gauges were located near each shelter. The shelters situated at the 48- and 65-psi overpressure levels were instrumented to obtain the magnitude of permanent deformations. The shelter located at the 30-psi level contained time-deflection records for wall-to-wall and ceiling-to-floor measurements. The shelters at the 30- and 65-psi levels each contained one SR/PT gauge in the main chamber. Soil pressure gauges were not installed because adjacent structures which had backfills of similar material were completely instrumented and the data obtained from these adjacent structures would be applicable to the family shelters.

Radiation instrumentation was comprehensive and included both gamma and neutron measurements. This work was accomplished by Project 39.1 and details can be found in the Project 39.9 report.



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Chapter 3

## RESULTS

Measurements of deflections, both permanent and transient, were so small they had little significance for structural analysis. There was a permanent deflection in the steel-plate door of the shelter at the 65-psi level. The blast pressures caused a symmetrical concavity in the plate which had a maximum depth of 1¼ in. at the center. Despite this distortion, the closure bolts were easily removed, and the door opened without difficulty.

Damage to the exposed portion of the ventilation pipes was severe. As expected, the air-driven ventilators on the exhaust pipes were blown away, but the welded-steel weather covers on the intake pipes remained undamaged. The vent pipes were bent into an approximately horizontal position (see Fig. 3.1).

The average attenuation factor for gamma radiation varied from 3000 to 4500. Such protection would have been adequate to prevent serious radiation damage to occupants. Specific details of the radiation measurements are available in the report of Project 39.1.

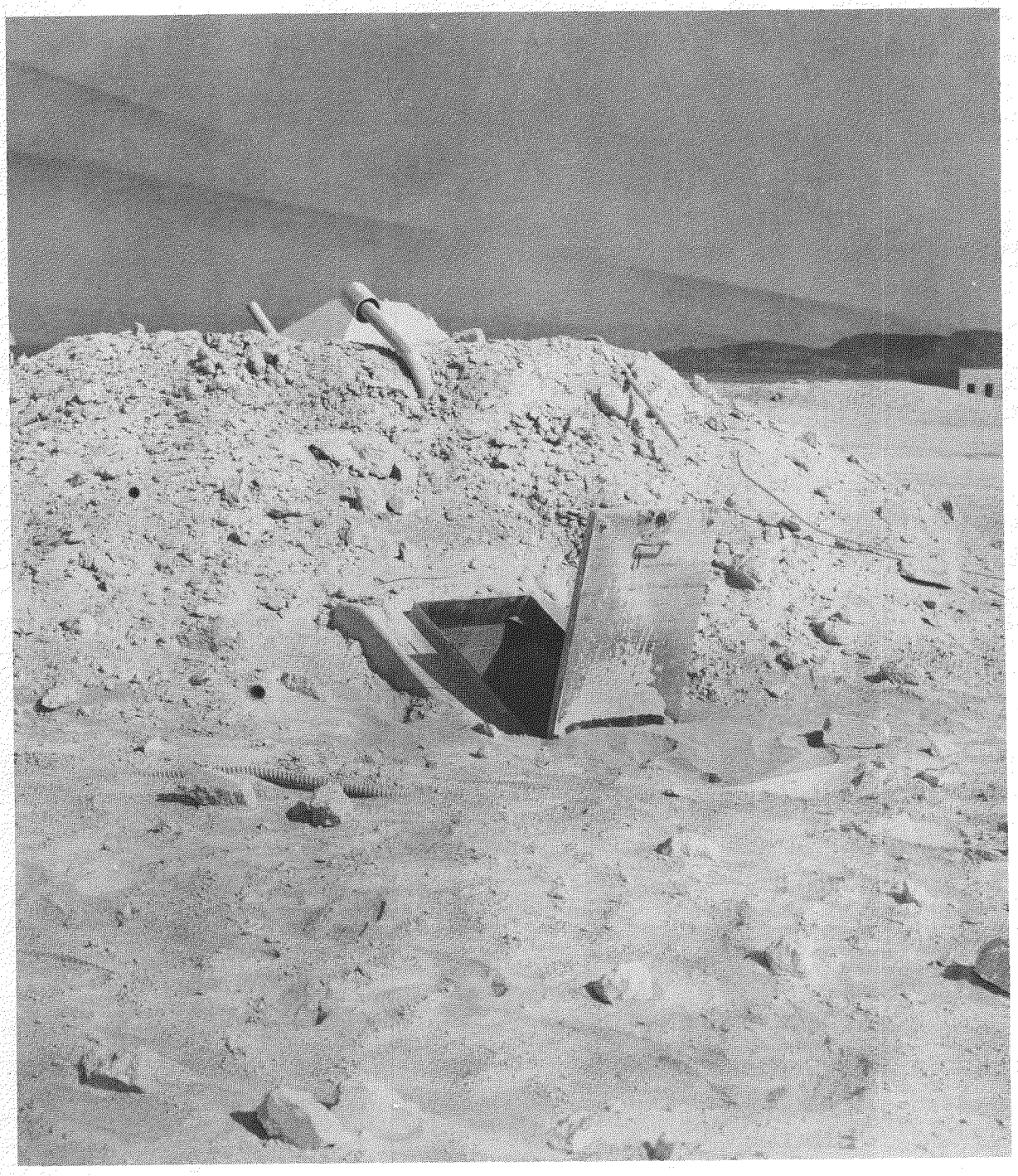

Fig. 3.1 - Ventilators of family shelter bent over by blast.



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Chapter 4

# CONCLUSIONS AND RECOMMENDATIONS

## 4.1 CONCLUSIONS

Lack of structural response to the blast pressures in the 30-psi range and unmeasurable permanent deflection in the 48- and 65-psi ranges indicate the design criteria were conservative. The fact that the compressive strength of the concrete, as determined by laboratory tests, was 4600 psi instead of the design strength of 3000 psi would account only to a limited extent for the lack of measurable deflections. In any case, the family-shelter design would probably sustain peak incident overpressures appreciably greater than 65 psi.

The usefulness of the ventilation system was virtually ended by its blast damage.

## 4.2 RECOMMENDATIONS

To ascertain the structural response of this type of shelter, future tests should be conducted at peak incident overpressure of 75 psi or more. The effect of high blast pressures on exposed piping should be more thoroughly investigated, and the results of those investigations should be applied to the ventilation systems of the present shelters.

Appendix A

## STRUCTURAL DESIGN CRITERIA FOR FAMILY SHELTER, MARK I

Design Stresses: $f_y$ = 40,000 psi (intermediate grade bars)

$f'_c$ = 3,000 psi

v = 120 psi or 540 psi (with bent bars)

u = 600 psi (with hooked bars)
300 psi (with unhooked bars)

Design Loads:

| | |
|---|---|
| Peak incident overpressure | = 30 psi |
| Static earth pressure | = 4.2 psi (vertical) |
| Lateral pressure factor | = 0.25 |
| Static earth pressure | = 1.8 psi (lateral) |
| Dead load | = 0.8 psi |
| Roof and floor loads | = 30 + 4.2 + 0.8 = 35 psi |
| Wall loads | = (¼ x 30) + 1.8 = 9.3 psi |



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Appendix B

## DETERMINATION OF ALLOWABLE SEALED-IN PERIODS FOR FAMILY SHELTER, MARK I

Nominally fresh air is assumed to be in the shelter at the commencement of occupancy.

$CO_2$ in exhaled air (per person), 4%

Total air exchange per hour (per person)*, 22.1 cf

Total $CO_2$ formation per hour (per person), 0.884 cf

Total $CO_2$ formation per hour for six persons, 5.30 cf

Recommended safe allowable concentration, $CO_2$, 5%

Recommended maximum allowable concentration, $CO_2$, 6%

Total volume of main chamber, 425 cf

Total safe allowable amount $CO_2$, 21.25 cf

Total maximum allowable amount $CO_2$, 25.5 cf

Safe allowable sealed-in period $\frac{21.25}{5.30} \times 60 = 241 \text{ min} \approx 4 \text{ hr}$

Maximum allowable sealed-in period $\frac{25.5}{5.3} \times 60 = 288 \text{ min} \approx 4\ 3/4 \text{ hr}$

*Sedentary Adult



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Appendix C

PLANS AND DETAILS OF FAMILY SHELTER, MARK I



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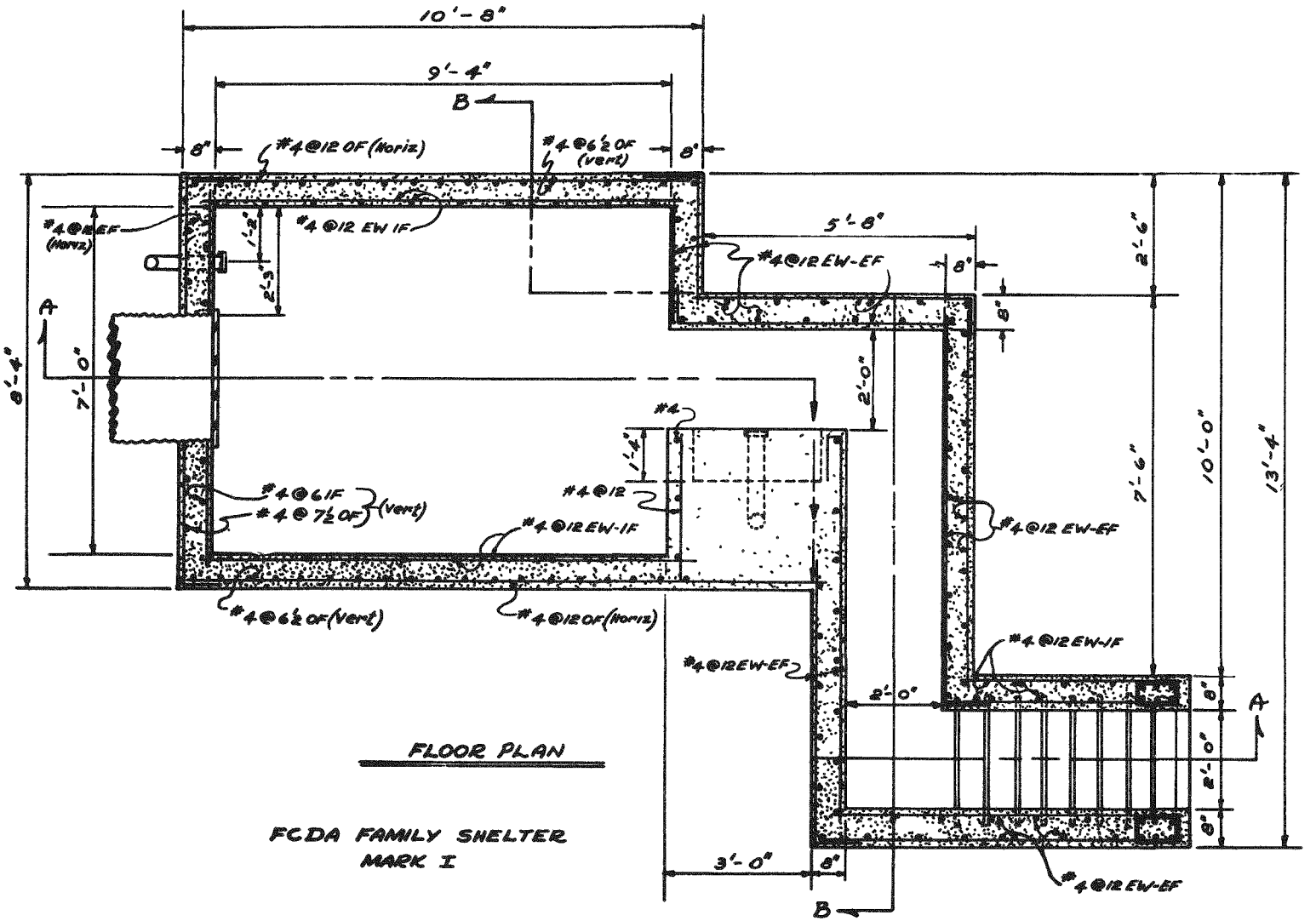


Fig. C.1 - Floor plan, FCDA family shelter, Mark I

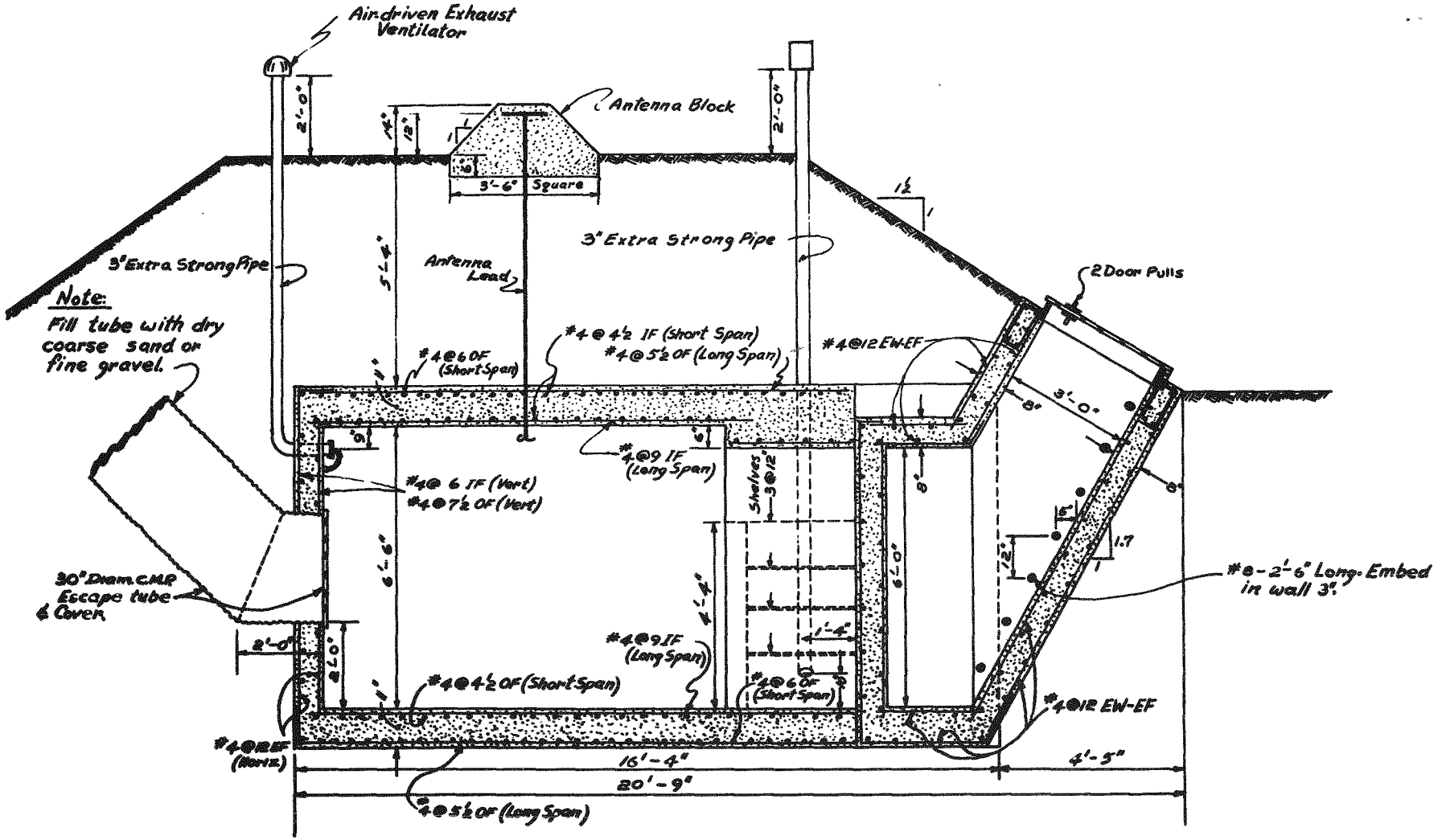


Fig. C.2 - Longitudinal section, FCDA family shelter, Mark I

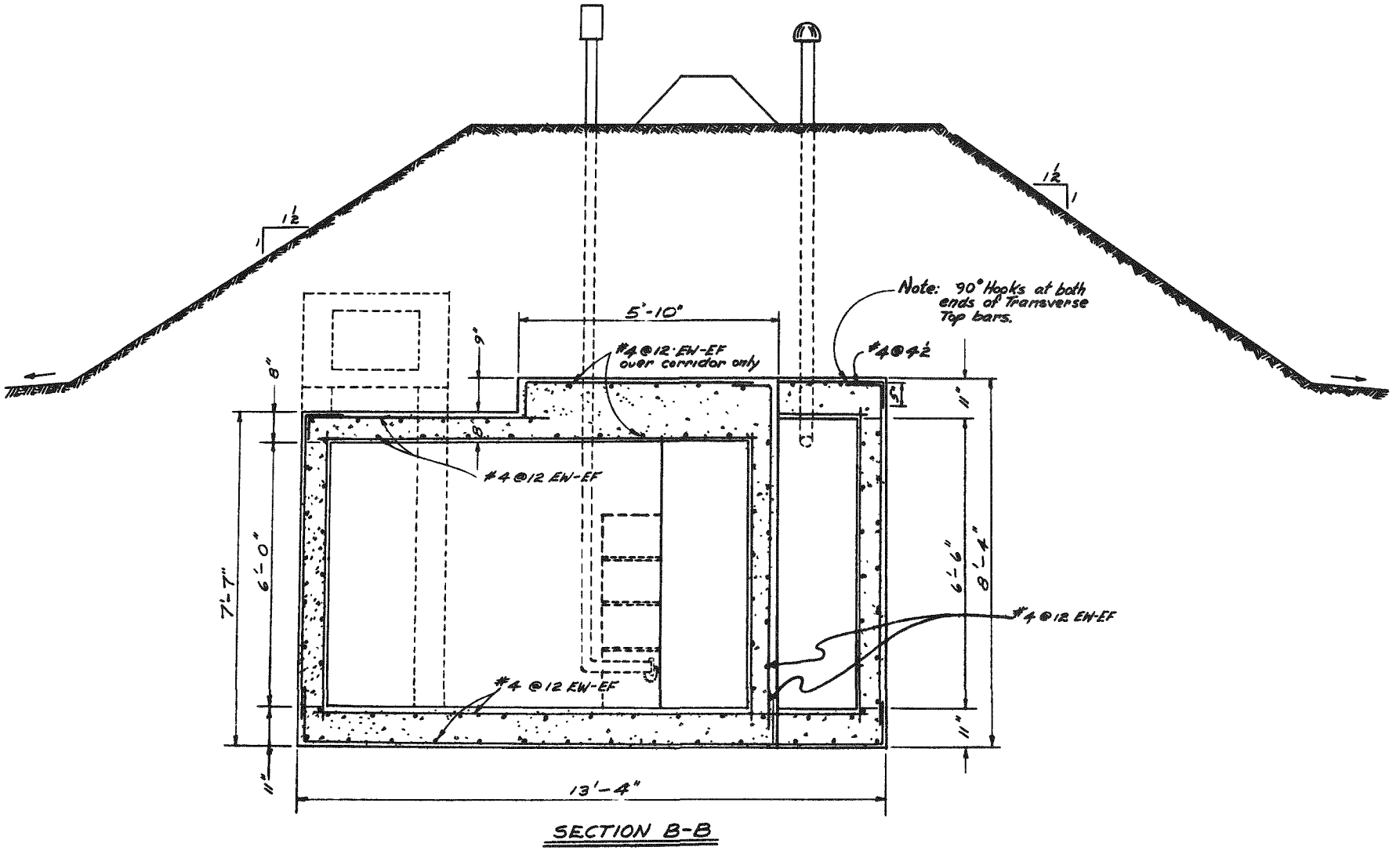


Fig. C.3 - Transverse section, FCDA family shelter, Mark I