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BLAST SHIELDS TESTING

by Walter V. Medenica

George C. Marshall Space Flight Center
Huntsville, Ala.

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DEFINITION OF SYMBOLS

Symbol	Definition
W	Equivalent weight of TNT, kilotons
r	Distance from center of explosion, ft
Z	$r/W^{1/3}$
p_{so}	Peak side-on overpressure, psi
t_0	Positive phase duration, sec
p_d	Dynamic pressure, psi
p_r	Reflected overpressure, psi
t_d	Duration of dynamic pressure, sec
t_c	Clearing time of reflected overpressure, sec
h'	Halfwidth of front face, ft
C_r	Velocity of sound in reflected region, ft/sec
T	Period of vibration, sec
m	Mass = weight/g
k	Spring rate, kips/in.
f_1	Natural frequency of blast shield, cps
f_2	Natural frequency of soil, cps
f_c	Combined natural frequency of blast shield and soil, cps

DEFINITION OF SYMBOLS (Concluded)

Symbol	Definition
x_m	Maximum allowed deflection, in.
x_y	Deflection at yield point, in.
p_m	Maximum pressure, psi
r_y	Effective "resistance" of structure to general yielding
R	Reflection ratio

BLAST SHIELDS TESTING

SUMMARY

Several types of protective shields, made of steel, were exposed to explosive blasts of RP-1 and liquid oxygen (LOX) or liquid hydrogen (LH_2) and LOX combinations, as a ride-along project of the Pyro Project at the Edwards A. F. B.:

A. Solid Arched Plates,

B. Angle Deflectors,

C. Wire Screen No. 1 (65.3 percent open area),

D. Wire Screen No. 2 (48.0 percent open area),

E. Solid Flat Plates,

F. Wire Screen No. 3 (27.0 percent open area),

The first four of the above shields were instrumented with strain gauges (SG) and pressure transducers (PT). Lack of funds prevented the instrumentation of the remaining shields.

INTRODUCTION

The impetus to the Blast Shields Testing Program was given by the catastrophic explosion of an S-IVB Stage at the test facility of McDonnell-Douglas in Sacramento, California, in which $2 000 000 worth of ground support equipment (GSE), located, unprotected, at different levels of the test stand, was lost.

The expected benefits of the Testing Program were:

1. Determine the best blast shield for the protection of GSE at S-IVB test stands in Sacramento.

2. Establish the relative values of several blast shields for protection of men or equipment.

3. Check the recommended design procedure for structural protection against blast [1-6].

The original plan of the blast shield testing program called for the schedule given in Table I.

TABLE I. ORIGINAL TESTING PLAN

Explosion Sequence	Type of Blast Shield	
	Test Stand #1	Test Stand #2
#1 & #2	Solid Arched Plates	Wire Screen #1
#3 & #4	Solid Flat Plates	Wire Screen #2
#5 & #6	Angle Deflector	Wire Screen #3

This schedule intended to utilize six out of twelve "drop tests" planned in the Pyro Project. In drop tests (Fig. 1), a tank consisting of two compartments simulating the propellant and the oxidizer tanks in a stage is filled with RP-1 and LOX or with LH_2 and LOX in stage-determined proportions. Then the tank is dropped approximately 30 ft on a system of cutting edges which pierce the bottom and the middle bulkhead of the tank, bringing the propellant and the oxidizer together, and mixing them. This mixture explodes spontaneously (in most cases); however, an igniter located on the ground, is used if no spontaneous explosion occurs. (For these and other aspects of the Pyro Project, the reader is referred to the upcoming final report by the Air Force Rocket Propulsion Laboratory (AFRPL) at Edwards, Calif.)

In preparation for the performance of the tests, the following was done:

1. The two test stands were designed by the Test Laboratory of MSFC and built by the Air Force Rocket Propulsion Laboratory, as shown on Figures 2 through 17 (which served as design drawings). The test stands were located as shown in Figure 18 (the difference in distances, 105.1 ft versus 104.1 ft, is unintentional).

2. The blast shields were instrumented by the personnel of MSFC Test Laboratory and the cables connected to three oscillograph recorders in the blockhouse (Figs. 19, 20, and 21). Strain gauges SG-1 and SG-2 were eliminated on the Angle Deflector and on wire screens. Strain gauges SG-7 through SG-12 on the Angle Deflector were placed on the third angle from the center of shield (Figs. 14 and 20) at the same vertical locations shown on Figure 20.

3. Three empty surplus cabinets (27 in. x 21 in. x 85 in.) were placed beside each other behind each blast shield to simulate GSE to be protected (Fig. 19).

These mock-up GSE consoles stool freely during the first two tests. They were anchored to concrete by expansion bolts during subsequent tests.

As a result of a lack of funds, the testing program had to be changed as shown on Table II.

The comparison with the original testing plan (Table I) produces the following principal differences:

1. One 25-kips Drop Test was replaced by a Titan I explosion.

2. Another Titan I explosion was added.

3. Pressure transducers and strain gauges on the blast shields (Figs. 19 and 20) were recorded during three tests only (284, 285, and 301).

It should be noted here that the instrumentation on the blast shields (Figs. 19 and 20) and that of the general Pyro Project, located primarily along the three instrumentation legs (Fig. 18), are two separate instrumentation systems.

PREPARATORY CALCULATIONS

The blast shields and the test stands were designed to resist a maximum of 40 percent equivalent TNT yield of 25 000 pounds of the RP-1 and LOX combination at a 100-foot distance from the center of explosion (ground zero).

TABLE II. ACTUAL TESTING PROGRAM

Test (Explosion)			Propellant & Oxidizer		Type of Blast Shield		Blast Shields Instrumentation
No. (Pyro)	Date	Type	Combination	Combined Weight (kips)	Test Stand #1	Test Stand #2	
284	Aug. 31 1967	Drop Test	RP-1 & LOX	25	Solid Arched Plates	Wire Screen #1	PT & SG*
285	Sep. 20 1967	Drop Test	RP-1 & LOX	25	Solid Arched Plates	Wire Screen #1	PT & SG
288 C	Oct. 31 1967	Drop Test	LH_2 & LOX	25	Solid Flat Plates	Wire Screen #2	None
289 A	Dec. 6 1967	Drop Test	LH_2 & LOX	25	Solid Flat Plates	Wire Screen #2	None
290	Jan. 3 1968	Drop Test	LH_2 & LOX	25	Solid Flat Plates	Wire Screen #2	None
300	Feb. 26 1968	Titan I	RP-1 & LOX	113.5	Angle De-flector	Wire Screen #3	None
301	Mar. 14 1968	Titan I	RP-1 & LOX	93.6	Angle De-flector	Wire Screen #2	PT & SG

* PT = Pressure transducers

SG = Strain gauges

W = Equivalent weight of TNT = 0.40 x 25 000
= 10 000 lb = 0.005 Kilotons (kt)

r = Distance = 100 ft.

$$Z = \frac{r}{W^{1/3}} = \frac{100}{(10\ 000)^{1/3}} = 4.64 \quad [3]$$

p_{so} = Peak side-on overpressure

$$= \frac{4120}{Z^3} - \frac{105}{Z^2} + \frac{39.5}{Z} = 45 \text{ psi}$$

W_1 = 1000 tons = 1.0 kt; r_1 = 550 ft for p_{so} = 45 psi

t_0 = Positive Phase Duration

$$\frac{t_0}{t_{01}} = \left(\frac{W}{W_1}\right)^{1/3} \qquad t_0 = 1.3(0.005)^{1/3} = 0.022 \text{ sec.} \quad [2]$$

p_d = Dynamic pressure = 35 psi

t_d = Duration of dynamic pressure = 0.030 sec.

p_r = Reflected overpressure = 150 psi

t_c = Clearing time of reflected overpressure [4]

$$= \frac{3h'}{C_r}$$

h' = Half the width of the front face (ft)

C_r = Velocity of sound in reflected region (ft/sec)

$$t_c = \frac{3 \times 6.5}{1700} = 0.011 \text{ sec.}$$

The spring rates for uniformily distributed blast pressure were calculated for two blast shields. The results are listed in Table III.

TABLE III. SPRING RATES OF BLAST SHIELDS*

Reference Point	Solid Arched Plates (kips/in.)	Angle Deflector (kips/in.)
1	335	290
2	311	231
3	392	371
4	4424	∞
Weight	4.8 kips	7.8 kips

* Reference points are given in Figure 21.

$$T = \text{Period of vibration} = 2\pi\left(\frac{m}{k}\right)^{\frac{1}{2}}$$

For Solid Arched Plates:

$$m = \frac{4.8}{386} = 0.0124$$

k = Spring Rate

$$T = 6.2832 \left(\frac{0.0124}{311}\right)^{\frac{1}{2}} = 0.040 \text{ sec}$$

$$f_1 = \text{Natural frequency of blast shield} = \frac{1}{T}$$

$$f_1 = \frac{1}{0.040} = 25 \text{ cps}$$

$$f_2 = \text{Natural frequency of soil [5]} = 25 \text{ cps}$$

$$f_c = \text{Combined natural frequency of blast shield and soil} = \frac{1}{T_c}$$

$$f_c = \frac{f_1 + f_2}{(f_1^2 + f_2^2)^{\frac{1}{2}}} = \frac{25 + 25}{(25^2 + 25^2)^{\frac{1}{2}}} = 17.278 \text{ cps}$$

$$T_c = \frac{1}{17.678} = 0.057 \text{ sec}$$

The proportioning of individual members of the blast shields was based on the allowance that maximum deflection under maximum pressure can be five times the deflection at the yield point of the steel used, that is:

$$\frac{x_m}{x_y} = 5 \quad .$$

This allowance produced the results given in Table IV.

TABLE IV. PSEUDO-STATIC PRESSURES

	Overpressure		
	Reflected	Peak Side-On	Dynamic
$\frac{t}{T}$	$\frac{0.011}{0.057} = 0.19$	$\frac{0.022}{0.057} = 0.39$	$\frac{0.030}{0.057} = 0.53$
$\frac{x_m}{x_y}$	5	5	5
$\frac{p_m}{r_y}$	5	2.8	2.2
Pseudo-Static Pressure	$\frac{150}{5} = 30$ psi	$\frac{45}{2.8} = 16.1$ psi	$\frac{35}{2.2} = 15.9$ psi

p_m = Max. pressure

r_y = Effective "resistance" of structure at general yielding [1]

Finally, the blast shield was proportioned for the above pseudo-static pressures with the dynamic yield stresses of A-36 steel as the allowable stresses [1]: Tension or Compression = 1.1 x 42 = 46.2 ksi
Shear = 1.1 x 25 = 27.5 ksi

A similar procedure was followed for other blast shields.

PROTECTIVE EFFECTIVENESS OF TESTED BLAST SHIELDS

The equivalent TNT explosive yields are calculated in Table V. Reference 6 served as the basis for this calculation.

The explosive yields in Table V are based on peak side-on overpressure measurement at 67 ft and 117 ft from ground zero, within the fireball. Pressure measurements at larger distances from ground zero would produce higher percentages of explosive yields, which is a characteristic of the explosive behavior of the liquid propellants.

Tables VI and VII list the recorded overpressures and compare them with the calculated peak side-on overpressures for the given distances and explosive yields [6]. The recorded measurements of pressure transducers PT-1A and PT-2A are listed in the tables for information only. They are not included in the average overpressures, p_1 and p_2, since they were not always recorded.

Table VIII repeats the reflection ratios from Tables VI and VII and introduces an effectivensss ratio.

The positive sign of the effectiveness ratio indicates a reduction of overpressure between the blast shield and the mock-up GSE console as a result of the protective effect of the blast shield. For example: the blast shields on Test Stand No. 1 (Solid Arched Plates and Angle Deflector) reduced the overpressure behind them by 33 percent in Test 284; by 65 percent in Test 285; and by 53 percent in Test 301.

TABLE V. DETERMINATION OF EQUIVALENT TNT EXPLOSIVE YIELDS

Test No.	Distance r (ft)	Recorded p_{so} (psi) On Instrumentation Legs:			Average p_{so} (psi)	$\frac{r}{W^{1/3}}$	W (lb TNT)	% Explosive Yield	
		3 o'clock	7 o'clock	11 o'clock				Calc.	Use
284	67	10.5	11.2	12.9	11.53	9.13	390	1.56	1.5
	117	4.25	3.88	4.30	4.14	16.30	370	1.48	
285	67	—	67.6	76.0	71.8	3.95	4880	19.52	20.0
	117	20.0	15.2*	22.3	21.15	6.82	5050	20.20	
301	67	41.0	—	—	41.0	5.05	2340	2.50	2.5
	117	11.79	13.72	12.40	12.64	8.74	2400	2.56	

* This measurement is assumed inaccurate

TABLE VI. OVERPRESSURES IN FRONT OF BLAST SHIELDS

Test No.	Test Stand No.	Recorded Peak Overpressures* (psi)				Distance r (ft) from ground zero	Explosive Yield		$\frac{r}{W^{1/3}}$	Calculated peak side-on overpressures p_{so} (psi)	Reflection Ratio $R_2 = \frac{p_2}{p_{so}}$
		PT-2	PT-2A	PT-4	Average p_2		%	W (lb TNT)			
284	1	8.6	10.0	9.0	8.8	102.6	1.5	375	14.23	5.2	1.69
	2	6.7	—	7.3	7.0	103.6			14.37	5.1	1.37
285	1	61.3	68.7	61.8	61.6	102.6	20.0	5000	6.00	27.8	2.22
	2	45.4	—	44.3	44.9	103.6			6.06	27.3	1.64
301	1	25.0	—	25.2	25.1	102.6	2.5	2340	7.73	16.2	1.55
	2	22.6	—	18.4	20.5	103.6			7.80	15.9	1.29

* Listed overpressures are those of the first highest peak (Fig. 24)

TABLE VII. OVERPRESSURES BETWEEN BLAST SHIELDS AND MOCK-UP GSE CONSOLES

Test No.	Test Stand No.	Recorded Peak Overpressures* (psi)				Distance r (ft) from ground zero	Explosive Yield		$\frac{r}{W^{1/3}}$	Calculated peak side-on overpressures p_{so} (psi)	Reflection Ratio $R_1 = \frac{p_1}{p_{so}}$
		PT-1	PT-1A	PT-3	Average p_1		%	W (lb TNT)			
284	1	5.6	6.4	5.4	5.5	107.1	1.5	375	14.85	4.8	1.14
	2	9.5	—	10.0	9.8	108.1			14.99	4.7	2.08
285	1	15.7**	23.1	20.0	20.0	107.1	20.0	5000	6.26	25.5	0.78
	2	74.1	—	76.4	75.3	108.1			6.32	25.0	3.01
301	1	10.8	—	29.7**	10.8	107.1	2.5	2340	8.06	14.8	0.73
	2***	12.9	—	10.2	11.6	108.1			8.14	14.6	0.79

* Listed overpressures are those of the first highest peak (Fig. 24).

** This measurement is considered inaccurate.

*** No mock-up GSE console was placed on Test Stand No. 2 during test 301.

TABLE VIII. EFFECTIVENESS OF BLAST SHIELDS

Test No.	Test Stand No.	Reflection Ratio		Effectiveness Ratio
		R_2	R_1	$= \left(\frac{R_2 - R_1}{R_2} \right) 100\%$
284	1	1.69	1.14	+33
	2	1.37	2.08	-52
285	1	2.22	0.78	+65
	2	1.64	3.01	-84
301	1	1.55	0.73	+53
	2	1.29	0.79	+39

The negative sign of the effectiveness ratio indicates an increase in overpressure between the blast shield and the console and a consequent lack of protection from the blast shield. For example: one blast shield on Test Stand No. 2 (Wire Screen No. 1, with 65.3 percent open area) increased the overpressure behind it by 52 percent in Test 284 and by 84 percent in Test 285.

This is a significant finding, and it means that placing a wire screen in front of equipment, with the purpose of protecting it, might actually aggravate the situation.

The reason for this phenomenon is not yet known. One might speculate that consoles on one side, and the wire screen with supporting frame on the other, created two "walls" between which the overpressure wave "bounced" back and forth, increasing the reflected overpressure. This speculation is supported to a certain degree, by the fact that the other wire screen (No. 2, with 48.0 percent open area) actually reduced the overpressure behind it by 39 percent in Test 301.

This might be partly due to absence of consoles during this test at Test Stand No. 2, and partly due to the smaller open area of this wire screen. The evaluation of strain gauge data in the next section of this report indicates that wire screens resist blast forces in direct proportion to their projected solid areas.

Another speculation is the possibility that the shock front velocity, and thus the overpressure, increased in passing between the wires of the wire screen. Further testing is required to determine the relative contributions of these components.

Based on the above three instrumented tests, a tentative conclusion might be drawn that wire screens with more than 50 percent open area do not reduce blast overpressure between the screen and the equipment to be protected. More likely, such wire screen will increase the overpressure and cause greater damage to the equipment.

The relative effectiveness of wire screens with less than 50 percent open area is not clear. Here again, a few more tests would give the answer. For the time being the only actual benefit one could expect from wire screens is a certain protection from light flying fragments. The tested wire screens which survived the blast well still were perforated by flying fragments (Fig. 22).

The effectiveness of solid arched plates in reducing the overpressure was expected, but the high effectiveness of the angle deflector is surprising, particularly in view of the ineffectiveness of the wire screens. The successful performance of the angle deflector could be explained as follows:

1. The dynamic pressure, which is high velocity wind, was greatly reduced by the change of direction around the angles, and deflected away from the GSE console.

2. A very high number of vortices around the edges of the angles reduced the other two components of the blast wave, the peak side-on and the reflected overpressure.

Solid flat plates (Table II, Figs. 16 and 17) were introduced into the program as a simpler version of solid arched plates. They were expected to deform plastically under blast, similar to explosive forming, absorb energy in the process, and finally assume the shape of the arched plates. Unfortunately, none of the blasts to which flat plates were exposed was of a higher yield, and none was instrumented. Instead of a hoped-for deflection of 10 to 12 inches above the chord, no explosion produced a deflection greater than 2 inches. But even these low yield explosions and low deflections of the plates cracked open the bottom welds of the plates. Since similar cracking of welds occurred also during blast testing of the pre-formed arched plates (Fig. 23), closer attention should be paid to connection details of both the flat and the arched plates in future testing and application. The connection between this type of blast shield and the supporting members should be as flexible as the shield itself if weld cracks are to be avoided. It is not an accident that welds cracked always at the bottom of the plates; the spring rates here are more than ten times as high as at higher locations of the blast shields (Table III).

The weight of the tested angle deflector per unit area is almost four times as high as that of the arched plates (42.2 lb/ft^2 versus 11.4 lb/ft^2). Since their effectiveness ratios are approximately equal (Table VIII), the solid arched plates are considered as the most effective of the tested and instrumented blast shields.

STRUCTURAL EVALUATION OF TEST RESULTS

This structural evaluation is based on recorded strains at the first highest peak of the same sign (tension or compression). As Figure 24 shows, the first highest peak of the same sign is usually the highest of all. This, of course, is to be expected, except in cases where the material under the strain gauge goes into the plastic region, as was the case with strain gauges SG-11 and 12 on Figure 24.

During Test 301, the strain gauges on Test Stand No. 1 jumped to their highest peak of all without indicating any plastic deformation of steel at approximately 0.070 sec after the first high peak of the same sign. By that time, the recorded overpressures had already returned to zero, and they remained at zero during this highest peak of the strain gauges. An explanation for this is that a piece of the exploded Titan missile or its supporting structure hit the blast shield at that instant, causing the jump in strain gauge readings without affecting the overpressure readings.

Table IX illustrates the comparison between the recorded overpressures in front of the blast shields (PT-2 and PT-4) and the calculated overpressures derived from strain gauge measurements. It will be noted that strain gauges SG-1, 2, 7, 8, 9, 10, 11, and 12 are missing in Table IX. The measurements of some of these strain gauges were inaccurate and some reached the plastic region of steel; therefore, they could not be properly evaluated. However, the satisfactory evaluation of strain gauges SG-3, 4, 5, 6, 13, and 14 made the evaluation of other strain gauges superfluous.

TABLE IX. STRAIN GAUGE EVALUATION

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Test No.	Test Stand No.	p_2* (psi)	Strain Gauge Measurements (ksi)			Equivalent Overpressure p_3 (psi)	Strain Gauge Measurements (ksi)			Equivalent Overpressure p_5 (psi)	Strain Gauge Measurements (ksi)			Equivalent Overpressure p_{13} (psi)
			SG-3	SG-4	Average		SG-5	SG-6	Average		SG-13	SG-14	Average	
284	1	8.8	1.6	-1.4	±1.5	8.9	7.3	-8.3	±7.8	8.2	-4.4	-2.5	-3.5	7.6
	2	7.0	—	—	—	—	1.7	-2.2	±1.95	4.0	-1.4	-0.8	-1.1	4.7
285	1	61.6	—	—	—	—	—	—	—	—	-30.8	-36.2	-33.5	73.1
	2	44.9	4.7	-4.9	±4.8	56.1	18.2	-18.6	±18.4	38.1	-17.3	-5.4	-11.35	48.8
301	1	25.1	4.8	-4.8	±4.8	18.6	23.1	-29.3	±26.2	23.1	-17.7	-6.7	-12.2	25.1
	2	20.5	3.8	-2.0	±2.9	26.9	9.6	-15.0	±12.3	20.4	-9.1	-6.6	-7.85	26.8

* Overpressures p_2 in column 3 are the averages of PT-2 and PT-4 measurements (Table VI).

The following basic assumptions were made for the strain gauge evaluation in Table IX:

1. Top horizontal beam (18 WF 70, Fig. 2) is simply supported.

2. Modulus of elasticity of the blast shields and the supporting structure is E = 30 000 000 psi.

3. Solid arched plates and angle deflector, together with the supporting structure (All 12 WF 40 and 18 WF 70 beams; Figs. 2 and 13), offer their full projected area to the resistance of the blast forces.

4. Projected solid area of wire screens is added to the full area of the supporting structure to give the blast resisting area.

The "equivalent overpressures" in columns 7, 11, and 15 of Table IX are calculated overpressures required to cause the preceding recorded stresses. By comparing these stress-calculated overpressures with recorded overpressures p_2 in column 3, it could be concluded that the above assumptions were correct. The recorded and stress-calculated overpressures are close enough for blast resistant design and for strain recording under blast conditions, where a combined accuracy of ±35 percent can be considered quite satisfactory. During each of the tests, the test stands were enveloped by the fireball and exposed to flying fragments from the exploded tanks or missiles. The greatest difference between the recorded and stress-calculated overpressures is listed for Test Stand No. 2 during Test 284; low strains decreased the accuracy of the strain gauges in this case.

This structural evaluation could be considered as a confirmation of the blast design method recommended in Reference 1.

CONCLUSIONS

1. Drop in overpressure behind a solid blast shield of the size used (9 x 12 ft) is approximately 50 percent.

2. Wire screens with more than 50 percent open area do not reduce overpressure between the screen and the equipment to be protected; they increase it.

3. Overpressure forces resisted by wire screens are in direct proportion to projected solid area of the wire screens (but this is not a measure of their protective value as blast shields).

4. Structural design methods for blast as specified in the references, particularly in Reference 1, have been confirmed as sufficiently accurate.

5. The cracks caused by blast occurred always at the most rigid location, at the bottom of blast shields, confirming the theory that relative, energy absorbing flexibility of a structure can be beneficial for resisting blast.

RECOMMENDATION

Ground Support Equipment (GSE) at any static test stand or launch pad should be located inside a blast resistant concrete building.

George C. Marshall Space Flight Center
National Aeronautics and Space Administration
Huntsville, Alabama, July 31, 1968
933-50-07-00-62

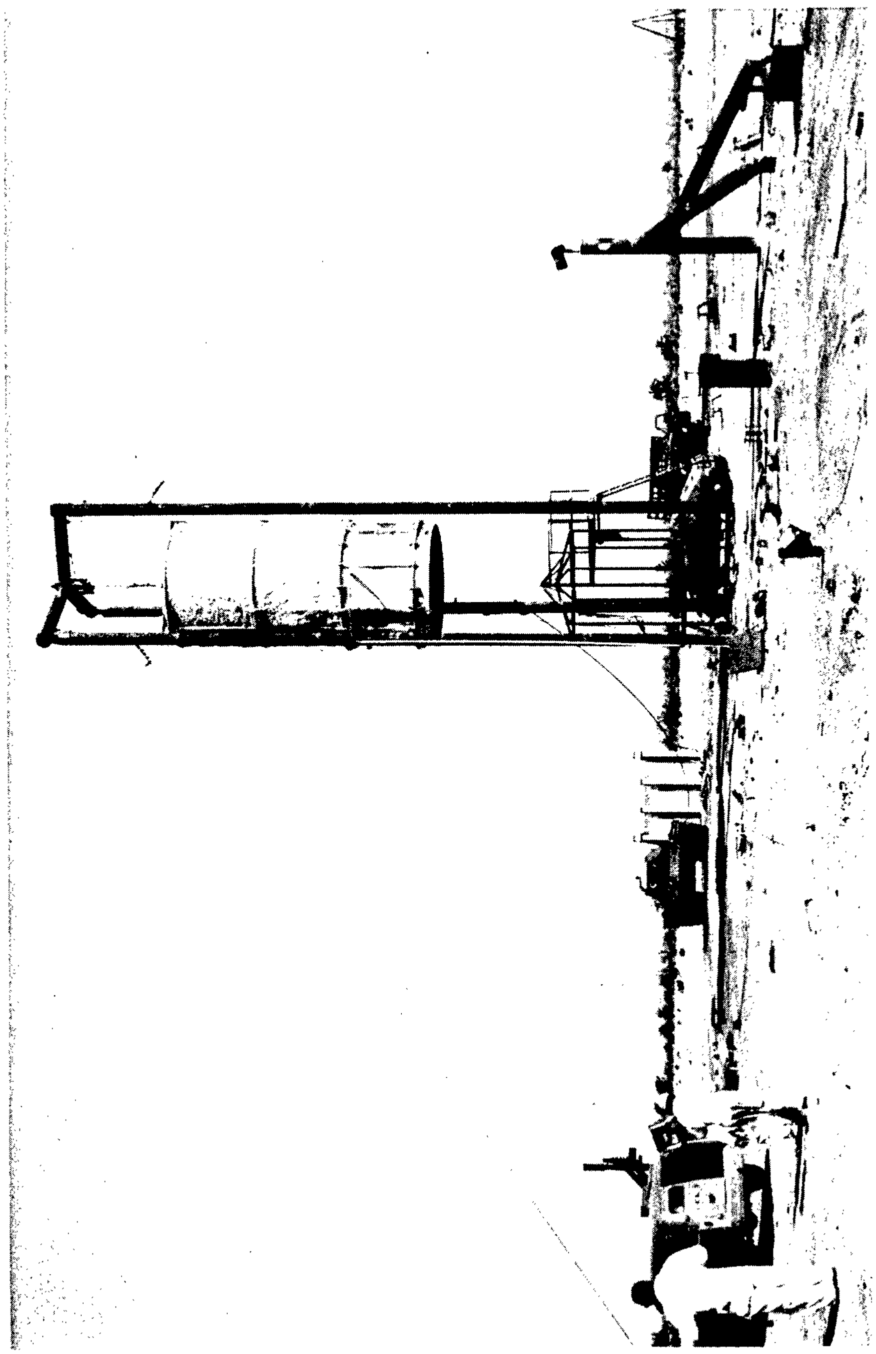


FIGURE 1. DROP TANK TEST FACILITY

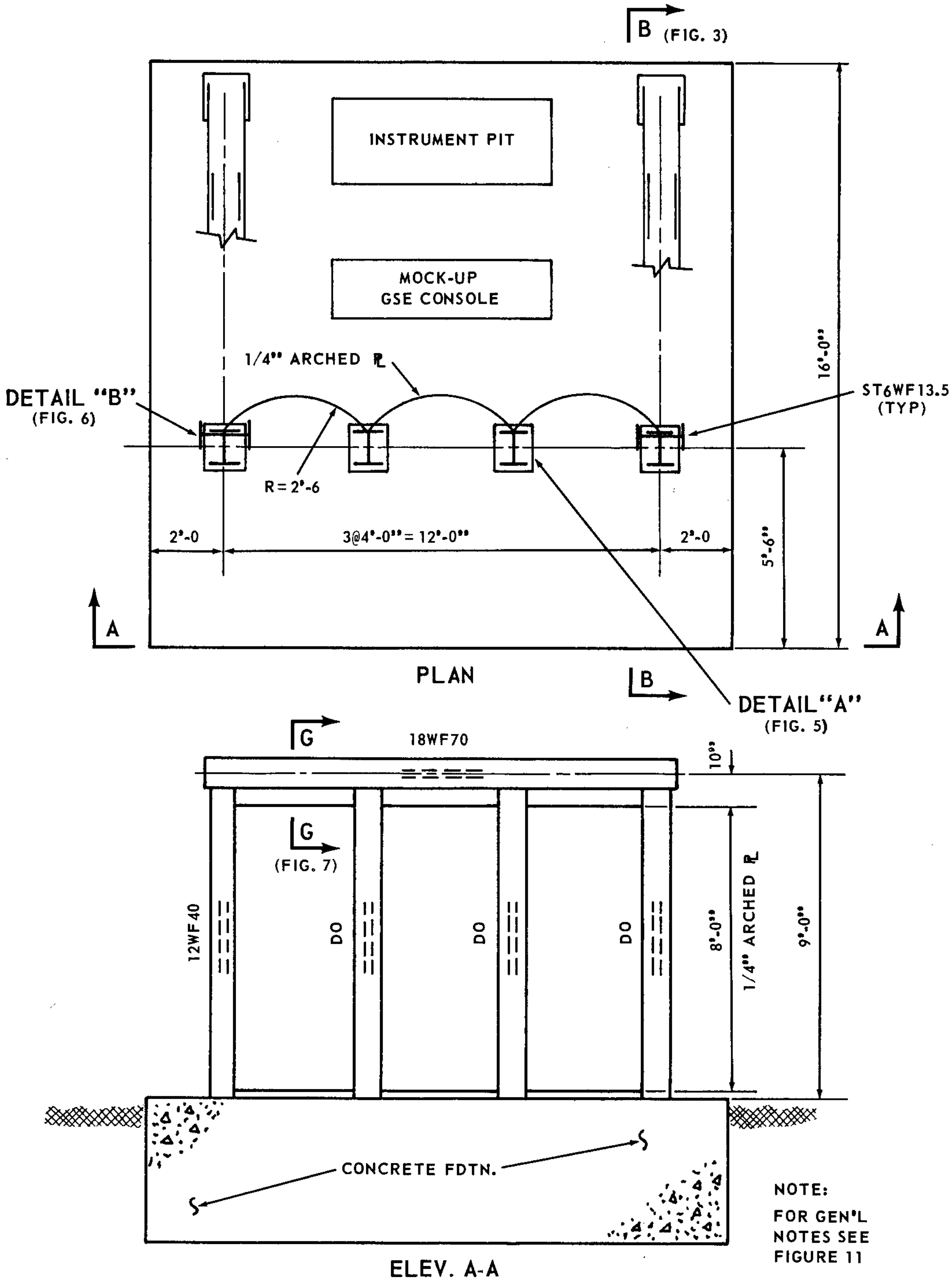
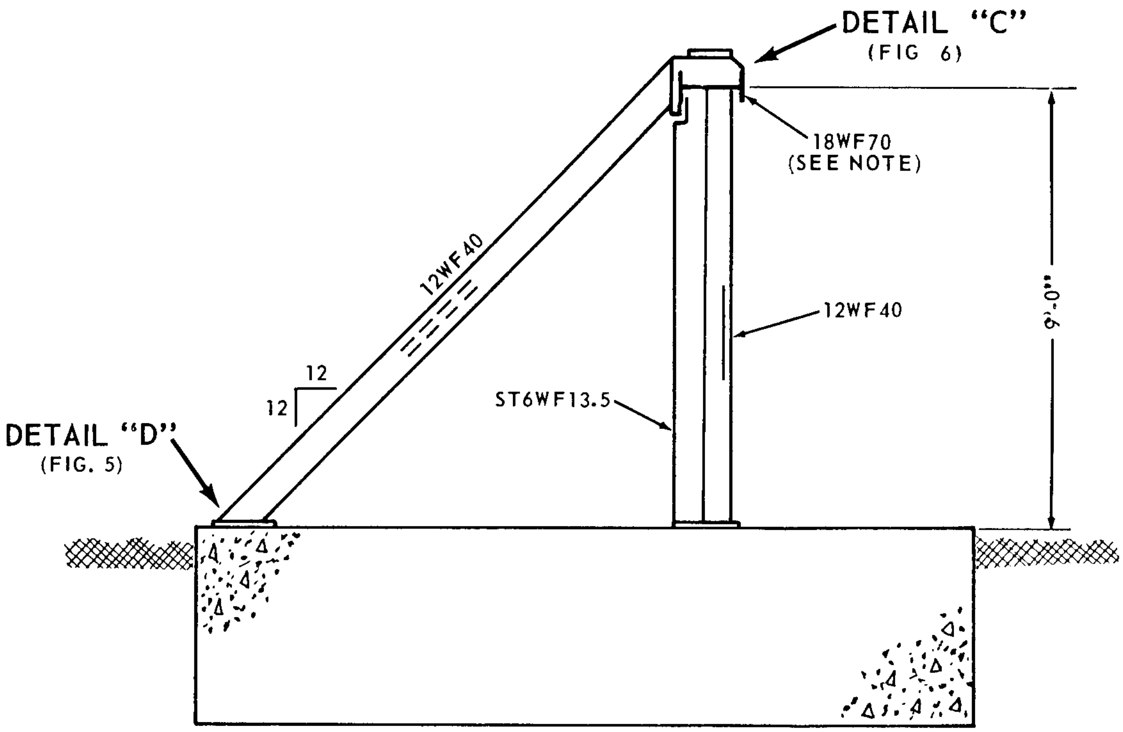


FIGURE 2. BLAST SHIELDS, ARCHED PLATES, PLAN AND ELEVATION VIEWS



SECT. B-B

(ARCHED ℙ NOT SHOWN FOR CLARITY)

NOTE: PROVIDE 1" DIA. DRAIN HOLES @ WEB ℄ OF 18WF 2'-0" C/C.

FIGURE 3. BLAST SHIELDS, ARCHED PLATES, SIDE VIEW

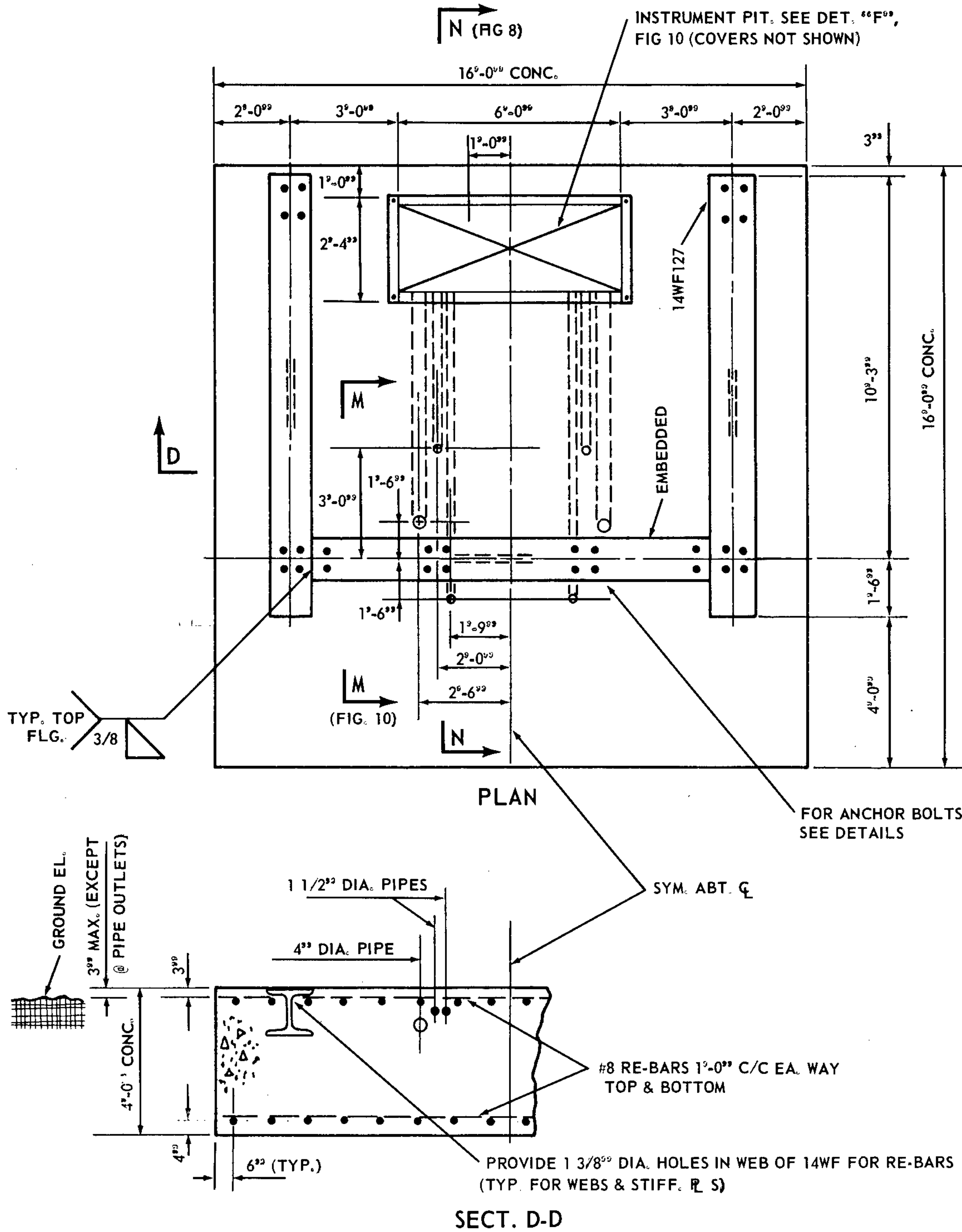
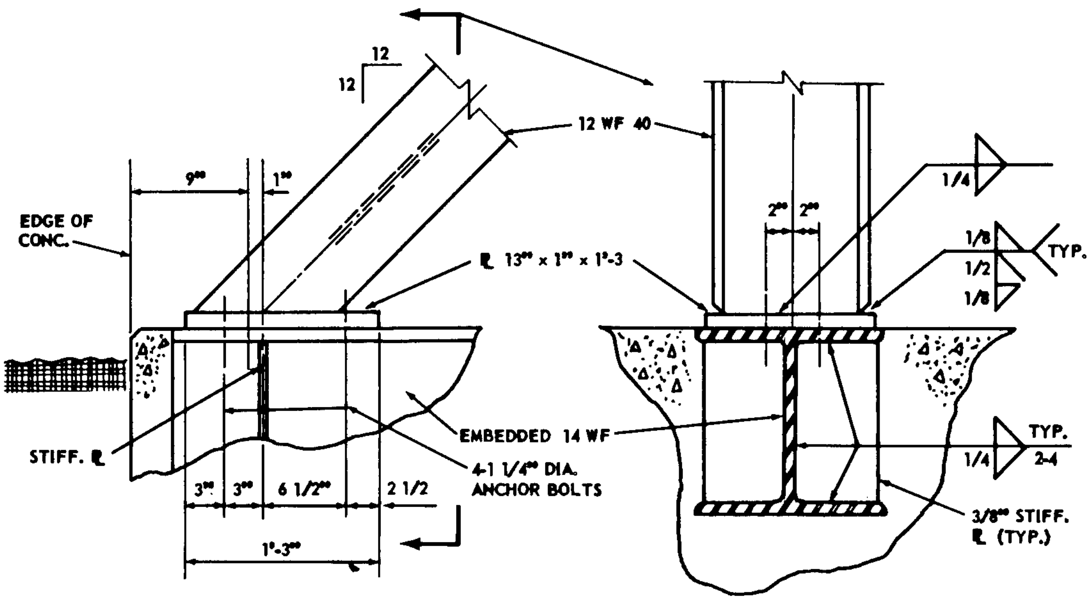
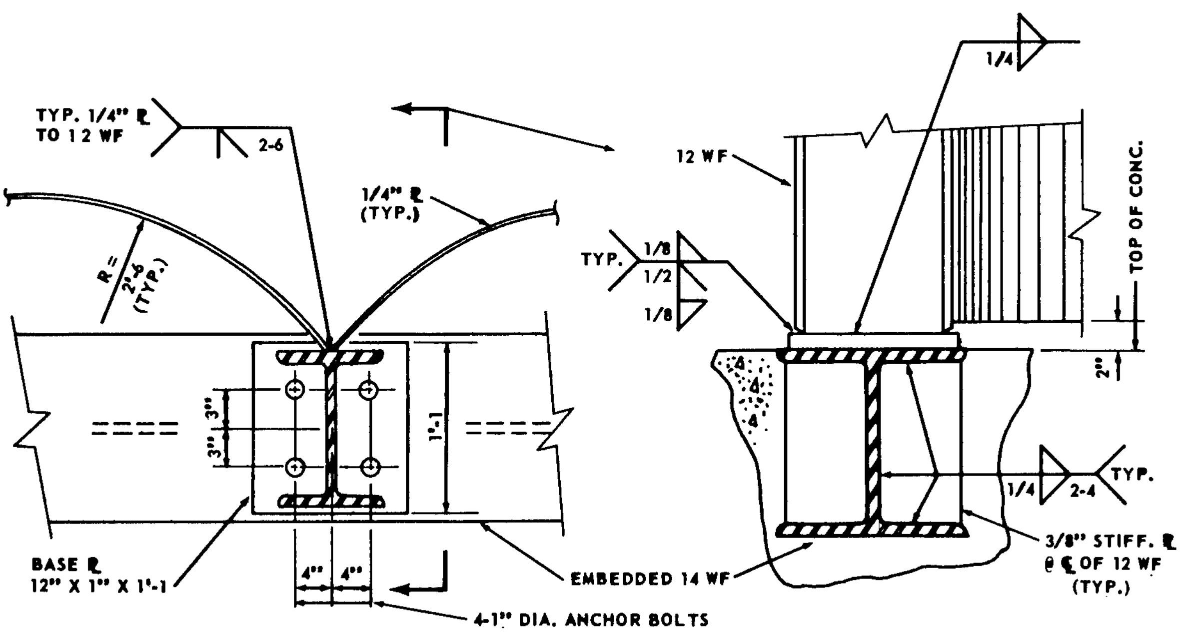


FIGURE 4. BLAST SHIELD FOUNDATION



DETAIL "D"
(FIG. 3)



DETAIL "A"
(FIG. 2)

FIGURE 5. BLAST SHIELD DESIGN DETAILS

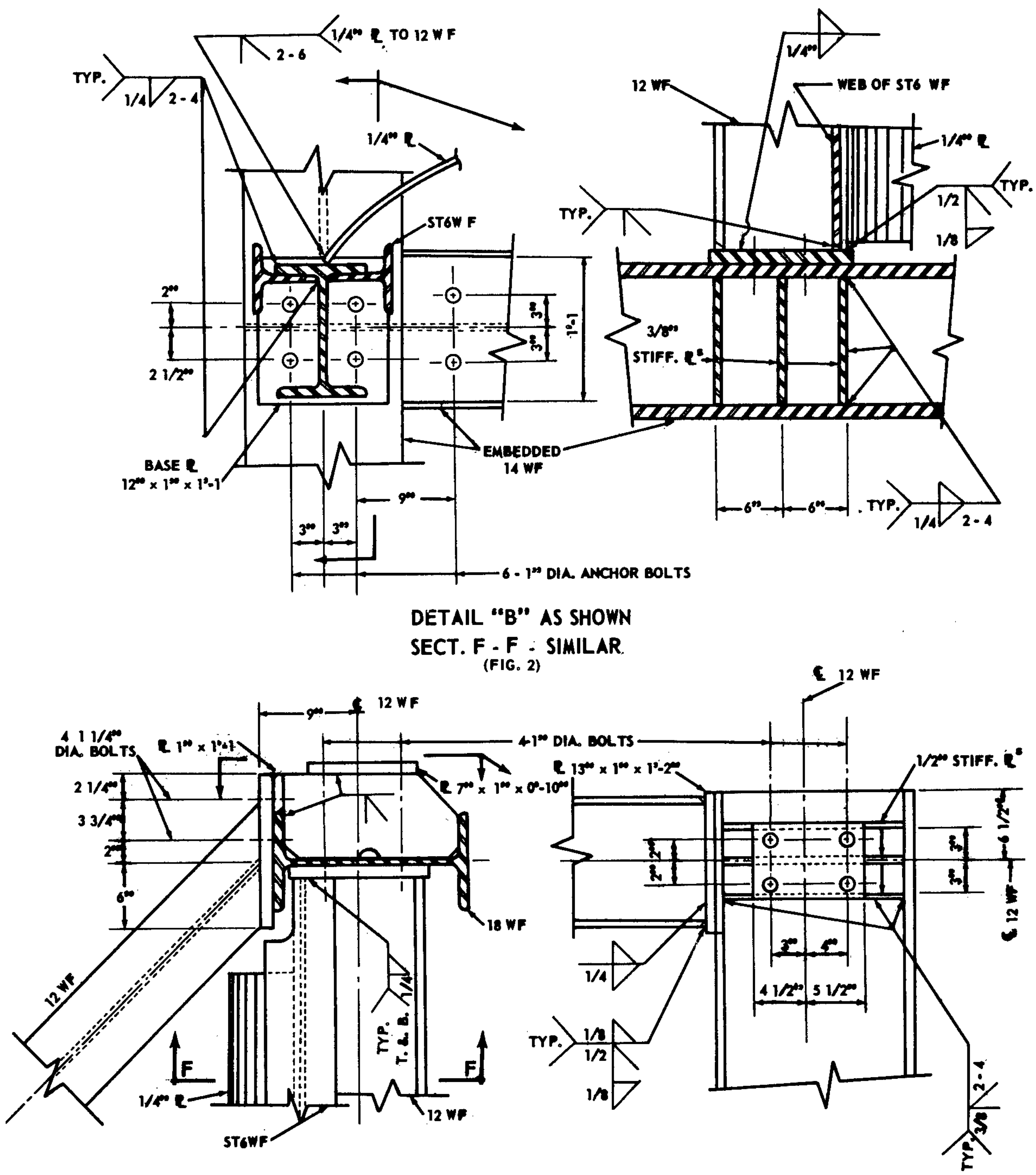
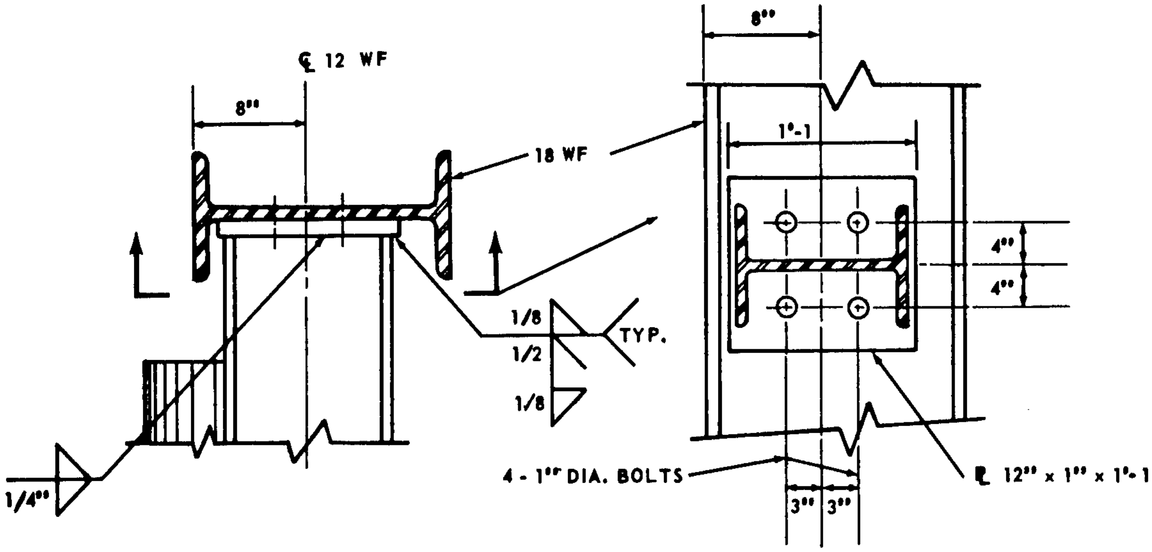
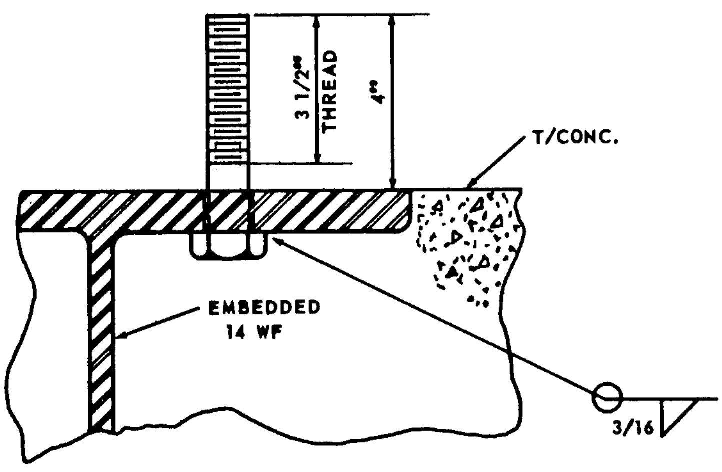


FIGURE 6. BLAST SHIELD DESIGN DETAILS



SECT. G - G
(FIG. 2)



TYP. DETAIL FOR ANCHOR BOLTS
(1" DIA. & 1 1/4" DIA.)

FIGURE 7. BLAST SHIELD DESIGN DETAILS

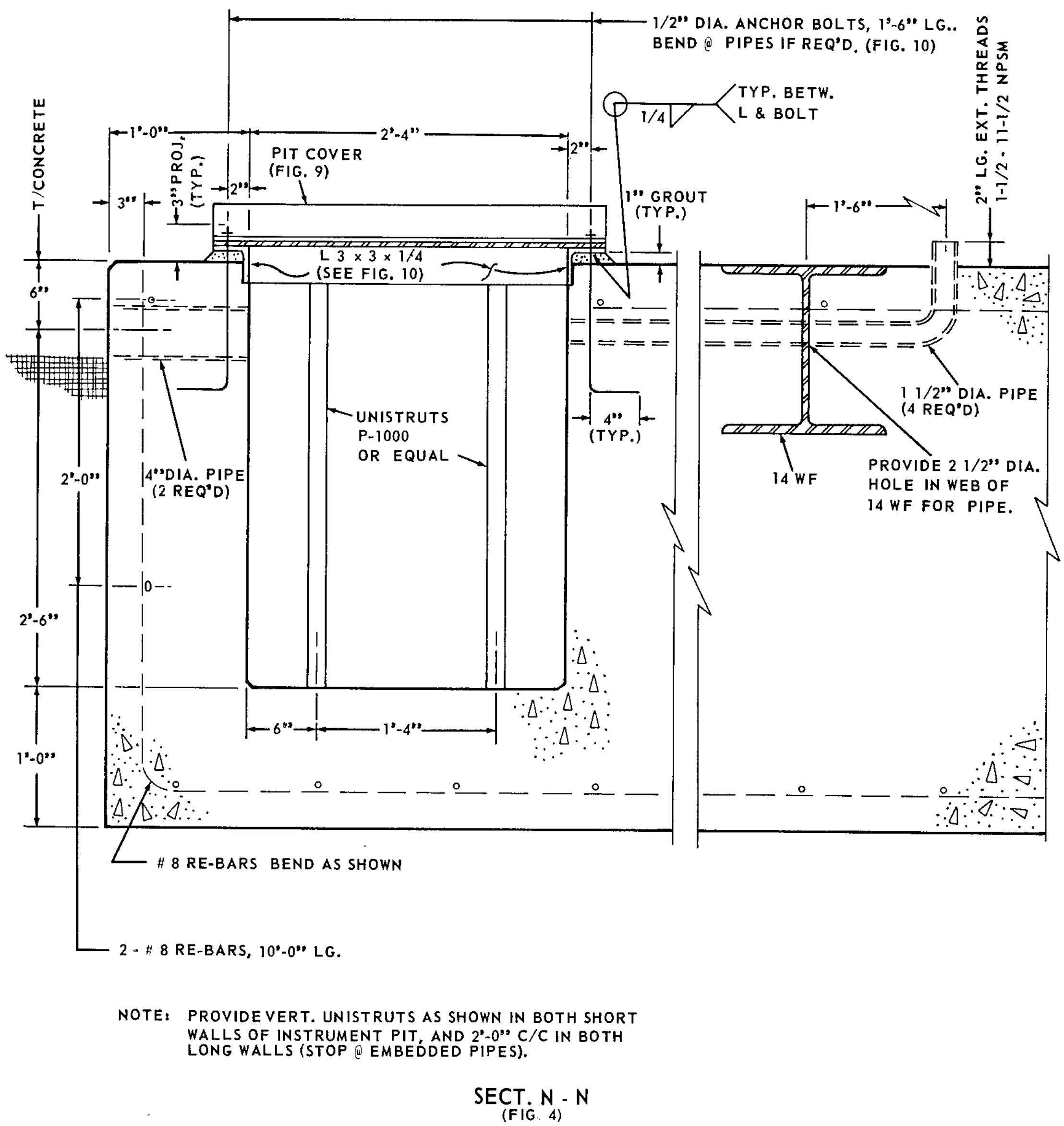
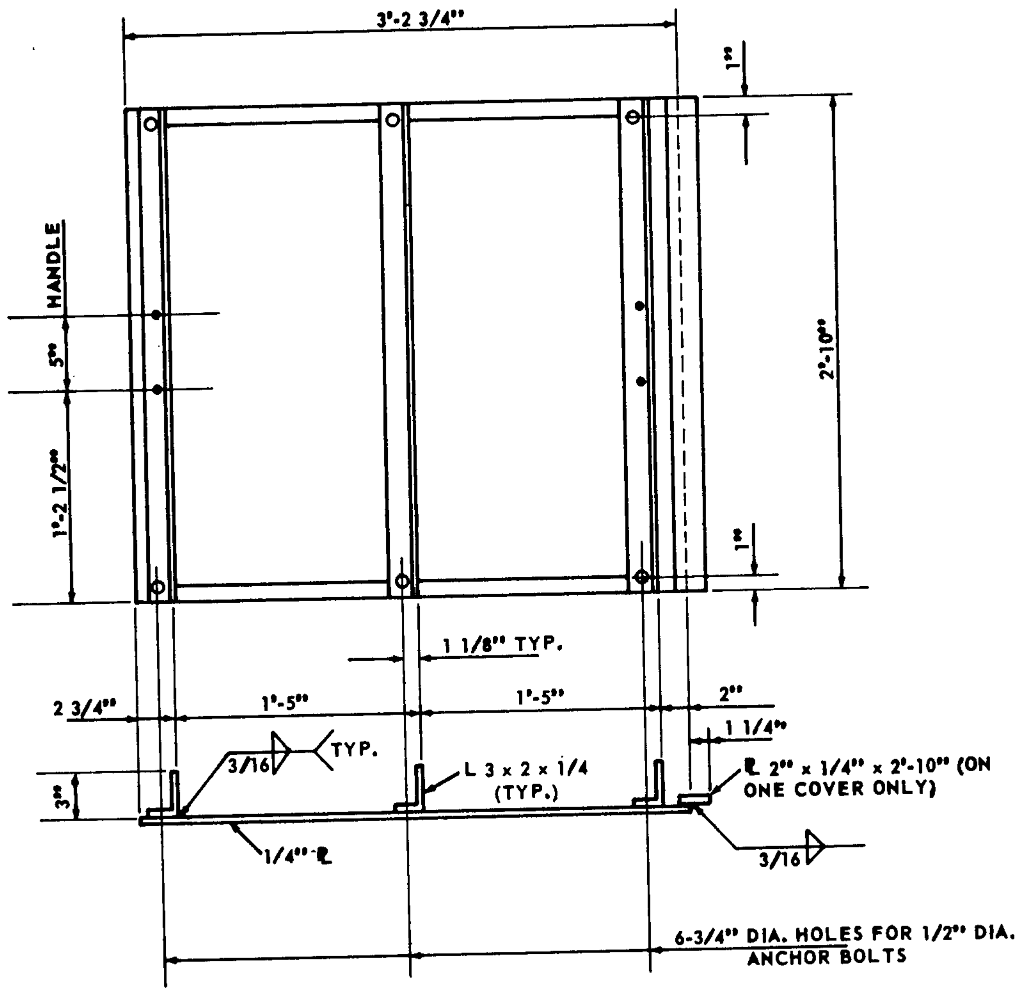
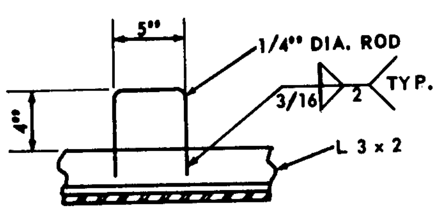


FIGURE 8. BLAST SHIELD INSTRUMENT PIT

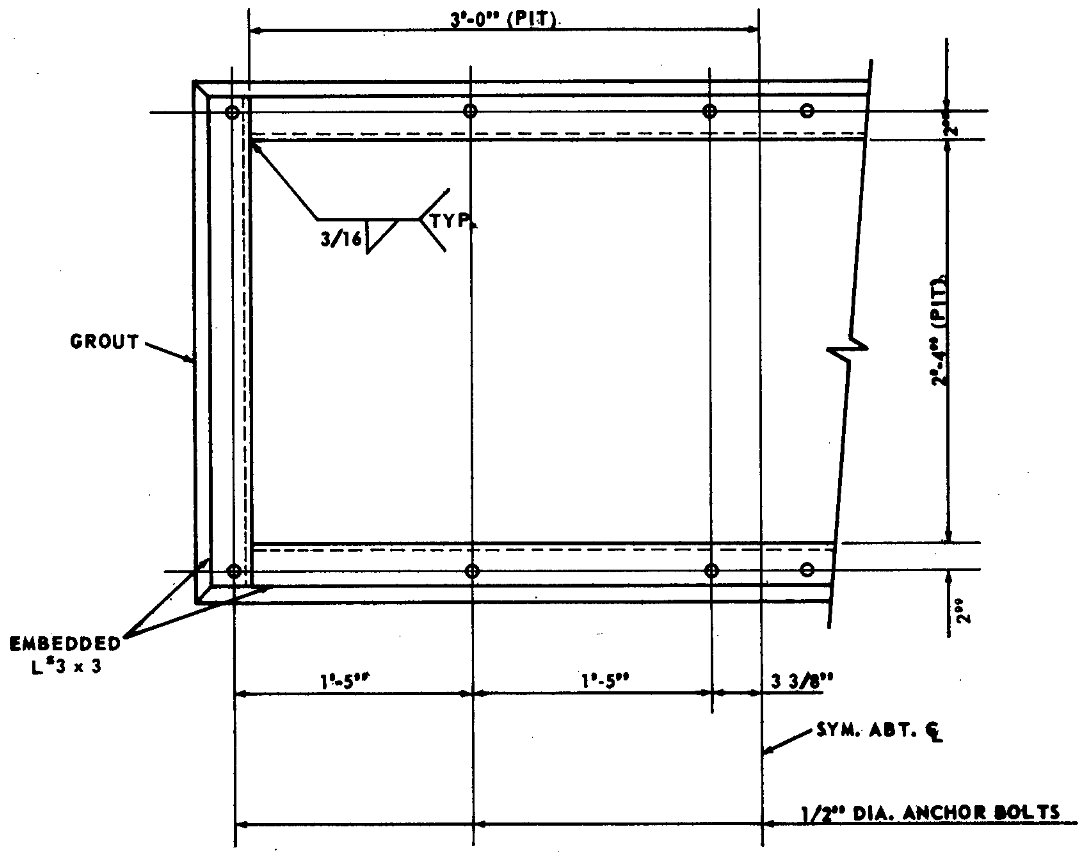


COVER FOR INSTRUMENT PIT (2 REQ'D)

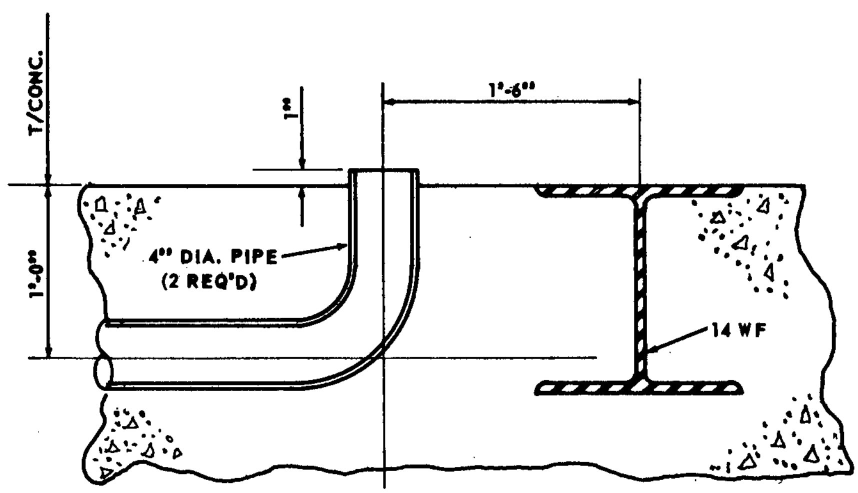


HANDLE DETAIL (2 REQ'D PER COVER)

FIGURE 9. INSTRUMENT PIT COVER



DETAIL "F"
(FIG. 4)



SECT. M - M
(FIG. 4)

FIGURE 10. INSTRUMENT PIT DETAILS

1. Concrete construction shall conform to A.C.I. building code, latest edition.

2. Concrete shall have a minimum compressive strength of 3000 psi after 28 days.

3. Steel re-bars shall be of deformed type with a minimum tensile strength of 60 000 psi.

4. Lap re-bars a minimum of 2'-6".

5. Chamfer all exposed concrete corners 3/4" x 45 degrees.

6. Structural steel work shall be done in accordance with A.I.S.C. specifications. Use A.S.T.M. A-36 steel.

7. Welding shall conform to A.W.S. code, A.W.S. D1.0-66.

8. All 1" dia. and $1\frac{1}{4}$" dia. bolts shall conform to A.S.T.M. specification A-490. Their bolt hole dia. shall be 1/16" larger than bolt dia., except bolt holes in base plates for anchor bolts which shall be 3/16" larger than bolt dia.

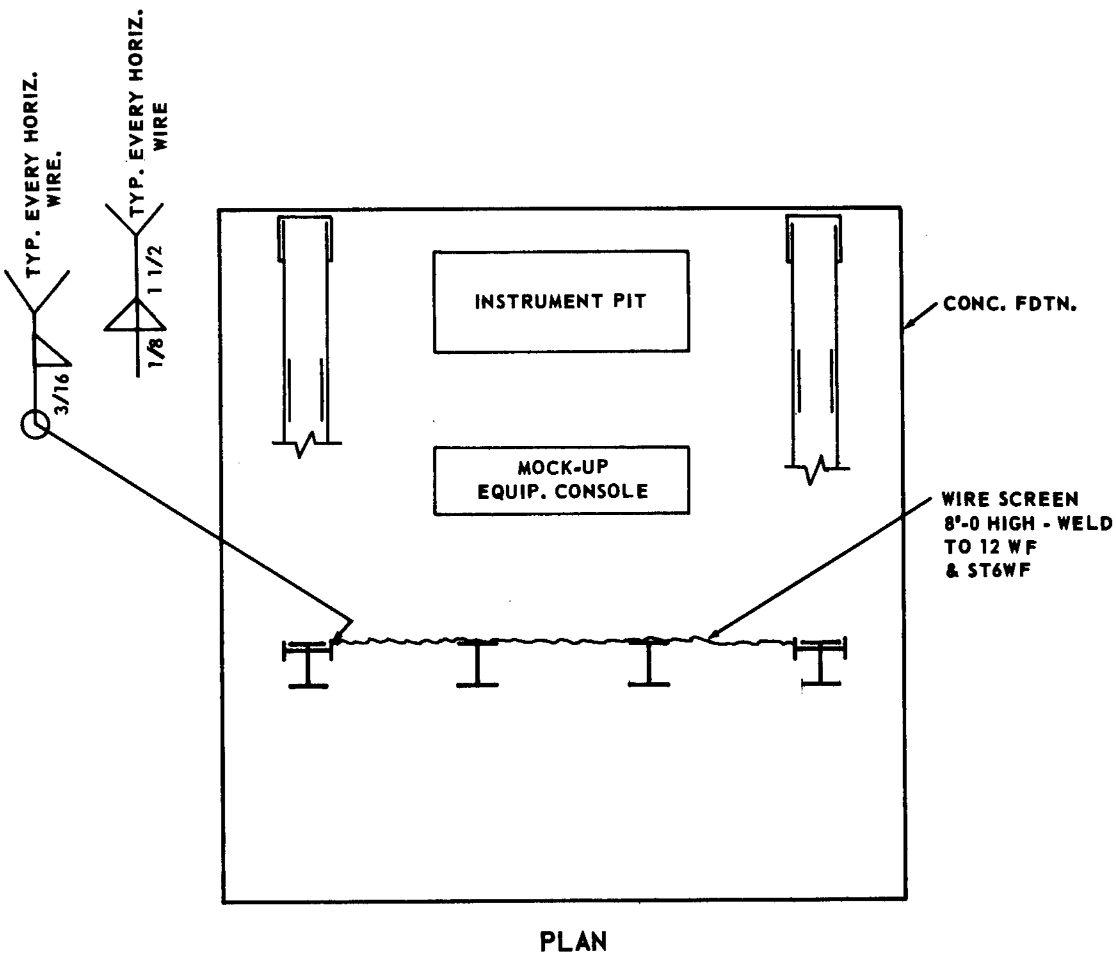
9. All $\frac{1}{2}$" dia. anchor bolts shall be of carbon steel. Their hole dia. shall be 1/16" larger than bolt dia., U.O.N.

10. All pipes shall conform to A.S.T.M. specifications A-53 or A-106. They shall be standard weight (schedule 40) with welded elbows. They shall be kept clean by removable plugs or caps at each end.

11. Paint structural steel with red primer, except surfaces under bolt heads, nuts, and/or washers.

12. Building tolerance = ± 1/8".

FIGURE 11. BLAST SHIELD DESIGN GENERAL NOTES



NOTES:

FOR ADDITIONAL DETAIL, SEE FIGURES 2 - 11.

WIRE SCREEN # 1 = "SQUARE MESH WIRE CLOTH", 1" C/C 0.192" DIA. OF WIRE (65.3% OPEN AREA).

WIRE SCREEN # 2 = "SQUARE MESH WIRE CLOTH", 5/8" C/C 0.192" DIA. OF WIRE (48.0% OPEN AREA).

WIRE SCREEN # 3 = " SQUARE MESH WIRE CLOTH", 2 1/2 MESHES PER INCH; 0.192" DIA. OF WIRE (27.0% OPEN AREA).

ASTM A-36 STEEL; CAMBRIDGE WIRE CLOTH CO. OR EQUAL

FIGURE 12. BLAST SHIELD, WIRE SCREEN, PLAN VIEW

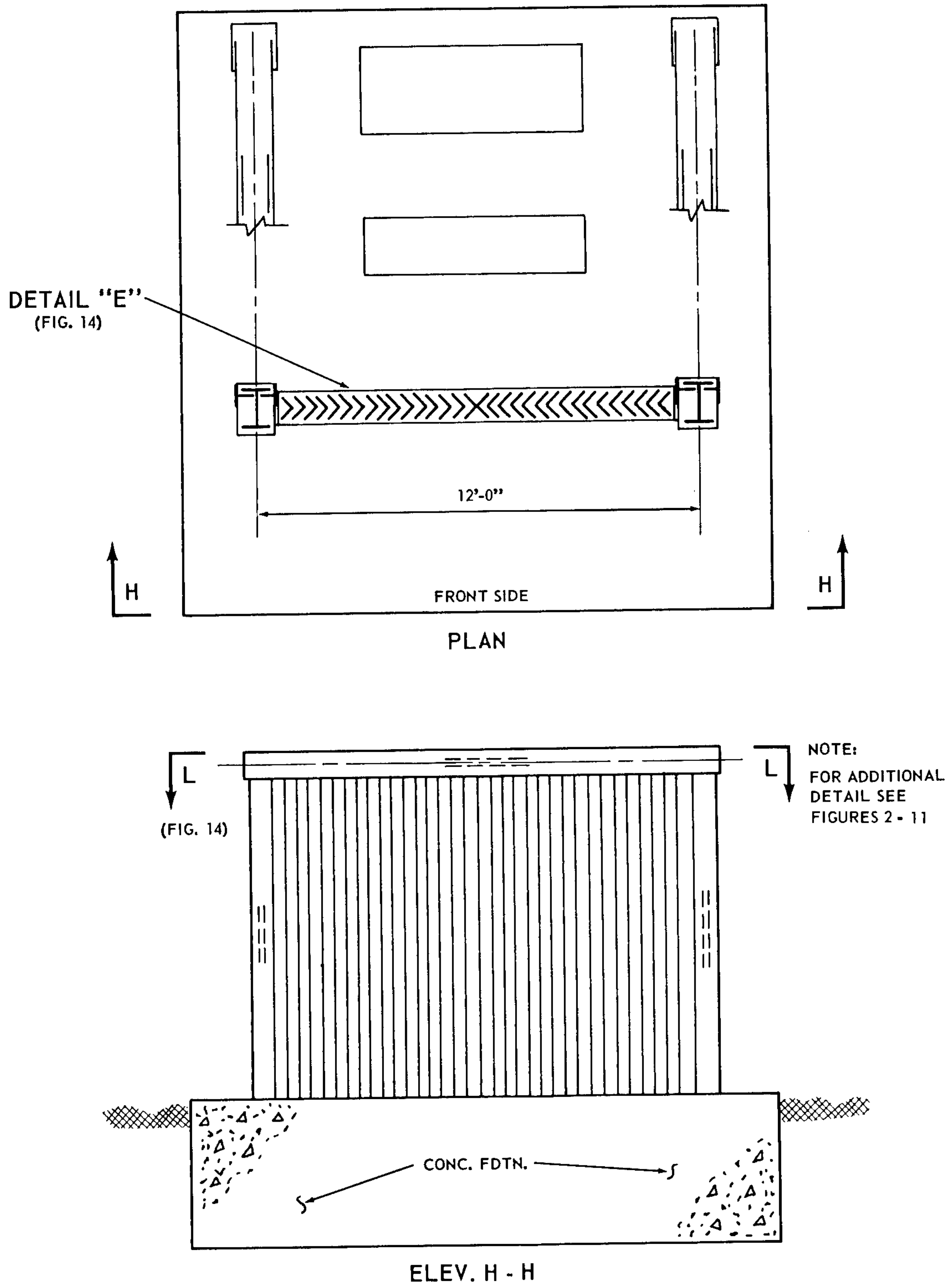
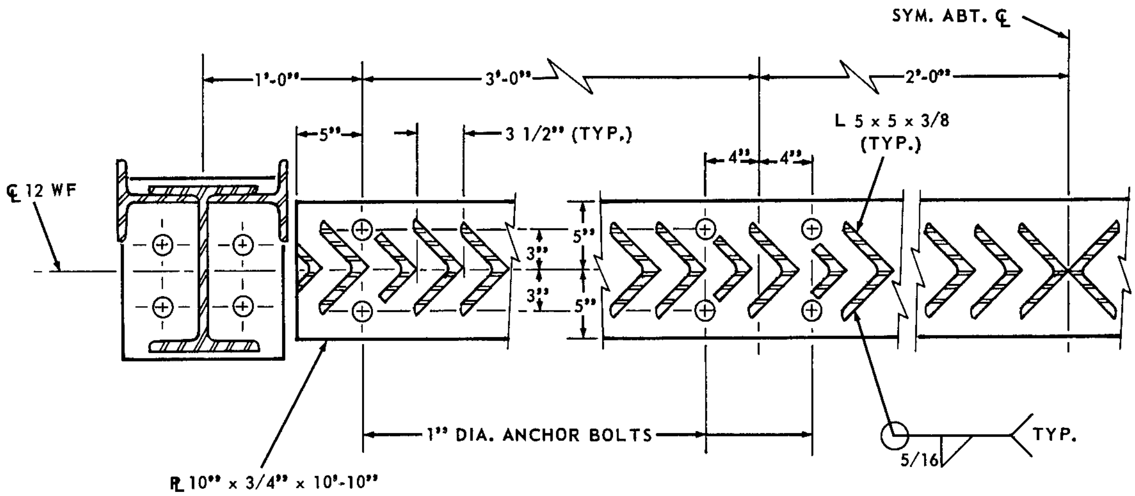
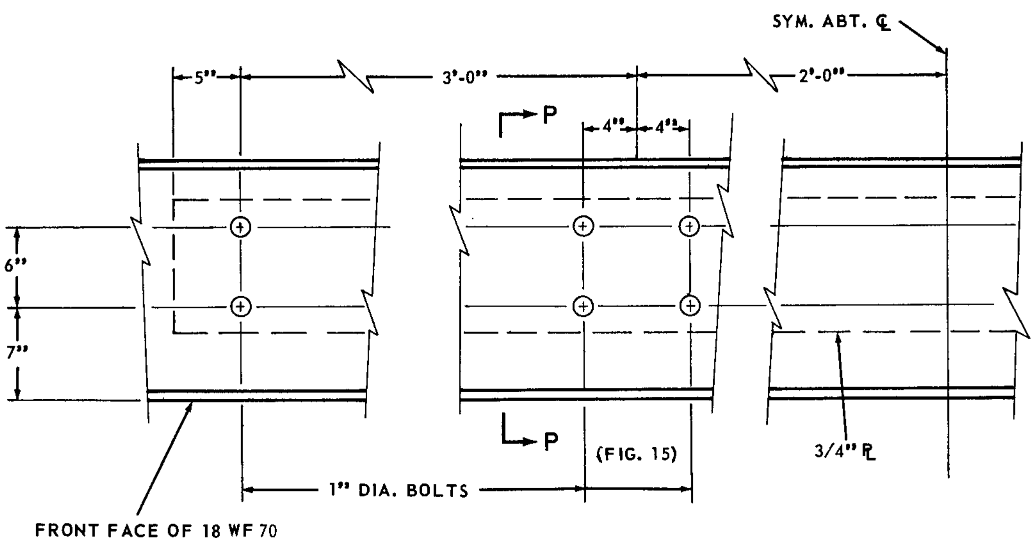


FIGURE 13. BLAST SHIELD ANGLE DEFLECTORS, PLAN AND ELEVATION VIEWS



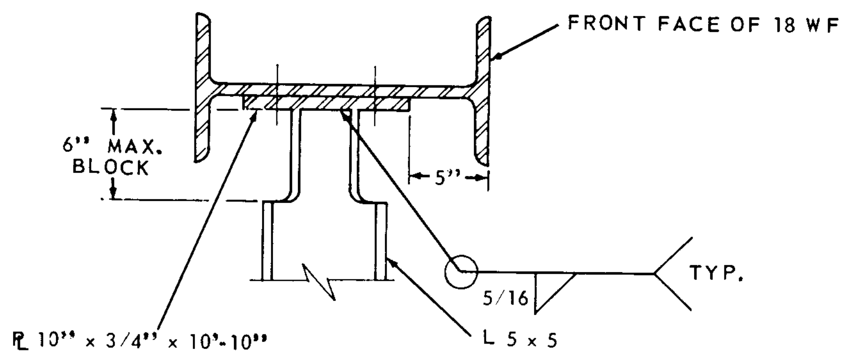
DETAIL "E"
(FIG. 13)
(EMBEDDED 14 WF 127 **NOT** SHOWN
FOR CLARITY - SEE DET. "B")

NOTE: BLOCK L^S TO CLEAR BOLTS & CUT AS SHOWN.



VIEW L - L
(FIG. 13)

FIGURE 14. ANGLE DEFLECTOR DETAILS



SECT. P - P
(FIG 14)

FIGURE 15. ANGLE DEFLECTOR DETAILS

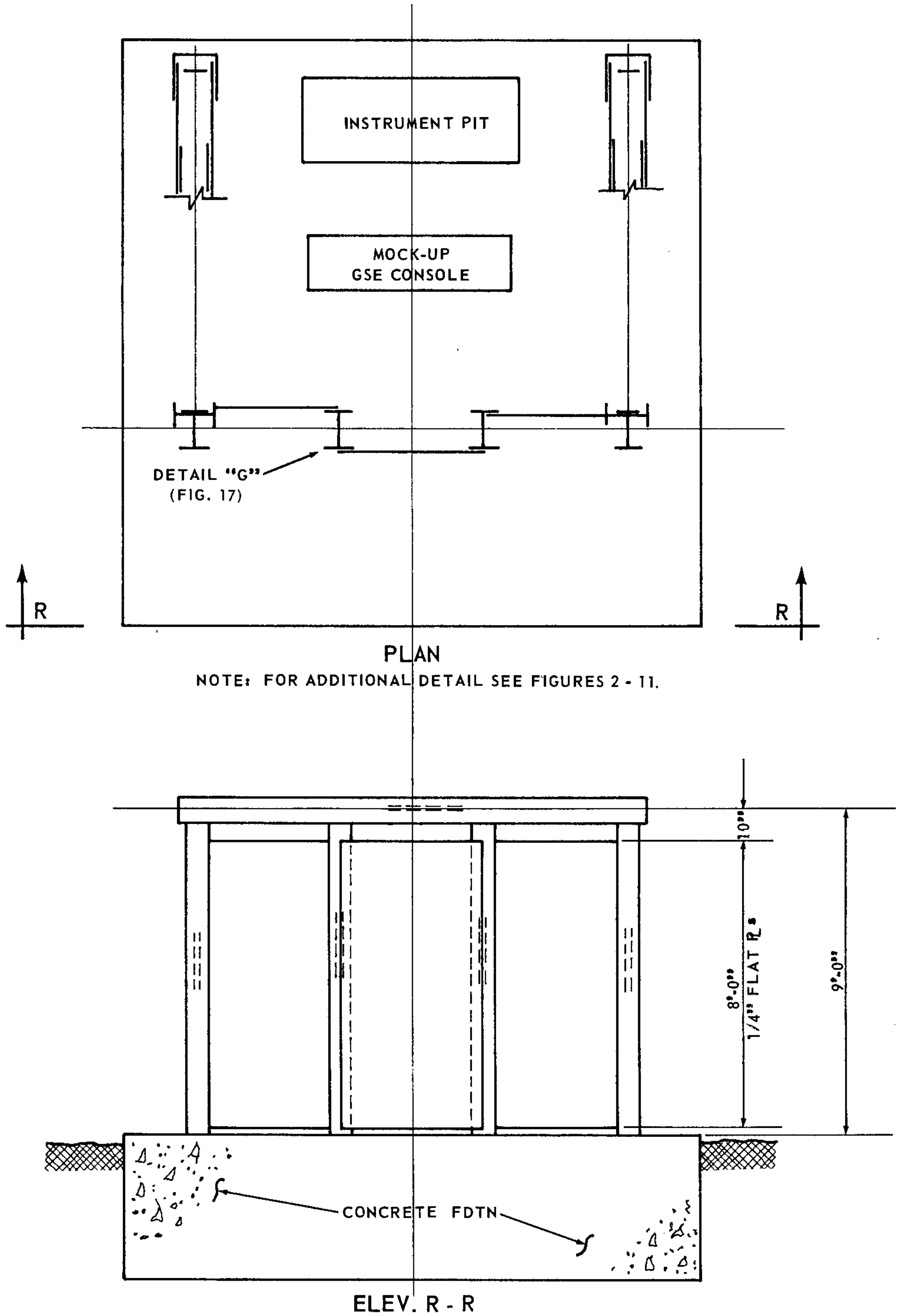
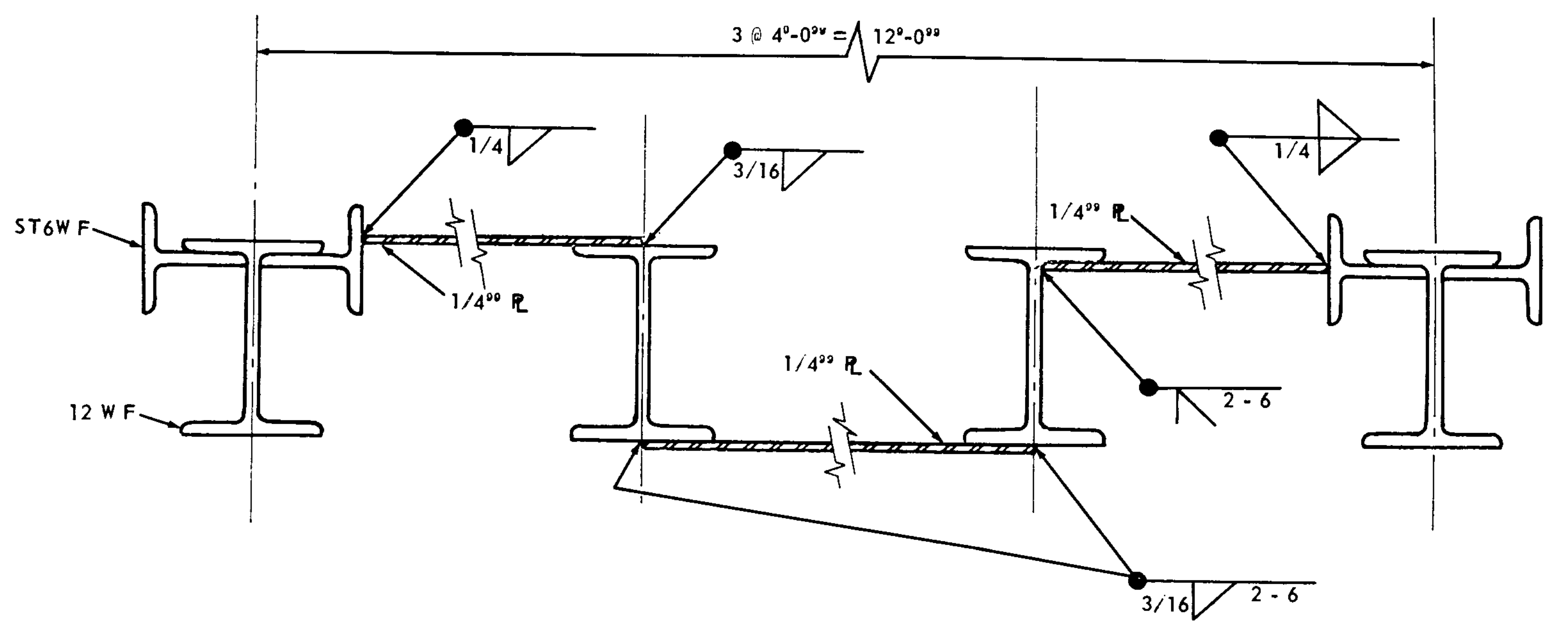


FIGURE 16. BLAST SHIELD, FLAT PLATE, PLAN AND ELEVATION VIEWS



DETAIL "G"
(FIG. 16)

FIGURE 17. FLAT PLATE DESIGN DETAIL

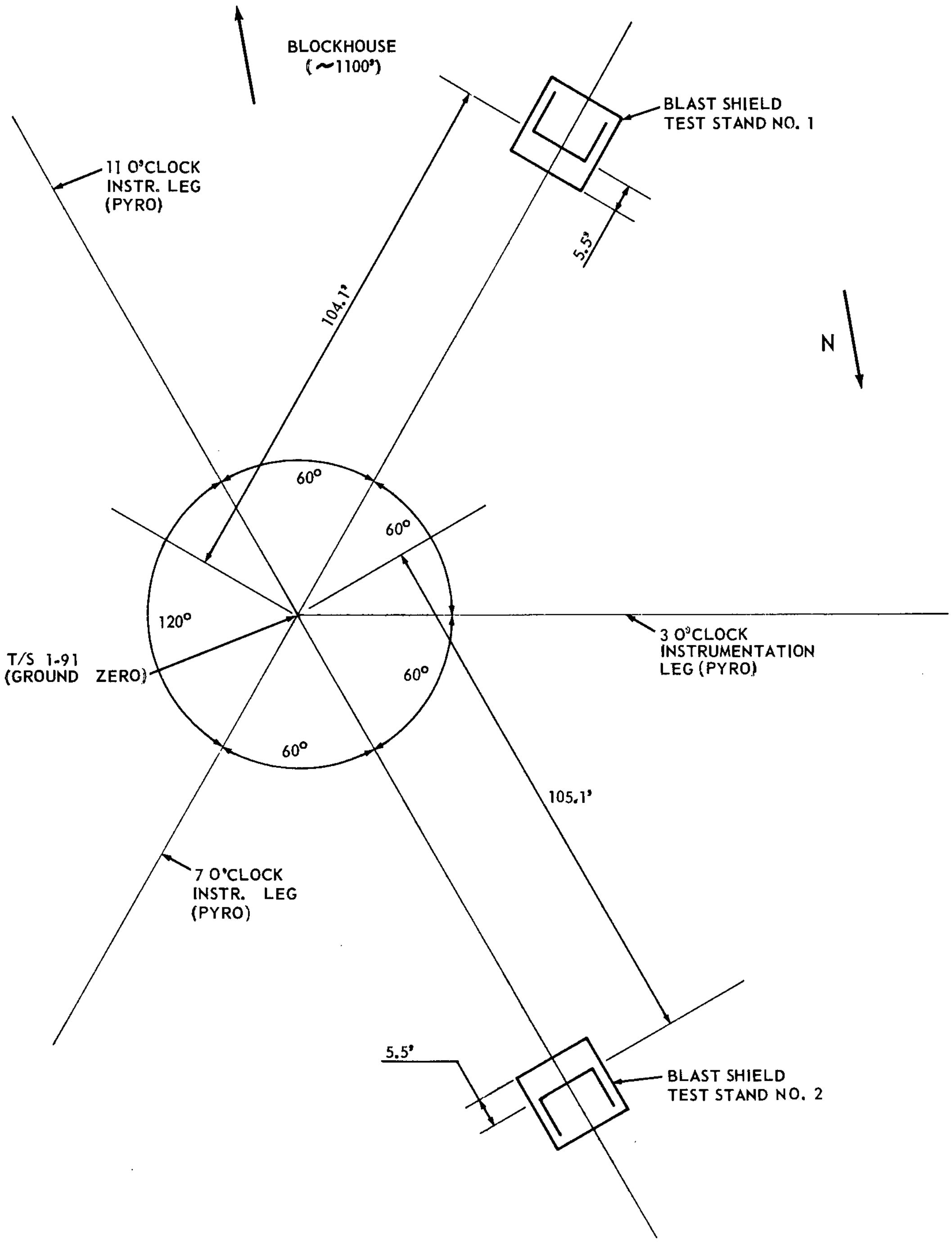


FIGURE 18. LOCATION OF TEST STANDS

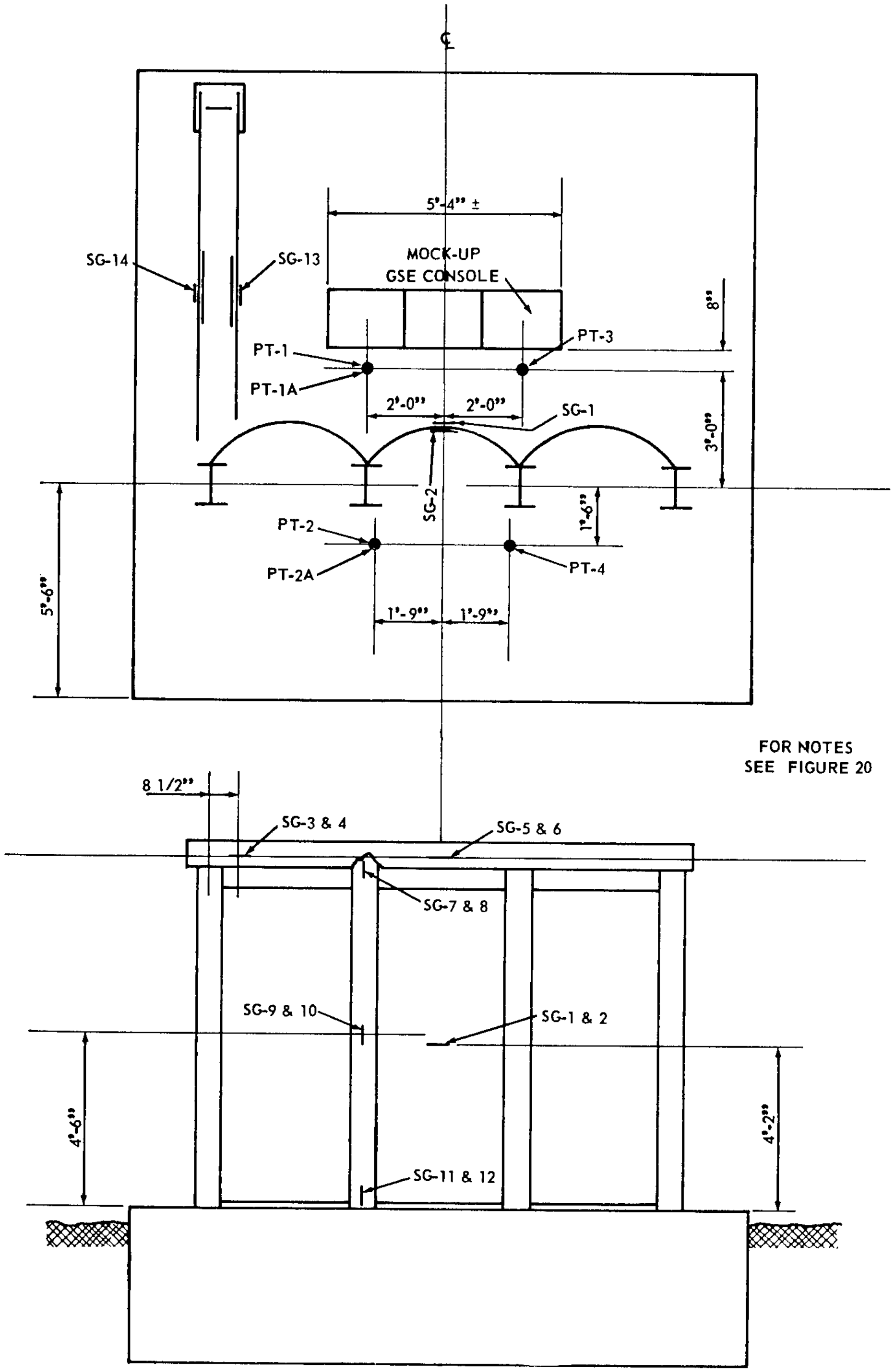
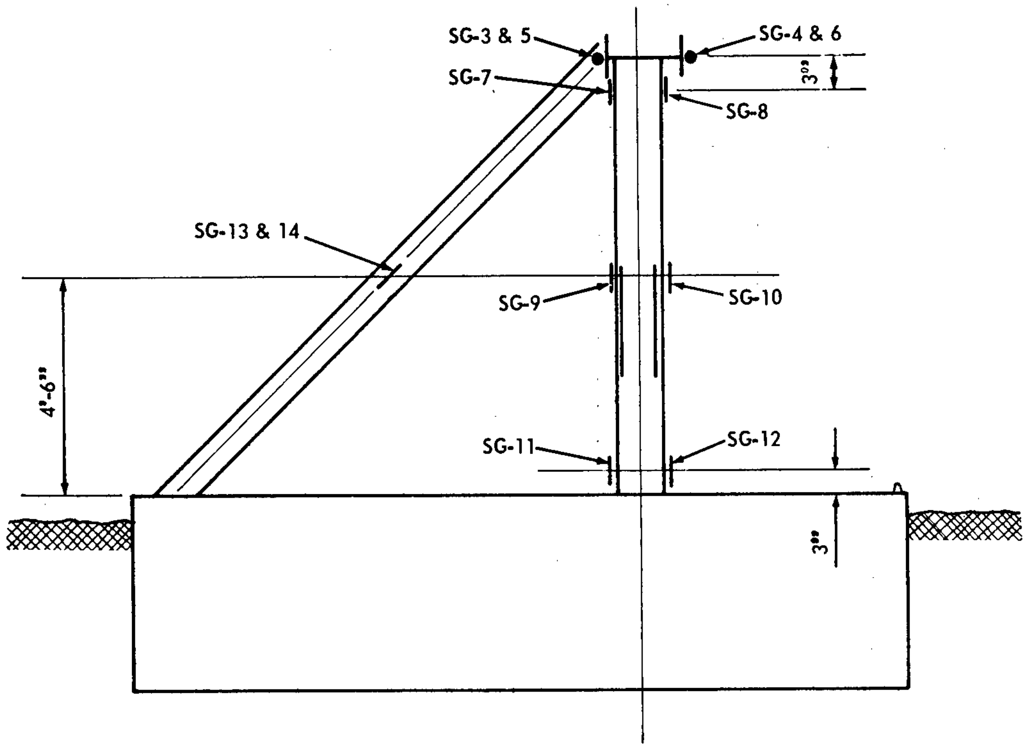
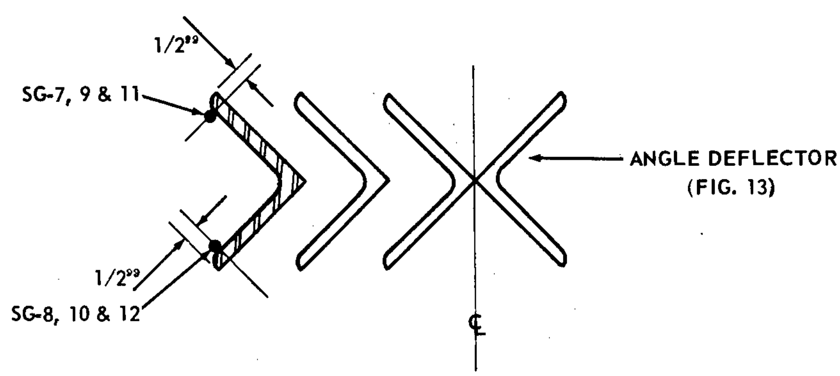


FIGURE 19. LOCATION OF INSTRUMENTATION





INSTRUMENTATION NOTES

1) PT-1 = PRESSURE TRANSDUCER # 1 (DYNISCO)
   PT-1A = PRESSURE TRANSDUCER # 1A (KISTLER)
   SG = STRAIN GAGE (MICRO-MEASUREMENTS)

2) EVEN NUMBERED MEASUREMENTS FACE THE BLAST.

3) PRESSURE TRANSDUCERS ARE INSTALLED IN THE CAPS SCREWED ON ENDS OF 1 1/2" DIA. PIPES (FIG. 8), WHICH PLACED THEM 2 1/2" ABOVE TOP SURFACE OF CONCRETE FOUNDATION.

FIGURE 20. INSTRUMENTATION LOCATION

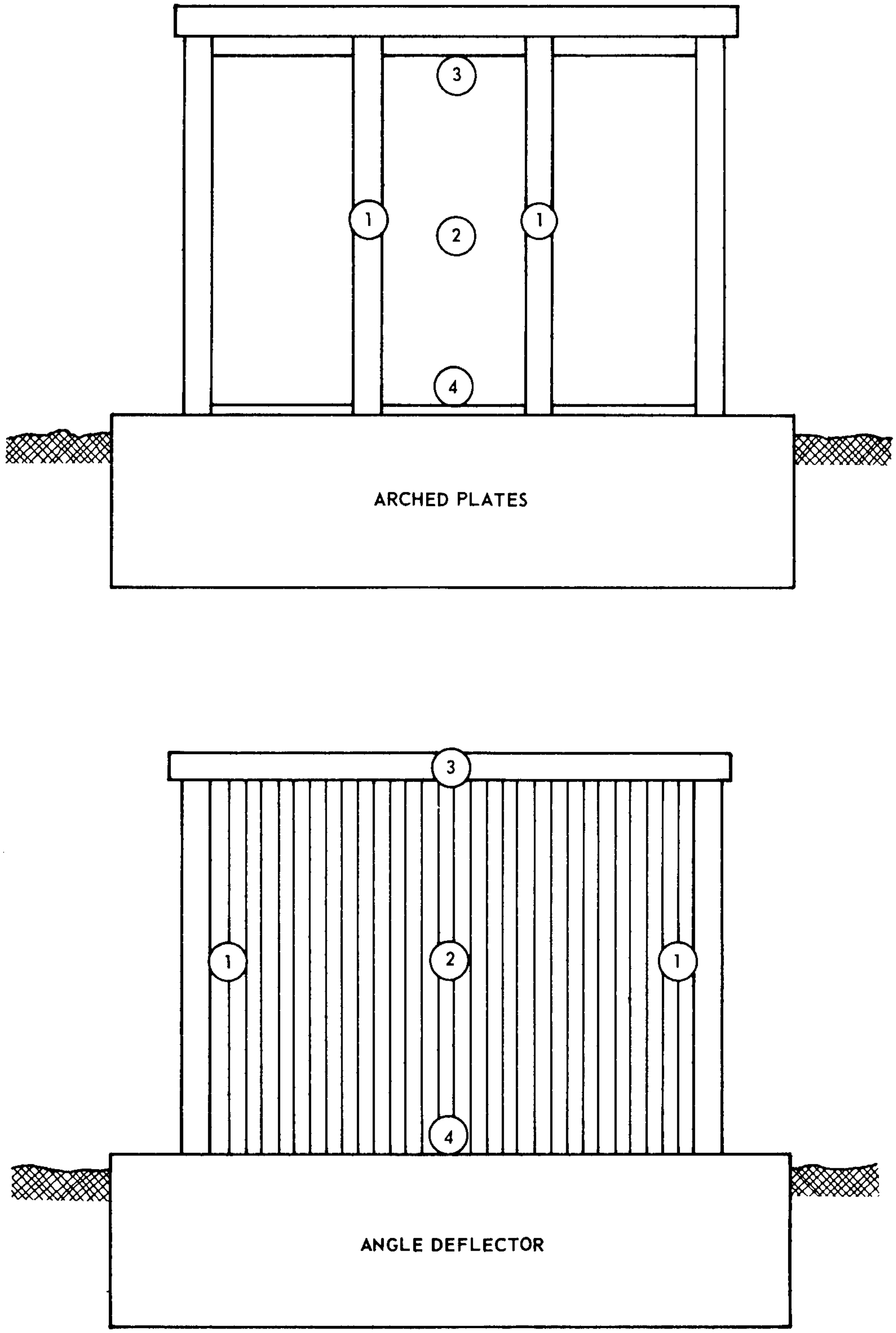


FIGURE 21. REFERENCE POINTS FOR TABLE III

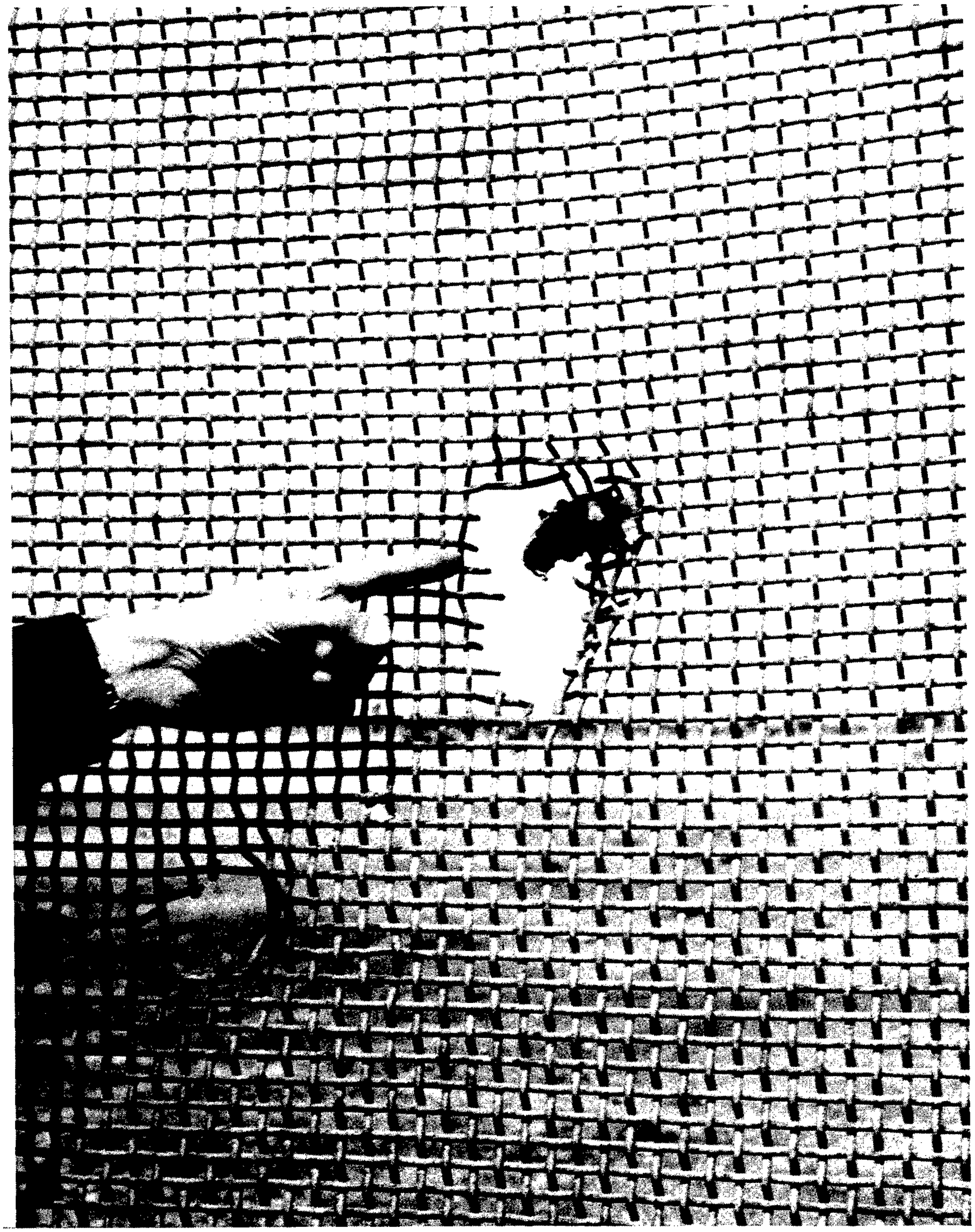


FIGURE 22. SHRAPNEL PERFORATION OF WIRE SCREEN, TEST 301

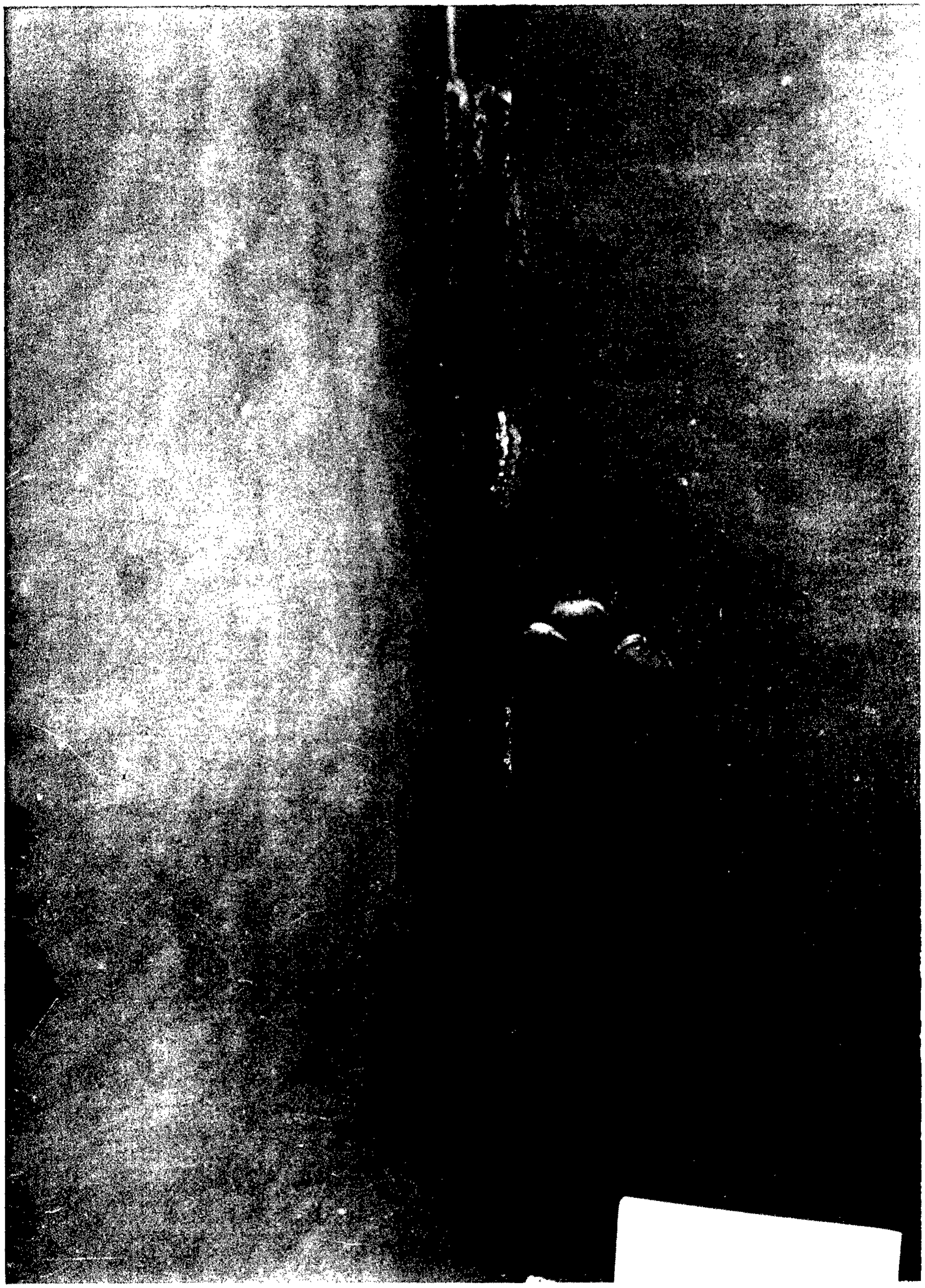


FIGURE 23. WELD CRACKS AT BOTTOM OF ARCHED PLATES, TEST 285

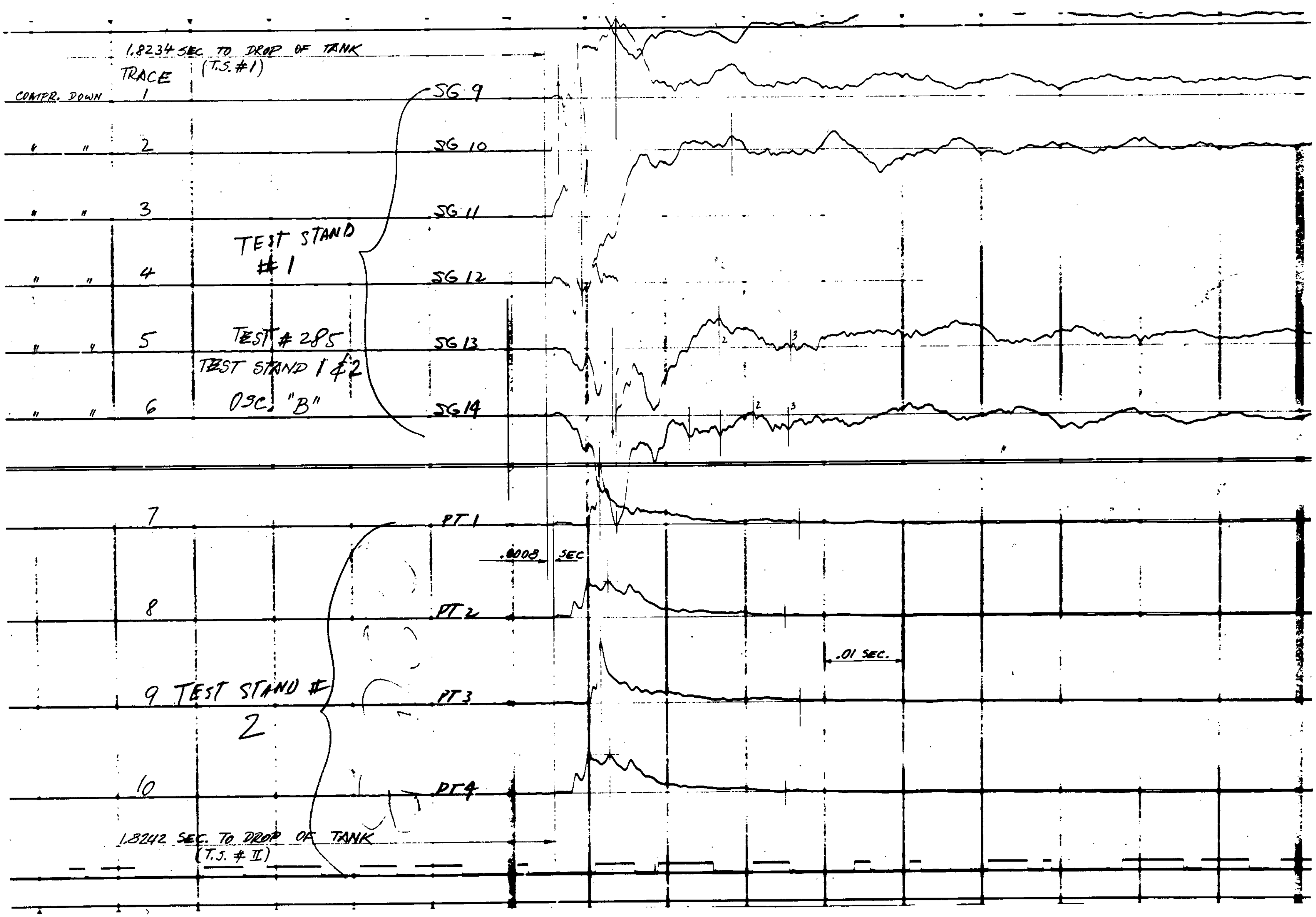


FIGURE 24. SAMPLE OF RECORDER OSCILLOGRAPHS, TEST 285

APPENDIX

ADDITIONAL INFORMATION ABOUT INDIVIDUAL TESTS

Test 284

This was a test of low yield which caused no damage to either of the two blast shields. The GSE consoles stood freely, unanchored, during this test. They were not knocked down, but slightly damaged, at Test Stand No. 1 (Fig. A-1); and completely destroyed at Test Stand No. 2 (Fig. A-2).

Test 285

The high yield caused slight damage to the blast shields. Bottom welds of arched plates cracked (Fig. 23) and bottom wires of the wire screen failed (Fig. A-3). The GSE consoles stood freely, unanchored, during this test. They were knocked down and damaged at Test Stand No. 1 (Fig. A-4), and completely destroyed at Test Stand No. 2 (A-5).

It will be noted on Figure 24 that traces of pressure transducers PT-2 and PT-4 indicate two peaks of practically equal magnitude, one immediately before and one immediately after PT-1 and PT-3 reached their peaks. The first peak on PT-2 and PT-4 is the reflected overpressure from the blast shield and the supporting structure; the second peak is the reflected overpressure from the GSE consoles (Fig. 19).

Traces of strain gauges SG-1 and SG-2 on the arched plates (Fig. 19) do not show only tension, as one might expect, but a succession of tension and compression. The reason for this is the arched depth of the plate (approximately 12 in.). The shock front and the reflected overpressure, from the front and from the back, reached different parts of the arched plates at different times, causing bending moments in the plate with consequent alternating stresses.

One general observation for all pressure transducers during all tests: the instruments do not indicate any negative phase. This is probably a result of the proximity of the pressure transducers to ground zero.

Test 288C

The explosive yield was approximately 13 percent, according to a preliminary AFRPL report, which should be equivalent to approximately 8 percent at the blast shield distance. Both blast shields and GSE consoles were damaged slightly (Figs. A-6 and A-7). The consoles were anchored to the concrete foundation for this test. Some bottom welds of flat plates cracked.

Test 289A

The explosive yield was approximately 3 percent, according to a preliminary AFRPL report, which should be equivalent to approximately 2.5 percent at the blast shield distance. No damage was noted on the blast shields, nor on the GSE consoles which were anchored to the concrete foundation for this test.

Test 290

The explosive yield was approximately 2.5 percent, according to preliminary AFRPL report, which should be equivalent to approximately 2.2 percent at the blast shield distance. No damage was noted on the blast shields, and slight damage on the GSE consoles which were anchored to the concrete foundation for this test (Figs. A-8 and A-9).

Test 300

This was the first Titan I test. The missile exploded prematurely. Since no measurements were recorded, the explosive yield was estimated by the damage caused to the blast shields and other structures. The AFRPL estimate is approximately 15 percent of the 113.5 kips of RP-1 and LOX on board, which would make it about 10 percent at the blast shield distances, or an equivalent weight of 11.35 kips of TNT. This is slightly higher than the assumed design weight of 10.0 kips of TNT.

Test Stand No. 1, with the angle deflector and the GSE consoles, withstood the blast very well. Some plastic deformations were noted on the angle deflector and on the supporting frame, as would be expected from the design calculations, but they both remained quite usable. They were used as they were, with no repair, during Test 301. The anchored GSE consoles on Test Stand No. 1 suffered moderate damage (Fig. A-10).

Wire screen No. 3 and the anchored GSE consoles on Test Stand No. 2 were completely destroyed (Fig. A-11).

Test 301

This Titan I test (Fig. A-12) of low explosive yield caused slight damage to Wire Screen No. 2, and no damage to the angle deflector (Figs. A-13 and A-14). Some holes were perforated in the wire screen by flying fragments, and some bottom wires were ripped loose from their welded connections. Here again the failure occurred at the most rigid location of the blast shield as was the case with arched and flat plates.

The same, damaged, GSE cabinets from Test 300 were exposed to blast again in this test. The shedding vortices of the overpressure wave around the blast shield, and the momentary higher overpressure behind the cabinets, pushed the cabinets against the blast shield. It is surprising that they were overturned now, and not during the stronger blast of Test 300. The reason for this is the weakening of anchorage during Test 300, so that relatively small overpressure was sufficient to overturn them during Test 301.

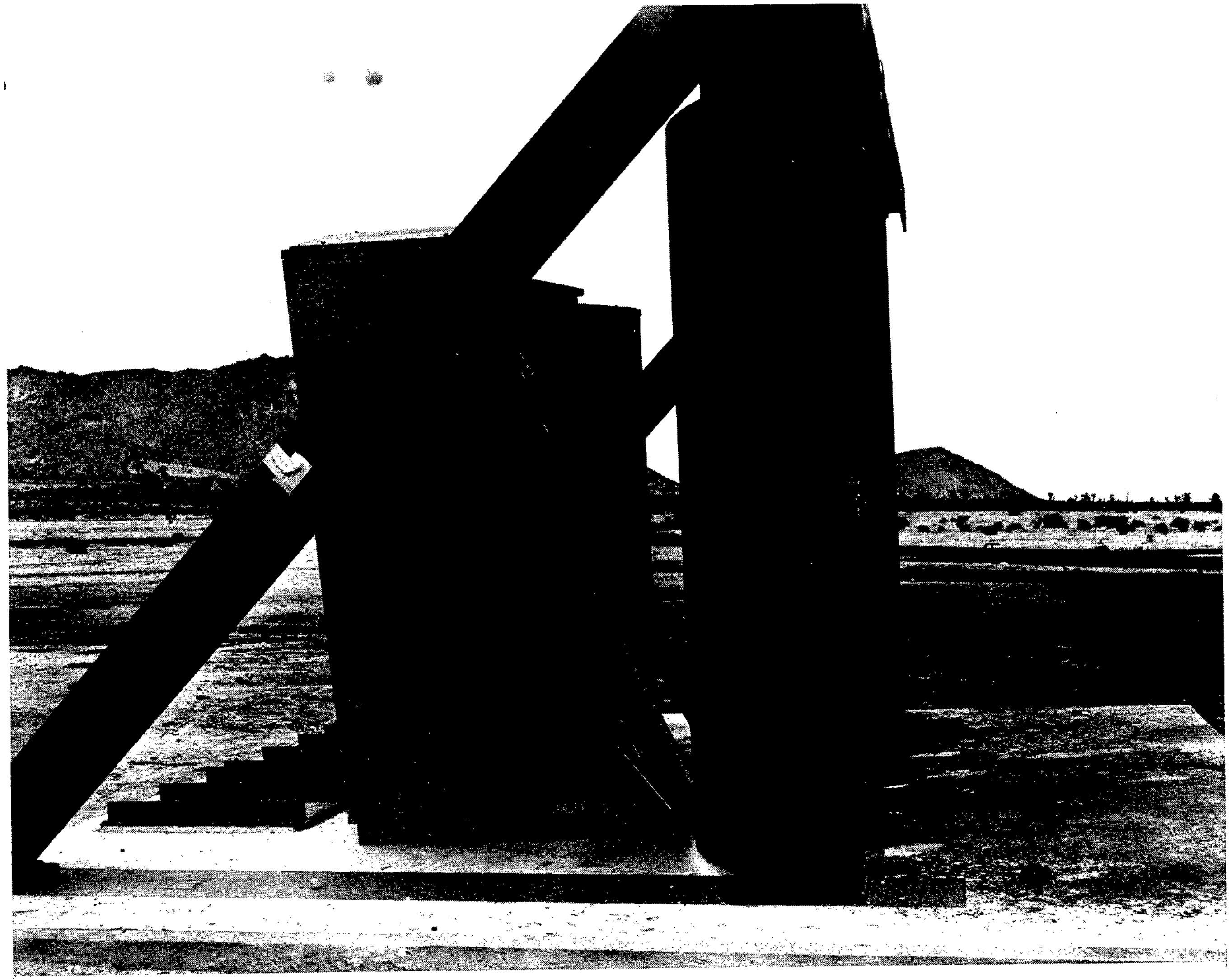


FIGURE A-1. TEST STAND NO. 1 AFTER EXPLOSION, TEST 284
(BLAST SHIELD: SOLID ARCHED PLATES)

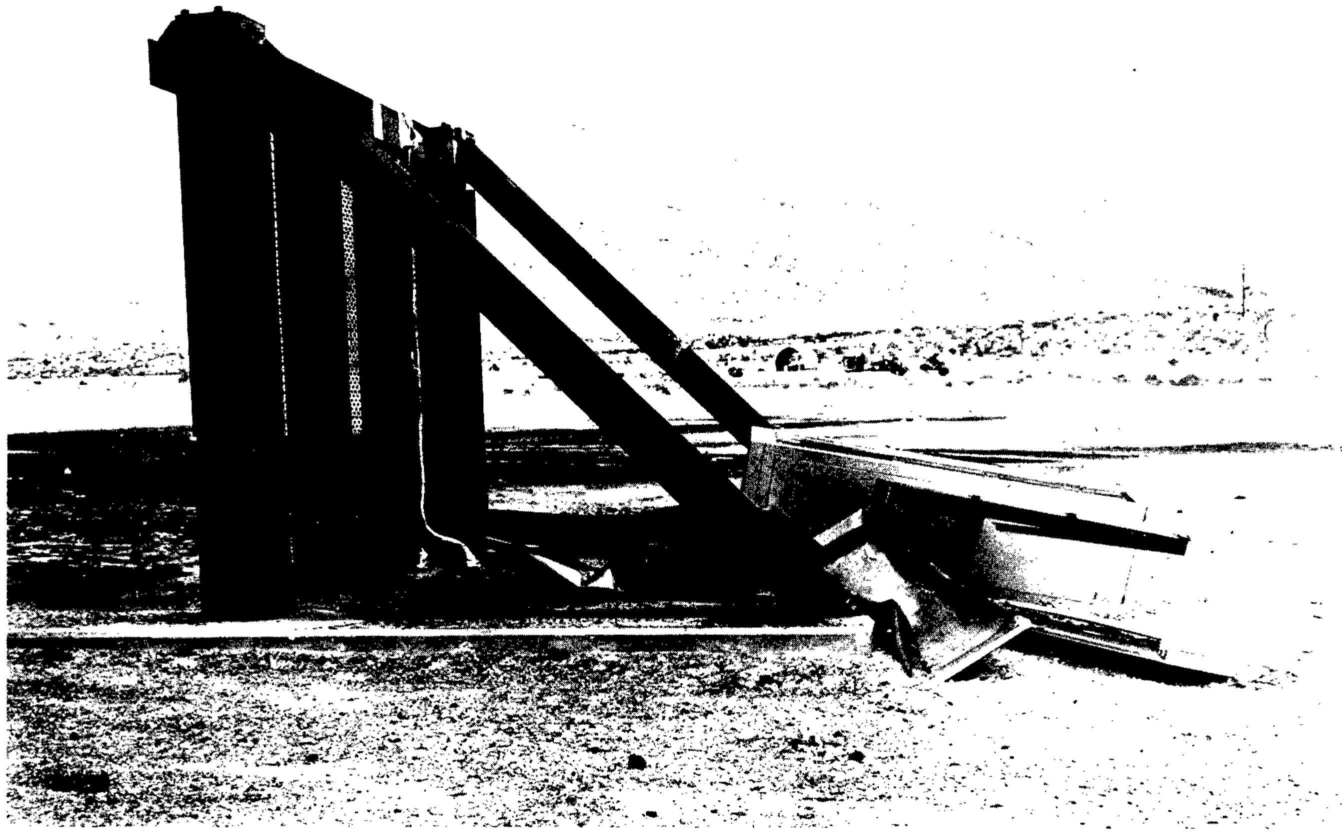


FIGURE A-2. TEST STAND NO. 2 AFTER EXPLOSION, TEST 284
(BLAST SHIELD: WIRE SCREEN NO. 1 WITH 65.3% OPEN AREA)

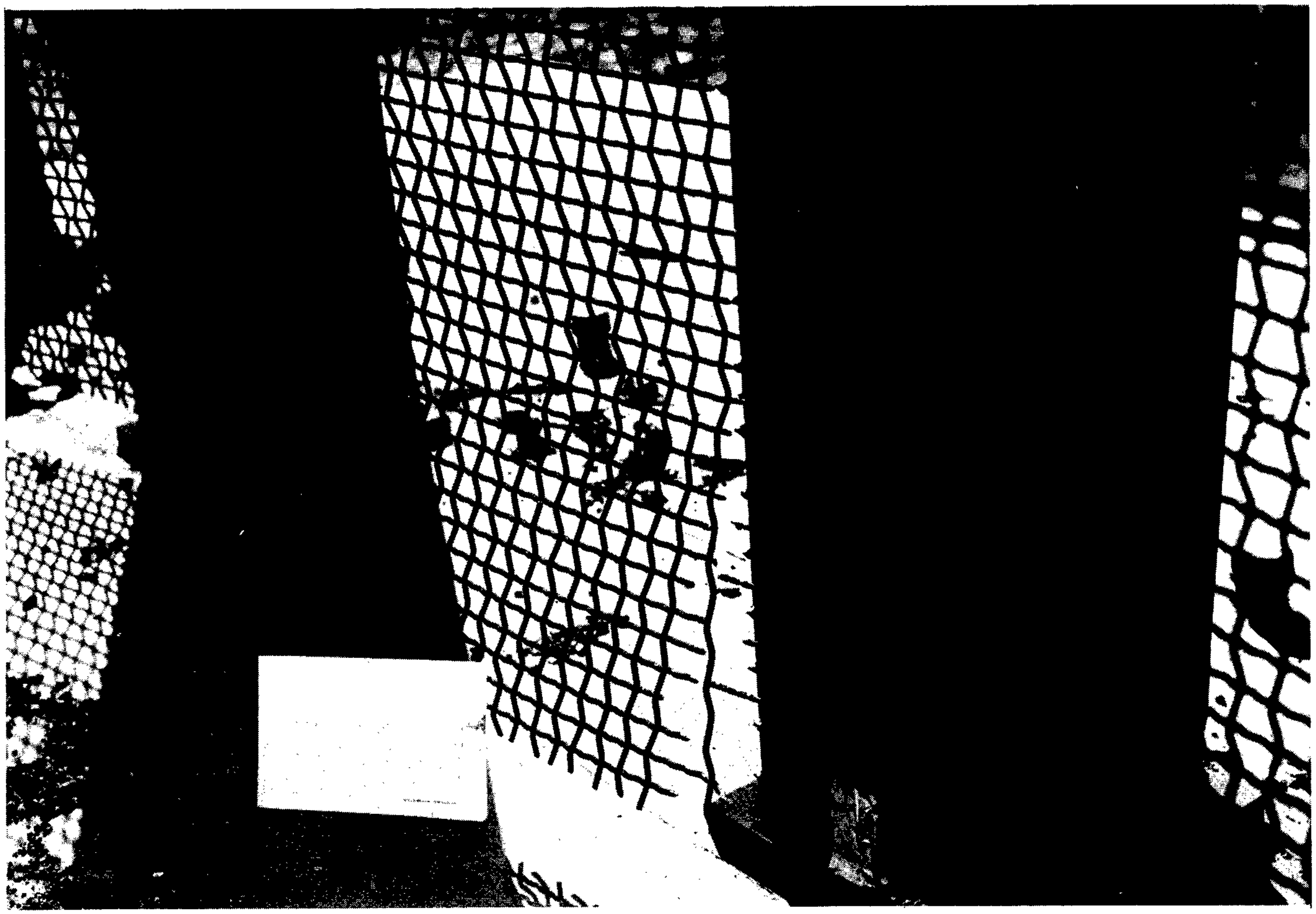


FIGURE A-3. TEST STAND NO. 2, FAILURE OF BOTTOM WIRES, TEST 285

FIGURE A-4. TEST STAND NO. 1 AFTER EXPLOSION, TEST 285
(BLAST SHIELD: SOLID ARCHED PLATES)

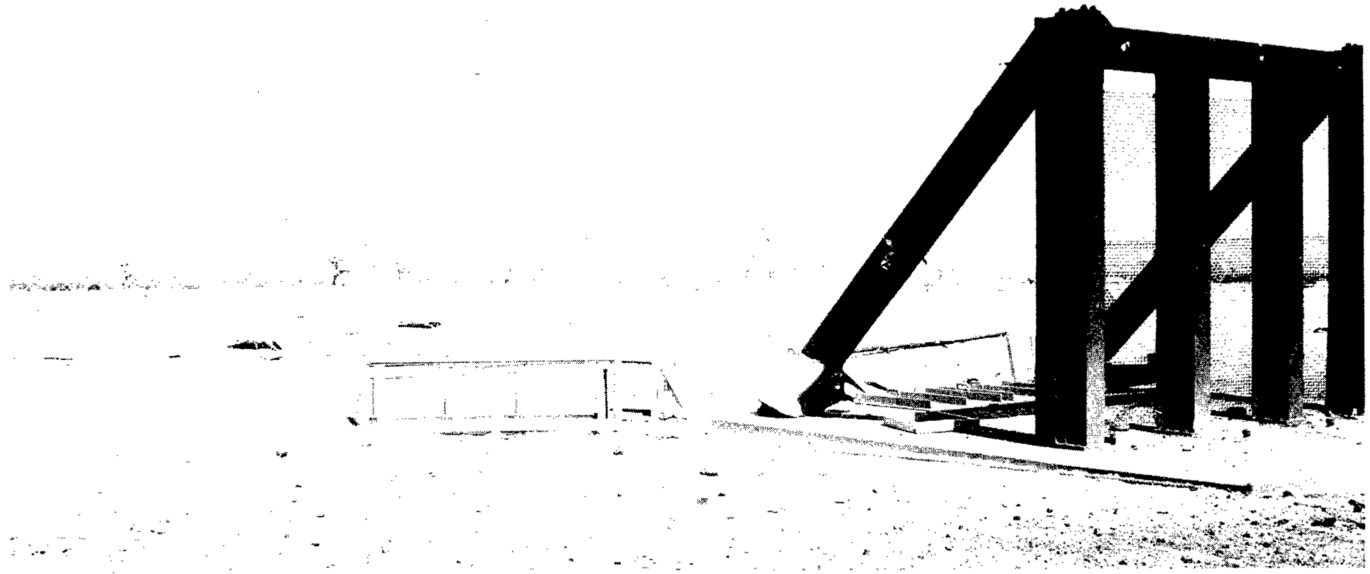


FIGURE A-5. TEST STAND NO. 2 AFTER EXPLOSION, TEST 285
(BLAST SHIELD: WIRE SCREEN NO. 1 WITH 65.3% OPEN AREA)

FIGURE A-6. TEST STAND NO. 1 AFTER EXPLOSION, TEST 288C
(BLAST SHIELD: SOLID FLAT PLATES)

FIGURE A-7. TEST STAND NO. 2 AFTER EXPLOSION, TEST 288C
(BLAST SHIELD: WIRE SCREEN NO. 2 WITH 48.0% OPEN AREA)

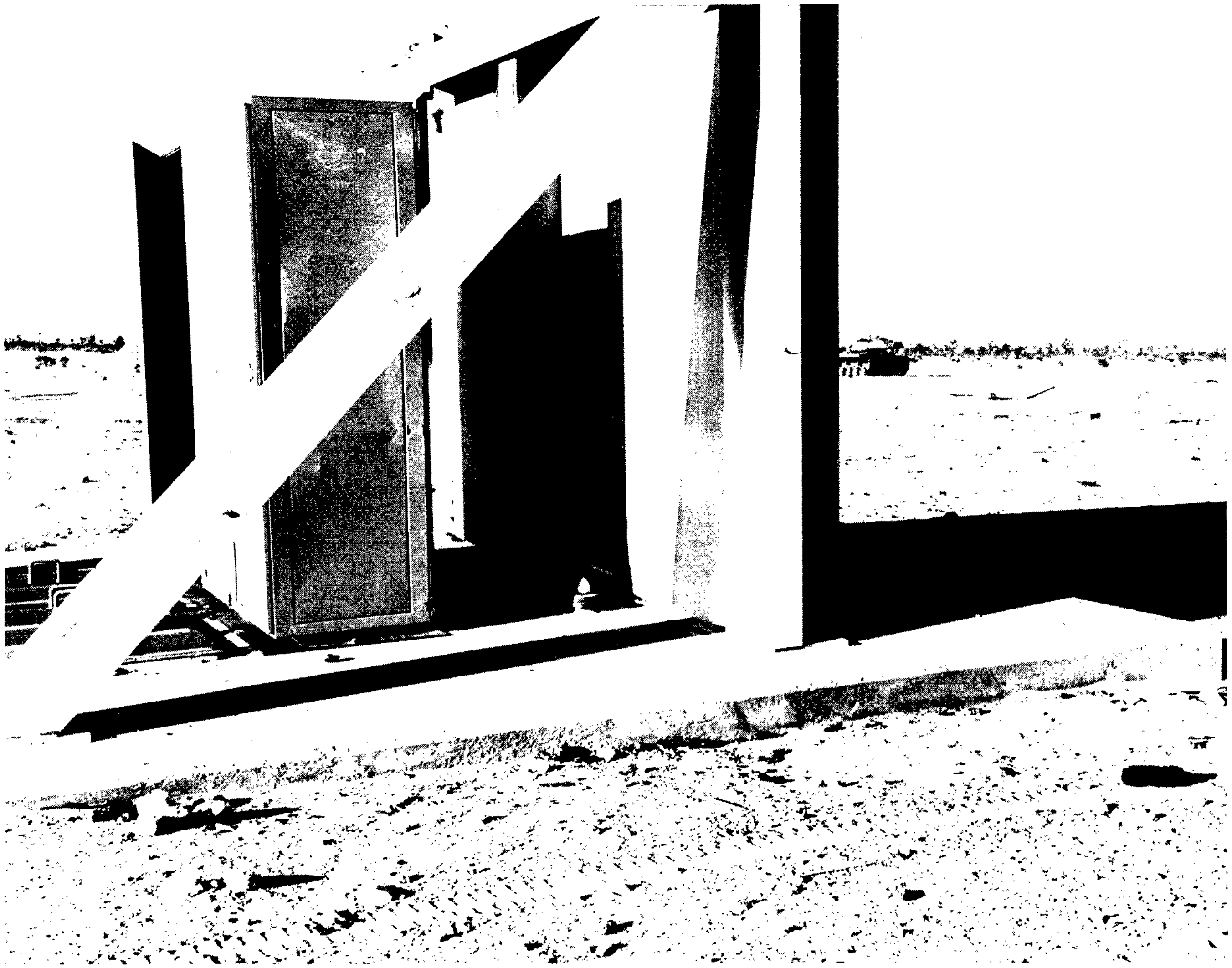


FIGURE A-8. TEST STAND NO. 1 AFTER EXPLOSION, TEST 290
(BLAST SHIELD: SOLID FLAT PLATES)

FIGURE A-9. TEST STAND NO. 2 AFTER EXPLOSION, TEST 290
(BLAST SHIELD: WIRE SCREEN NO. 2 WITH 48.0% OPEN AREA)

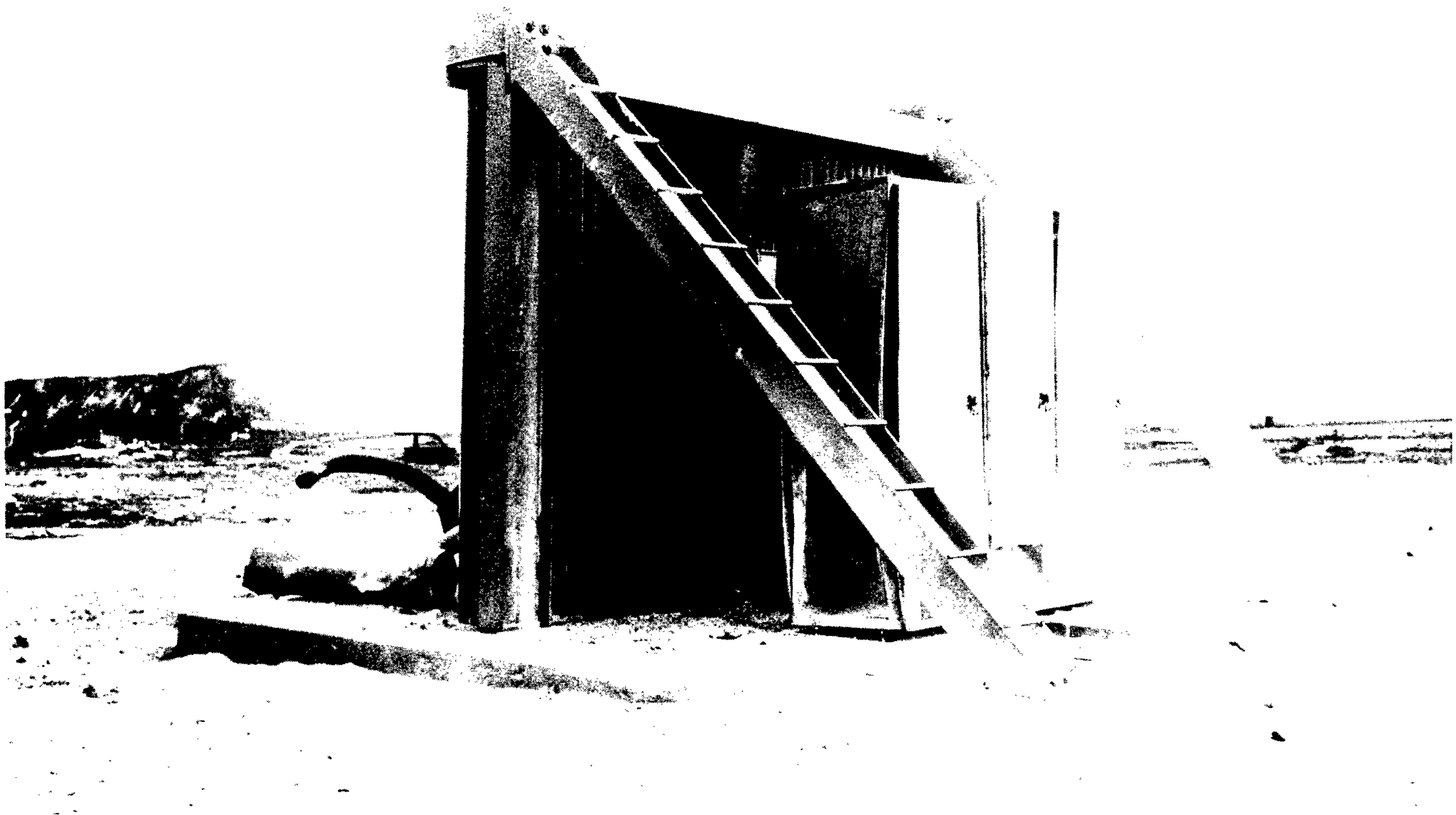


FIGURE A-10. TEST STAND NO. 1 AFTER EXPLOSION, TEST 300
(BLAST SHIELD: ANGLE DEFLECTOR)

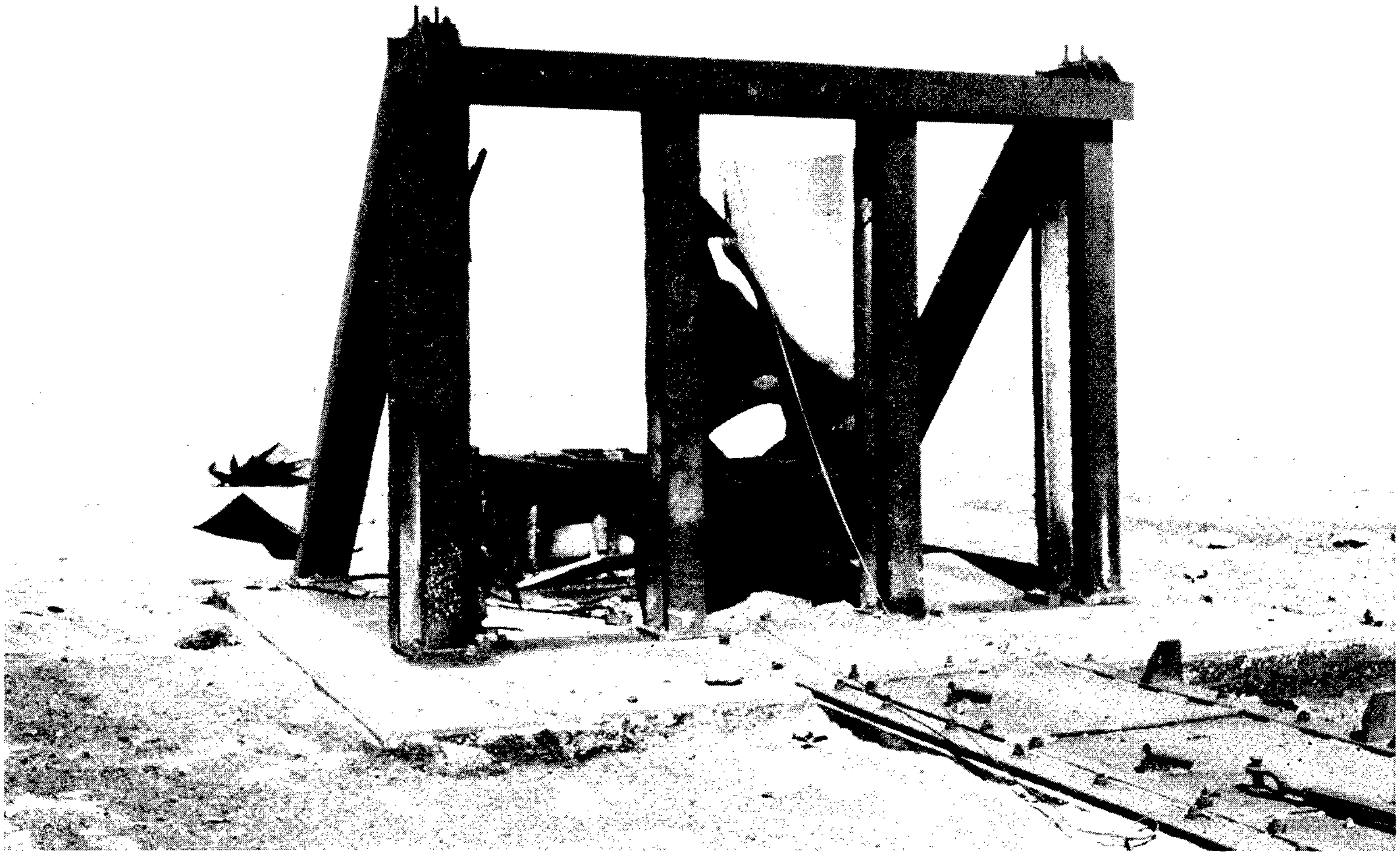


FIGURE A-11. TEST STAND NO. 2 AFTER EXPLOSION, TEST 300
(BLAST SHIELD: WIRE SCREEN NO. 3 WITH 27.0% OPEN AREA)

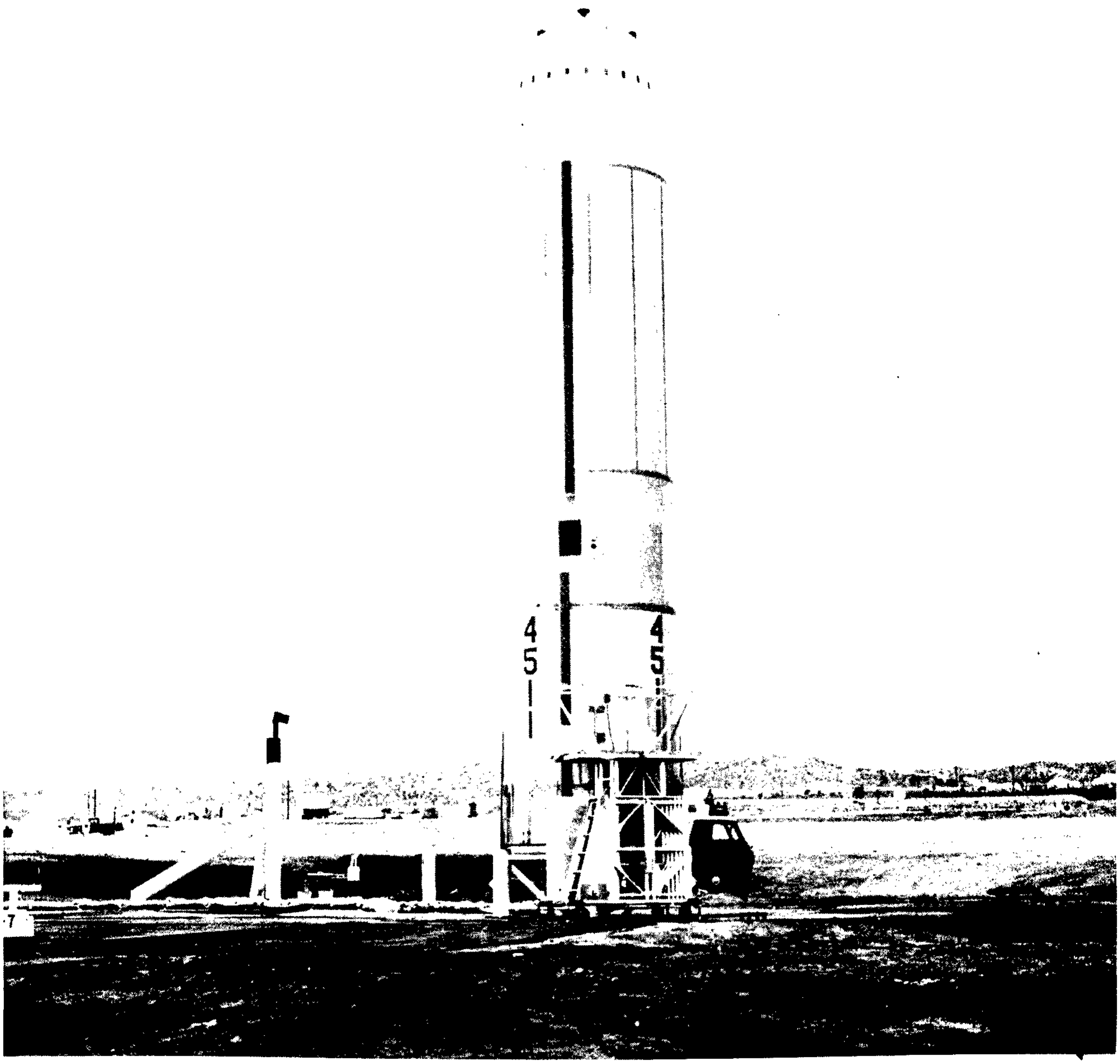


FIGURE A-12. TITAN I BEFORE EXPLOSION, TEST 301

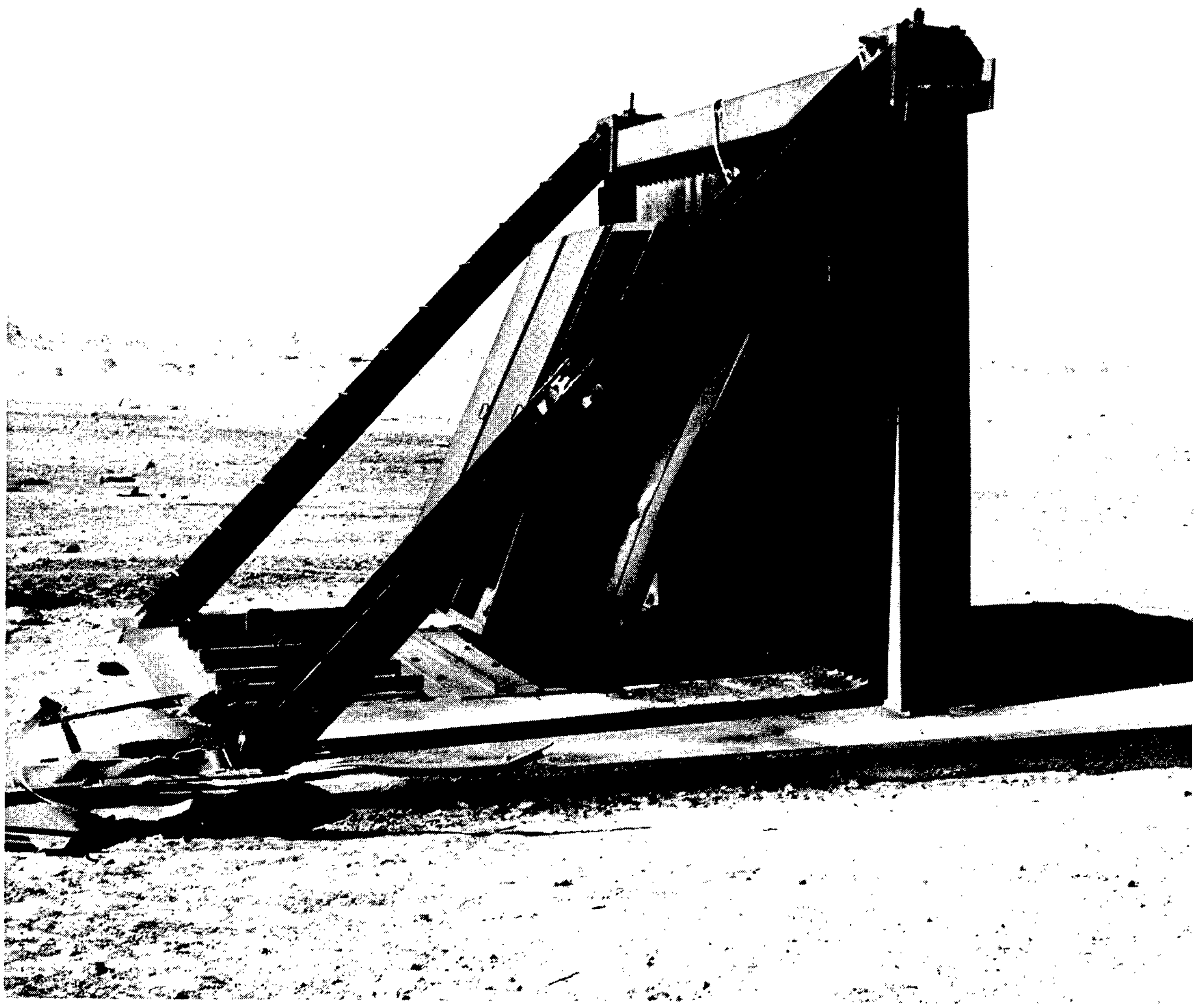


FIGURE A-13. TEST STAND NO. 1 AFTER EXPLOSION, TEST 301
(BLAST SHIELD: ANGLE DEFLECTOR)

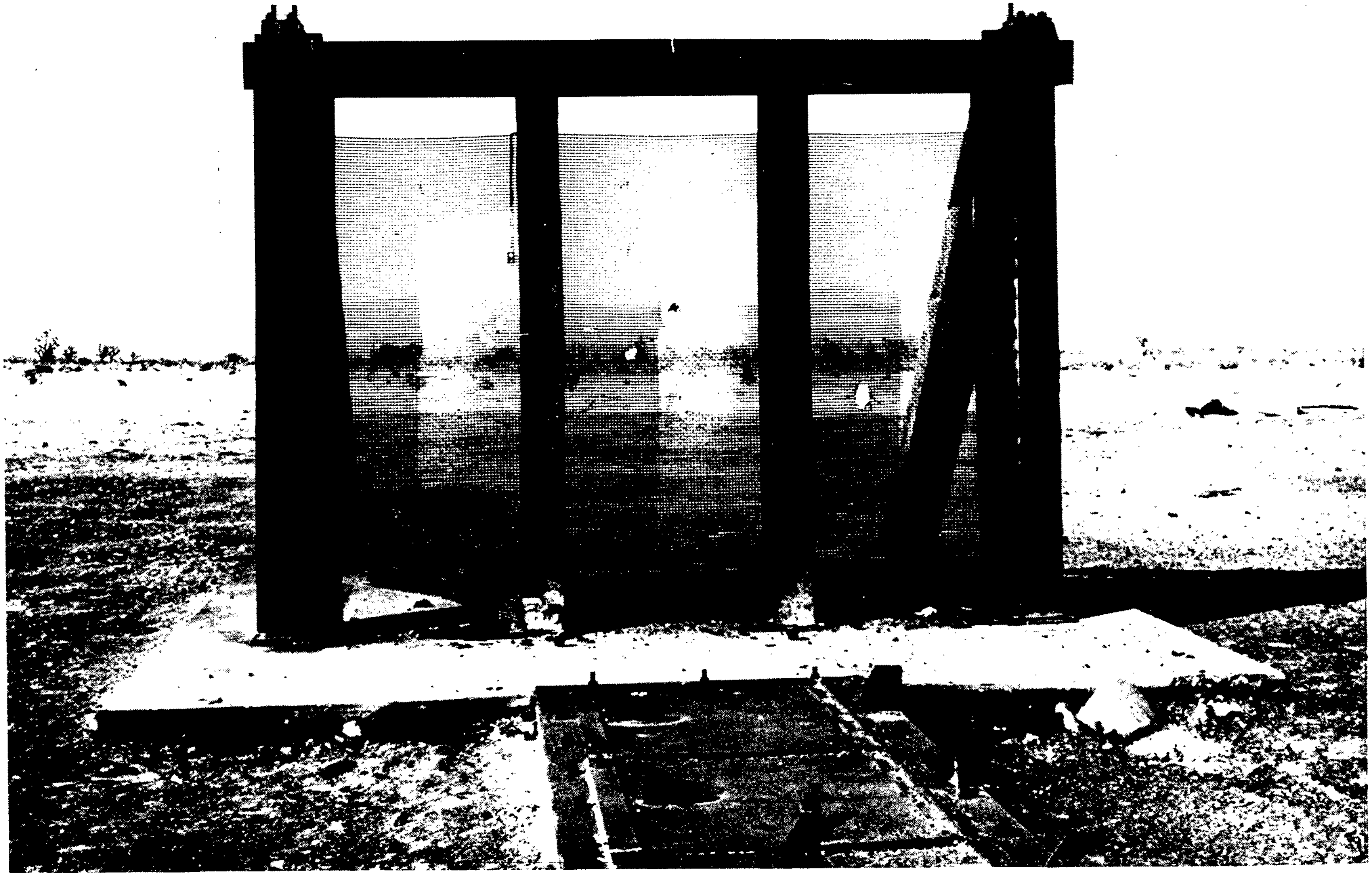


FIGURE A-14. TEST STAND NO. 2 AFTER EXPLOSION, TEST 301
(BLAST SHIELD: WIRE SCREEN NO. 2 WITH 48.0% OPEN AREA)

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NASA-Langley, 1968 — 11 M763

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