# DESIGN VALIDATION EXPERIMENTS FOR THE KEY WORKER BLAST SHELTER

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## ABSTRACT

Design calculations for the blast shelter included the effects of soil arching. In the past, soil arching has been ignored for dynamic loads at shallow burial depths; however, recent test data indicate structural loading is significantly reduced by arching, even at very shallow burial depths. The result is a more efficient structural design than was previously thought possible.

Experiments to be conducted on 1/4-scale structural elements during June through October 1983 will provide loading and response data for the structural design. Specific design parameters that will be investigated include depth of burial, backfill soil specifications, concrete strength, and the effects of multiple weapon detonations. Static testing, using the Large Blast Load Generator facility at WES, will be conducted in the laboratory. All dynamic testing will be performed at remote field sites using a High-Explosive Simulation Technique known as a Foam HEST to simulate nuclear overpressures. Instrumentation will document the overpressure loading, free-field stresses and motions in the backfill, interface loads on the buried structure, structural deformations, and instructure shock levels. Results from these experiments will be used to validate and/or improve the blast shelter design and the computational procedures used for the design calculations.

## INTRODUCTION

This research program is jointly sponsored by the Federal Emergency Management Agency (FEMA) and the Defense Nuclear Agency (DNA), and is being conducted by personnel in the Structural Mechanics Division of the Structures Laboratory at WES.

Key worker shelters will be used to house personnel operating critical industry within high-risk areas of the country during and after a nuclear attack. Current civil defense planning calls for the evacuation of nonessential personnel to safe (lower risk) host areas, and the construction of approximately 20,000 to 40,000 shelters to protect the key workers remaining behind. Both deliberate- and expedient-type shelters are planned. The current deliberate shelter designs are 100- and 400-man capacity, and the expedient shelter designs are 20- to 30-man capacity. The specifications require that the shelters be capable of resisting the blast loading, radiation, and associated effects at the 50 psi overpressure level for a 1-Mt weapon. The FY83 research program will concentrate on supporting the design of a deliberate facility. Expedient shelter design concepts will be tested in FY84.

Computational procedures developed in the DNA sponsored Shallow Buried Structures research program at WES have been used for design calculations. Therefore, the shelter designs take full advantage of the load mitigating effects of soil-structure interaction, the initial capacity increasing effects

of inplane thrust loads in the structure roof, and large deflection membrane resistance of the roof slab. These effects allow a much more cost efficient design than would otherwise be possible. However, careful attention must be given to backfill specifications, to assure that the soil friction forces required for soil arching will occur, and to concrete strength and reinforcement details, to assure that the roof can respond as a membrane without premature failure.

The USAE Huntsville Division (HND) is responsible for the shelter designs. The floor plan of the HND 100-man shelter design is shown in Figure 1. This research program will evaluate the design details used in this 100-man blast shelter.

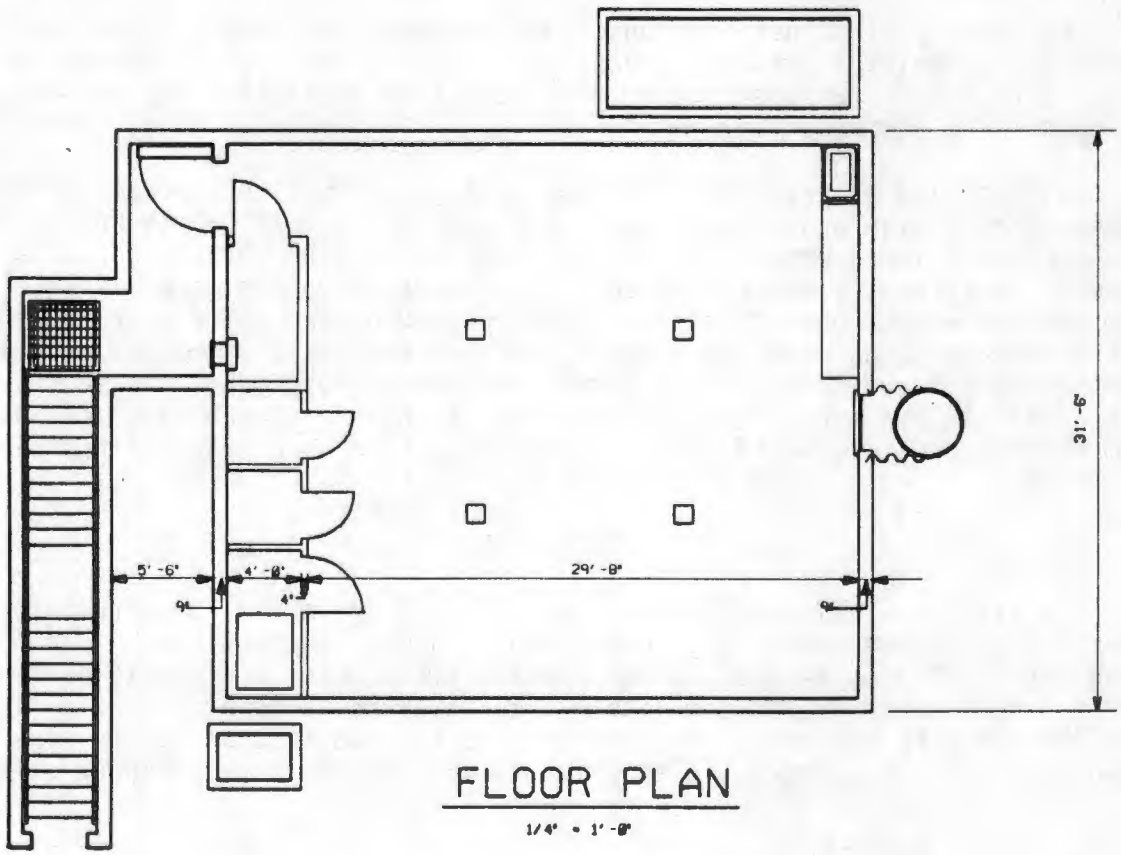



Figure 1. 100-man blast shelter from Mr. Paul LaHoud, USAE, Huntsville Division.

## OBJECTIVES

(1) Verify computational procedures used for design calculations: The calculational methods are based on structural response data collected in test at 2,000 to 10,000 psi. These data need to be verified at the 50 psi overpressure level.

(2) Evaluate structural design concepts: Test data will be used to evaluate design concepts, such as the use of corrugated sheet metal to form the roof and protect against fragments, and the effectiveness of the beam-column

construction supporting the concentrated loads that will be arched onto the roof beams.

(3) Investigate and recommend minimum allowable concrete strength specifications: To take full advantage of soil arching, the structure is relatively flexible and large roof deflections are expected. However, the concrete must be strong enough to prevent bond failure at the roof supports when the roof is responding in the membrane mode.

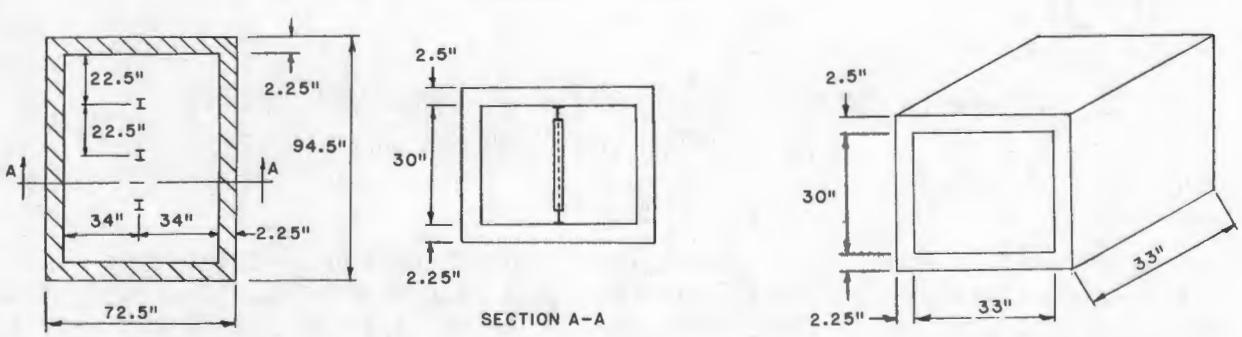
(4) Investigate and recommend backfill specifications: Because soil arching is assumed in the design calculations, it is very important that a high shear strength backfill be used. However, to minimize cost, the backfill specifications should be as unrestrictive as possible.

(5) Develop structural response computational procedures to predict response from multiple weapon detonations: Two of the test structures will be retested to obtain response and loading data from multiple loadings, and to document large response failure modes.

(6) Evaluate stirrup reinforcement configuration: Reinforcement ties between the tension and compression rebar mats can significantly increase the moment capacity of a cross section and improve the roof performance as it responds in a tensile membrane mode. The increased moment capacity results from the increased concrete confinement provided by the stirrup reinforcement. As the roof responds into the tensile membrane mode, the stirrup ties will confine the cracked concrete and force the two reinforcement mats to respond as a unit. In practice, placing these ties is a labor intensive, costly, item. Therefore, alternate, easily installed, stirrup configurations will be evaluated.

## TEST PLAN

A series of static and dynamic tests, using 1/4-scale box structures and box structural elements will be conducted. Static tests using the Blast Load Generator facilities at the WES and dynamic tests using a High-Explosive Simulation Technique (HEST) to simulate nuclear overpressures at a remote field test site will be performed. In addition to the two test structure types shown in Figure 2, a one-way slab element will be used for the shear stirrup




a. Type 1 Element

b. Type 2 Element

Figure 2. Test elements.

configuration tests. The Type 1 structure will be used to investigate roof-wall interaction, the girder-column design, and the girder-wall interaction. The Type 2 element will be used to investigate concrete strength, backfill types, and effects of depth of burial. Reinforcement details for both Type 1 and 2 elements are shown in Figure 3.

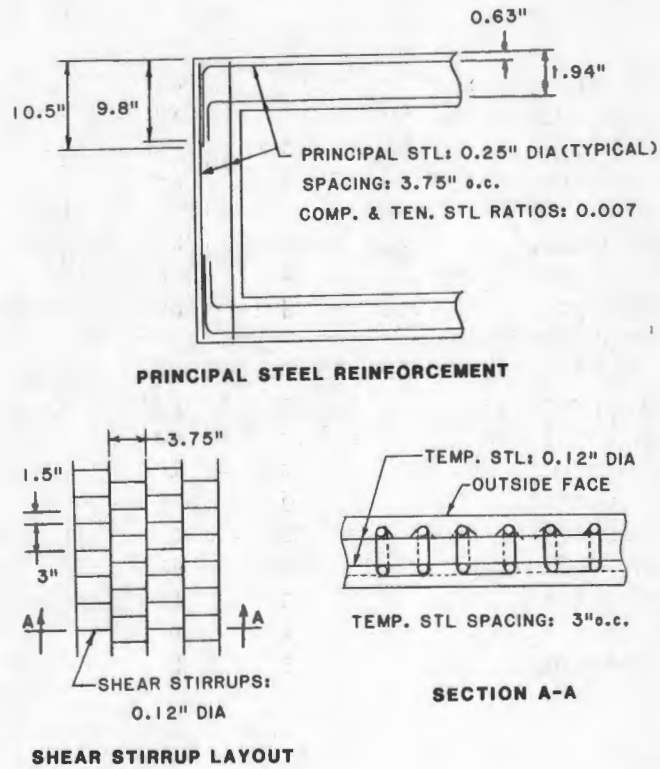



Figure 3. Steel reinforcement details.

Table 1 presents a test matrix showing the parameter to be investigated and number of tests. The Type 1 element will be a baseline test. The first static and dynamic test on Type 2 elements will have the same test configuration as the Type 1 element tests, to establish a basis of comparing the results of the remaining Type 2 element tests to the baseline tests.

Approximately 500 channels of data will be recorded during these tests. Airblast gages will document the overpressures generated by the Foam HEST, soil stress gages will be used to measure the free field stress environment, interface pressure gages will record the magnitude and distribution of pressure on the roof, walls, and floor of the structure, and strain, deflection, and acceleration gages will document structural response.

## ANALYSIS

Several pretest calculations have been performed. Iso-damage curves for design level damage (maximum roof deflection equal 5% of roof span), and for severe damage (maximum roof deflection equal 20% of roof span) are shown in Figure 4. Numbers shown on the curves are ranges (in ft) at which the indicated overpressure occurs from a surface burst. The structural configuration

Table 1. Test matrix.

| Test Parameters | Element Type | $f'_c$ psi | Backfill | DOB ft | Number of Tests Static | Number of Tests Dynamic |
|---|---|---|---|---|---|---|
| Baseline | 1 | 4000 | Sand | 1 | 1 | 1 |
| Baseline | 2 | 4000 | Sand | 1 | 1 | 1 |
| Concrete strength | 2 | 2500 | Sand | 1 | 1 | 1 |
| Backfill type | 2 | 4000 | * | 1 | 2 | 2 |
| Depth of burial | 2 | 4000 | Sand | 0 | 1 | 1 |
| Multiple hits** | 1 or 2 | 4000 | Sand | 1 | 0 | 1 or 2 |
| Alternate shear stirrup designs | Slab | 4000 | Sand | 0 | 6-10 | 0 |

* Two alternate backfill types are to be tested.

** Multiple hits will be made on a previously tested Type 1 or 2 element.

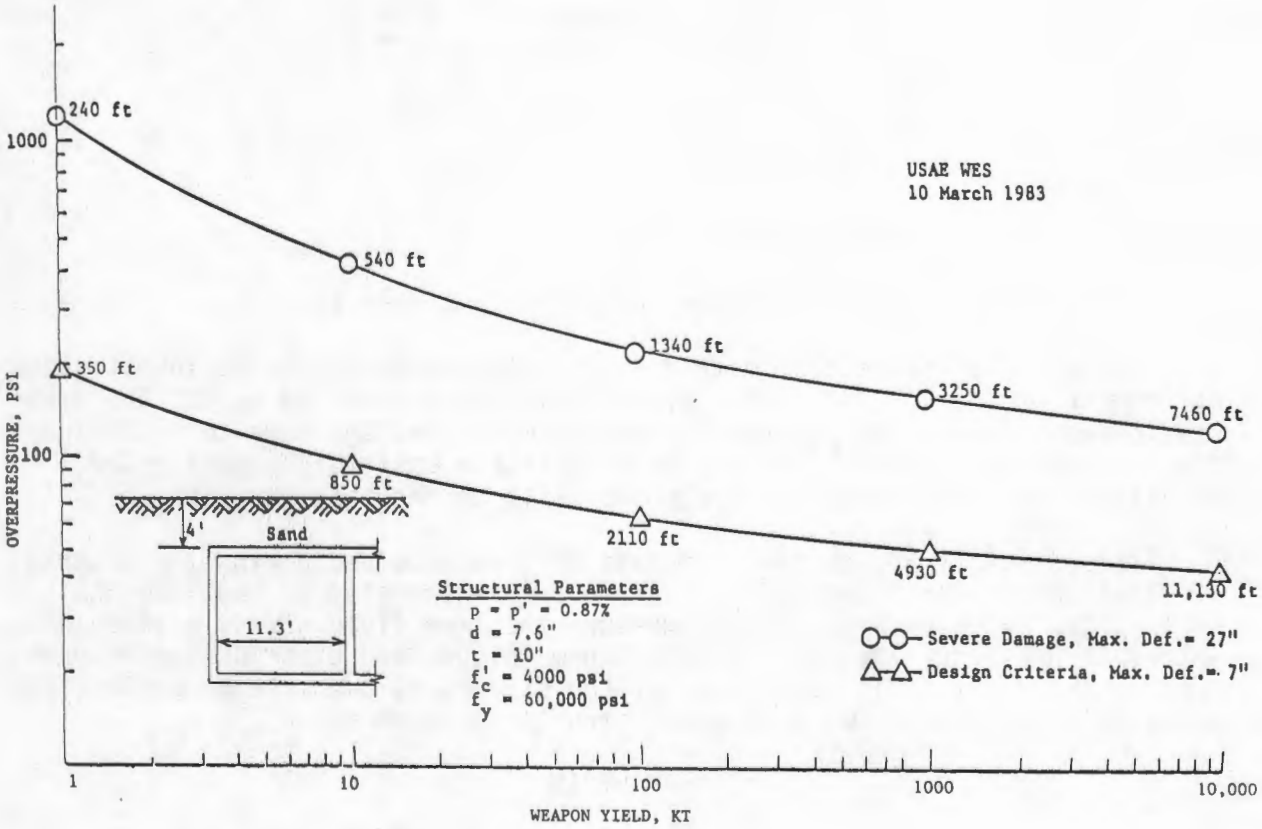



Figure 4. Iso-damage curves for 100-man capacity key worker blast shelter.

and structural parameters are shown in Figure 4, where p is percent of reinforcement steel, d is the effective depth of the roof, t is the total thickness of the roof, $f'_c$ is the compressive concrete strength, and $f_y$ is the yield strength of the reinforcement steel. In Figure 5 the structure described in Figure 4 is analyzed in sand and clay backfill materials at various depths-of-burial (DOB). The angle $\phi$ (PHI) is the angle of shear capacity for the backfill soil. The computer program RCCOLA (1) was used to investigate the effect of shear stirrup spacing. Results of this analysis indicate that a 6 in. stirrup spacing will assure flexural response without a premature shear failure.

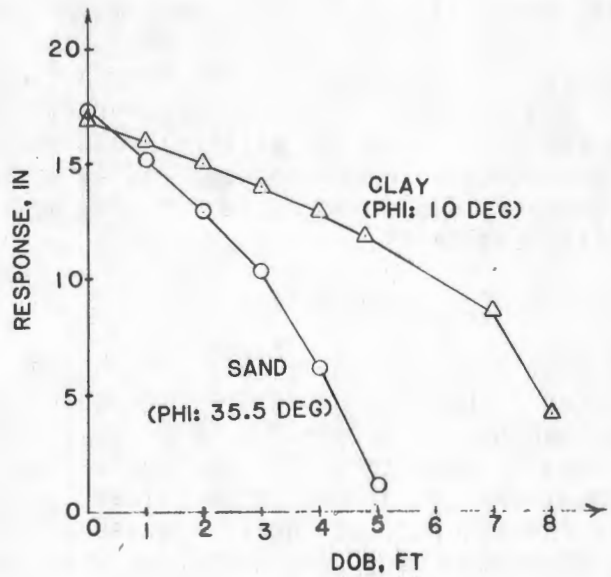



Figure 5. Response vs. depth of burial for a 1 mt weapon at an overpressure of 50 psi for two backfills

REFERENCES

1. S. A. Mahin and V. V. Bertero, RCCOLA, A Computer Program for Reinforced Concrete Column Analysis; User's Manual and Documentation, Department of Civil Engineering, University of California, Berkeley (1977).