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JUN 81 J V ZACCOR, C WILTON, R D BERNARD

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June 1981

# INDUSTRIAL HARDENING: 1980 TECHNICAL REPORT

## FINAL REPORT

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by

J.V. Zaccor, C. Wilton, and R.D. Bernard

for

Federal Emergency Management Agency  
Washington, D.C. 20472

Contract No. EMW-C-0154, Work Unit 1124E  
Dr. Michael A. Pachuta, Project Officer

**FEMA REVIEW NOTICE:**

*This report has been reviewed in the Federal Emergency Management Agency and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the Federal Emergency Management Agency.*

Scientific Service, Inc.  
517 East Bayshore, Redwood City, CA 94063

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## Section 1

### INTRODUCTION AND BACKGROUND

This report summarizes the results of a program to continue the development of an industrial preparedness manual. The manual was designed to provide a practical self-help procedure for industry to apply to reduce vulnerability to disasters - both nuclear and natural. The current effort constitutes the third phase in the program. In Phase I, a working draft of the manual (Ref. 1) was developed by Scientific Service, Inc. (SSI), for the Defense Civil Preparedness Agency (now, Federal Emergency Management Agency) under Contract No. DCPA01-77-C-0228. Phase II of the program consisted of testing and demonstrating the manual in industry under Contract No. DCPA01-78-C-0278 (Ref. 2).

Phase III of the program (performed under Contract No. EMW-C-0154), the subject of this report, had as its objectives: Continuing the development of the manual and incorporating revisions based on the results of the demonstration in the Phase II testing program; conducting additional analytical and experimental work to develop vulnerability data and hardening techniques; testing the changes and additions to the manual within selected industries, and exploring identification of potential inducements that would stimulate industry to plan and prepare for emergencies.

The manual serves as a guide for identifying and organizing activities that employ, upon warning, plant personnel and resources to accomplish the related tasks of protecting production equipment - and employees and their dependents - through a disaster emergency. The objective is to increase significantly the post-disaster survival of people, and the production resources required to maintain them. The approach is two-part and requires preplanning. It involves moving everyone - and everything critical and particularly susceptible - away from vulnerable areas to outlying regions where they can be dispersed and protected more simply, and it

involves protecting key production resources that are left in the impacted region. The procedure of moving people out of an incipient disaster area is called Crisis Relocation; the procedure of reducing industrial vulnerability, generally, has been termed "hardening". The latter is the main subject of this report.

Industrial hardening encompasses virtually any method to protect equipment against: Damage from ground motions and building collapse; crushing, overturning, and impact; hurricane winds, and flying missiles and debris; fires; and the electromagnetic pulse (EMP) phenomenon associated with nuclear weapons. Such equipment protection methods include:

- (1) Evacuation of equipment - or particularly vulnerable or critical control and subassemblies - out of the disaster area
- (2) Shielding remaining equipment against building collapse, missiles, flying debris
- (3) Using expedient measures to strengthen underground facilities so they are less likely to collapse
- (4) Preventing equipment from sliding and/or overturning
- (5) Removing combustibles and eliminating ignition sources
- (6) Disconnecting long conductors, such as antennas and power cables, from electronic and electrical equipment (or installing EMP protection on communication equipment)

Methods, required resources, and alternatives for hardening have been compiled into an integrated collection of booklets, each of which is designed to be self-contained including instructions, worksheets, and examples, and to be compatible with Crisis Relocation. Figure 1 identifies the ten booklets, and their relationship, in a flow diagram.

The manual is arranged so that each of the booklets can be assigned to a coordinator to plan and supervise the completion of each of the activities (concurrently, if necessary). The booklets are designed to guide the user towards a more efficient appraisal of resources and methods to protect equipment, using locally available options. There are two phases to the process: the planning phase,

# CRISIS RELOCATION INDUSTRIAL HARDENING PLAN

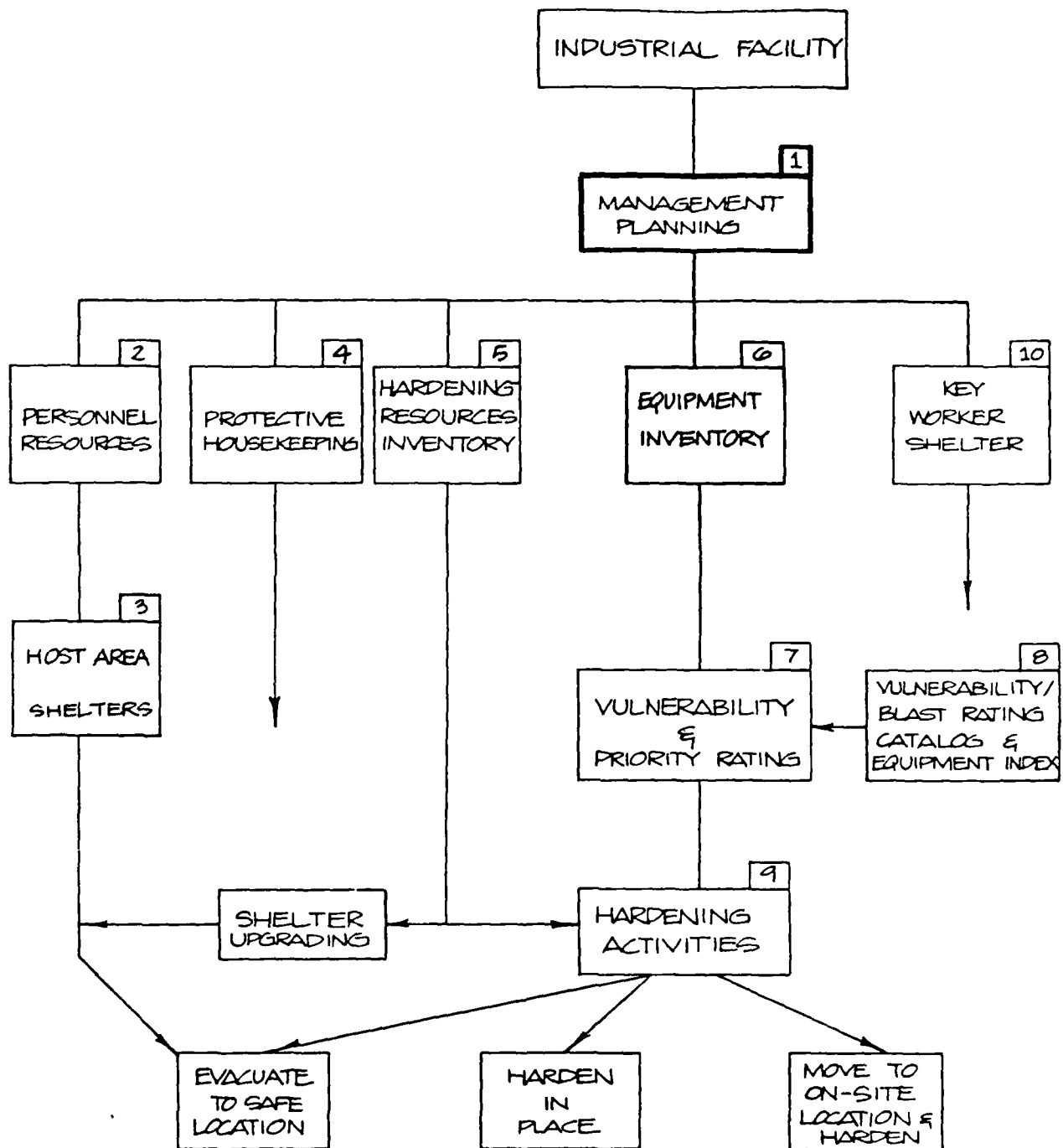


Fig. 1. Crisis Relocation Industrial Hardening Plan.

which is best completed well in advance of any disaster; and the execution phase, which can be carried out in a short time period on warning of an impending disaster. Priorities for hardening attention are established in the planning stage, systematically, by plant personnel, applying in-house perceptions of the relative importance of equipment to company production objectives. In the execution phase, resources are allocated according to rank and the hardening activities carried out.

The remainder of the report is organized as follows: Section 2 discusses the changes to the manual; Section 3 presents the results of a small scale shock tube investigation into hardening techniques; and conclusions and recommendations for future work are presented in Section 4.

## Section 2

### DISCUSSION OF RESEARCH ACCOMPLISHED

The research accomplished during this program falls under four major headings: Manual development; laboratory tests; industry demonstrations; and manual review.

#### MANUAL DEVELOPMENT

As noted in Figure 1, the manual comprises an integrated collection of 10 booklets. During this program two of these booklets were developed; four underwent major revisions; and four were subjected to minor revision. In addition, based on comments from industry reviewers and field testing by SSI personnel substantial changes were made to the format of the manual. These included: Changes to make the manual more readable including changing the type style, addition of more pictures and sketches, and a substantial reduction in the amount of verbiage; the separation of one booklet (Personnel Resources) into two (Personnel Resources and Host Area Shelters), and elimination of one of the planned booklets (Structural Analysis); and the simplification of many of the work sheets and procedures. With regard division of the original Personnel Resources booklet into two, Phase II testing indicated that activities were required in two separate locales: one at or near the plant location, involving evacuation and its support activities, and the other at a remote location in the host area, involving the development of shelters and their support activities. Because these activities would be widely separated geographically and would most likely be done by separate groups of people, then to be practical, two separate guidance booklets were required.

Elimination of the Structural Analysis booklet was also a practical expedient. Field surveys and structural analysis of a representative segment of industrial structures showed that the structures were more vulnerable than most industrial

equipment, would most likely be severely damaged at overpressures of about 2 psi (and so cause damage to equipment), and that with the exception of a few very strong structures it was not practicable in terms of labor and resources to harden most industrial structures. In general, from the point of view of resources, it is much easier to remove the equipment or harden it in place than to attempt to make the structure survive and protect the equipment.

The specific work accomplished under the present program on each of the 10 existing booklets is described below.

#### **Booklet 1, Management Planning**

Field testing in industry had indicated that the original version of this booklet was too long; i.e., it contained too much information and did not have the right material to get industry management's attention and make them understand the problem and take action to implement the planning process. Thus, several changes were made, the most noteworthy of which were the removal of much of the unnecessary verbiage and an increased emphasis on the natural disaster protection benefits achieved by implementing the hardening program. Several versions of this booklet were developed during the program, each being tested in the field and then subsequently revised based on the comments received.

#### **Booklet 2, Personnel Resources**

The original booklet was divided into two, with this book being concerned only with the activities at and near the plant. These activities include maintaining an effective industrial unit by developing employees and their dependents into an efficient survival team. Specific changes to this booklet included:

1. Eliminating the complex procedures for last minute planners, i.e., simplifying those aspects that participants in Phase II and reviewers found confusing
2. Adding requirements to develop a personnel (employee and dependent) skills list for use in a crisis period

3. Adding preparations for the handicapped and those on medications
4. Providing planning information for civil defense planners on host area space requirements, personnel capabilities and skills, and special care requirements.

### **Booklet 3, Host Area Shelters**

This is a new addition to the manual and was based largely on the SSI shelter development programs, Ref. 3 and 4. Included is information on:

1. Development of shelter requirements
2. Interfacing with local and host area civil defense personnel to obtain information and guidance
3. Methods for assessing structures to determine strength, location where shoring is required, and methods for upgrading the structures for use
4. Materials and equipment lists and estimates of time required to prepare shelters based on use or occupancy
5. Logistics, preparation plans, and upgrading sequences to use once crisis relocation is initiated
6. Alternative options for establishing host area shelter facilities using either permanent or expedient shelters

### **Booklet 4, Protective Housekeeping**

Major revisions were made to this booklet including:

1. Incorporation of hazardous materials as one of the serious problems that must be handled under industrial protection

2. Development of a list of the most common hazardous chemicals and an analysis of compatible and incompatible combinations. (This is important when deciding which chemicals should or should not be stored together.)
3. Addition of a hardening procedure developed to deal specifically with the hazardous materials in an **average** plant. (Procedures for some specific plants, such as petroleum refineries will require considerably more effort.)
4. More attention to consideration of natural disasters in the material

#### **Booklet 5, Hardening Resources Inventory**

This booklet has been completely revised to speed up those efforts where the information is applied, and to simplify the allocation of resources when implementing hardening so that there would be less chance for error. The revised version:

1. Divides resources into seven different types or categories that are directly related to specific hardening applications;
2. Reorganizes the inventory process so that each list consists of all the types of materials and equipment that would be used for a particular phase of hardening;
3. Provides several illustrations of types of applications and representative lists of typical resources for that application to provide guidance for the inventory teams;

#### **Booklet 6, Equipment Inventory**

Only minor modifications were made to this booklet. These were based on the comments received from the industry reviewers and included:

1. Improving the definitions of replacement/repair ratings so that

they were more easily understood;

2. Changing the description on the decision process for deciding hardening priorities;
3. Modifying the explanations and procedures to make the booklet more understandable and usable.

#### **Booklet 7 ,Vulnerability and Priority Rating**

Minor modifications were made to this booklet as a result of reviewers comments and research completed during the program. These changes were:

1. Changing the procedures for predicting collateral damage. (The premise that most industrial structures will be severely damaged at 2 psi makes the problem of collateral damage much more important.)
2. Simplifying the rating procedure so that it was more easily understood by industry personnel.

#### **Booklet 8, Vulnerability/Blast Rating Catalog and Equipment Index**

Considerable effort was devoted to revising the blast rating and vulnerability aspects of this booklet since these were quite incomplete in the working draft version. The following changes were made:

1. The blast ratings were reviewed and some individual class changes were made to eliminate inconsistencies, which placed items of equipment in the wrong category. An example: rugged power tools and delicate electrical meters were combined in the previous edition because they were both classed as small electrical equipment.
2. A more complete example of the use of the catalog was included as a result of reviews.

3. Information not essential to the hardening process was eliminated. In some cases data were added for completeness and explanation. Upon review and analysis it became clear that while useful in a research report, it became confusing in a manual used by the average industry employee.
4. Minor format changes were made to make the booklet easier to use; for example, the page numbers were changed to be the same as the equipment category so that information processing would be faster.
5. Many new items of equipment were analyzed as to their blast rating, and this information was included in the booklet.
6. Items of equipment were also identified as potential hardening resources.

#### **Booklet 9, Hardening Alternatives**

Considerable theoretical and experimental work was devoted to the difficult problem of hardening alternatives. While this booklet is far from being complete, the following changes were made:

1. Additional hardening alternatives were included and described. Particular emphasis was devoted to situations brought up during the Phase II demonstration program which pointed up the problems with hardening and securing equipment in urban areas where all the surrounding area is paved and dirt for burial is not readily available.
2. Concepts to assist with the hardening process were developed and tested in the laboratory and in the SSI shock tube. These included: Expedient anchors; simple berms; methods for controlling hazardous materials; tie downs; methods for tying equipment together.

3. The results of field tests in industry were also included. These tests revised several previous notions on the evacuation of equipment and the time required to implement various hardening alternatives

#### **Booklet 10, Key Worker Shelters**

This was a new booklet, developed during this program. Much of the information used was developed under shelter development and testing programs currently underway at SSI. This material was carefully adapted to the special needs of the industrial facility that decides to develop a plan using its own resources until a local or civil defense plan is implemented. This booklet includes a plan and the necessary worksheets to:

1. Determine the minimum number of key workers required
2. Establish the shelter requirements and criteria
3. Survey existing structures for use as shelters and develop upgrading plans
4. Identify expedient shelter alternatives - including decision information to assess and construct the shelter
5. Provide information for developing shelter closure and entry alternatives
6. Provide shelter stocking information and stocking checklists
7. Develop and have ready a complete plan and schedule for implementation

## SCALE MODEL EXPERIMENTS

Three types of experiment were conducted in this program, using models, to assess three expedient hardening concepts. These experiments consisted of evaluating the potential of expedient anchors, stability, and berms as means to reduce the damage from weapons effects.

To understand the nature of the contribution expected from these expedient concepts it is important first to appreciate the difference between the static overpressure and the dynamic overpressure. While both occur suddenly, solid objects with no enclosed air spaces (e.g., a steel casting as opposed to a steel cabinet) will not be affected significantly by the static overpressure. This is because the static overpressure is due to the random motion of molecules and very quickly becomes a uniform pressure around any object in the path of the pressure wave. For those objects that do have enclosed air spaces, many (perhaps most) cannot come to equilibrium fast enough (between the inside and outside) to prevent collapse of the frame and/or panels. Such collapse generally damages anything inside (for example, a typical light-metal-framed, metal-paneled industrial building). Items of the sort described are called pressure-sensitive targets, whereas those not affected by static overpressures are called drag-sensitive targets. (Of course, some items may be both, but the pressure effects will do their damage first.) The drag is caused by the directed motion of the air molecules (as opposed to the random motion that causes the static overpressure). This directed motion pushes on objects much like the current in a stream.

While static overpressure forces damage objects by sudden crushing, drag forces damage objects by overturning them, by accelerating them and forcing them to impact other objects (or vice versa, in which case objects are then termed missiles), or occasionally by snapping them off from fixed mounts (e.g., like telephone poles in a hurricane). Impacts, of two objects colliding, can generate phenomenal stresses. For example, a piece of steel moving at 90 miles an hour and colliding with a stationary piece will create stresses that generally cause yielding in the steel because the stress exceeds 140,000 psi. Terminal velocities of steel fragments can easily exceed 90 miles per hour and concrete fragments can exceed

three times this, at distances (from any large explosion) that corresponds to 20 psi. Twenty psi is a level that seems reasonable to set as a target for industrial hardening because it is feasible to achieve and will provide benefits depicted in Figure 2. The net result of these considerations is that very important hardening options will be simple measures designed to prevent overturning and relative motions that lead to collisions involving equipment. Hence anchors and ditches and berms become of obvious interest because they can be used to prevent collisions. Less apparent, but nevertheless promising for the same reason, is some kind of packaging that can increase equipment stability to prevent overturning or excessive displacement under dynamic overpressure loadings. These expedient methods to reduce damage were assessed for feasibility in the SSI 12-inch shock tube.

### **SSI Shock Tube**

#### **General Characteristics**

SSI's 12-inch shock tube is shown schematically in Figure 3. The inside dimension is 11 inches square and the overall length is 78 feet. The tube has six interchangeable sections mounted on wheels and flanged at the ends for bolting together. There are four sections 15 feet long, one section 13 feet long, and a special test section 5 feet long with a dirt bin and transparent walls and ceiling (Figure 4). The length of the pulse passing the test section is determined by the compression chamber length. The 13-foot compression chamber shown in Figure 3 produces a nominally 20 msec square wave pulse at the test section; adding a 15-foot section increases the pulse length to 40 ms.

The 15-foot section of expansion chamber - between the compression chamber and the test section - is required to iron out perturbations initiated by non-uniformity at the bursting diaphragm (which holds back the higher pressure gas in the compression chamber) when it is ruptured on signal. The compression chamber pressure determines the magnitude of the shock pulse, and the diaphragm is selected to fragment on rupture. Downstream from the test section, screens are placed between sections to break up the pulse reflected back upstream. The first screen was 70% open, the second screen was 40% open, and the end was 0% open. This enabled observations to be made without significant interference from the inevitable reflections that occur.

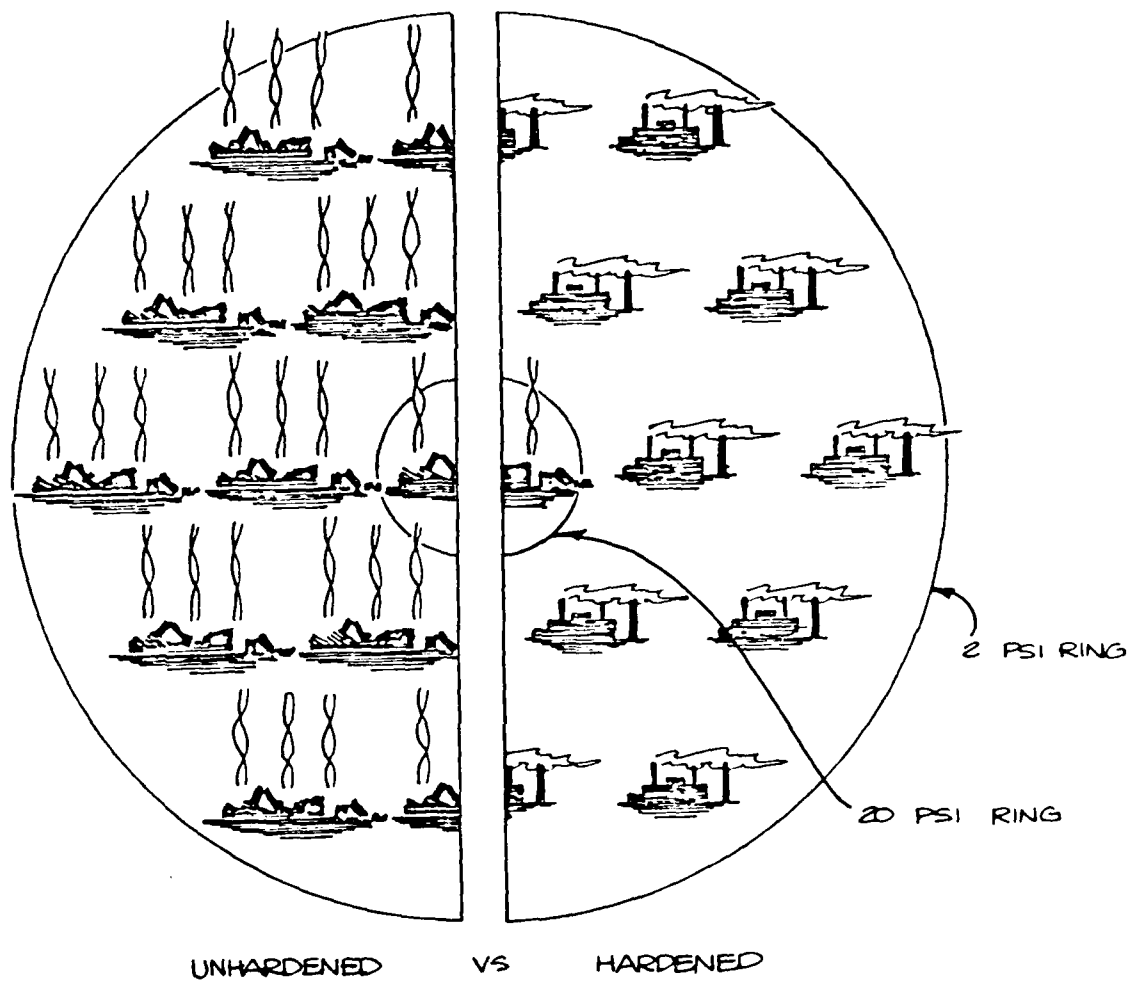
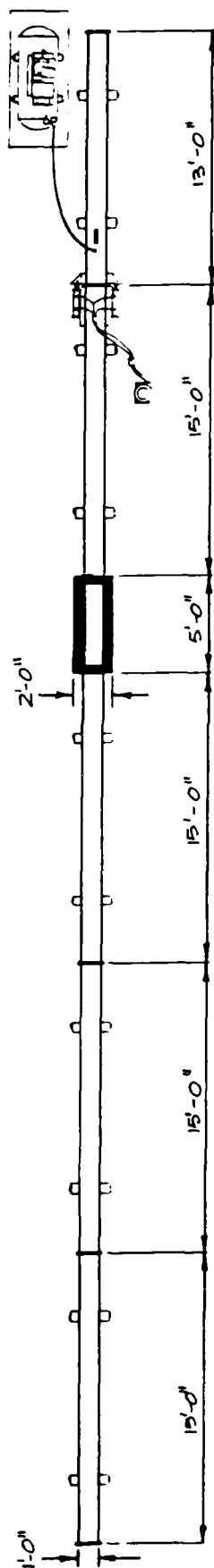
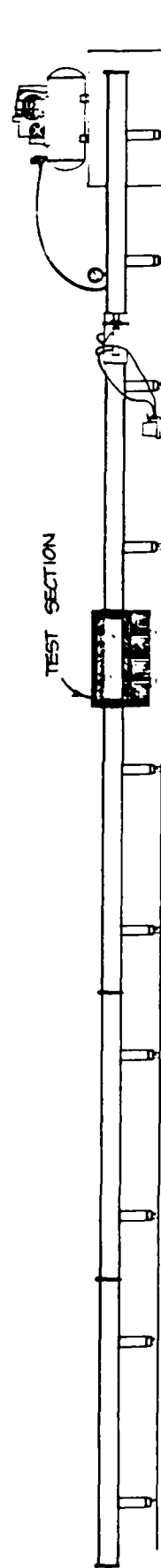


Fig. 2. Relative Damage to Hardened and Unhardened Industrial Equipment From Nuclear Attack.



TOP VIEW



ELEVATION

Fig. 3. Twelve-Inch Shock Tube.

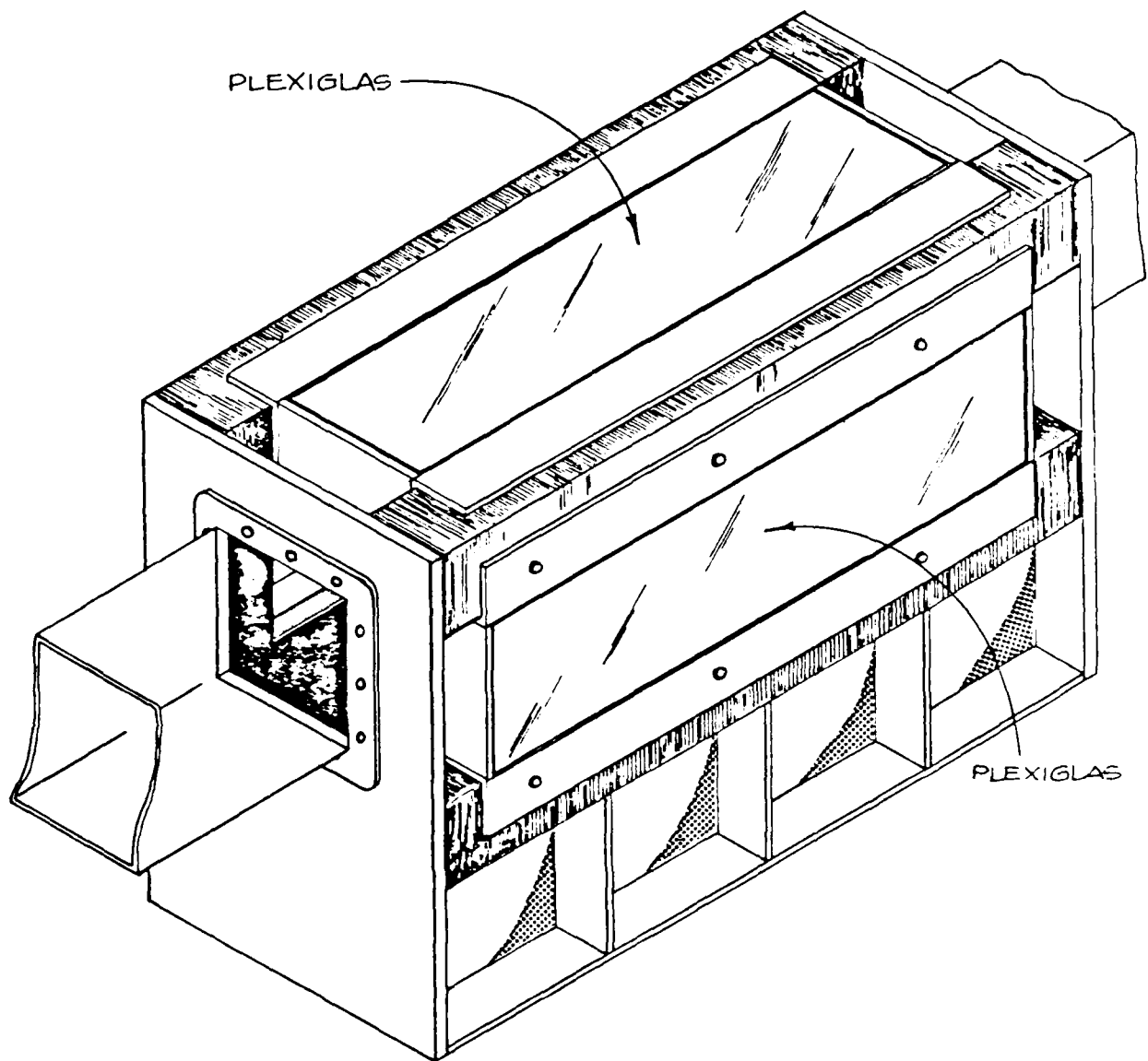


Fig. 4. Test Section of Shock Tube.

### Limit on Model Sizes

The shock tube dimensions limit the size of model that can be tested in it because the models obstruct the gas flow. To limit perturbations from models, the arbitrary decision was made that the upper limit to shock tube area cut off by models would be set at 20%. This limitation helped establish the size of the items that were tested in the shock tube. These were either one-tenth scale or one-seventieth scale, as follows: The one-seventieth scale models were used where effects of topography were of interest. In this case, a 12-foot berm (144 inches) would become 2.06 inches high at one-seventieth scale. It would run from wall to wall in the shock tube, so cut off, roughly, 19% of the open area. Objects placed behind the berm were also scaled at 1/70. For the other objects, scaled for studies not related to topography (e.g., barrels), the scale was set at one-tenth full size (23 in. in diameter and 33 in. high). Thus, to study an assembly of seven scaled barrels in a hexagonal close pack array, an area limited to 2.3 in. x 3.3 in. and 3 units wide was cut off, or about the same overall portion of the tube (19%) that the one-seventieth scale berm did.

### Weapon Size vs Model Size

For the test program conducted, square wave pulses 20 ms and 40 ms long were applied at nominal overpressures between 10 psi and 20 psi. These scaled impulses applied in the tube correspond to weapon sizes roughly between 0.01 and 70 MT, full scale, depending on model size and burst height (Table 1). Figure 5 shows a cutaway view of typical test configurations exposed to scaled shock pulses, nominally in the 3 to 20 MT range, to observe mitigating effects of berms, and Figure 6 shows the test configurations used to observe mitigating effects of stabilized arrays subjected to scaled pulses nominally in the 0.01 to 0.15 MT range.

Because masses scale as the cube of the scale factor (1/10 or 1/70), and the blast loaded frontal areas presented to the shock scale as the square of the scale factor, artifacts simulating equipment were required to have mass densities 10 times and 70 times greater than those of the prototypes in order that accelerations be the same for model and prototype. Thus, shock wave accelerations of a full barrel of oil (specific gravity 0.85) may be simulated fairly closely at 1/10 scale by a solid brass cylinder (specific gravity 8.7).

Table 1  
WEAPON-SHOCK TUBE SCALING

| Weapon Size<br>(MT) | Full Scale<br>Surface Burst<br>Peak Overpressure |        | Square Wave<br>Impulse<br>Equivalent<br>(t - ms) | Shock Tube<br>Scaled<br>@ 1/10<br>Equivalent<br>(t - ms) |  | Scaled<br>@ 1/70<br>Equivalent<br>(t - ms) |
|---------------------|--------------------------------------------------|--------|--------------------------------------------------|----------------------------------------------------------|--|--------------------------------------------|
|                     | 10 psi<br>(time, t, - ms)                        | 20 psi |                                                  |                                                          |  |                                            |
| .010                | 543                                              |        | 200                                              | 20                                                       |  |                                            |
| .022                |                                                  | 543    | 200                                              | 20                                                       |  |                                            |
| .085                | 1087                                             |        | 400                                              | 40                                                       |  |                                            |
| .180                |                                                  | 1087   | 400                                              | 40                                                       |  |                                            |
| 4.0                 | 3806                                             |        | 1400                                             |                                                          |  | 20                                         |
| 8.0                 |                                                  | 3806   | 1400                                             |                                                          |  | 20                                         |
| 31.0                | 7611                                             |        | 2800                                             |                                                          |  | 40                                         |
| 70.0                |                                                  | 7611   | 2800                                             |                                                          |  | 40                                         |

OPTIMUM BURST HT.

| Weapon Size<br>(MT) | Full Scale<br>Surface Burst<br>Peak Overpressure |        | Square Wave<br>Impulse<br>Equivalent<br>(t - ms) | Shock Tube<br>Scaled<br>@ 1/10<br>Equivalent<br>(t - ms) |  | Scaled<br>@ 1/70<br>Equivalent<br>(t - ms) |
|---------------------|--------------------------------------------------|--------|--------------------------------------------------|----------------------------------------------------------|--|--------------------------------------------|
|                     | 10 psi<br>(time, t, - ms)                        | 20 psi |                                                  |                                                          |  |                                            |
| .007                | 543                                              |        | 200                                              | 20                                                       |  |                                            |
| .015                |                                                  | 543    | 200                                              | 20                                                       |  |                                            |
| .060                | 1087                                             |        | 400                                              | 40                                                       |  |                                            |
| .130                |                                                  | 1087   | 400                                              | 40                                                       |  |                                            |
| 2.7                 | 3806                                             |        | 1400                                             |                                                          |  | 20                                         |
| 6.0                 |                                                  | 3806   | 1400                                             |                                                          |  | 20                                         |
| 22.0                | 7611                                             |        | 2800                                             |                                                          |  | 40                                         |
| 46.0                |                                                  | 7611   | 2800                                             |                                                          |  | 40                                         |

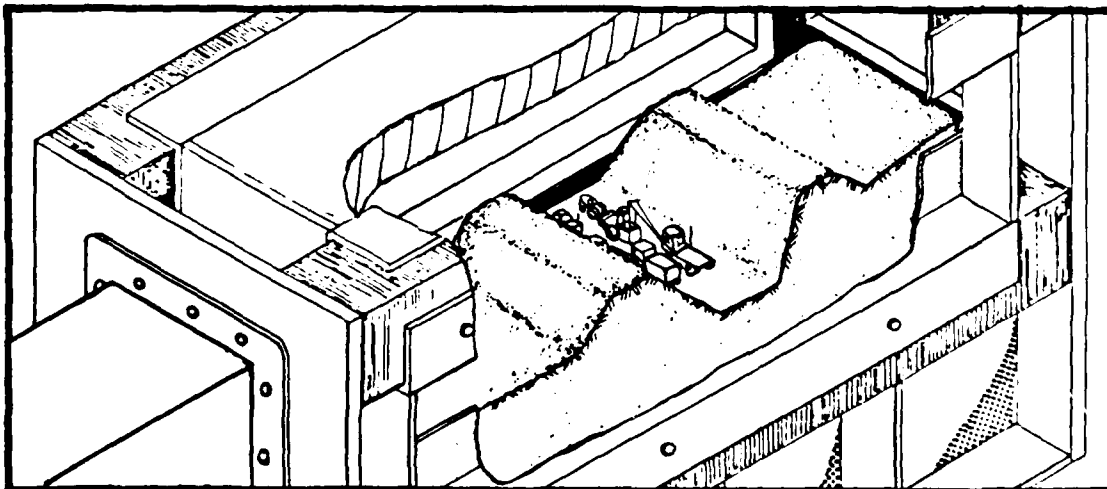
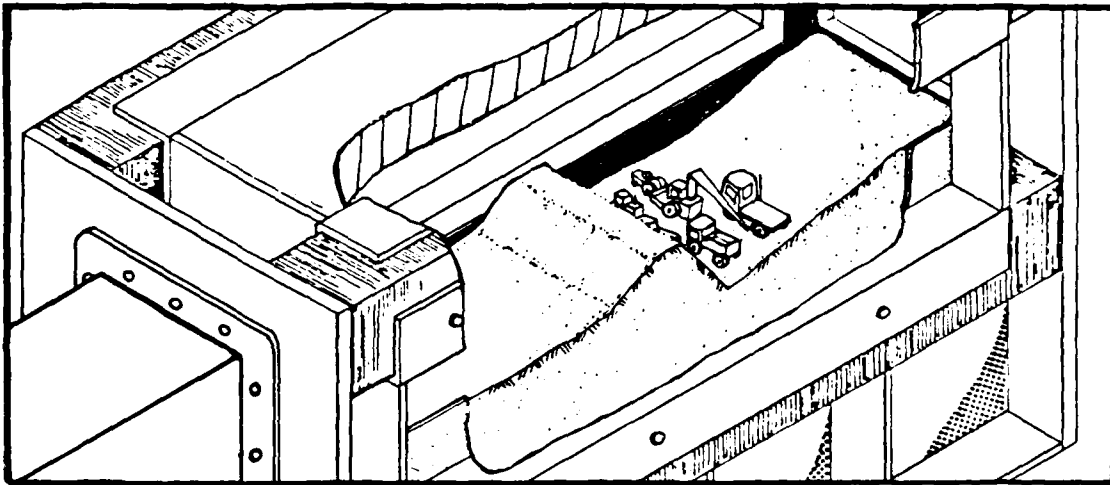
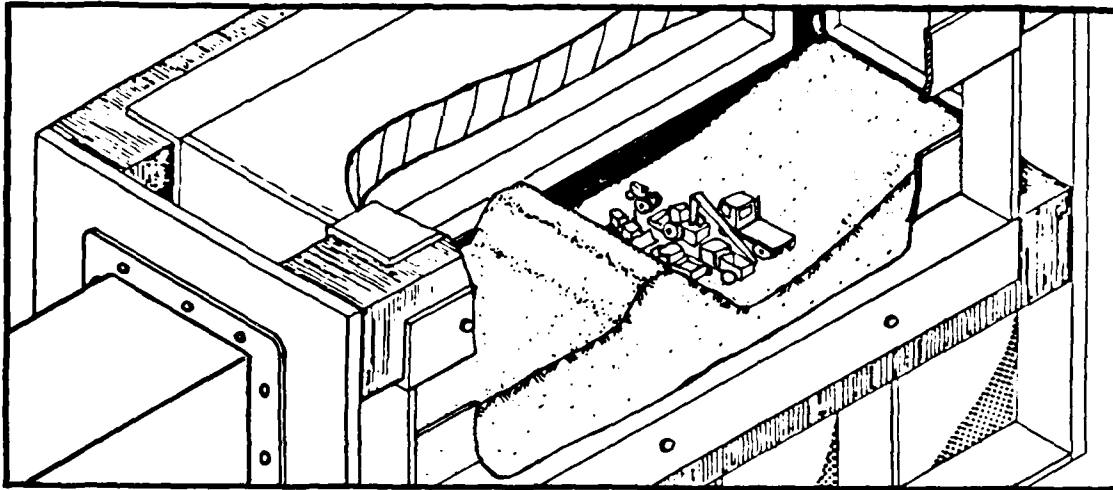
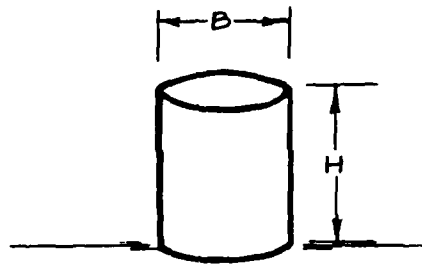
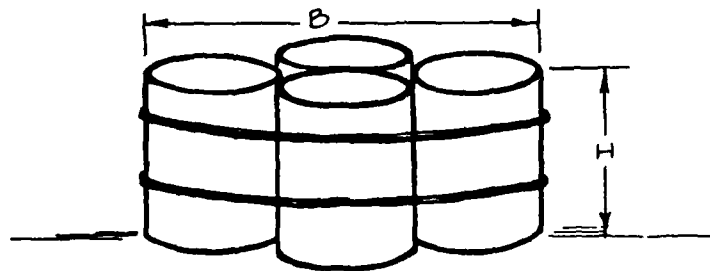


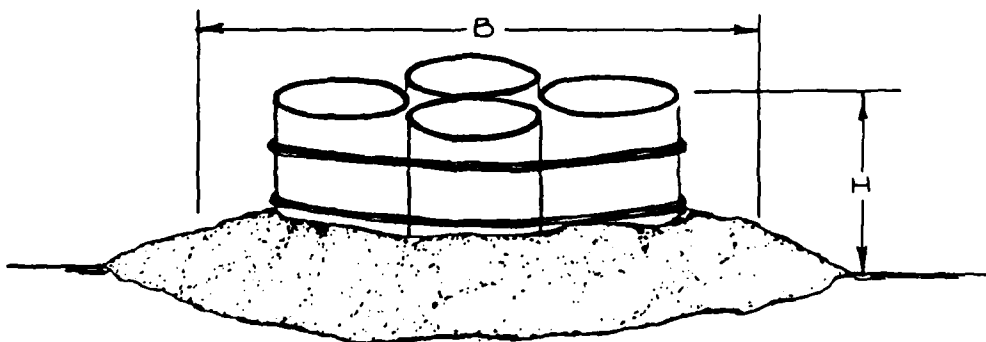
Fig. 5. Cutaway View of Berm and Ditch Test Configurations.



A. Poor Stability.  $H > B$



B. Better Stability through Banding.  $H < B$



C. Best Stability through Banding and Partial Burial.  $H \ll B$

Fig. 6. Schemes to Improve Stability.

A practical upper limit to specific gravity of models is 11.3 (set by cost of materials). Lead was the material used to simulate artifacts for the topographic studies, so the apparent specific gravities could not exceed 11.3/70, or 0.16. Table 2 provides apparent specific gravities of typical construction equipment. Cutoff for shock tube models studied, therefore, should occur at the third item in the table. However, as a 20% variation was accepted in the gas flow, a 20% variation in specific gravity was considered acceptable also. Thus, items on the list in Table 2, from the third one on, could be modeled reasonably well. For the tests conducted, items 3, 4, and 6 were modeled.

## **Tests and Results**

### **Expedient Anchor Tests**

Expedient anchors are intended to immobilize materials (or equipment) to prevent overturning or sliding into other vulnerable objects in areas where there are missiles and collapsing buildings. The ideal expedient anchor is one that can be emplaced quickly and will restrain several tons of load per anchor - something like a section of tread from a caterpillar tractor. Figure 7 shows the kind of ridged plate anchor tested. The intent was to evaluate whether the static overpressures on the anchor plate can be used as a soil confining pressure to increase the shear strength of the soil - because shear strength is a function of confining pressure.

In the initial study, pseudodynamic tests were conducted to assess what ridge and depth spacing to try in the shock tube. A practical anchor size (area) is something equal to, or less than, the cross-section of the vertical area that it is to anchor. An anchor plate area half that of its typical load package was selected arbitrarily. The typical load package is expected to be about 5 ft high so an anchor design with an area of 2.5 ft x 1 ft that could restrain each lineal foot of package was sought initially. The design is intended to work at 20 psi peak overpressure, where the peak dynamic pressure is about 7 psi and the peak load on a 5 ft x 1 ft area of the package is equal to

$$7 \text{ lb/in.}^2 \times 5 \text{ ft} \times 1 \text{ ft} \times 144 \text{ in.}^2/\text{ft}^2 = 5,040 \text{ lb.}$$

Under these conditions, the peak normal force on the 2.5 ft x 1 ft plate of the ridged anchor is equal to

$$20 \times 2.5 \times 1 \times 144 = 7,200 \text{ lb.}$$

Table 2

## APPARENT SPECIFIC GRAVITIES OF TYPICAL HEAVY CONSTRUCTION EQUIPMENT

| Item             | Gross weight<br>(lb) | Overall Dimensions (ft) |       |        | Specific Gravity<br>(gms/cm <sup>3</sup> ) |
|------------------|----------------------|-------------------------|-------|--------|--------------------------------------------|
|                  |                      | Height                  | Width | Length |                                            |
| Generators       | 125                  | 1                       | 1     | 2      | 1.0                                        |
| 16-ton<br>Crane  | 32,000               | 10.5                    | 8     | 24     | 0.254                                      |
| 12-ton<br>Crane  | 24,000               | 10                      | 8     | 24     | 0.200                                      |
| Pickup<br>Truck  | 3,000                | 6                       | 6     | 16     | 0.148*                                     |
| Arc<br>Welder    | 400                  | 4                       | 4     | 8      | 0.08*                                      |
| Panel<br>Truck** | 4,000                | 8                       | 8     | 14     | 0.07                                       |

\* Adjusted for actual dimensions

\*\* Approximate

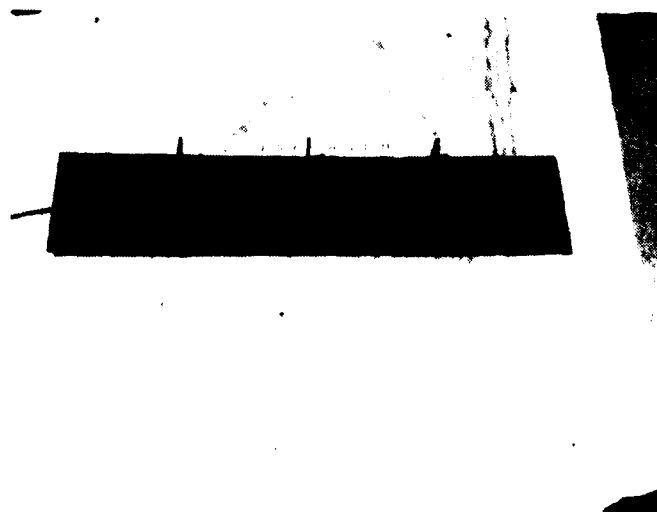


Fig. 7. Photograph of Ridged Anchor Plate.

(assuming no air pressure gets under the plate). Compared to this "normal" force, the 5,040-lb anchor load capability (70% of the normal force) seems quite reasonable based on the observation that caterpillar tractors have a drawbar load capability slightly over 100% of the normal force that the tractor weight applies on the treads. To simulate component loads in the anchor tests, a pair of rams oriented at right angles were used. With the vertical load fixed to simulate the static overpressure, the horizontal ram load was increased until failure of the anchor occurred. The ratio of the failure load to the load anticipated from the dynamic pressure was derived for different soil and anchor combinations and static overpressures. These are summarized in Table 3.

Based on the data of Table 3, a pair of one-tenth scale anchors were made to test in the shock tube - at a nominal 20 psi overpressure, in topsoil. These anchors failed, and the shear failure in the soil was observed to be characteristic of the kind of failure to be expected. But, because the ram tests had been successful, some reason for the failure of the scaled anchors in the shock tube was sought. It was postulated that either the pressure got under the plate, or the one-tenth scale ridges (only 0.2 in. deep) were invalid in "full scale" soil, despite the appearance of the classical shear failure. The latter postulate was easier to evaluate, so a new test configuration was considered and tried.

The largest practical package that will fit in the SSI shock tube for testing an anchor was a movable sail that provided a 90-in.<sup>2</sup> loading area. This was attached to an anchor built with a plate area 6 in. by 30 in. (or 180 in.<sup>2</sup>) and 18 linear inches of ridges, 2 in. deep (the anchor in Figure 7). The largest load that could be applied to test this anchor did not cause a shear failure in the soil (or even move the anchor) in three tests. Air-pressure gauges located in the shock tube were used to measure the loads. The recorded pressure ranged from 17 psi to 18 psi (corresponding roughly to anchor loads of 1,500 to 1,600 lb). Thus, a 4 ft by 1 ft plate with 5 ridges would appear sufficient to restrain 5,000 lb. This should be tested in the field.

Table 3  
FAILURE LOAD AS A PERCENT OF DEMAND LOAD  
(Anchors 18 in. long, Ridges 2 in. deep)

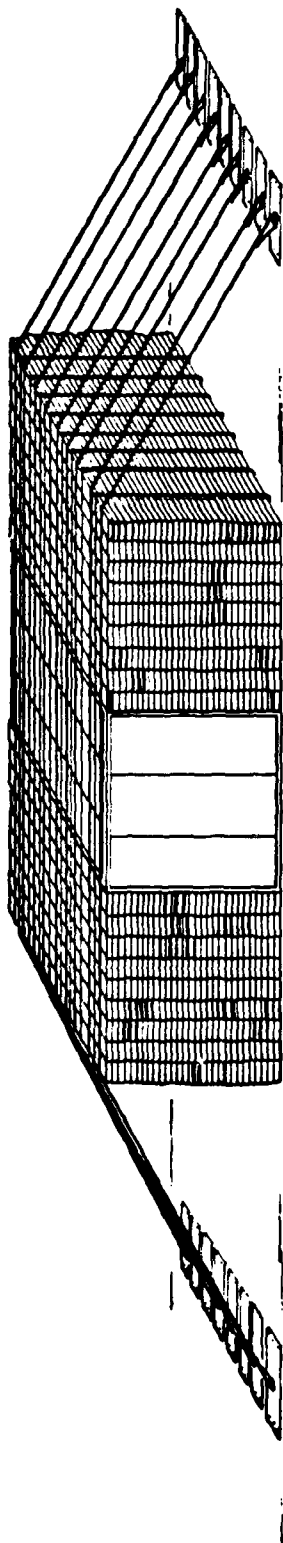
| STATIC OVERPRESSURE EQUIVALENT |        |              |      |              |              |                                       |             |                                              |      |
|--------------------------------|--------|--------------|------|--------------|--------------|---------------------------------------|-------------|----------------------------------------------|------|
| Soil<br>Ridge<br>Type          | 10 psi |              |      | 20 psi       |              |                                       | 40 psi      |                                              |      |
|                                | Sand   | Top-<br>soil | Clay | Sand         | Top-<br>soil | Clay                                  | Sand        | Top-<br>soil                                 | Clay |
| Single<br>@ 9"                 |        |              |      | Fail<br>27%* | Pass<br>113% |                                       | Fail<br>7%  | Fail 74%<br>Fail 68%<br>Fail 68%             |      |
| Two<br>6" apart                |        |              |      | Fail<br>41%  | Pass<br>143% |                                       | Fail<br>10% | Fail 75%<br>Fail 73%<br>Fail 73%             |      |
| Three<br>4½" apart             |        |              |      | Fail<br>55%  | Pass<br>180% | Pass<br>Average 143%<br>std. dev. 24% | Fail<br>12% | Fail 73%<br>Fail 73%<br>Fail 80%<br>Fail 67% |      |

\* Percent of required load achieved.

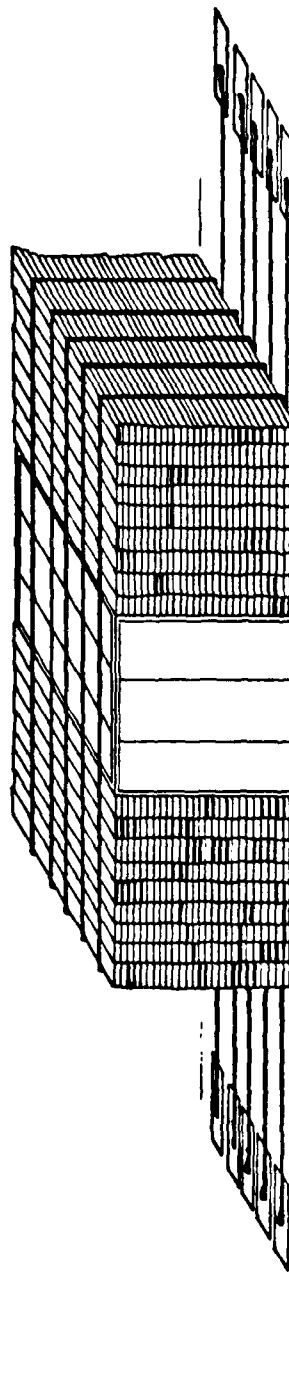
### Package Stability Tests

To be effective, anchors should be applied to restrain stable arrays, e.g., as in Figure 8B. Stability depends on configuration. If the stacks of lumber in Figure 8B were removed from each side of the configuration, the package in the middle would become unstable in the direction of the cable and could overturn and tumble. To determine more about the stability of objects, arrays of scale-model barrels were studied, in terms of the height-to-base ratio (H/B), as identified in Figure 6. Barrels were selected because they can be readily studied, full scale in the field, at minimum cost. Moreover, barrels are typically found at industrial plants - often filled with hazardous materials that should not be allowed to escape. Thus, the shock tube barrel-stability tests can be directly verified in the field, and have immediate pertinence to hardening hazardous materials (to neutralize them so they do not become an additional concern during recovery operations).

In the SSI shock tube, 46 stability tests were conducted with one-tenth scale barrels at 10 psi overpressure. These tests involved 29 single barrels, and 10 clusters of three and 7 clusters of seven barrels, standing on dirt and on concrete. The tests are summarized in Table 4. Four of the single barrel tests on dirt involved partial burial - below the normal ground level - and six single barrel tests involved sprinkling dirt around the base of the barrels. At 10 psi, single barrels have a 50% chance of overturning; burying 5% of the barrel does not help. At 10% burial, there is no overturning, but the barrels get tilted at about 15 to 20 degrees. A 10% burial is much simpler than 100% burial, but with multiple barrel arrays it was observed that they merely slide (remaining stable without overturning or tumbling). (Certainly, banding barrels, or other items, in clumps is even easier than 10% burial -- particularly if there is no open dirt area handy.) It was observed that arrays move less on dirt than on concrete. Further, dirt sprinkled around an array does not seem to provide any benefit. On concrete, a scaled seven-barrel array moves one-third to two-thirds of an array diameter with a 40 ms square wave pulse (0.07 MT equivalent), so would be expected to move  $(1.0/0.07)^{1/3}$  times farther or less than two array diameters under a 10 psi loading from a 1 MT weapon. Thus, at 10 psi, anchors would not be necessary for arrays where  $H/B < 1/2$  and array spacings are 2B, even when these arrays stand on concrete. Typical test arrangements for tests of barrels are shown in Figure 9.



A. Anchors Subject to Uplift and Drag.



B. Anchors Subject to Drag Principally.

Fig. 8. Tiedown Alternatives.

Table 4  
10 psi SHOCK TUBE TEST RESULTS

|                         |                                 | Still Standing<br>Percentage | Displacement<br>Average | Number<br>of Tests |
|-------------------------|---------------------------------|------------------------------|-------------------------|--------------------|
| DIRT                    | Single Barrel Standing          | 46%                          | 0.44                    | 13                 |
|                         | Three Barrels Standing          | 100%                         | 0.58                    | 3                  |
|                         |                                 | 100%                         | 0.75                    | 3                  |
|                         | Seven Barrels Standing          | 100%                         | 0.29                    | 3                  |
|                         | Single Barrel, Loose Dirt Piled | 50%                          | 0.00                    | 6                  |
|                         | Single Barrel, Buried 5%        | 0%                           | —                       | 1                  |
|                         | Single Barrel, Buried 10%       | 100%                         | 0.00                    | 3                  |
|                         | Three Barrels, 40 ms            | 100%                         | 2.63                    | 1                  |
| CONCRETE<br>20 ms/40 ms | Single Barrel Standing          | 50%                          | 0.32                    | 6                  |
|                         | Three Barrels Standing          | 100%                         | 3.19                    | 3                  |
|                         |                                 |                              | 6.75                    |                    |
|                         |                                 |                              | 7.88                    |                    |
|                         | Seven Barrels Standing          | 100%                         | 2.63                    | 4                  |
|                         |                                 |                              | 5.06                    |                    |
|                         |                                 |                              | 2.18                    |                    |
|                         |                                 |                              | 2.25                    |                    |

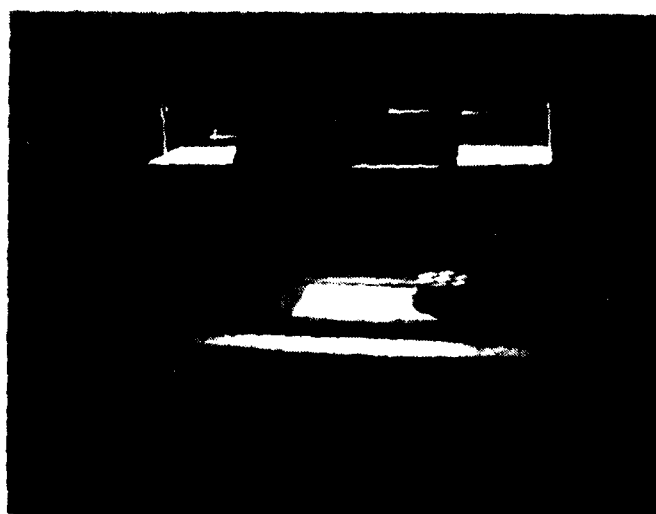
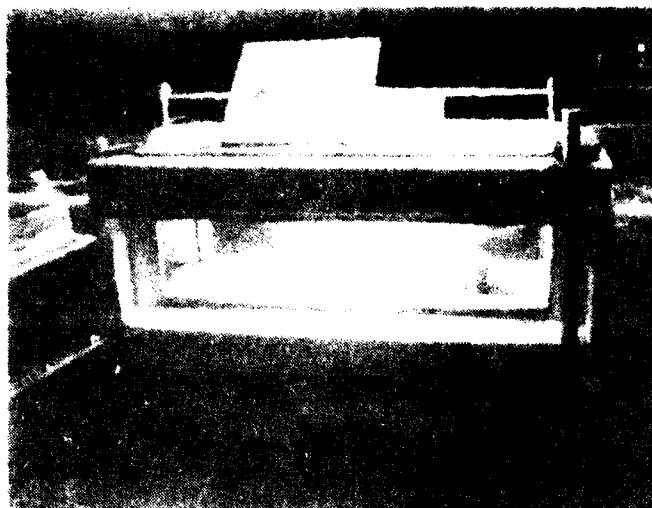


Fig. 9. Test Arrangement for Three- and Seven-Barrel Tests.

Not as many tests were conducted at 20 psi because of the additional time required to pump the shock tube compression chamber up to the 95 psi reservoir pressure required. (Either a larger compressor, or heavier duty hydraulic rams to seal the chamber at the bursting diaphragm, would suffice to speed up the higher pressure tests. However, some additional expansion chamber lengths are also desirable at the higher shock overpressures, to iron out the reflections -- so the higher pressure tests were principally used as verification tests.) The higher overpressure with a 20 ms square wave pulse (the same **total** impulse as the 10 psi square wave pulse) confirmed about 1/2 B movement so that on concrete a 20 psi loading from a 1 MT weapon is likely to cause a seven barrel array to slide less than 4B array diameters, while on dirt it is more likely to move less than 2B. Therefore, at 20 psi, anchors are probably not necessary for arrays where  $H/B < 1/2$  and array spacings are 4B, even when these arrays stand on concrete.

#### Ditch and Berm Tests

Benefits from ditches and berms are essentially the same. An object in a ditch or behind a berm has very low vulnerability to missiles and considerably less vulnerability to drag forces than objects in the open. To the extent the object is not pressure sensitive, either option (ditch or berm) is effective for hardening equipment. The missile protection afforded is the easier to appraise. It is merely a question of trajectories and velocities. The narrower the ditch (or the berm spacing) the less likely a high velocity object will impact equipment inside, provided the object has a foot or two of ditch or berm above it and provided the object does not fall from a high altitude. If there are no high buildings near, a high altitude missile is unlikely and so, therefore, is a missile impact.

The drag problem is more difficult to evaluate because an important factor in the gas flow is the vortex behavior at discontinuities (e.g., at the edges of ditches and crowns of berms), which does not scale (Ref. 5). The desirable behavior, of course, would be to redirect the gas particle velocity so that it jumps over the ditch or berm without pushing the objects inside around. This is not entirely possible unless the ditch is filled with a liquid (water would do but for detrimental effects on equipment). Moreover, a liquid could provide protection for submerged and de-aerated pressure-sensitive targets at the same time because these cease to be

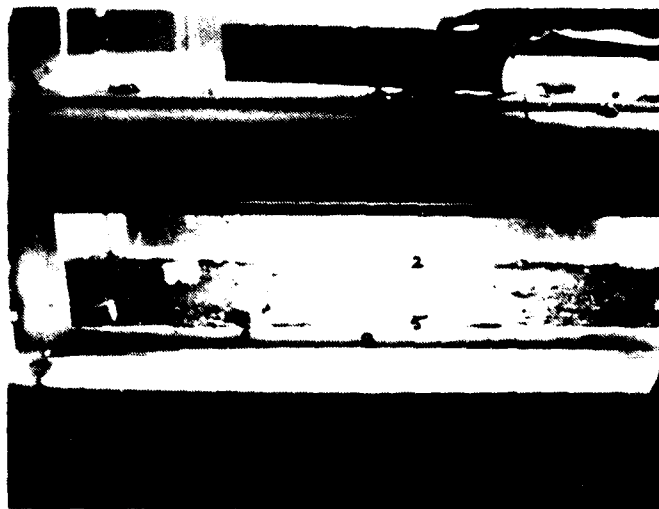
pressure sensitive when all the internal air spaces are filled with relatively incompressible fluid. Thus, an inexpensive, non-inflammable, low-compressibility liquid that evaporates quickly, with no residue, could have a major impact on industrial hardening. Until such a liquid is developed, however, there will be drag forces to consider in efforts to use ditches and berms for hardening. For the present study, the objective of the berm tests conducted in the shock tube was to identify acceptable berm spacings (i.e., which particular larger scale tests would provide the quickest verification).

Figure 10 shows a "before and after" pair of pictures for a test, equivalent to 5 MT full scale, conducted at 14 psi to observe beneficial effects berms might have on the drag on packages located in front, between, and behind the berms. The major deleterious effect on packages occurs ahead of the berms (flow is from right to left). To provide comparison, Figure 11 shows a companion picture pair for a 5 MT equivalent test conducted at 14 psi where there were no berms at all. The packages are all of the same dimensions (1 in. by 1 in. by  $2\frac{1}{4}$  in.) equivalent to about 6 ft x 6 ft x  $13\frac{1}{2}$  ft full scale, but different mass densities ranging from 0.086 to 0.140 (see Table 2). The berms are clearly effective in reducing drag forces on those packages located between them - where missile protection is also afforded. Figure 12 shows that at 18 psi the (nominally) 5 MT equivalent blast wave dumped a package that was in front of the forward berm onto one of the packages between the berms - a situation that is obviously undesirable and can be avoided by not allowing packages to be placed nearby, outside berm pairs.

To observe how items behave with less area in contact with the ground, the equivalent of four wheels were attached to the packages to make them into simulated panel trucks (the most vulnerable type of vehicle because of the small mass and large area presented to the gas flow - see Table 3). Figures 13 and 14 show the effect of two orientations of panel trucks to a 10 psi pulse from a 25 MT equivalent explosion with berms spaced a distance equivalent to 35 ft apart. Clearly the vehicles were moved about in both cases; the end-on configuration is apparently of little benefit. The berm spacing was tightened up to an equivalent distance of 23, ft and the configuration of Figure 14 (now reversed) was repeated for the same overpressure and weapon size, as seen in Figure 15. It appears that this time the

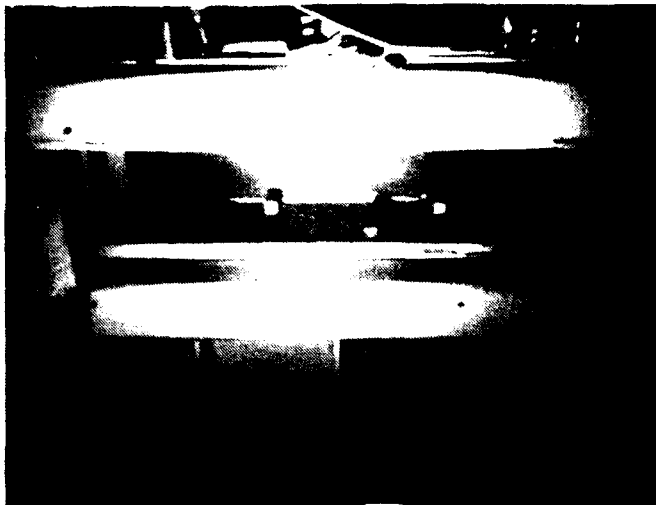


Before

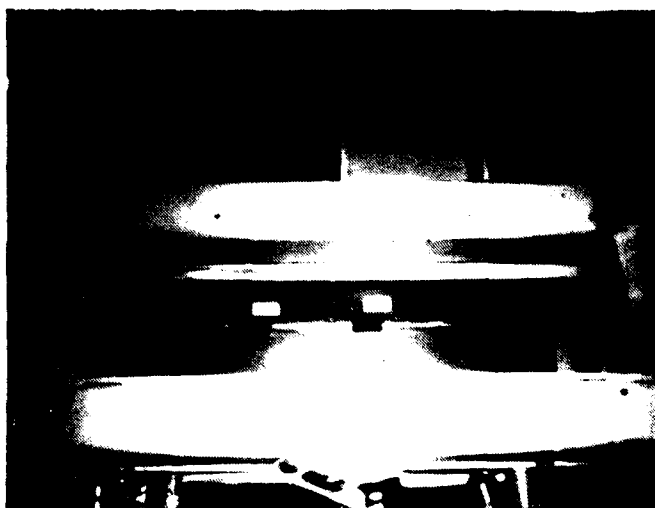


After

Fig. 10. Package Berm Arrangement on Dirt - 14 psi, 20 ms Pulse.

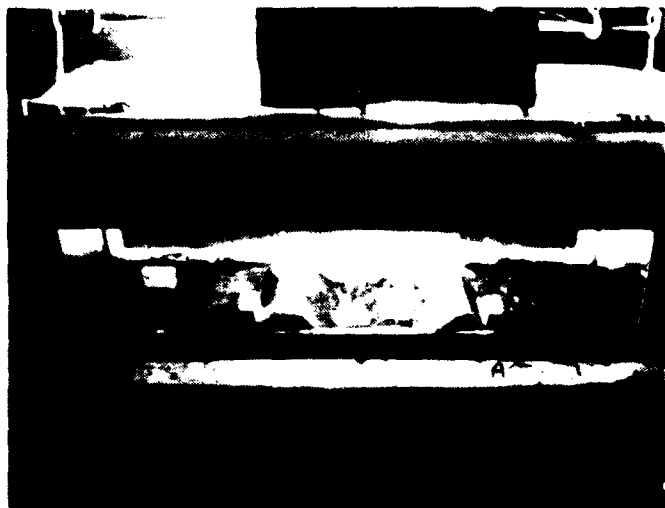


(a) Top



(b) Bottom

Fig. 11. Package Arrangement Without Worm on Dirt - 1. psi, 20 ms Square Wave Pulse.

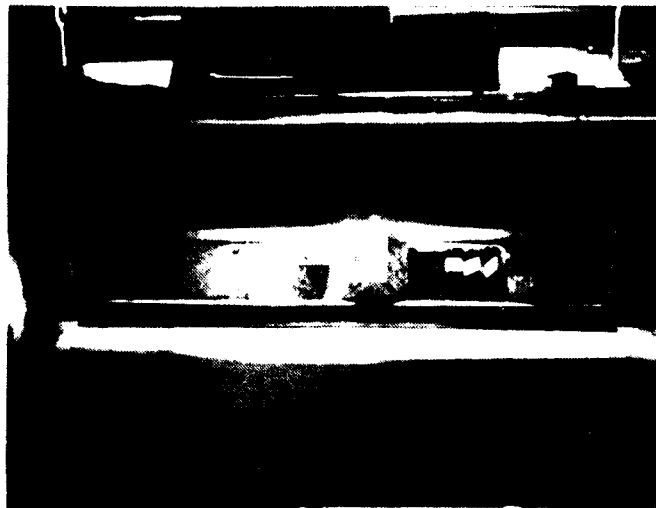


Before

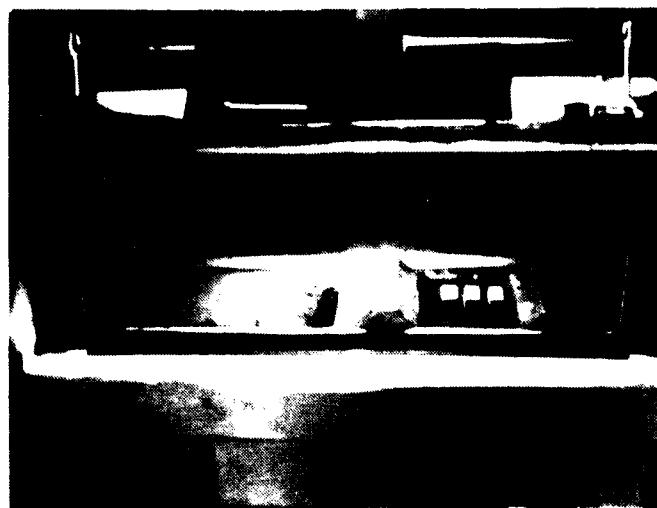


After

Fig. 12. Package Berm Arrangement on Dirt - 18 psi, 20 ms Pulse.

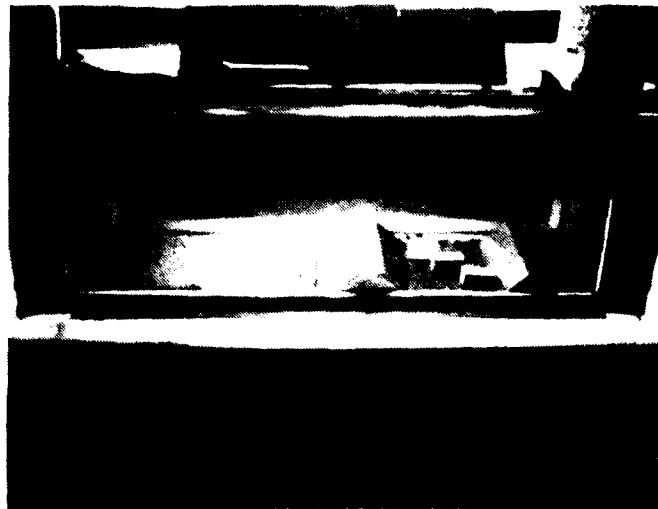


Before



After

Fig. 13. Vehicles Oriented Side On - 10 psi, 40 ms Pulse.

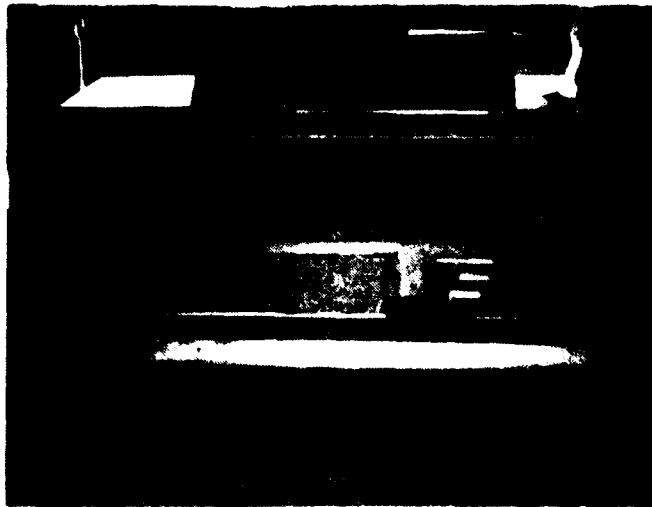


Before

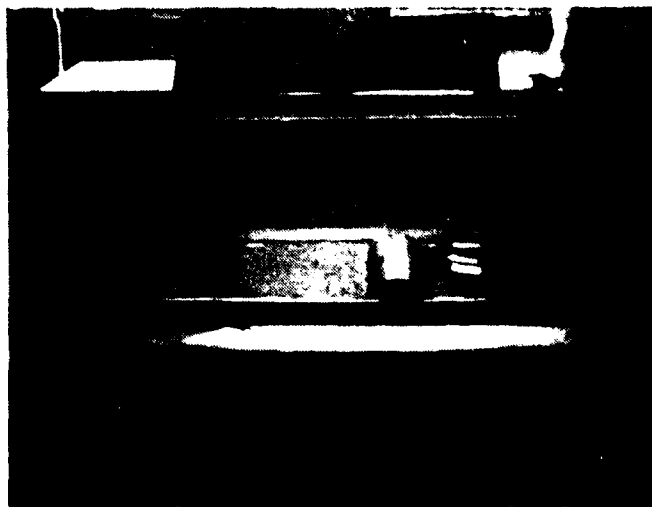


After

Fig. 14. Vehicle: Oriented End On - 10 psi, 40 ms. Pulse.



Before



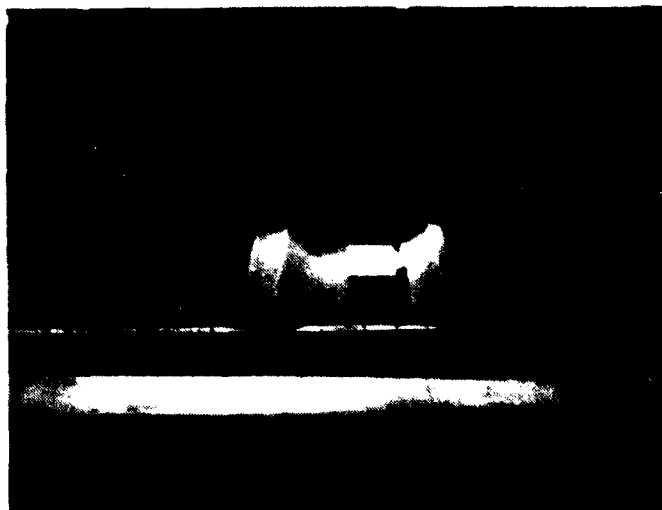
After

Fig. 15. Vehicle Oriented and on  $\pm 10$  per cent Pulse.

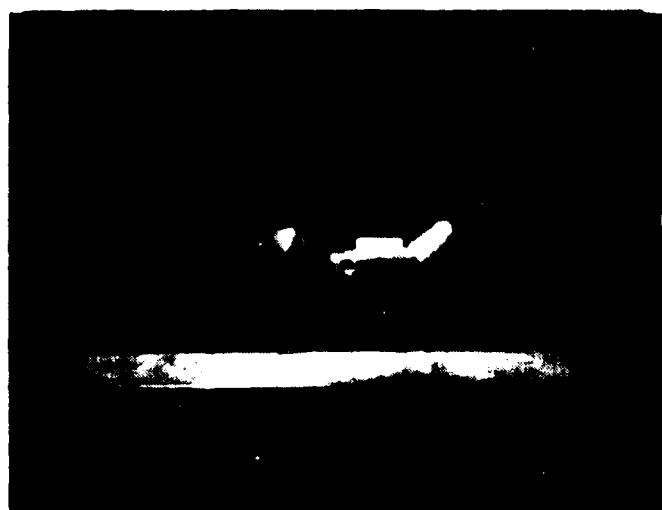
end-on configuration for the vehicle closest in to the forward berm (on the far side) was little affected. Note that in an actual nuclear attack, it would be unlikely that the direction of burst would be known, or guessed properly, so that the problem of just where to locate objects between two berms always exists. In the test shown in Figure 16, a tight package of three vehicles was made so that dimensions in both directions were about equal, and this time a (nominally) 5 MT pulse was simulated at 10 psi with the berm spacing of Figure 15 retained. Here, there was little movement evident.

Figure 17 shows the effect of a 25 MT loading at 10 psi on a scaled 12-ton crane and a pickup truck (compare the densities of these with that for the panel trucks in Table 3). The berm spacing is the same as in Figure 15. The crane moved about 1 ft and the pickup truck was slewed the equivalent of about 3 ft. In the Figure 18 the test, berm spacing was maintained, but the orientation of the crane and pickup truck was reversed, the weapon size simulated was reduced to (nominally) 5 MT and the overpressure was increased to 17 psi so that total impulse is about the same as on the previous test. In the broadside position the crane moved several feet but the pickup truck slewed in its end-on position, about the same as it did side-on in the previous test.

It appears that packages, vehicles, and equipment can be protected fairly well from drag effects, as well as from missiles, by means of ditches and berms. For vehicles, it also appears necessary to develop some means to increase the area in contact with the ground, or else to amass larger assemblages of vehicles using tires or sandbags wedged between. As a practical note, it does no good to protect a vehicle from drag and missiles if the engine compartment components are not protected against collapse of the hood due to static overpressure. Perhaps the simplest way to protect against panel collapse is to remove panels whenever they could be a problem -- engine hoods, fenders, doors, windshields.



Before



After

Fig. 16. Vohl 10. (a)  $\mu = 10$  pol, 20 m. (b)  $\mu = 10$ .

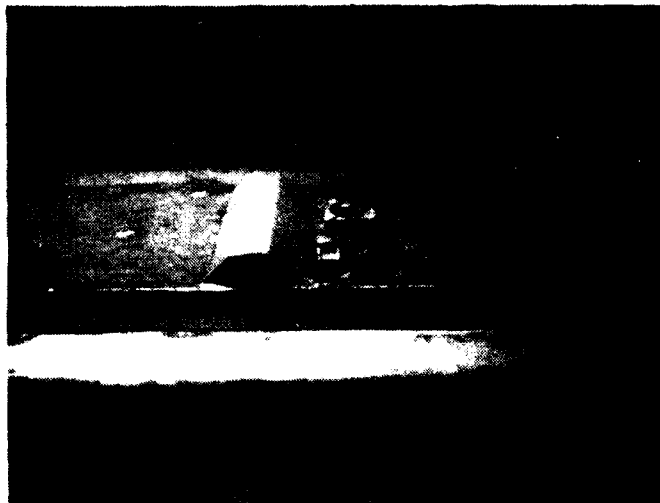


Figure 17

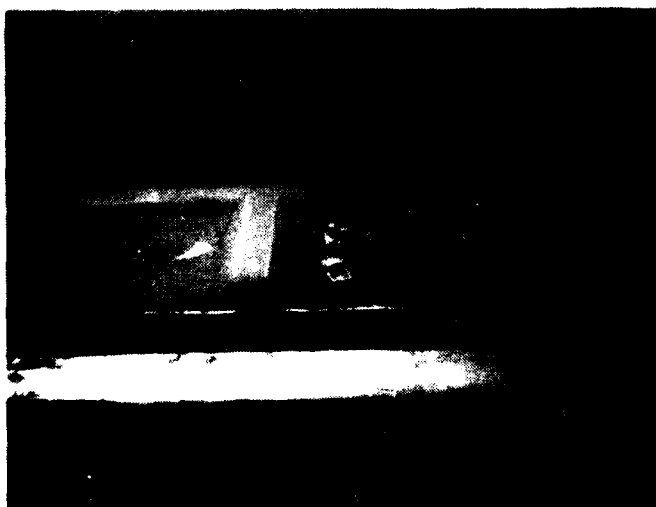


Figure 18

Fig. 17. Crane and large container in the dark.



Fig. 17.



Fig. 18.

Fig. 18. Crane and Lister. (Note - This is a photograph of the same object as in Fig. 17.)

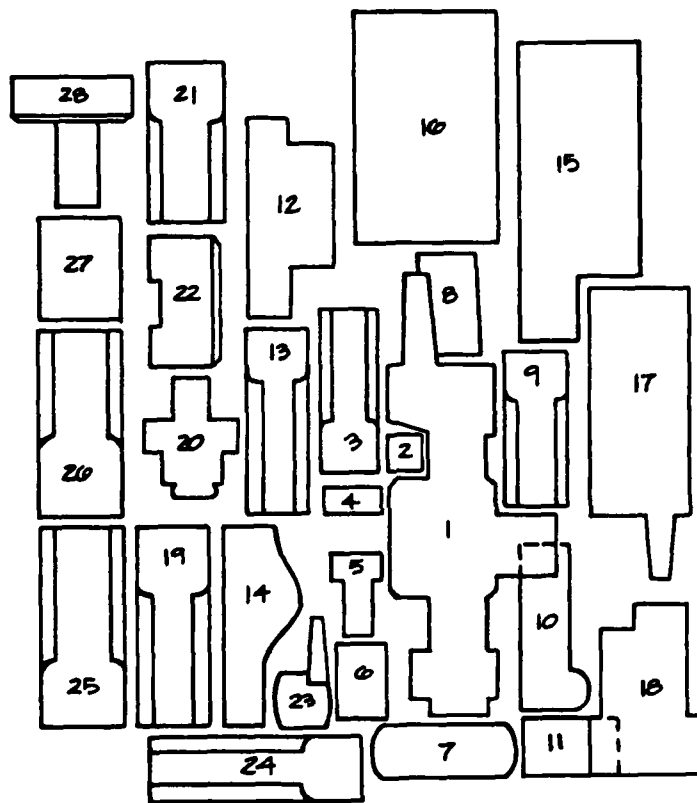
### Section 3

#### **HARDENING DEMONSTRATION**

A demonstration was conducted at the Driesbock Machine Tool Company in Belmont, California. This company reconditions used machine tools of all types and is one of the half dozen or so companies in the San Francisco Bay region that is both equipped and has personnel knowledgeable enough to move large pieces of equipment. The purpose of the demonstration was to develop additional data on methods of hardening machinery, particularly when some of it is so large as to be unmovable without special expertise and equipment unlikely to be available in a general emergency.

The demonstration involved 28 pieces of machinery, two of which would not be movable by plant personnel at those plants where they would typically be used. The hardening plan was to cluster equipment around the two large pieces, "tie" all of the equipment tightly together as a unit, and protect this unit from damage caused by falling or flying debris. The tying might consist of welding channel or I-beams between items, or welding a crib around the whole cluster. In the latter case, automotive tires would be used as bumpers or fenders between the machines and the crib would be covered with chain link fence or welded wire fabric (such as used to reinforced concrete slabs) and filled with rubble, bricks, concrete block, lumber, etc., to cover the equipment and protect it from a collapsing roof. Non-combustible materials are desirable for the top layer. In the study, all the moving was done by two employees (professional movers) of the machine tool company. The documentation included written records, still photography, and movies.

Figure 19 shows a floor plan of the 28 clustered pieces of machinery. (Table 5 identifies the items in the figure.) Figures 20 through 23 show typical machinery involved. Most of the equipment was moved by forklift. One unit was moved by an overhead crane and one unit was moved on rollers in order to compare time required;



NORTH

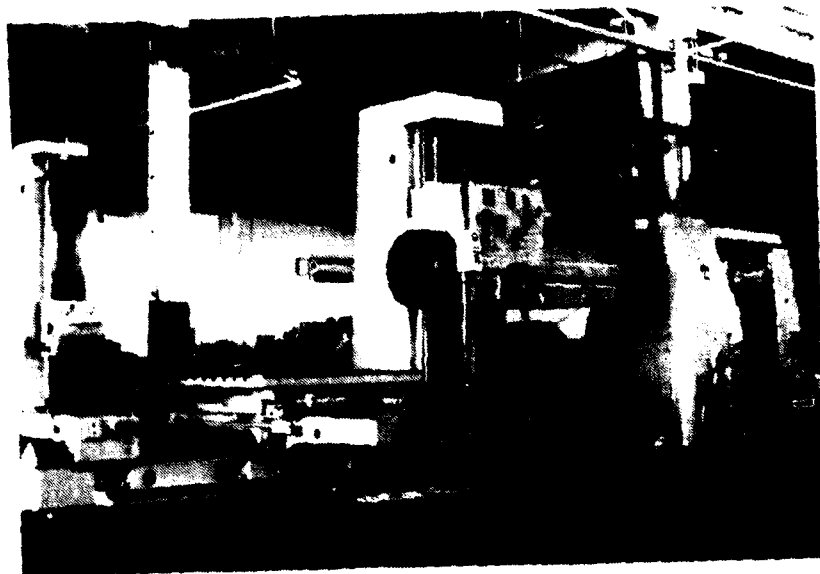
Fig. 19. Layout Showing Pieces of Equipment Clustered for Hardening (see Table 5).

Table 5: LIST OF EQUIPMENT AND MOVINGS TIMES

| DESCRIPTION             | WEIGHT   | COST      | ACTUAL TIME | ESTIMATED TIME WITH INEXPERIENCED PERSONNEL | ESTIMATED TIME IN ACTUAL MACHINE SHOP. |
|-------------------------|----------|-----------|-------------|---------------------------------------------|----------------------------------------|
| 1 UNION HORIZONTAL MILL |          | \$100,000 | N/A         | 4 HOURS                                     | 10 HOURS                               |
| 2 SPOT WELDER           | 200 LBS  | \$400     | 10 MIN.     | 10 MIN.                                     | 25 MIN.                                |
| 3 LATHE                 | 6000 LBS | \$5,000   | 3 MIN.      | 6 MIN.                                      | 26 MIN.                                |
| 4 SHEAR                 | 400 LBS  | \$400     | 3 MIN.      | 6 MIN.                                      | 6 MIN.                                 |
| 5 GRINDER               | 400 LBS  | \$800     | 5 MIN.      | 10 MIN.                                     | 25 MIN.                                |
| 6 SURFACE GRINDER       | 1000 LBS | \$2950    | 4 MIN.      | 10 MIN.                                     | 25 MIN.                                |
| 7 COMPRESSOR            | 400 LBS  | \$2600    | 3 MIN.      | 10 MIN.                                     | 20 MIN.                                |
| 8 MILL                  | 3000 LBS | \$3000    | 7 MIN.      | 15 MIN.                                     | 30 MIN.                                |
| 9 LATHE                 | 2500 LBS | \$3000    | 5 MIN.      | 10 MIN.                                     | 30 MIN.                                |
| 10 DRILL                | 6000 LBS | \$11,950  | 10 MIN.     | 25 MIN.                                     | 45 MIN.                                |
| 11 BOREMATIC            | 4000 LBS | \$10,000  | 5 MIN.      | 10 MIN.                                     | 25 MIN.                                |
| 12 SURFACE GRINDER      | 3000 LBS | \$13,000  | 6 MIN.      | 10 MIN.                                     | 25 MIN.                                |
| 13 TURRET LATHE         | 3000 LBS | \$4,950   | 6 MIN.      | 12 MIN.                                     | 30 MIN.                                |
| 14 GRINDER              | 2000 LBS | \$12,000  | 5 MIN.      | 10 MIN.                                     | 30 MIN.                                |

Table 5: LIST OF EQUIPMENT AND MOVING TIMES (contd)

| DESCRIPTION      | WEIGHT     | COST      | ACTUAL TIME | ESTIMATED TIME WITH INEXPERIENCED PERSONNEL | ESTIMATED TIME IN ACTUAL MACHINE SHOP |
|------------------|------------|-----------|-------------|---------------------------------------------|---------------------------------------|
| 15 HEALD MILL    | 6000 LBS   | \$12,500  | 20 MIN.     | 50 MIN.                                     | 80 MIN.                               |
| 16 VERTICAL MILL | 40,000 LBS | \$150,000 | N/A         | 4 HOURS                                     | 6 HOURS                               |
| 17 LE BLOND      | 8000 LBS   | \$2500    | 30 MIN.     | 50 MIN.                                     | 80 MIN.                               |
| 18 GRINDER HEALD | 6000 LBS   | \$12,900  | 4 MIN.      | 10 MIN.                                     | 30 MIN.                               |
| 19 LATHE         | 4000 LBS   | \$10,000  | 5 MIN.      | 10 MIN.                                     | 25 MIN.                               |
| 20 GRINDER       | 1000 LBS   | \$3000    | 4 MIN.      | 10 MIN.                                     | 30 MIN.                               |
| 21 LATHE TURRET  | 3000 LBS   | \$6,000   | 8 MIN.      | 20 MIN.                                     | 40 MIN.                               |
| 22 CUT OFF SAW   | 600 LBS    | \$2000    | 7 MIN.      | 14 MIN.                                     | 30 MIN.                               |
| 23 PUNCH PRESS   | 4000 LBS   | \$6500    | 25 MIN.     | 50 MIN.                                     | 80 MIN.                               |
| 24 LATHE         | 3000 LBS   | \$6000    | 8 MIN.      | 15 MIN.                                     | 35 MIN.                               |
| 25 LATHE         | 4000 LBS   | \$12,000  | 5 MIN.      | 10 MIN.                                     | 30 MIN.                               |
| 26 LATHE         | 3000 LBS   | \$6,000   | 7 MIN.      | 15 MIN.                                     | 30 MIN.                               |
| 27 SHAPER        | 4000 LBS   | \$3500    | 5 MIN.      | 15 MIN.                                     | 35 MIN.                               |
| 28 CUT OFF SAW   | 800 LBS    | \$1600    | 6 MIN.      | 12 MIN.                                     | 25 MIN.                               |



Two milling machines too large to move in average plant  
(greater than 20 tons each)



Addition of compressor (Item 7) to complex  
(Note use of tires for fenders)

Fig. 20. Immovable Equipment Used as a Nucleus for Clustering  
Lighter Equipment.



rollers and tucks used for moving



Bridge crane used for moving

Fig. 21. Plant Equipment Used for Moving Equipment into the Cluster.

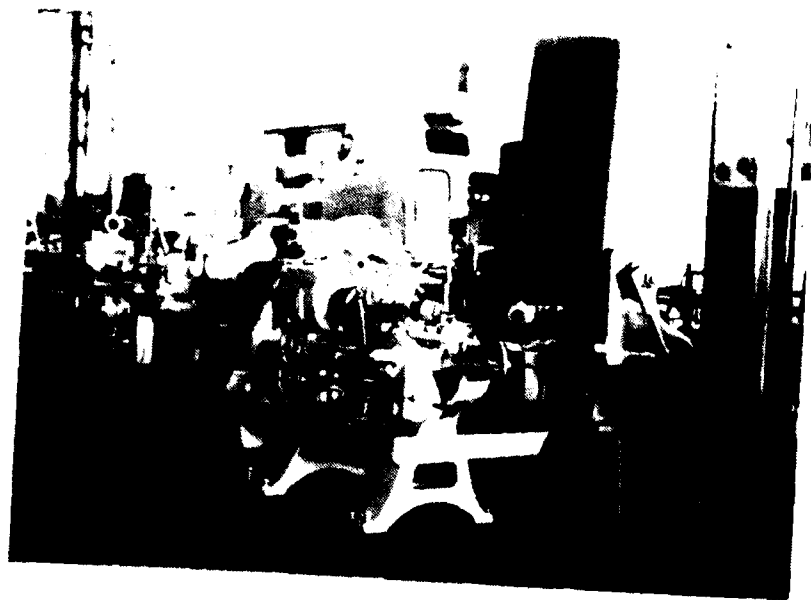


Handles, knobs protected with tire fenders

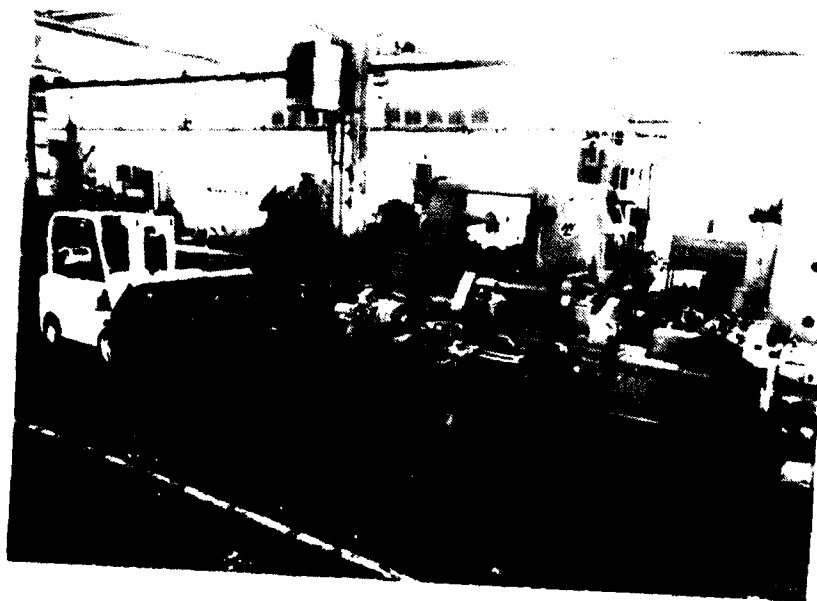


Key factor is to prevent relative motion.

Fig. 22. Rubber Tires Used as Fenders Between Pieces of Equipment to Reduce Relative Motion.



The more air inert, the better



Packing needs to be close to work.

Fig. 23. Cluster Mass should be large to Minimize Its Motion.

by rollers it took approximately three times as long to move. Figure 24 shows the machinery after the completed move and the crib, Figure 25 shows the crib filled with material to cushion the equipment against roof collapse and also shows the welded wire fabric cover to hold the array together until the roof does collapse.

Table 5 gives the approximate weight and cost of each machine and the actual time to put the machines into the hardening package, along with the estimated time for inexperienced personnel to do the same job. Also included in this latter estimate is an estimate of the time required to disconnect the machine, mechanically, from its base and its electrical hookup. The total time required to rearrange the equipment into the Figure 19 array was six hours including the discussion time and breaks for photography. If the machinery were to be evacuated, more time would be required, but most important would be the availability of transportation to evacuate the machines. Approximately eight 40-foot trailers would be needed to move the machinery used in this demonstration. It was estimated that an additional eight hours would be required to put the 26 movable machines on trailers, trucks, etc., and tie the machinery down enough to survive a trip. Some of the pieces would not require professional movers, but most of them would - some with special equipment.

Discussion with Driesbock personnel provided several important points. These are summarized below:

- (1) Most small machine shops have no personnel qualified to move the machinery.
- (2) Even in large machine shops, maintenance personnel are not very experienced in moving machinery.
- (3) If the equipment weighs over 20,000 lb, it is better not to move it unless experienced personnel are available.
- (4) Punch presses and radial arm drills are very dangerous to move because of their high centers of gravity.
- (5) About 80% of the machinery moved from this company must be moved and installed by professional movers, generally company personnel.

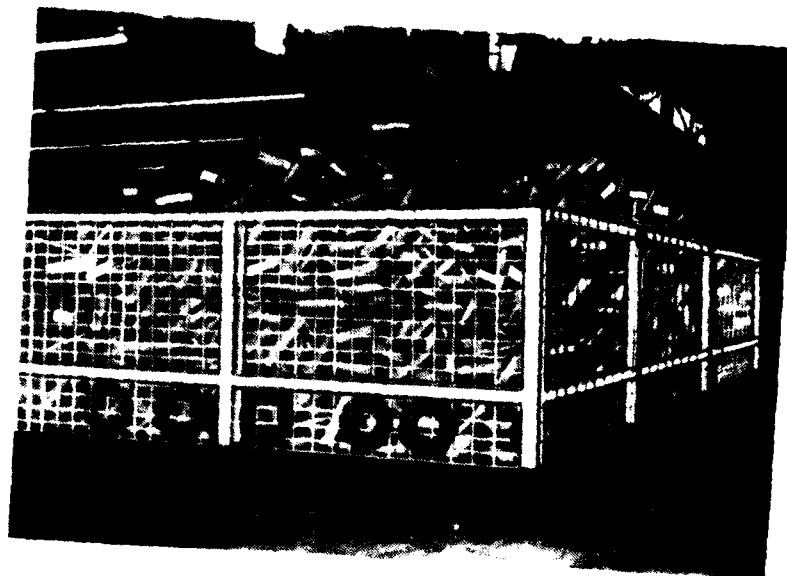


Dense pack of filter material between

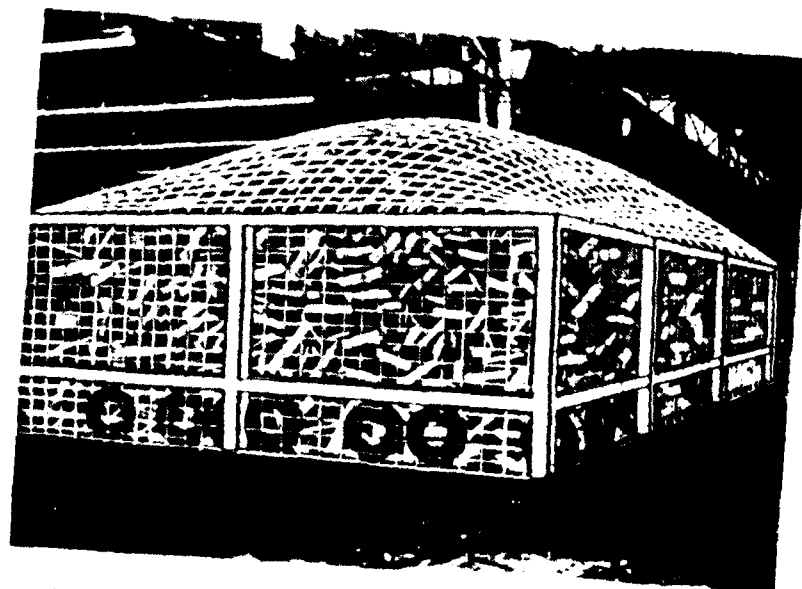


framed partition. The material was mounted in it  
and covered with welded wire mesh.

Fig. 24. Final Closure of Filter Material Between Wire Grids.



Wire Surplus - Used for the purpose of the and wood



Crib package covered with heavy chain link fence  
on welded wire fabric

Fig. 25. Crib Filled With Wood and Tires, Topped With Additional Wire Mesh to Restrict Packing Material Until Foot Collapses.

Companies such as this one are likely to have a large number of pieces of production equipment that are neither tied down nor wired into a power source. Their personnel will be able to load and move this equipment out of risk areas in the shortest possible time because they have the required handling equipment, the trucks, and the knowledge. In addition, through their marketing staff they are familiar with what equipment is to be found in which plants - both in their immediate neighborhood and surrounding areas. Such companies might have the capability not only to evacuate their own equipment but to move their handling equipment to pre-selected plants in their neighborhood (on their way out of the risk area) to load and prepare additional equipment for evacuation. An optimum cross-section of heavy equipment could be evacuated this way if a specific list of equipment and this activity were preplanned. This latter option should be assessed in later phases for its merit as a hardening program element.

## Section 4

### SUMMARY AND CONCLUSIONS

The new booklets make greater use of pictorial presentations and worksheets to simplify the discussion of tasks. Roughly a dozen draft copies have been printed and sent out for review by industry. To date, only two have been completed and returned. These two reviewers were participants in the previous demonstrations, and were involved in review and application of the earlier manual. Both reviewers are action oriented and not disposed towards paper studies and excessive planning. Both commented that the manual is too long - that nobody would have time to read it in an emergency. That is undoubtedly true - it is expected that most plants, if not all, would be better off if they prepared well in advance. In addition, both reviewers operate small companies so would undertake all the management and coordination themselves, simply because there is no one that they could assign to coordinate the tasks. Thus, a couple of hours of reading and contemplation seems to them to be more than adequate and all that should be required.

Setting aside the comments about the length of the booklets, it does appear that the second edition was easier for the two responding reviewers to understand and, perhaps, even more palatable, though the latter is more difficult to gauge. If questions about natural disaster applications are any measure, it appears that slightly more interest was evident. The bulk of the information covering natural disasters in order to capture management attention was inserted in Booklet 1, and it appears to have been effective. Booklet 2 has been simplified (the complex example has been eliminated) and the references to shelter development placed entirely into Booklets 3 and 10.

Booklet 3 is in two parts -- one for Host Area shelters in assigned areas and one for developing shelter if no area is assigned. The latter section was considered

necessary when one of the participants called his local OCD to ask where his Host Area was and discovered that, for now, he was on his own. Further discussion brought out the additional problem that in his county, evacuation by private vehicle (even though no Host Area was assigned) would be prohibited. As he planned on evacuating his whole shop on his own truck, in accordance with one of the industrial hardening options, it is understandable that he was disturbed at this apparent impasse. It is certainly an impasse that could cause a great deal of trouble if not resolved.

Booklet 4, Protective Housekeeping, now includes some procedures on how to deal with hazardous materials, including a listing of most common chemicals divided into groups to show those that are compatible and incompatible. These groupings can be applied either for storage or for hardening purposes.

Booklet 5 revision has been principally to develop inventory worksheets around specific hardening options, or steps in hardening, so that there are now seven separate worksheets, each of which identifies hardening resources by intended application and giving quantity and location available. This will simplify keeping track of consumption of these resources as they are committed to various hardening tasks. To make compiling the inventory lists easier, each includes illustrations of typical applications along with a list of typical and not so typical materials that can be used.

Booklets 6 - 8 are not greatly changed from the original versions. Some oversights pointed out by reviewers in the Phase II effort were corrected in Booklet 7, and some inconsistencies were eliminated in the vulnerability ratings listed in Booklet 8. An initial effort was made to determine if, perhaps, the vulnerability assessment might be skipped entirely - by developing hardening alternatives to achieve minimum target values for vulnerability when hardened. This appears to be manageable and could greatly simplify the task of allocating hardening resources -- but better data are required on expedient hardening of pressure-sensitive equipment.

Booklet 9 was changed to incorporate results of the Misers Bluff field tests

(Ref. 6) and SSI laboratory shock tube tests; pictorial descriptions were used to give general ideas for hardening alternatives. Booklet 10 is entirely new, added to provide information to those industries interested in developing key worker shelters. Post-attack rescue of key worker personnel was found to be a critical factor in reviewers comments insofar as key worker shelters were considered at all.

The degree to which the booklets have been simplified is, perhaps, much less important than the degree of success that might be achieved in attempting to apply the content of the booklets to harden a plant. This will vary even among similar plants, and the most practical way to establish expectations for performance success is to conduct a statistically significant number of hardening exercises (Phase IV). In the long run, hardening exercises must be conducted by laymen familiar with the equipment and production processes, but not weapons effects, if we are to obtain statistical variation in hardening success that can be expected in a real emergency.

There are really only two basic options that can be used for protecting equipment (or people), with all other options being some innovative derivative of these two. The two alternatives are to relocate so as to get out of the risk area, or to develop a shield that reduces vulnerability sufficiently to provide protection even in the risk area. In the latter case, it is also important to appreciate whether the shielding is to protect from pressure, drag, missiles, fire, radiation, or all of these.

Perhaps the most effective means for moving large quantities of heavy industrial equipment is over water, hence developing this mode of transport as an evacuation expedient could prove very effective. It would appear that mustering tugs and barges, and development of expedient waterfront loading areas, could make a world of difference to the task of evacuating equipment from regions such as the greater San Francisco Bay Area. Hastily erected pontoon bridges or piers along the bay frontage could facilitate loading barges so that clogged highway arterials could be avoided. Moreover, waterways might also provide the best routes for post-attack evacuation of key workers from risk areas -- because there will be little debris clogging them. This is likely to be true even if some part of the waterway becomes a specific target; large water bodies are self-repairing after explosions in them.

As an alternative to dispersal, the shielding concept can be applied — or it can serve as an adjunct as well. Whichever it is, an ideal shield is one that is always in place so that no warning time is required to prepare it. It is noteworthy that Sweden, Switzerland, and Norway, though scarcely major powers, have managed to develop and market such underground facilities, carved out of rock, that are always prepared and can operate through a nuclear attack. In this country, even a moderate amount of added structural strength, if combined with moderate dispersal of facilities and placed underground, could provide significant blast protection. Figure 2 indicated the effect that 20 psi shelters can have on survival. Compared with standard construction, such facilities uniformly dispersed inside the 2 psi circle of the target area will deny over 90% of the targets as casualties.

It would be desirable to have some portion (perhaps 10% to 20%) of U.S. industry prepared with structures (housing production equipment) that could be hardened in a matter of hours to survive 20 psi. Based on a FEMA study of underground facilities built in Oklahoma to provide tornado protection (Refs. 7 and 8), this need not be expensive. In that study, it was found that of 13 earth-covered school structures, all but two could be strengthened in a matter of hours to one day to provide substantial radiation protection ( $P_f$  1000) and blast protection up to 36 psi. A few dollars more per square foot could purchase readily installed 40 psi blast protection for new industrial facilities. But what would induce them to go underground in the first place? In general, according to the FEMA study, there are many benefits to attract adherents to underground facilities: Significant energy savings, reduced vandalism, less breaking and entering, preservation of open space, protection from tornadoes and earthquakes, lower maintenance cost (no outside painting), and some lesser items. If two or three facilities were initiated in each Federal district and hard data gathered on the everyday performance benefits, to provide an inducement, many more such facilities might be constructed.

A key factor in developing or identifying industrial hardening alternatives is the existence of credible reference data on equipment vulnerability. One of the major shortcomings of historical data is that in the early days of nuclear weapons testing, investigators went to great lengths to develop "realistic" environments for testing equipment vulnerability. Consequently, the great majority of existing data

developed on the subject of equipment vulnerability is not inherent vulnerability, but rather the vulnerability in some established "typical" environment. The concept of industrial hardening is premised on changing that environment. The possibilities for improvement are considerable, but a vital piece of information is missing from the early data -- the inherent vulnerability of equipment to overpressure damage in a missile-free environment. This sort of information cannot be obtained with scale models. Full-scale items must be subjected to field tests, but neither the items nor the tests of them have ever been budgeted. Despite the fact that production equipment is quite expensive, such tests are needed. Moreover, it is pointless to use damaged equipment because the major question is whether such equipment will be functional after the test. Sufficient numbers of actual tests to be significant will run several tens of millions, but these tests should be conducted.

Despite the many uncertainties as yet unanswered, the shock tube experiments, analytical assessments, and reported results from the Misers Bluff field tests were applied in the interim to develop some new equipment vulnerability ratings and hardening alternatives, which have been presented in the revised Booklet 9. Some of these concepts will be tested further in a forthcoming field test, but not all. However, some simple hardening concepts not yet presented in the booklets (e.g., expedient anchors) will be evaluated in the forthcoming field test. Field (and shock tunnel) tests are expected to provide input for future revisions to the booklets. A combination of full-scale field and shock tunnel tests, and scale model tests conducted in laboratory shock tubes in conjunction with these, provide the most effective as well as most efficient way to assess technical aspects of equipment hardening.

It may be concluded that more such progress will be needed, applicable on a broad front and on a continuing basis, if FEMA intends to convince industry of a serious national concern for industrial preparedness. Establishing, generally, the need for and feasibility of industrial hardening is necessary to capture industry attention, but it is not sufficient to generate positive action. Moreover, even if money were advanced to industry to plan, there would still be the question of priorities -- planning for industrial hardening does not build customer relations, generate revenues, or improve profit margins. Thus, there are two factors that

government must bring to bear on the problem of industrial preparedness planning if it is to achieve success. It must develop credibility for the overall plan and end result of industrial hardening, and it must somehow make it profitable for industry to invest in preparation.

To develop overall credibility, more convincing vulnerability data need to be developed and publicized, credibility of warning time and feasibility of response by laymen in a short time period must be established, and industry's dependency on electrical power and fuel must be recognized by a well-publicized program to establish expedient power and fuel alternatives that will operate in a post-attack world. To make preplanning profitable, the most promising option is to improve profit margins of new facilities by inducing industry to build them underground.

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### INDUSTRIAL HARDENING: 1980 TECHNICAL REPORT

Scientific Service, Inc. Redwood City, CA, June 1981  
Contract No. EMW-C-0154, Work Unit 1124E

Unclassified  
71 pages

This report presents the results of the third phase of a program to continue the development and testing of an Industrial Hardening Manual. The purpose of this manual is to enable U.S. industry to reduce its vulnerability to disaster, either nuclear or natural. The manual is intended to provide industry with a self-help guide for implementing industrial protection, which includes methods to enable a facility to resist fire, nuclear weapons effects, and natural disaster damage to vital equipment.

Phase I of the program resulted in the development of a working draft. Phase II included tests of the manual in industry, and research to develop improved hardening techniques. Phase III, the subject of this report, included revision of the manual based on demonstrations and tests from Phase II, analytical work on equipment vulnerability and protection, structural analysis, scale-model shock tube tests, and hardening demonstrations in industry. Effort was also devoted to identifying potential inducements to stimulate industry to preplan and prepare for emergencies.

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Contract No. EMW-C-0154, Work Unit 1124E

Unclassified  
71 pages

This report presents the results of the third phase of a program to continue the development and testing of an Industrial Hardening Manual. The purpose of this manual is to enable U.S. industry to reduce its vulnerability to disaster, either nuclear or natural. The manual is intended to provide industry with a self-help guide for implementing industrial protection, which includes methods to enable a facility to resist fire, nuclear weapons effects, and natural disaster damage to vital equipment.

Phase I of the program resulted in the development of a working draft. Phase II included tests of the manual in industry, and research to develop improved hardening techniques. Phase III, the subject of this report, included revision of the manual based on demonstrations and tests from Phase II, analytical work on equipment vulnerability and protection, structural analysis, scale-model shock tube tests, and hardening demonstrations in industry. Effort was also devoted to identifying potential inducements to stimulate industry to preplan and prepare for emergencies.

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