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MEMORANDUM REPORT NO. 2757

SHOCK WAVE ATTENUATION BY PERFORATED
PLATES WITH VARIOUS HOLE SIZES

Charles Kingery
Richard Pearson
George Coulter

June 1977

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AUTHORS' COMMENTS

Both the English system of units and SI units have been used in this report with the exception of the data tables where the gage calibrations and computer output for overpressure are in pounds per square inch. Dual scales were not used because the primary objective of the tables is to determine ratios and percentages of input pressure and transmitted pressure which would be the same in either system of units.

There is also a need to keep continuity of the present results with previously published results (Reference 1) conceived with the same subject matter. All equations developed in this report satisfy both systems of units.

I. INTRODUCTION

This is the second* in a series of reports which define the parameters affecting the attenuation of shock waves passing through vented wall plates. Results are reported here for the attenuation of shock waves through single perforated plates as a function of the number and size of vent holes in a plate.

A. Background

Under the US Army's Production Base Modernization (PBM) program for munition processing facilities, a two-phase program has been initiated to develop suppressive shields. One phase, the Category Shield program, will produce a series of shields for specific munition applications.

For the second phase, the Applied Technology Development Phase, a major responsibility has been given to the Ballistic Research Laboratory (BRL). The basic requirement of this phase is to develop a general technology base for suppressive shields. The basic design criteria require containment of fragments and attenuation of the blast wave from accidental explosions in munition processing plants. This report is concerned with the blast attenuation part of the requirement.

B. Objectives

1. Define and determine the suppressive structure parameters which affect the attenuation of the blast wave.
2. Develop an understanding of blast wave suppression so as to design an efficient blast suppressor.

The objective of this report is to present results obtained from a study of pressure attenuation of shock waves passing through perforated plates. The variables were hole size, number of holes, and incident peak overpressure.

II. EXPERIMENT

This section describes the experimental equipment and design of the perforated plates.

A. Instrumentation

The shock waves were generated inside a 4-inch (10.2 cm) inside diameter shock tube. The driver section used was 12 inches (30.48 cm)

*The first report is entitled, "Shock Wave Attenuation by Single Perforated Plates," Charles Kingery and George Coulter, BRL Memorandum Report 2664, August 1976.

long; driver gas was helium. The test station was located 100 inches (254 cm) from the diaphragm at the driver section. Another 200 inches (508 cm) of tube was added downstream of the test station to delay the return of reflections from the closed end.

The short driver section was chosen so as to form a peaked decaying shock wave similar to that produced by a high explosive detonation. Calibrated aluminum and copper diaphragm materials were used to contain the driver gas in the compression chamber until the desired pressure was obtained. Figure 1 shows a sketch of the shock tube.

Pressure-time profiles of the shock waves were recorded at the locations shown in the sketch. The transducers were tourmaline crystal type, Model ST-4, manufactured by Susquehanna Instruments Company. They were threaded into the shock tube wall as nearly flush as possible. Charge amplifiers, Kistler Model 506; and oscilloscopes, Tektronix Model 502-A; completed the recording instrumentation.

B. Plate Design

The perforated plates were designed to investigate the effect of number of holes and hole size on shock wave attenuation for different incident peak overpressures*. Several vent areas, A_v , in the range from 5-50 percent were chosen for testing. The number and diameter of the holes were varied for each of the several percentages of area vented.

Single steel plates, 0.25 inch (0.64 cm) thick, were bolted between the flanges of the shock tube at the point shown in Figure 1. The number, diameter, and size of the holes in the various plates are listed in Table I. Sketches of the plates are shown in Figure 2.

III. RESULTS

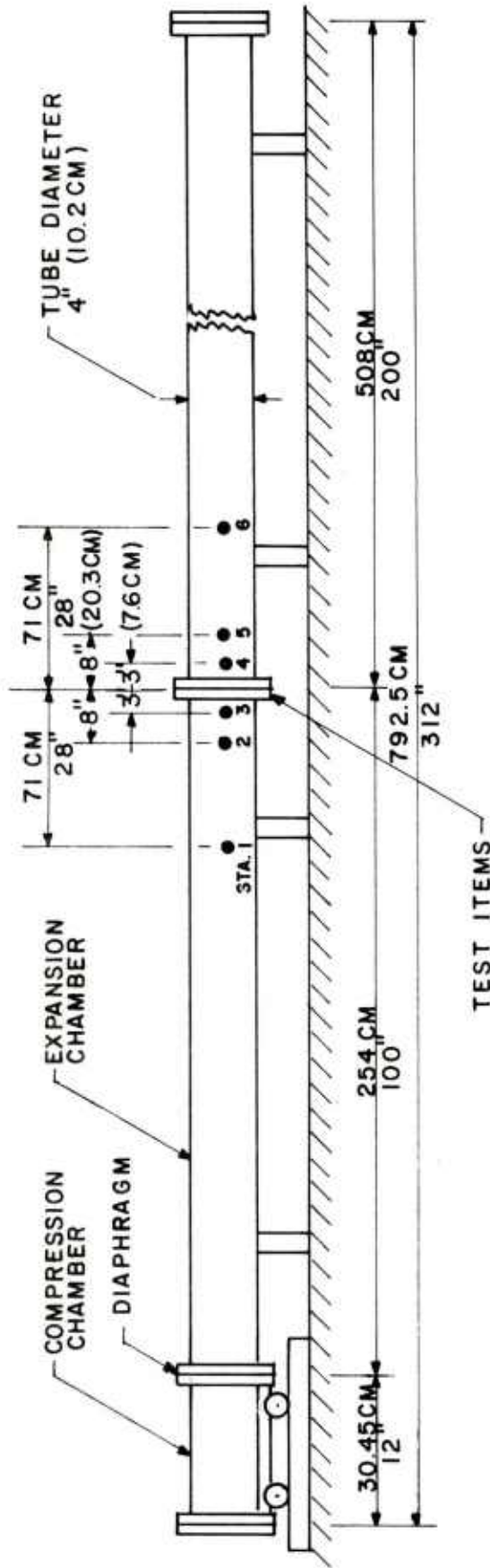
The test results are presented in three sections covering the shock tube calibration, the transmitted pressure, and the pressure transmission ratio.

A. Shock Tube Calibration

The shock tube was calibrated by measuring the attenuation of the shock waves with distance along the shock tube when no plates were installed; i.e., when $A_v = 100$ percent open.

This was done by measuring a series of shock over-pressure levels between gage Station 3 and Station 6. The earlier work, as noted in

*All pressures discussed in this report are overpressures, not absolute values.



● - GAGE PORTS
1/2 - 20 NF

Figure 1. Shock Tube Test Setup

Table I. Test Plates

| Plate No. | No. of Holes | Hole Diameter | | Hole Area | | A_V Area Vented Percent |
|-----------|--------------|---------------|---------|---------------------|--------------------|---------------------------------|
| | | inches | (cm) | inches ² | (cm ²) | |
| 1 | 3 | 0.50 | (1.27) | 0.196 | (1.267) | 4.69 |
| 2 | 52 | 0.125 | (0.32) | 0.012 | (0.080) | 5.1 |
| 3 | 5 | 0.50 | (1.27) | 0.196 | (1.267) | 7.81 |
| 4 | 6 | 0.50 | (1.27) | 0.196 | (1.267) | 9.37 |
| 5 | 105 | 0.125 | (0.32) | 0.012 | (0.080) | 10.2 |
| 6 | 16 | 0.50 | (1.27) | 0.196 | (1.267) | 25.0 |
| 7 | 256 | 0.125 | (0.32) | 0.012 | (0.080) | 25.0 |
| 8 | 68 | 0.25 | (0.64) | 0.049 | (0.322) | 26.6 |
| 9 | 307 | 0.125 | (0.32) | 0.012 | (0.080) | 30.0 |
| 10 | 392 | 0.125 | (0.32) | 0.012 | (0.080) | 38.2 |
| 11 | 105 | 0.25 | (0.64) | 0.049 | (0.322) | 41.0 |
| 12 | 1 | 2.81 | (7.14) | 6.202 | (40.04) | 49.4 |
| 13 | 32 | 0.50 | (1.27) | 0.196 | (1.267) | 50.0 |
| - | 1 | 4.0 | (10.2) | 12.566 | (81.073) | 100. |

$$A_V = \frac{\text{Hole Area} \times \text{Number of Holes}}{\text{Cross-Section Area of Shock Tube}} \times 100$$

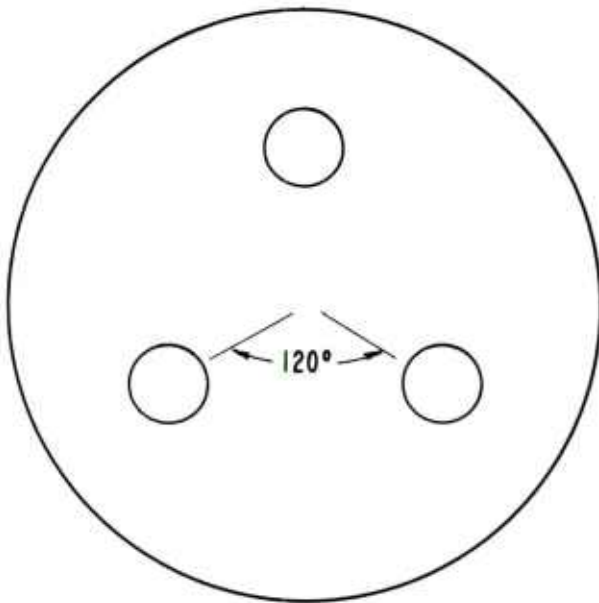


PLATE 1 - 4.69 % OPEN
3 HOLES, 1/2" DIA.

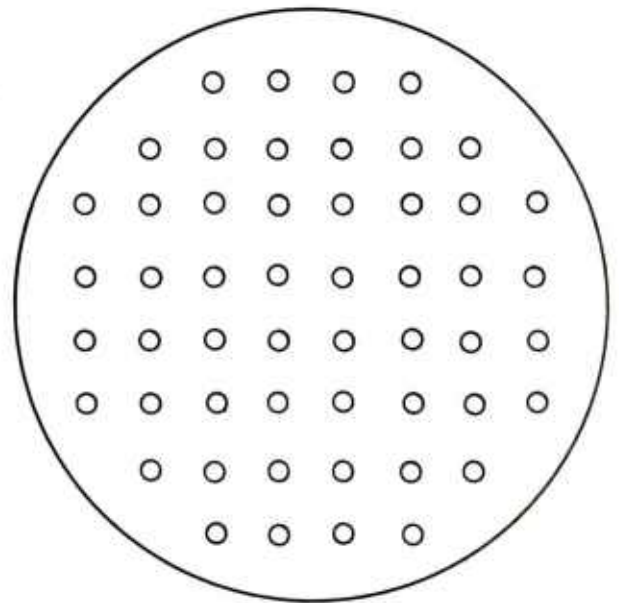


PLATE 2 - 5.1 % OPEN
52 HOLES, 1/8" DIA.

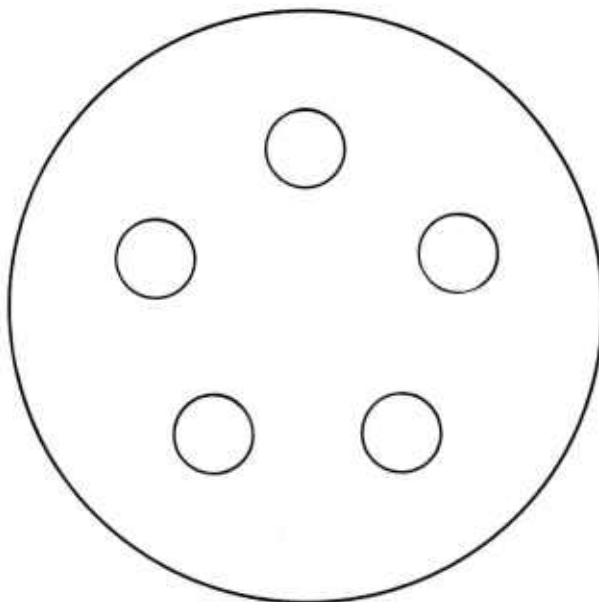


PLATE 3 - 7.81 % OPEN
5 HOLES, 1/2" DIA.

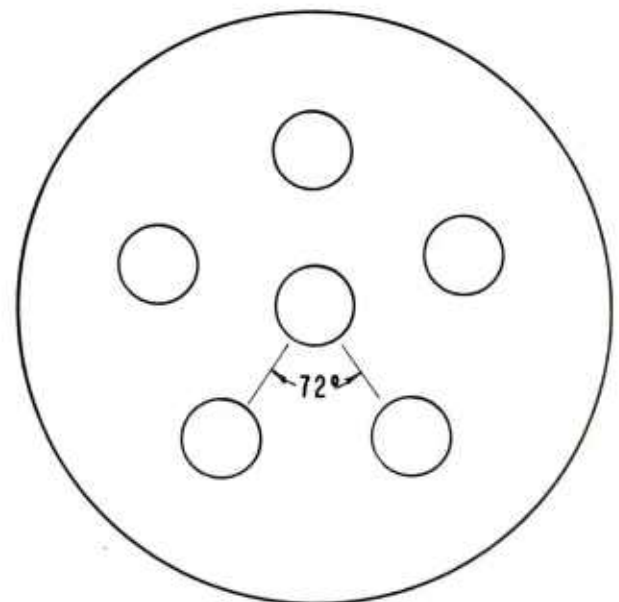


PLATE 4 - 9.37 % OPEN
6 HOLES, 1/2" DIA.

Figure 2. Arrangement of Holes in the Test Plates

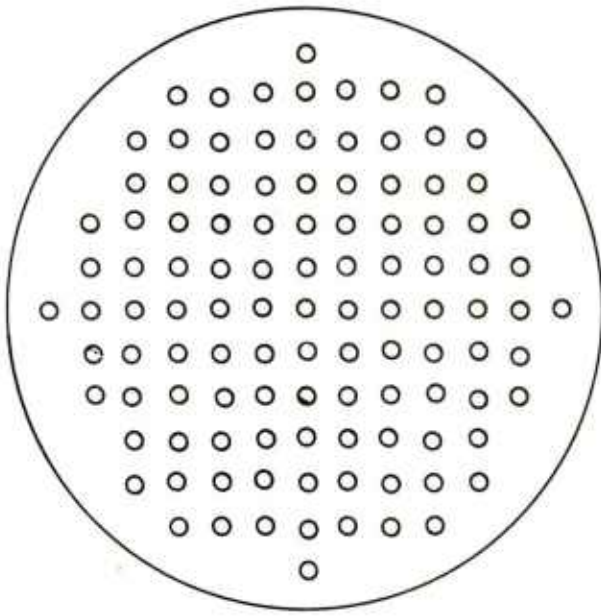


PLATE 5 - 10.2% OPEN
105 HOLES, 1/8" DIA.

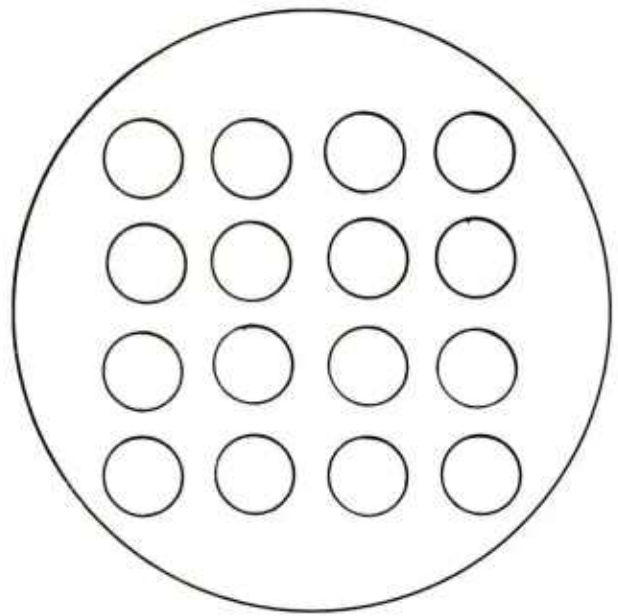


PLATE 6 - 25% OPEN
16 HOLES, 1/2" DIA.

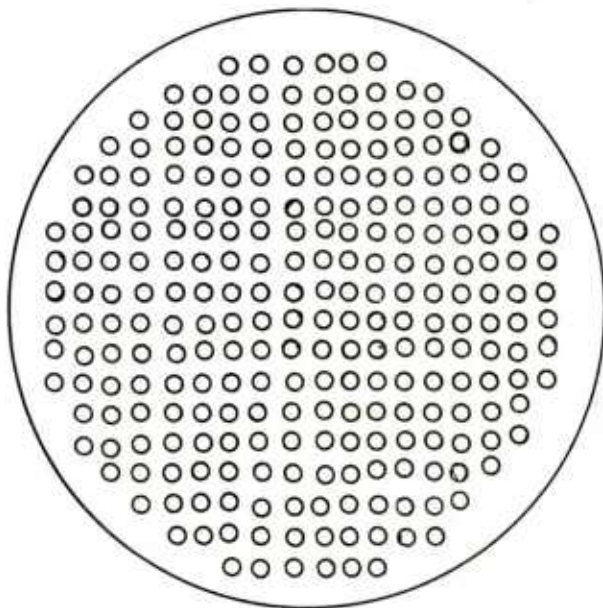


PLATE 7 - 25% OPEN
256 HOLES, 1/8" DIA.

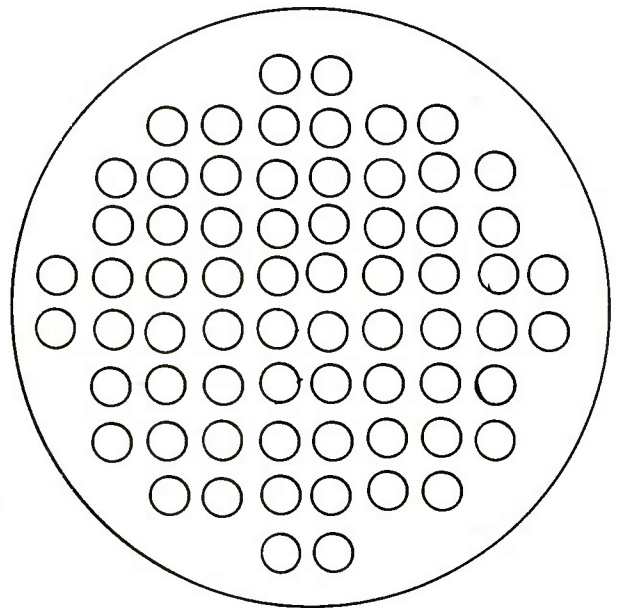


PLATE 8 - 26.6% OPEN
68 HOLES, 1/4" DIA.

Figure 2. (Cont'd) Arrangement of Holes in the Test Plates

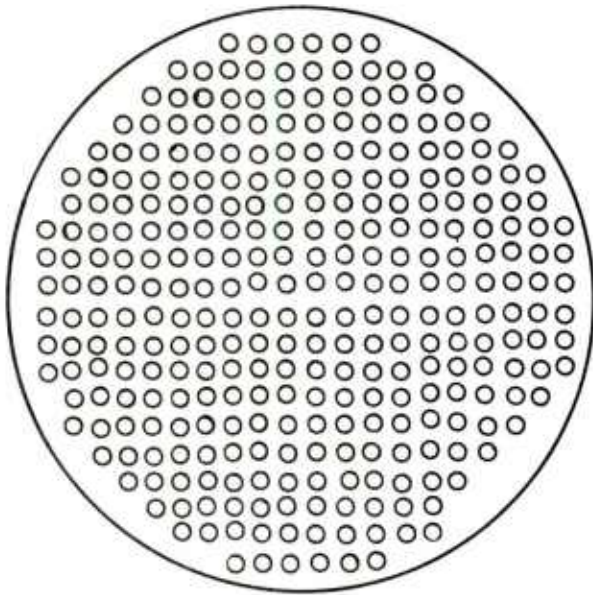


PLATE 9 - 30 % OPEN
308 HOLES, 1/8" DIA.

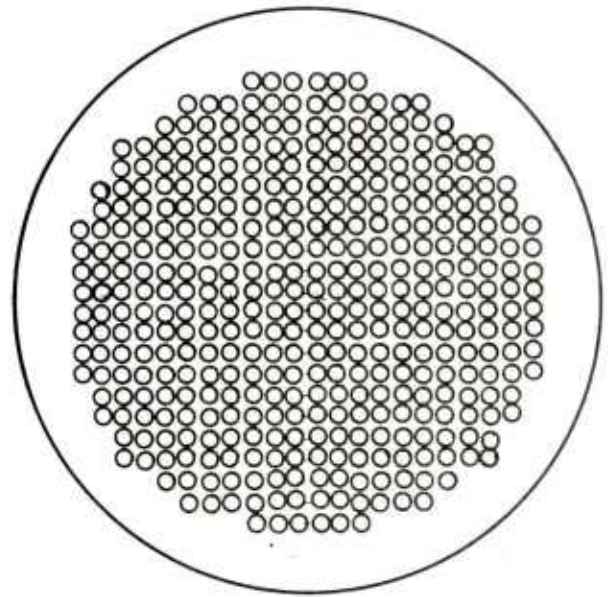


PLATE 10 - 38.2 % OPEN
392 HOLES, 1/8" DIA.

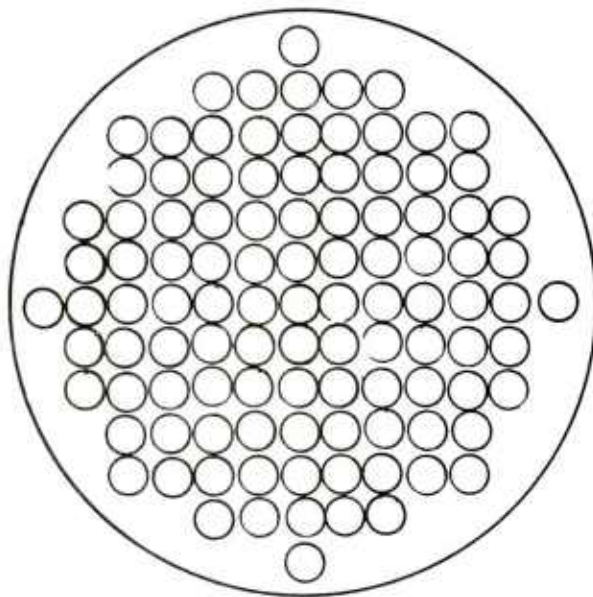


PLATE 11 - 41 % OPEN
105 HOLES, 1/4" DIA.

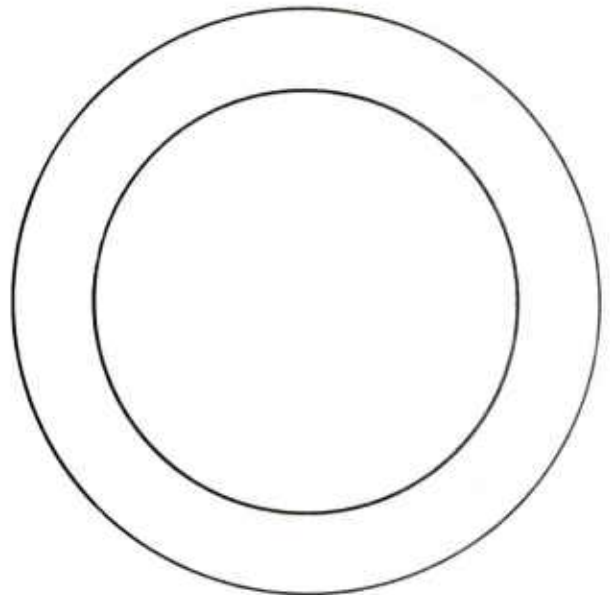


PLATE 12 - 49.4 % OPEN
1 HOLE, 2-13/16" DIA.

Figure 2. (Cont'd) Arrangement of Holes in the Test Plates

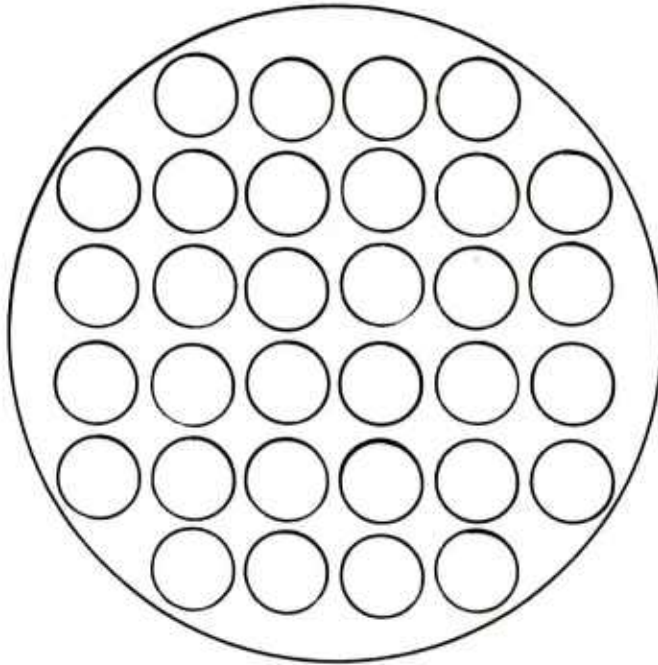


PLATE 13 - 50 % OPEN
32 HOLES, 1/2" DIA.

Figure 2. (Cont'd) Arrangement of Holes in the Test Plates

Reference 1, determined a calibration curve for the shock tube over a range of overpressure from 45 psi (310 kPa) to 218 psi (1503 kPa). This curve with data points is presented in Figure 3. The straight line fit is represented by Equation 1,

$$P_T 100 = 0.7855 P_I \quad (1)$$

when $P_T 100$ is the transmitted pressure for $A_V = 100$ percent and P_I is the input pressure.

The peak overpressure measured at Station 6 when a perforated plate is in the shock tube will be compared to the value calculated from Equation 1 for the input pressure of a given shot.

Figures 4 through 6 show typical record traces within the calibrated range of the shock tube. The upper traces are the input condition at Station 3 and the lower traces are attenuated pressures recorded at Station 6 for the unobstructed shock tube.

B. Transmitted Pressure

Section A described the pressure transmitted down the unobstructed shock tube. This section will deal with the pressure transmitted down the shock tube when plates with various vented areas are inserted in the tube. Presented in Figure 7 is a typical set of traces from the shock tube when obstructed by a perforated plate. Other representative pressure-time traces are grouped in the Appendix.

Tables II through XIV list the attenuation results of the shock wave-plate interactions. Columns 2 and 3 of the tables list the input pressure (P_I) at Station 3 and the attenuated, transmitted pressure (P_T) at Station 6, respectively. Column 5 lists the transmitted pressure for the unobstructed no-plate case ($A_V = 100\%$) as calculated from Equation 1 above.

Figure 8 shows how the transmitted pressure (P_T) varies with input pressure (P_I) for various percentages of vented plate area. The family of curves (the solid lines) for the control plates with half-inch holes may be represented by the equation:

$$P_T = C P_I \quad (2)$$

¹Charles Kingery and George Coulter, "Shock Wave Attenuation by Single Perforated Plates," BRL Memorandum Report 2664, August 1976. (AD #B013764L)

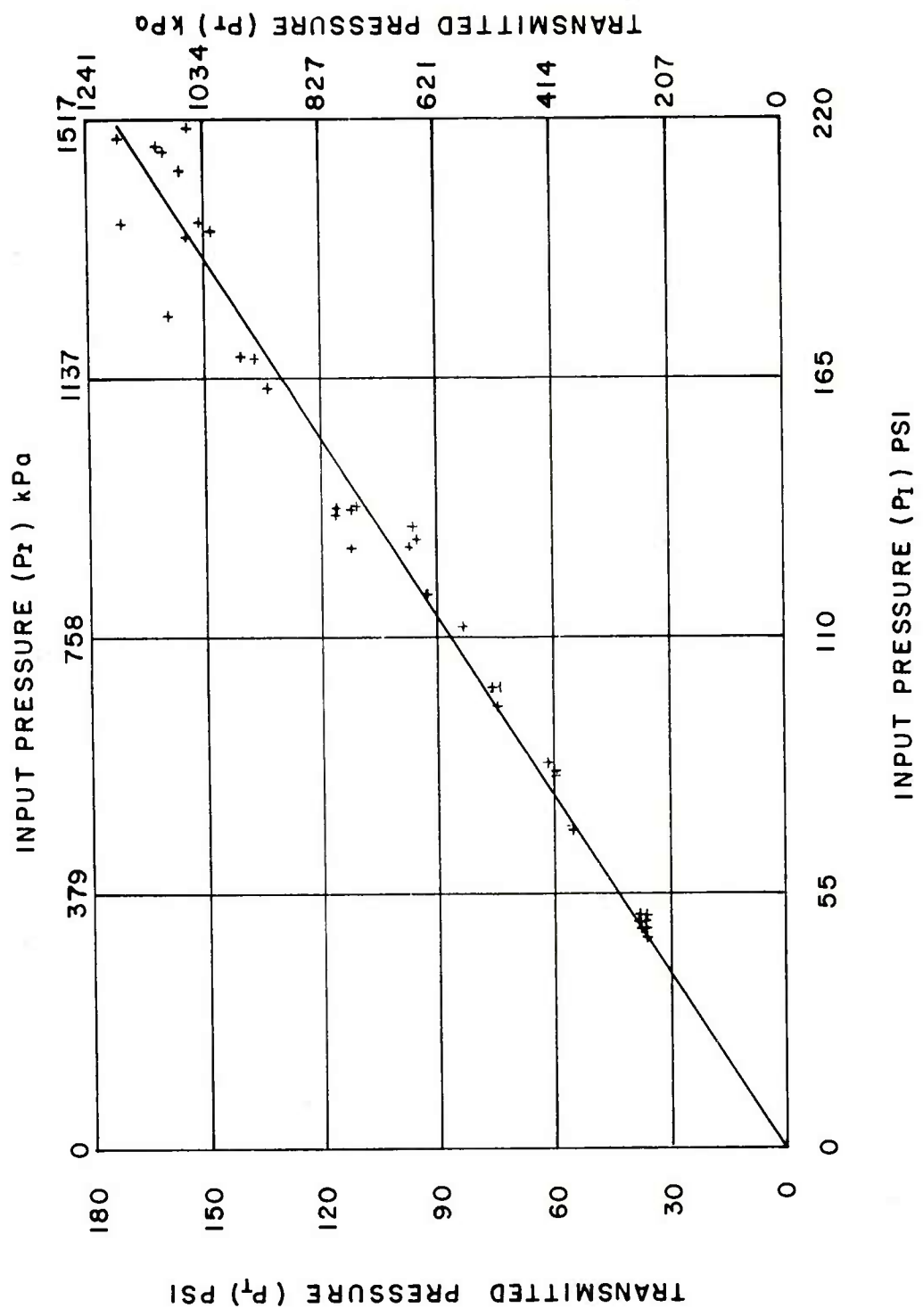
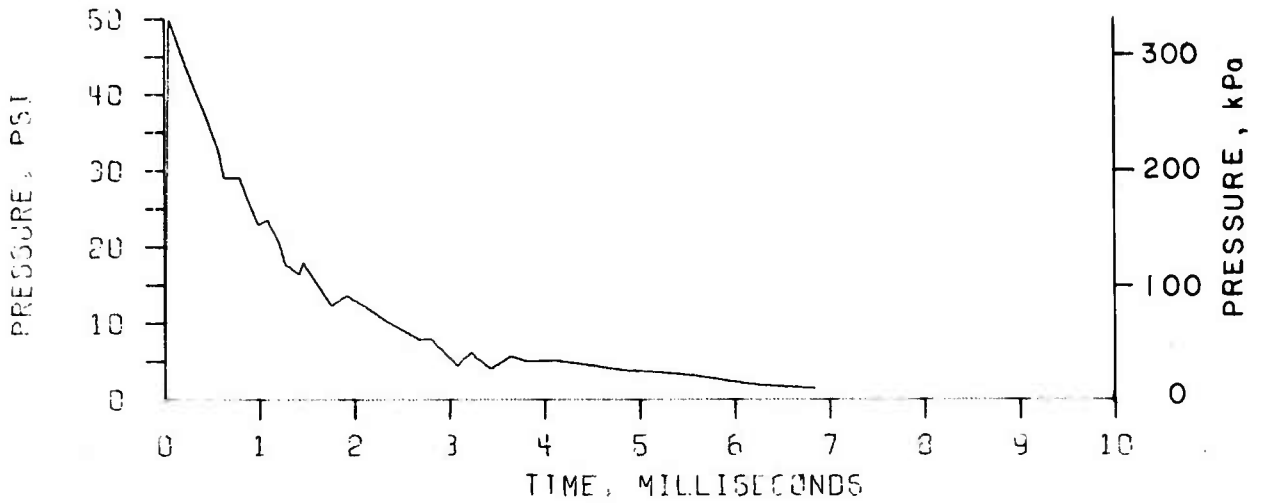


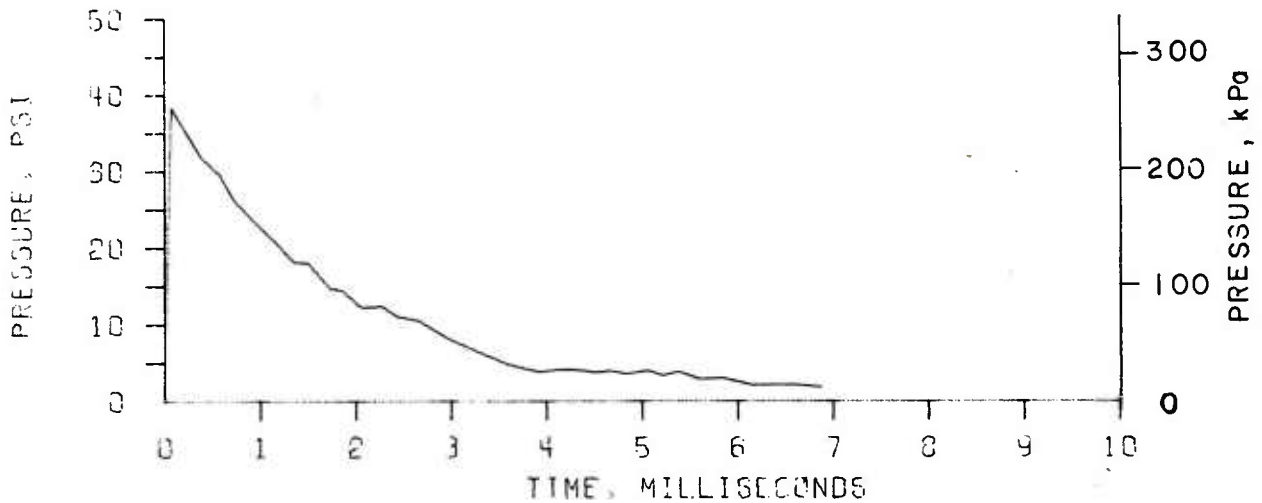
Figure 3. Input Pressure P_I versus Transmitted Pressure P_T for A_v of 100 Percent

SHOT 8 CH3
SUPPRESSIVE STRUCTURES



(A) INPUT PRESSURE

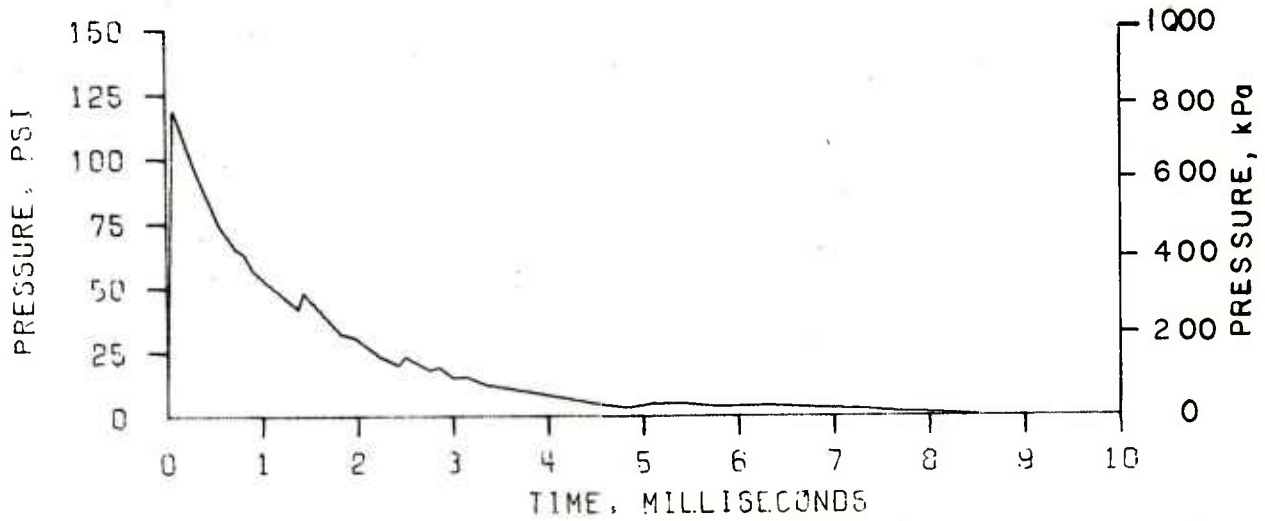
SHOT 8 CH6
SUPPRESSIVE STRUCTURES



(B) TRANSMITTED PRESSURE

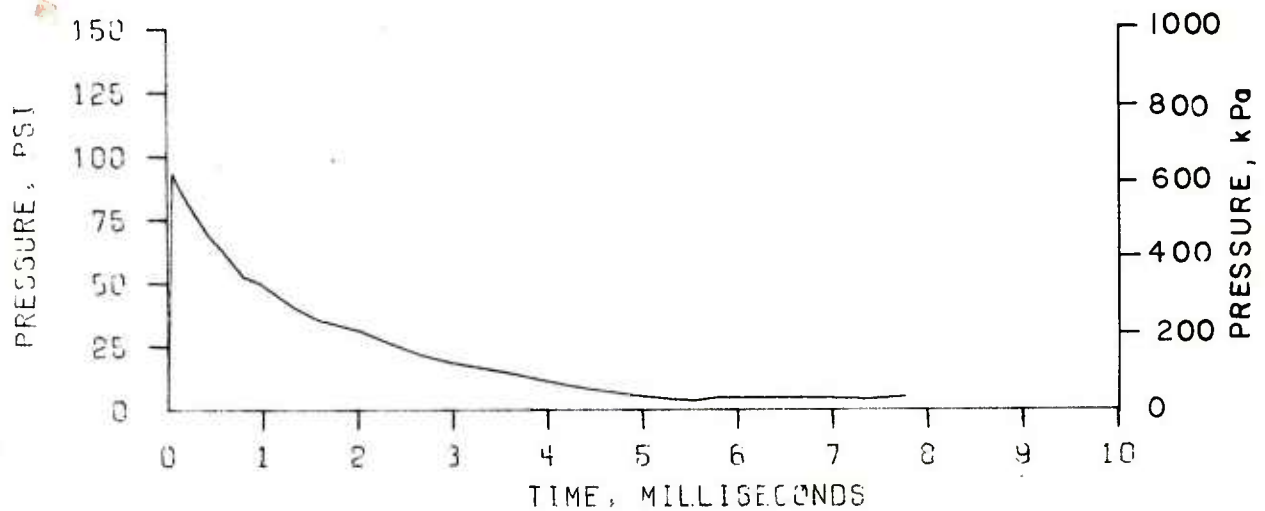
Figure 4. Pressure versus Time Recorded at Station 3 and 6 for an Input Pressure of 50 psi (345 kPa)

SHOT 9 CH3
SUPPRESSIVE STRUCTURES



(A) INPUT PRESSURE

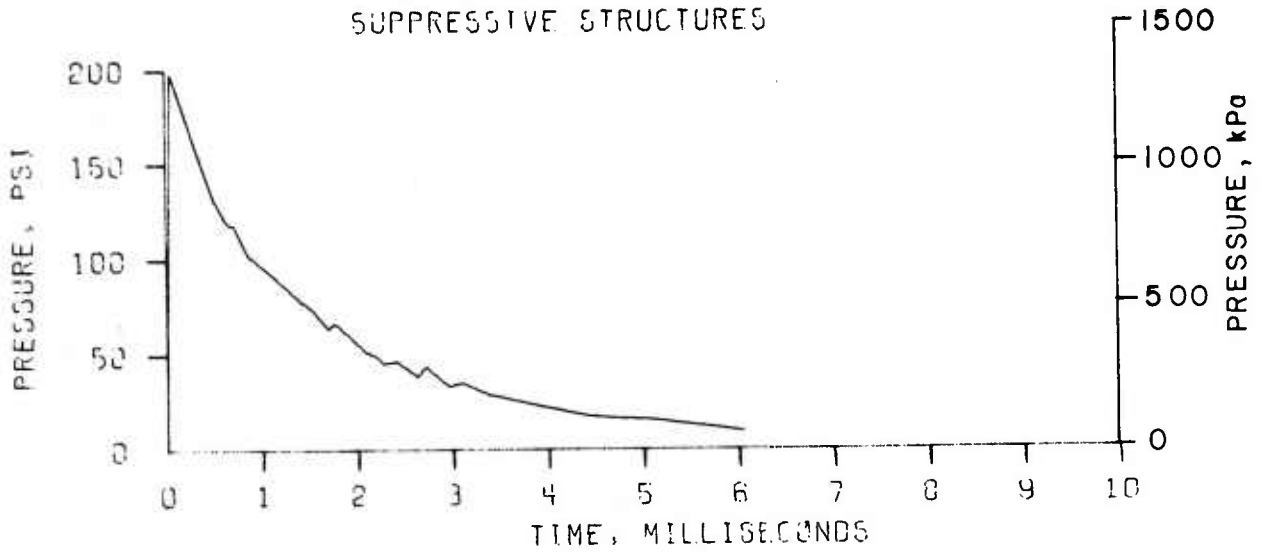
SHOT 9 CH6
SUPPRESSIVE STRUCTURES



(B) TRANSMITTED PRESSURE

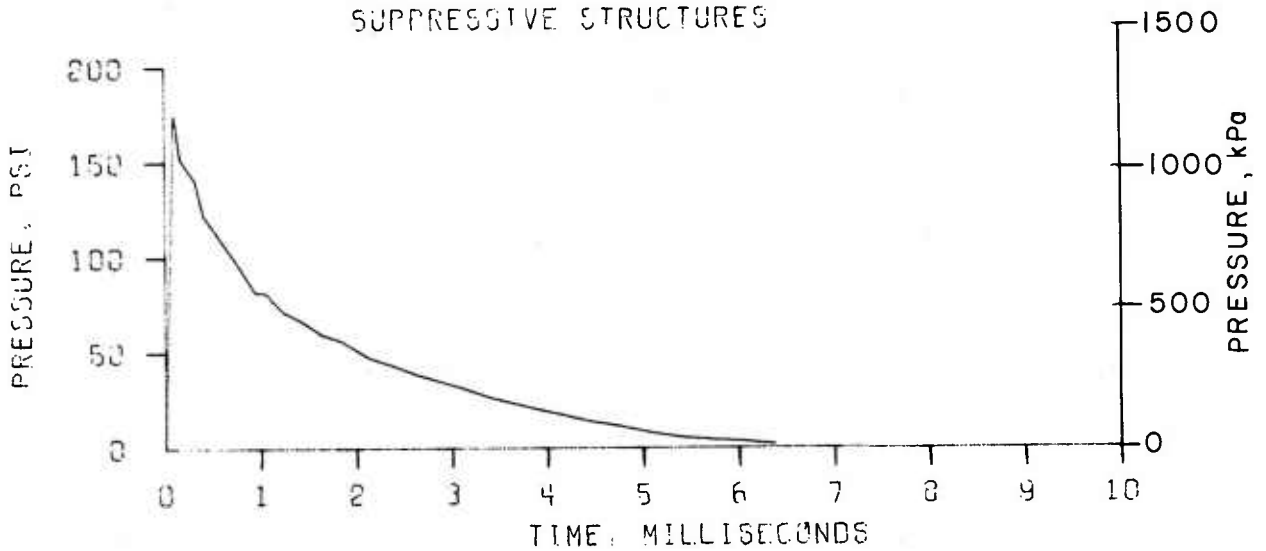
Figure 5. Pressure versus Time Recorded at Station 3 and 6 for an Input Pressure of 119 psi (820 kPa)

SHOT 10 CH3
SUPPRESSIVE STRUCTURES



(A) INPUT PRESSURE

SHOT 10 CH6
SUPPRESSIVE STRUCTURES



(B) TRANSMITTED PRESSURE

Figure 6. Pressure versus Time Recorded at Station 3 and 6 for an Input Pressure of 195 psi (1344 kPa)

SHOT 13 CH3
SUPPRESSIVE STRUCTURES

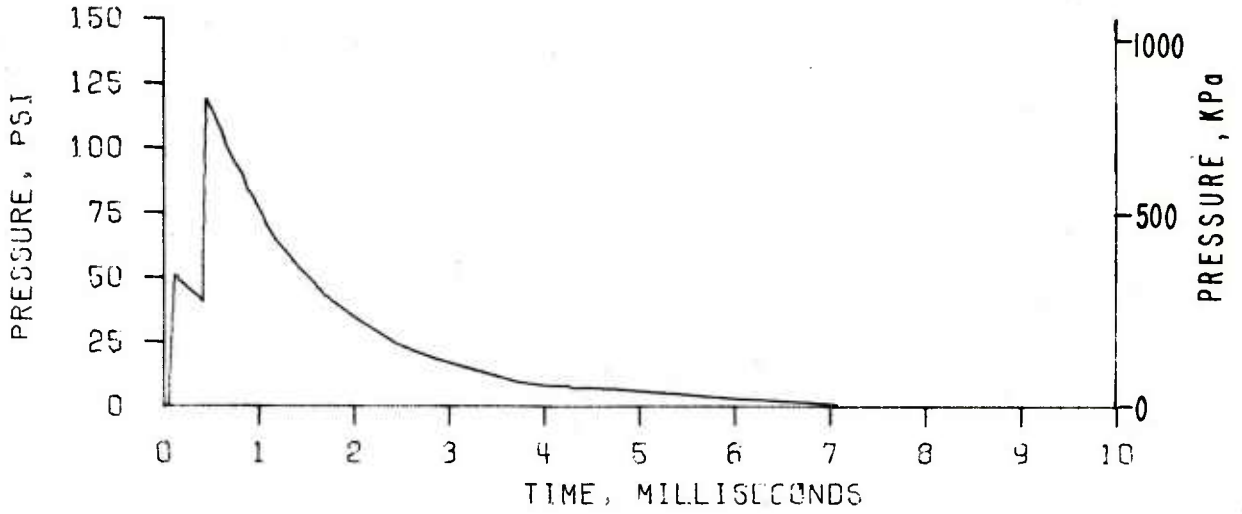


PLATE 6 - INPUT PRESSURE

SHOT 13 CH6
SUPPRESSIVE STRUCTURES

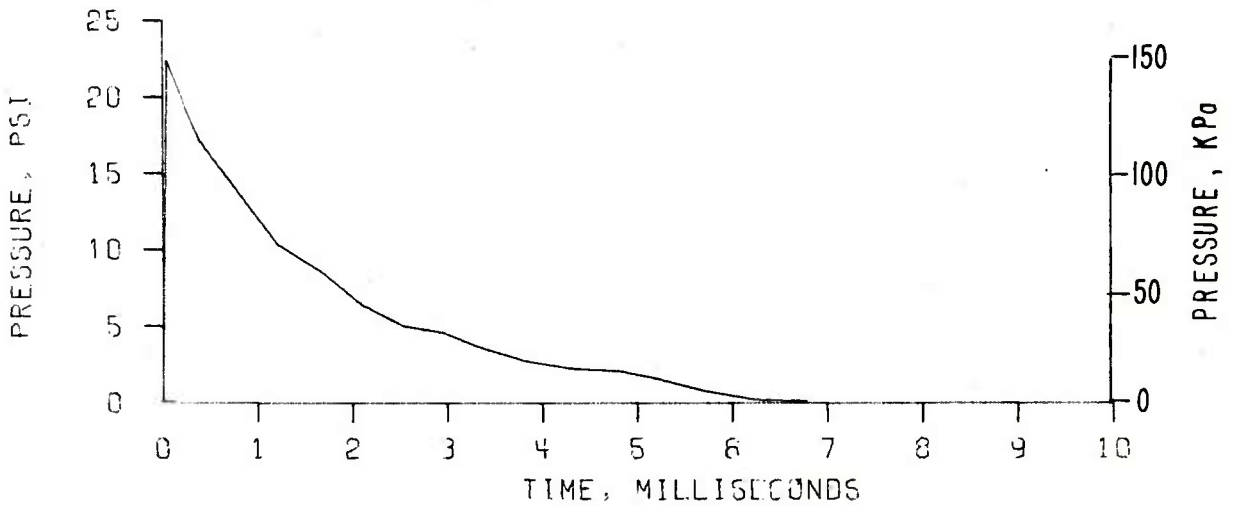


PLATE 6 - TRANSMITTED PRESSURE

Figure 7. Pressure versus Time at Stations 3 and 6 for Input Pressure of 50 PSI - 25 Percent Open

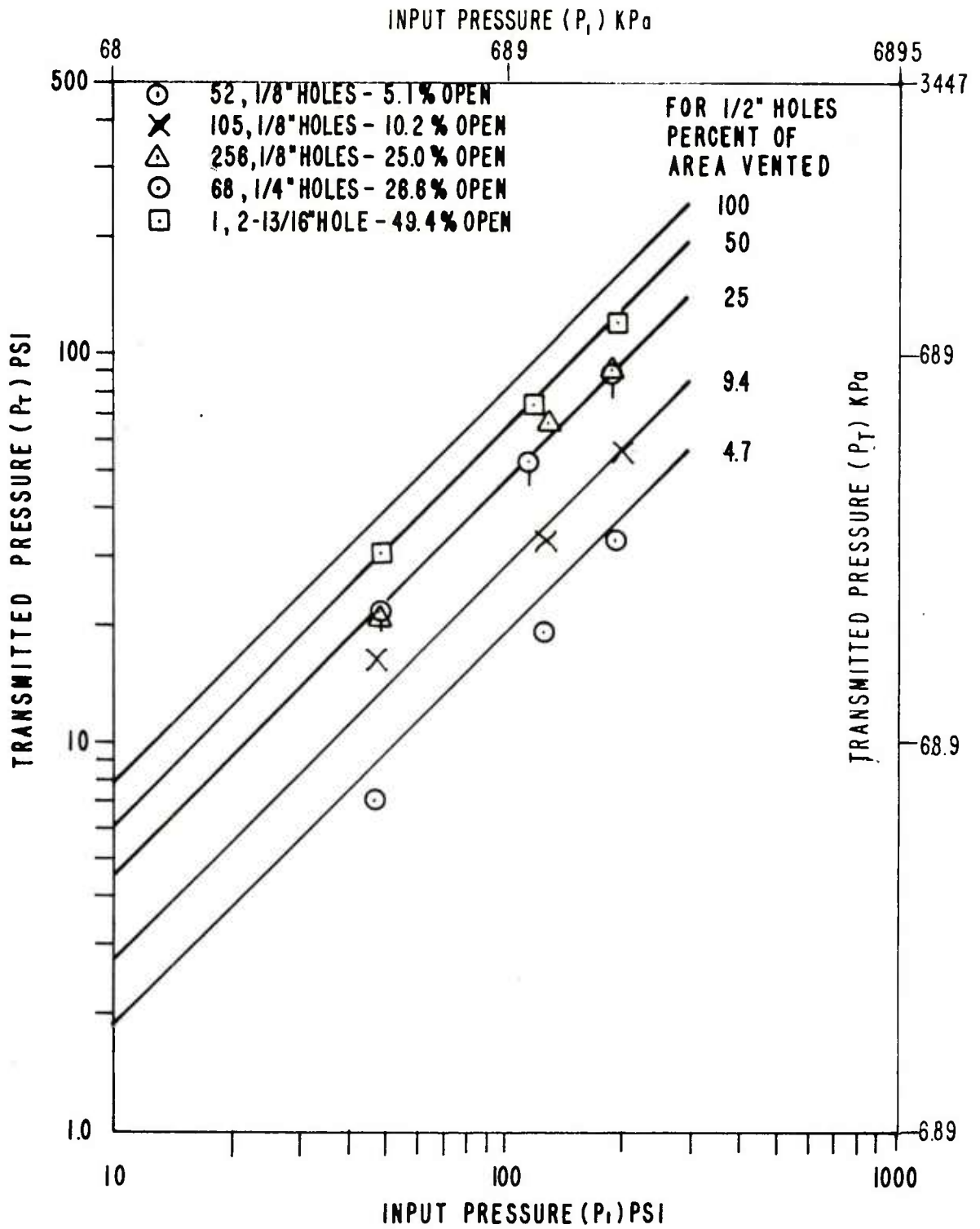


Figure 8. Transmitted Pressure versus Input Pressure for Different Percentages of Area Vented

where C is a function of the plate area vented. Values of C were calculated from a simple ratio of the data P_T for x percent opening (Column 3) divided by P_I (Column 2). The C values are listed in Column 4 of Tables II through XIV.

It can be seen from the average values of C listed in Tables II through XIV that there is no significant effect of the hole size or number of holes in a plate with the exception of Plate 2 and Plate 5 both with 1/8-inch diameter holes consisting of 52 and 105 in number.

C. Pressure Transmission Ratio

The last two columns of Tables II through XIV contain quantities that are helpful in defining the effectiveness of a perforated plate attenuator. The first quantity is defined as the transmission ratio (P_{TR}). It is defined as

$$P_{TR} = \frac{P_T \text{ with vented plate}}{P_T \text{ 100 without a plate}}, \quad (3)$$

where P_T is the transmitted pressure in each case.

A second quantity, the percentage of attenuation may be more helpful in some cases. It is equal simply to $(1 - P_{TR}) \times 100$. The average values listed of these quantities in Tables II through XIV are summarized in Table XV.

An equation of the form

$$P_{TR} = B A_V^N \quad (4)$$

was used to fit the data for the transmission ratio (P_{TR}) as a function of area vented (A_V). B and N have the values of 0.1094 and 0.5135, respectively, for plates with half-inch holes for area vented below 50 percent.

The data from the new plates listed in Table XV show little scatter from the values established from plates with the one-half inch diameter holes.

For a given A_V and P_I the value of P_T can be determined by calculating P_{TR} from Equation 4 and P_T 100 from Equation 1 and substituting in to Equation 3 to obtain

$$P_T = (0.7855 P_I) P_{TR} \quad (5)$$

It also follows that by dividing both sides of Equation 5 by P_I , one obtains from Equation 2,

$$C = 0.7855 P_{TR}, \text{ and} \quad (6)$$

if C is determined from Tables II through XIV then

$$P_{TR} = C/0.7855. \quad (7)$$

A direct comparison of the experimental values of the Pressure Transmission Ratio (P_{TR}) and the percent of pressure attenuation listed in Tables II through XIV has been made with values calculated using Equation 4. These comparisons are made in Table XV.

The values of pressure transmission ratio and pressure attenuation percent from Table XV have been plotted in Figures 9 and 10, respectively. The solid line represents the calculated values from Equation 4 which was established from the experimental values obtained from the plates with half-inch (1.27 cm) holes. The symbols indicate how well the data compare when obtained from plates with different hole sizes. The data from a A_V of 5.1 and 10.2 percent differ most from the trend established from previous tests. It should be noted in Table XV that when plates with a similar A_V are tested the values of attenuation percent are also similar.

IV. CONCLUSIONS

Based upon the experimental results obtained, a perforated plate did not change appreciably its ability to attenuate shock waves when the hole size was changed. It was only at the small values of A_V with 1/8 hole size that a deviation from the established trend was noted.

There was no trend established for pressure transmission ratio or attenuation percent as a function of input pressure (P_I) for a given A_V . The expression

$$P_T = C P_I$$

appears to be valid for range of pressures and vent areas tested.

Table II. Pressure Attenuation Plate 1,
3, 1/2-Inch Holes - 4.69 Percent Open

| Shot Number | Input Pressure (P _I) | Transmitted Pressure (P _T) A _v = 4.69% | Ratio (C) P _T 4.69/P _I | Transmitted Pressure (P _T) A _v = 100% | Ratio (P _{TR}) P _T 4.69/P _T 100 | Attenuation Percent |
|----------------|--|---|---|--|--|------------------------|
| | psi | psi | | | | |
| 18 | 197.0 | 35.8 | 0.182 | 154.5 | 0.232 | 76.8 |
| 19 | 192.0 | 38.9 | 0.203 | 150.6 | 0.258 | 74.2 |
| 20 | 120.9 | 20.4 | 0.169 | 94.8 | 0.215 | 78.5 |
| 21 | 123.3 | 23.8 | 0.193 | 96.8 | 0.246 | 75.4 |
| 22 | 127.0 | 21.7 | 0.171 | 99.6 | 0.218 | 78.2 |
| 23 | 49.3 | 9.8 | 0.199 | 38.6 | 0.254 | 74.6 |
| 24 | 49.1 | 9.3 | 0.189 | 38.5 | 0.242 | 75.8 |
| 25 | 51.2 | 9.2 | 0.180 | 40.1 | 0.229 | 77.1 |
| Average | | | | | | 76.3 |
| Average | | | | | | 0.237 |

NOTE: Psi x 6.894757 = kPa.

Table III. Pressure Attenuation, Plate 2,
52, 1/8-Inch Holes - 5.1 Percent Open

| Shot Number | Input Pressure (P_I) psi | Transmitted Pressure (P_T) $A_V = 5.1\%$ | | Ratio C $P_T 5.1/P_I$ | Transmitted Pressure (P_T) $A_V = 100\%$ | | Ratio (P_{TR}) $P_T 5.1/P_T 100$ | Attenuation Percent |
|----------------|---------------------------------------|--|-------|--------------------------|--|-------|---|------------------------|
| | | psi | psi | | psi | psi | | |
| 77 | 193.6 | 30.9 | 152.1 | 0.160 | 152.1 | 0.203 | 79.7 | |
| 78 | 199.1 | 33.5 | 156.4 | 0.168 | 156.4 | 0.214 | 78.6 | |
| 79 | 126.1 | 22.3 | 99.1 | 0.177 | 99.1 | 0.225 | 77.5 | |
| 80 | 126.1 | 16.6 | 99.1 | 0.132 | 99.1 | 0.168 | 83.2 | |
| 81 | 128.3 | 18.1 | 100.8 | 0.141 | 100.8 | 0.180 | 82.0 | |
| 82 | 46.5 | 7.2 | 36.5 | 0.155 | 36.5 | 0.197 | 80.3 | |
| 83 | 47.6 | 7.2 | 37.4 | 0.151 | 37.4 | 0.193 | 80.7 | |
| 84 | 46.5 | 6.8 | 36.5 | 0.146 | 36.5 | 0.186 | 81.4 | |
| Average | | | | 0.154 | | 0.196 | 80.4 | |

Table IV. Pressure Attenuation, Plate 3,
5, 1/2-Inch Holes - 7.81 Percent Open

| Shot Number | Input Pressure (P_I) psi | Transmitted Pressure (P_T) | Ratio C | Transmitted Pressure (P_T) | Ratio (P_{TR}) | Attenuation Percent |
|----------------|---------------------------------------|-----------------------------------|-------------------|-----------------------------------|--------------------------|------------------------|
| | | $A_V = 7.81\%$ psi | $P_T / 7.8 / P_I$ | $A_V = 100\%$ | $P_T / 7.81 / P_T / 100$ | |
| 296 | 197.6 | 47.8 | 0.242 | 155.0 | 0.308 | 69.2 |
| 297 | 196.4 | 53.3 | 0.271 | 154.1 | 0.345 | 65.4 |
| 282 | 67.9 | 17.0 | 0.250 | 53.2 | 0.319 | 68.0 |
| 283 | 70.2 | 16.1 | 0.229 | 55.0 | 0.293 | 70.7 |
| Average | | | | | | 68.3 |
| | | | | | | 0.248 |

Table V. Pressure Attenuation, Plate 4,
6, 1/2-Inch Holes - 9.37 Percent Open

| Shot Number | Input Pressure (P_I) | Transmitted Pressure (P_T) | | Ratio C $\frac{P_T}{P_I} \frac{9.3}{100}$ | Transmitted Pressure (P_T) $A_V = 100\%$ | Ratio ($\frac{P_{TR}}{P_T}$) | | Attenuation Percent |
|----------------|--------------------------------|-----------------------------------|-------|--|--|------------------------------------|-----------------------------------|------------------------|
| | psi | $A_V = 9.37\%$ | psi | | | $\frac{P_T}{P_I} \frac{9.37}{100}$ | $\frac{P_T}{P_I} \frac{100}{100}$ | |
| 14 | 210.0 | 65.0 | 164.8 | 0.309 | 164.8 | 0.394 | 0.394 | 60.5 |
| 30 | 194.8 | 57.5 | 152.8 | 0.295 | 152.8 | 0.376 | 0.376 | 62.4 |
| 31 | 191.0 | 54.0 | 149.9 | 0.283 | 149.9 | 0.360 | 0.360 | 64.0 |
| 15 | 121.0 | 30.2 | 94.9 | 0.250 | 94.9 | 0.318 | 0.318 | 68.1 |
| 28 | 120.9 | 31.1 | 94.9 | 0.257 | 94.9 | 0.328 | 0.328 | 67.2 |
| 29 | 124.5 | 31.2 | 97.9 | 0.251 | 97.9 | 0.319 | 0.319 | 68.1 |
| 16 | 50.5 | 13.5 | 39.6 | 0.267 | 39.6 | 0.341 | 0.341 | 65.9 |
| 26 | 49.3 | 13.6 | 38.6 | 0.276 | 38.6 | 0.352 | 0.352 | 64.8 |
| 27 | 48.8 | 14.2 | 38.2 | 0.291 | 38.2 | 0.372 | 0.372 | 62.8 |
| Average | | | | 0.276 | | 0.351 | 0.351 | 64.9 |

Table VI. Pressure Attenuation, Plate 5,
105, 1/8-Inch Holes - 10.2 Percent Open

| Shot Number | Input Pressure (P_I) psi | Transmitted Pressure (P_T) $A_V = 10.2\%$ | | Ratio (C) $\frac{P_T}{P_I} 10.2/P_I$ | Transmitted Pressure (P_T) $A_V = 100\%$ | | Ratio (P_{TR}) $\frac{P_T}{P_I} 10.2/P_T 100$ | Attenuation Percent |
|----------------|---------------------------------------|---|--|---|--|--|--|------------------------|
| | | psi | | | | | | |
| 75 | 216.8 | 53.2 | | 0.245 | 170.3 | | 0.312 | 68.8 |
| 76 | 185.1 | 52.4 | | 0.283 | 145.4 | | 0.360 | 64.0 |
| 72 | 128.9 | 30.9 | | 0.240 | 101.2 | | 0.305 | 69.5 |
| 73 | 129.4 | 33.0 | | 0.255 | 101.6 | | 0.325 | 67.5 |
| 74 | 122.8 | 31.9 | | 0.260 | 96.5 | | 0.331 | 66.9 |
| 71 | 47.2 | 13.4 | | 0.284 | 37.1 | | 0.361 | 63.9 |
| Average | | | | 0.261 | | | 0.332 | 66.8 |

Table VII. Pressure Attenuation, Plate 6,
16, 1/2-Inch Holes - 25 Percent Open

| Shot Number | Input Pressure (P _I) psi | Pressure (P _T) | | Ratio (C) P _T 25/P _I | Transmitted Pressure (P _T) A _V = 100% | | Ratio (P _{TR}) P _T 25/P _T 100 | Attenuation Percent |
|----------------|---|----------------------------|-----|---|--|-----|--|------------------------|
| | | A _V = 25% | psi | | A _V = 100% | psi | | |
| 11 | 205.0 | 99.0 | psi | 0.483 | 160.9 | psi | 0.615 | 38.5 |
| 32 | 195.0 | 94.5 | psi | 0.486 | 153.0 | psi | 0.617 | 38.2 |
| 33 | 191.0 | 93.3 | psi | 0.488 | 149.9 | psi | 0.622 | 37.8 |
| 12 | 121.0 | 53.8 | psi | 0.445 | 94.9 | psi | 0.567 | 43.3 |
| 34 | 123.8 | 56.0 | psi | 0.452 | 97.1 | psi | 0.576 | 42.3 |
| 35 | 118.6 | 55.3 | psi | 0.466 | 93.1 | psi | 0.594 | 40.6 |
| 13 | 51.2 | 22.4 | psi | 0.438 | 40.1 | psi | 0.559 | 44.1 |
| 36 | 49.8 | 22.6 | psi | 0.454 | 38.3 | psi | 0.590 | 41.0 |
| 37 | 49.3 | 21.7 | psi | 0.440 | 38.6 | psi | 0.562 | 43.8 |
| Average | | | | 0.461 | | | 0.589 | 41.1 |

Table VIII. Pressure Attenuation, Plate 7,
256, 1/8-Inch Holes - 25 Percent Open

| Shot Number | Input Pressure (P_I) psi | Pressure (P_T) | | Ratio (C) P_T 25/ P_I | Transmitted Pressure (P_T) $A_V = 100\%$ | | Ratio (P_{TR}) P_T 25/ P_T 100 | Attenuation Percent |
|----------------|---------------------------------------|--------------------|-----|------------------------------|--|--|---|------------------------|
| | | $A_V = 25\%$ | psi | | $A_V = 100\%$ | | | |
| 158 | 187.7 | 88.9 | | 0.474 | 147.4 | | 0.603 | 39.7 |
| 162 | 194.5 | 91.1 | | 0.468 | 152.8 | | 0.596 | 40.4 |
| 160 | 132.7 | 65.5 | | 0.494 | 104.2 | | 0.628 | 37.2 |
| 161 | 128.2 | 64.4 | | 0.502 | 100.7 | | 0.640 | 36.0 |
| 163 | 48.3 | 20.0 | | 0.414 | 37.9 | | 0.527 | 47.3 |
| 164 | 48.3 | 20.0 | | 0.414 | 37.0 | | 0.527 | 47.3 |
| | | Average | | 0.459 | | | 0.587 | 41.3 |

Table IX. Pressure Attenuation, Plate 8,
68, 1/4-Inch Holes - 26.6 Percent Open

| Shot Number | Input Pressure (P _I) psi | Transmitted Pressure (P _T) | | Ratio (C) P _T 26.6/P _I | Transmitted Pressure (P _T) A _V = 100% | | Ratio (P _{TR}) P _T 26.6/P _T 100 | Attenuation Percent |
|----------------|---|---|-----|---|--|--|--|------------------------|
| | | A _V = 26.6% | psi | | A _V = 100% | P _T 26.6/P _T 100 | | |
| 61 | 195.2 | 89.4 | | 0.458 | 153.3 | | 0.583 | 41.7 |
| 62 | 197.5 | 92.7 | | 0.469 | 155.1 | | 0.597 | 40.2 |
| 63 | 116.2 | 55.3 | | 0.476 | 91.1 | | 0.607 | 39.3 |
| 64 | 118.4 | 53.2 | | 0.449 | 93.0 | | 0.572 | 42.8 |
| 65 | 118.4 | 51.1 | | 0.432 | 93.0 | | 0.549 | 45.0 |
| 66 | 47.2 | 20.8 | | 0.441 | 37.1 | | 0.561 | 43.9 |
| 67 | 48.2 | 21.9 | | 0.454 | 37.9 | | 0.578 | 42.1 |
| 68 | 48.8 | 23.4 | | 0.479 | 38.3 | | 0.610 | 38.9 |
| Average | | | | 0.457 | | | 0.582 | 41.8 |

Table X. Pressure Attenuation, Plate 9,
308, 1/8-Inch Holes - 30 Percent Open

| Shot Number | Input Pressure (P_I) psi | Pressure (P_T) | | Ratio (C) $\frac{P_T}{P_I} \text{ 30/P I}$ | Transmitted Pressure (P_T) $A_v = 100\%$ | | Ratio (P_{TR}) $\frac{P_T}{P_T} \text{ 30/P}_T \text{ 100}$ | Attenuation Percent |
|----------------|---------------------------------------|--------------------|-----|---|--|--|--|------------------------|
| | | $A_v = 30\%$ | psi | | $A_v = 100\%$ | | | |
| 156 | 188.8 | 101.1 | | 0.535 | 148.3 | | 0.682 | 31.8 |
| 157 | 187.7 | 102.2 | | 0.544 | 147.4 | | 0.693 | 30.7 |
| 153 | 130.9 | 68.1 | | 0.520 | 102.8 | | 0.662 | 33.8 |
| 154 | 135.0 | 71.1 | | 0.527 | 106.0 | | 0.670 | 33.0 |
| 155 | 130.4 | 67.8 | | 0.520 | 102.4 | | 0.662 | 33.8 |
| 150 | 49.2 | 22.6 | | 0.459 | 38.6 | | 0.585 | 41.5 |
| 151 | 51.2 | 23.1 | | 0.449 | 40.5 | | 0.571 | 42.9 |
| 152 | 51.0 | 22.6 | | 0.443 | 40.0 | | 0.564 | 43.6 |
| Average | | | | 0.500 | | | 0.636 | 36.4 |

Table XI. Pressure Attenuation, Plate 10
392, 1/8-Inch Holes - 38.2 Percent Open

| Shot Number | Input Pressure (P_I) psi | Pressure (P_T) $A_V = 38.2\%$ psi | Ratio (C) $P_T 38.2/P_I$ | Transmitted | | Attenuation Percent |
|----------------|---------------------------------------|---|-----------------------------|-------------------------------------|--|------------------------|
| | | | | Pressure (P_T) $A_V = 100\%$ | Ratio (P_{TR}) $P_T 38.2/P_T 100$ | |
| 165 | 206.0 | 111.1 | 0.539 | 161.8 | 0.687 | 31.3 |
| 166 | 200.2 | 108.9 | 0.544 | 157.2 | 0.693 | 30.8 |
| 167 | 132.7 | 80.0 | 0.603 | 104.2 | 0.767 | 23.2 |
| 168 | 135.0 | 76.7 | 0.568 | 106.0 | 0.723 | 27.6 |
| 169 | 51.3 | 28.9 | 0.563 | 40.3 | 0.717 | 28.3 |
| 170 | 50.6 | 28.3 | 0.559 | 39.7 | 0.712 | 28.8 |
| Average | | | 0.563 | | 0.716 | 28.3 |

Table XII. Pressure Attenuation, Plate 11,
105, 1/4-Inch Holes - 41.0 Percent Open

| Shot Number | Input Pressure (P_I) psi | Pressure (P_T) $A_V = 41\%$ psi | Ratio (C) $P_T 41/P_I$ | Transmitted Pressure (P_T) $A_V = 100\%$ | Ratio (P_{TR}) $P_T 41/P_T 100$ | Attenuation Percent |
|----------------|---------------------------------------|---|---------------------------|--|--|------------------------|
| | | | | | | |
| 58 | 201.5 | 110.6 | 0.549 | 158.3 | 0.699 | 30.1 |
| 59 | 193.0 | 105.5 | 0.547 | 151.6 | 0.696 | 30.4 |
| 60 | 197.4 | 110.6 | 0.560 | 155.1 | 0.713 | 28.7 |
| 55 | 120.6 | 67.0 | 0.556 | 94.7 | 0.707 | 29.3 |
| 56 | 118.4 | 66.0 | 0.557 | 93.0 | 0.710 | 29.0 |
| 67 | 122.8 | 64.9 | 0.529 | 96.5 | 0.673 | 32.7 |
| 52 | 49.3 | 28.7 | 0.582 | 38.7 | 0.741 | 25.9 |
| 53 | 48.8 | 28.2 | 0.578 | 38.3 | 0.736 | 26.4 |
| 54 | 47.7 | 28.7 | 0.602 | 37.5 | 0.766 | 23.4 |
| Average | | | | | | 28.4 |
| | | | | | | 0.716 |

Table XIII. Pressure Attenuation, Plate 12,
1, 2-13/16-Inch Hole - 49.4 Percent Open

| Shot Number | Input Pressure (P_I) psi | Pressure (P_T) $A_V = 49.4\%$ psi | | Ratio (C) $P_T 49.4/P_I$ | | Transmitted Pressure (P_T) $A_V = 100\%$ | | Ratio (P_{TR}) $P_T 49.4/P_T 100$ | | Attenuation Percent |
|----------------|---------------------------------------|---|-------|-----------------------------|-------|--|-------|--|-------|------------------------|
| | | | | | | | | | | |
| 43 | 188.6 | 116.1 | 116.1 | 0.616 | 0.616 | 148.1 | 148.1 | 0.784 | 0.784 | 21.6 |
| 44 | 195.4 | 122.6 | 122.6 | 0.627 | 0.627 | 153.5 | 153.5 | 0.799 | 0.799 | 20.1 |
| 45 | 193.4 | 122.0 | 122.0 | 0.631 | 0.631 | 151.9 | 151.9 | 0.803 | 0.803 | 19.7 |
| 46 | 115.9 | 71.0 | 71.0 | 0.613 | 0.613 | 91.0 | 91.0 | 0.780 | 0.780 | 22.0 |
| 47 | 117.1 | 71.0 | 71.0 | 0.606 | 0.606 | 92.0 | 92.0 | 0.772 | 0.772 | 22.8 |
| 48 | 117.0 | 73.1 | 73.1 | 0.625 | 0.625 | 91.9 | 91.9 | 0.795 | 0.795 | 20.5 |
| 49 | 46.9 | 29.8 | 29.8 | 0.635 | 0.635 | 36.8 | 36.8 | 0.809 | 0.809 | 19.1 |
| 50 | 48.2 | 30.9 | 30.9 | 0.641 | 0.641 | 37.9 | 37.9 | 0.816 | 0.816 | 18.4 |
| 51 | 48.2 | 30.3 | 30.3 | 0.629 | 0.629 | 37.9 | 37.9 | 0.800 | 0.800 | 20.0 |
| Average | | | | 0.625 | 0.625 | | | 0.795 | 0.795 | 20.5 |

Table XIV. Pressure Attenuation, Plate 13,
32, 1/2-Inch Holes - 50 Percent Open

| Shot Number | Input Pressure (P_I) psi | Pressure (P_T) $A_V = 50\%$ psi | Ratio (C) $P_T 50/P_I$ | Transmitted Pressure (P_T) $A_V = 100\%$ | Ratio (P_{TR}) $P_T 50/P_T 100$ | Attenuation Percent |
|----------------|---------------------------------------|---|---------------------------|--|--|------------------------|
| 4 | 198.0 | 114.0 | 0.575 | 155.3 | 0.734 | 26.6 |
| 5 | 200.0 | 127.0 | 0.635 | 156.9 | 0.809 | 19.1 |
| 42 | 195.5 | 116.1 | 0.594 | 153.4 | 0.757 | 24.3 |
| 6 | 121.0 | 74.2 | 0.613 | 94.9 | 0.782 | 21.8 |
| 40 | 113.6 | 77.4 | 0.681 | 89.1 | 0.869 | 13.1 |
| 41 | 117.0 | 76.3 | 0.652 | 91.8 | 0.831 | 16.9 |
| 7 | 49.2 | 30.0 | 0.610 | 38.6 | 0.778 | 22.2 |
| 38 | 50.0 | 31.2 | 0.624 | 39.2 | 0.796 | 20.4 |
| 39 | 50.0 | 31.2 | 0.624 | 31.2 | 0.796 | 20.4 |
| Average | | | | | | 20.5 |

Table XV. Pressure Attenuation versus Area Vented

| Plate Number | Number of Holes | Area Vented | A_V | | P_{TR} | | Attenuation Percent | |
|--------------|-----------------|-------------|---------|-------------|--------------|------------|---------------------|------------|
| | | | Percent | Area Vented | Experimental | Calculated | Experimental | Calculated |
| 1 | 3* | 4.69 | | | 0.237 | 0.242 | 73.6 | 75.8 |
| 2 | 52*** | 5.10 | | | 0.196 | 0.253 | 80.4 | 74.7 |
| 3 | 5* | 7.81 | | | 0.317 | 0.314 | 68.3 | 68.6 |
| 4 | 6* | 9.37 | | | 0.351 | 0.345 | 64.9 | 65.5 |
| 5 | 105*** | 10.2 | | | 0.332 | 0.360 | 66.8 | 64.0 |
| 6 | 16* | 25.0 | | | 0.589 | 0.571 | 41.1 | 42.9 |
| 7 | 256*** | 25.0 | | | 0.587 | 0.571 | 41.3 | 42.9 |
| 8 | 68** | 26.6 | | | 0.582 | 0.590 | 41.8 | 41.0 |
| 9 | 308*** | 30.0 | | | 0.636 | 0.627 | 36.4 | 37.3 |
| 10 | 392*** | 38.2 | | | 0.716 | 0.710 | 28.3 | 29.0 |
| 11 | 105** | 41.0 | | | 0.716 | 0.737 | 28.4 | 26.3 |
| 12 | 1 | 49.4 | | | 0.795 | 0.810 | 20.5 | 19.0 |
| 13 | 32* | 50.0 | | | 0.795 | 0.815 | 20.5 | 18.5 |

*Hole Diameter 0.50 in. (1.27 cm).

**Hole Diameter 0.25 in. (0.64 cm).

***Hole Diameter 0.125 in. (0.32 cm).

$$\text{Pressure Transmission Ratio } (P_{TR}) = 0.1094 A_V^{0.5135}$$

$$A_V < 55$$

$$\text{Pressure Attenuation Percent} = (1 - P_{TR}) \times 100$$

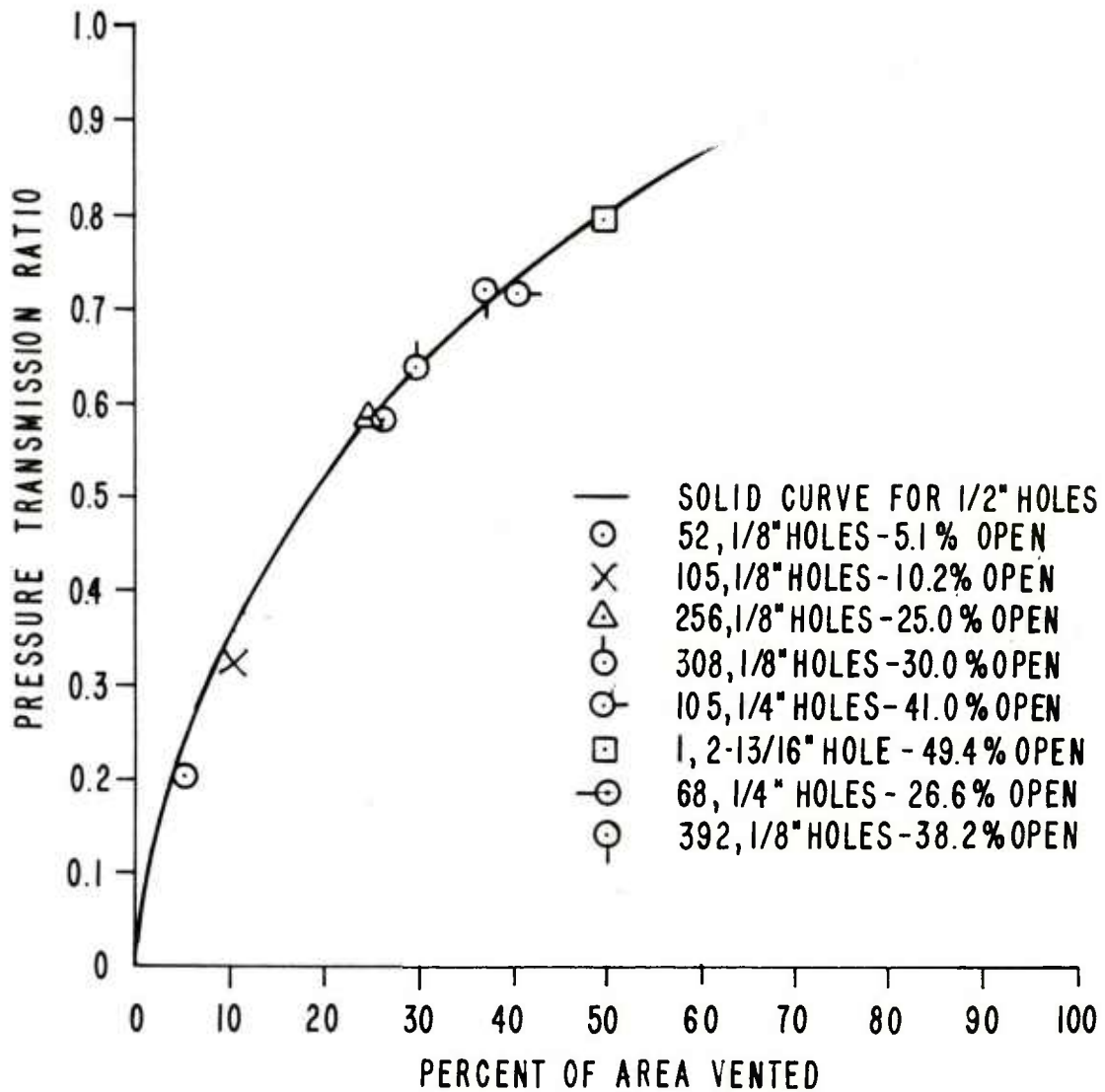


Figure 9. Pressure Transmission Ratio as a Function of Percent of Area Vented

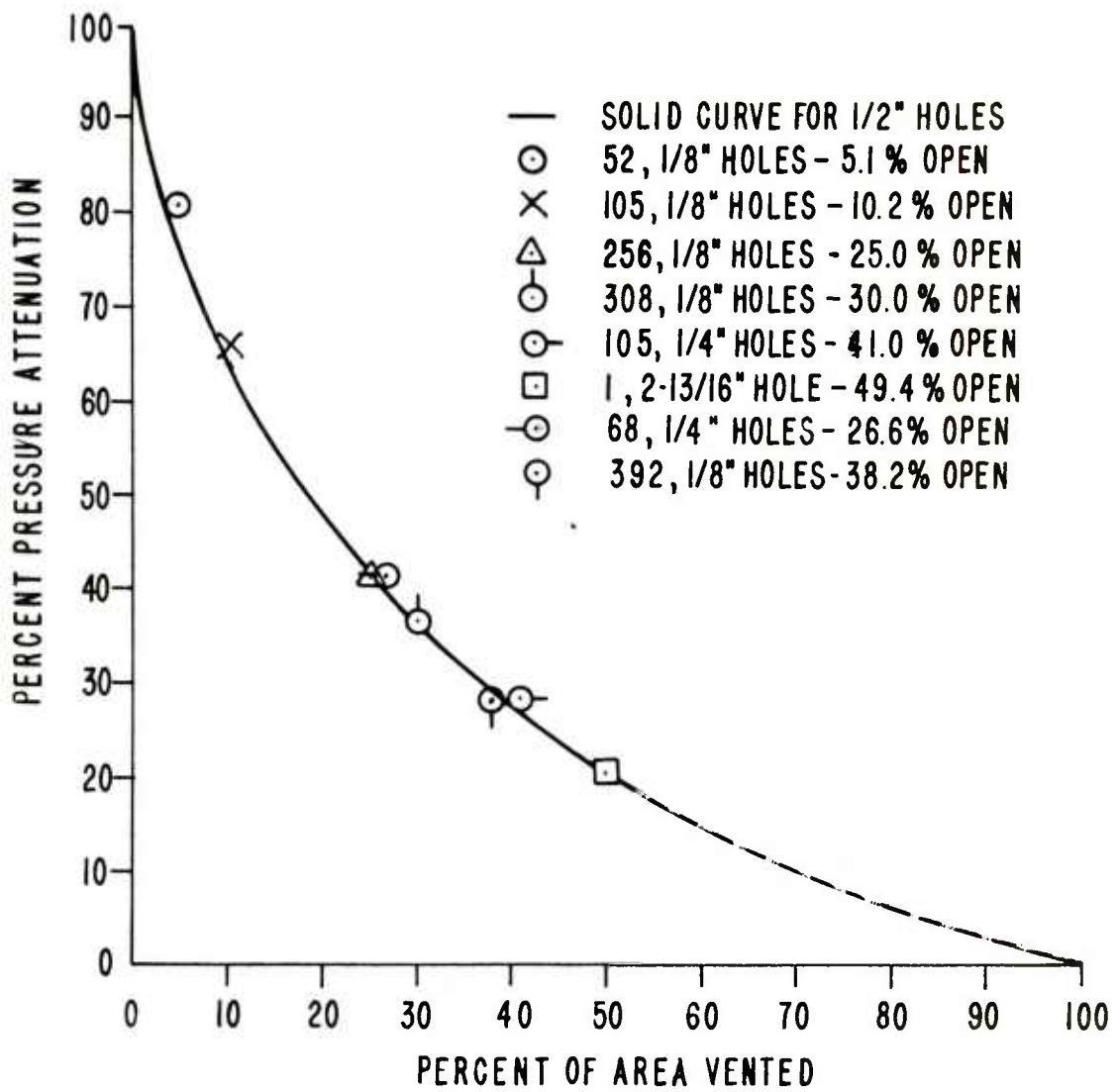


Figure 10. Percent Pressure Attenuation as a Function of Percent of Area Vented

APPENDIX

PRESSURE-TIME DATA

This Appendix shows a selection of records which represent the pressure as a function of time at Station 3 (CH3) and Station 6 (CH6). Station 3 was located 0.75 tube diameter upstream from the target plate. Station 6 was located 7 tube diameters downstream of the target plate - a distance sufficient to allow the transmitted shock wave (P_T) to reform after passing the perforated plate.

Table A-I presents data for the target plates. Plate number, shot number, area vented, and hole diameter describe the target plates.

The pressure-time records are listed according to percent of area open. The upper trace (CH3) is the input record (P_I). The initial peak is the side-on value; the second peak is the portion of the shock wave reflected upstream from the target plate. The lower trace is the transmitted pressure at Station 6 (CH6).

Table A-I. Data for Pressure-Time Records

| <u>Plate No.</u> | <u>Shot No.</u> | <u>Area Vented Percent</u> | <u>Hole Diameter inches</u> |
|------------------|-----------------|----------------------------|-----------------------------|
| 1 | 22 | 4.69 | 1/2 |
| 2 | 81 | 5.1 | 1/8 |
| 3 | 297 | 7.81 | 1/2 |
| 4 | 29 | 9.37 | 1/2 |
| 5 | 76 | 10.2 | 1/8 |
| 6 | 32 | 25.0 | 1/2 |
| 7 | 160 | 25.0 | 1/8 |
| 8 | 63 | 26.6 | 1/4 |
| 9 | 153 | 30.0 | 1/8 |
| 10 | 168 | 38.2 | 1/8 |
| 11 | 66 | 41.0 | 1/4 |
| 12 | 51 | 49.4 | 2-13/16 |
| 13 | 7 | 50.0 | 1/2 |

SHOT 22 CH3
SUPPRESSIVE STRUCTURES

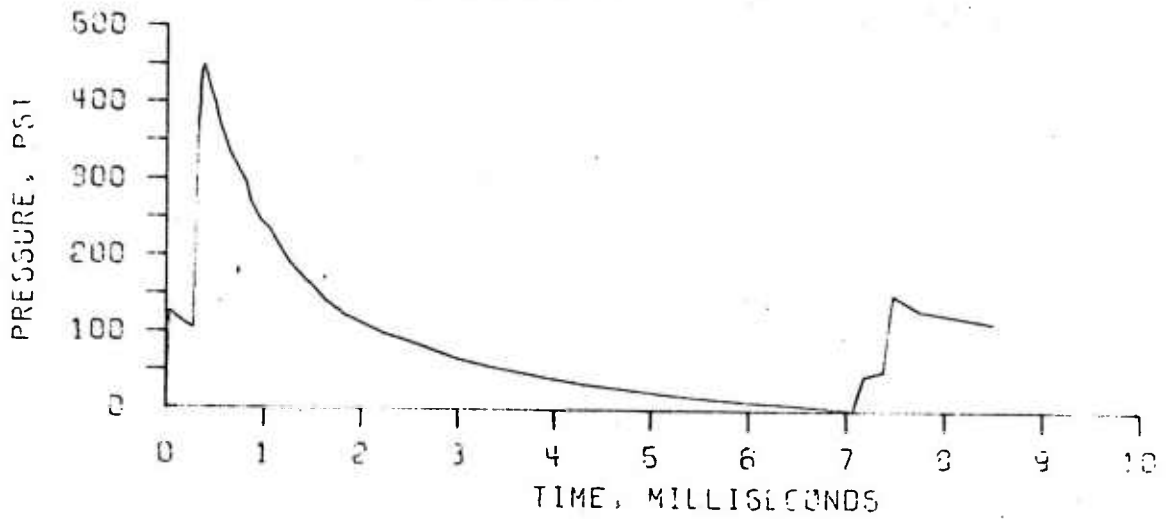


PLATE 1 -INPUT PRESSURE

SHOT 22 CH6
SUPPRESSIVE STRUCTURES

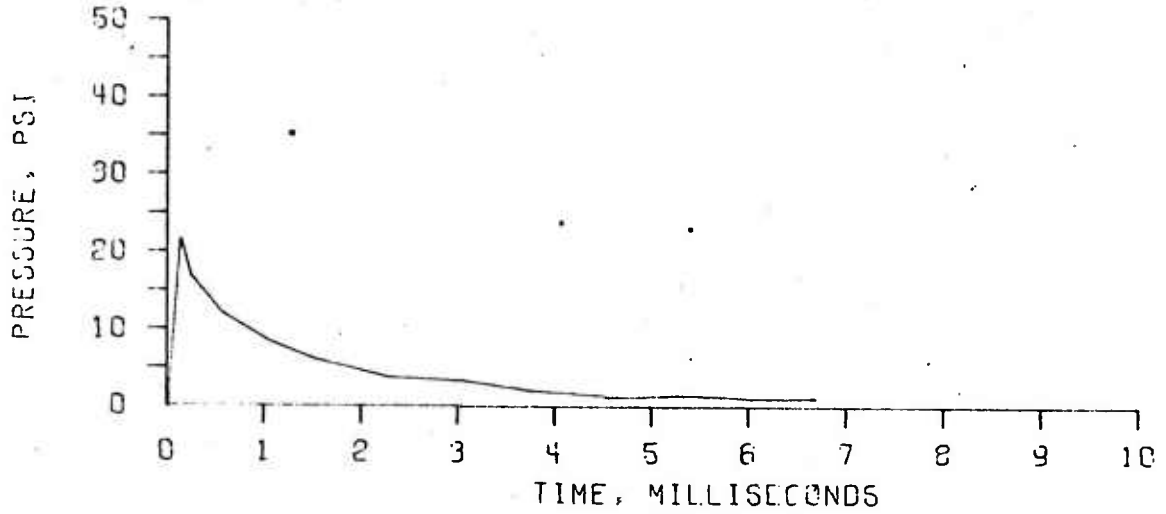


PLATE 1 -TRANSMITTED PRESSURE

Figure A-1. Pressure-Time Traces Recorded at Stations 3 and 6 - 4.69 Percent Open

SHOT 81 CH3
SUPPRESSIVE STRUCTURES

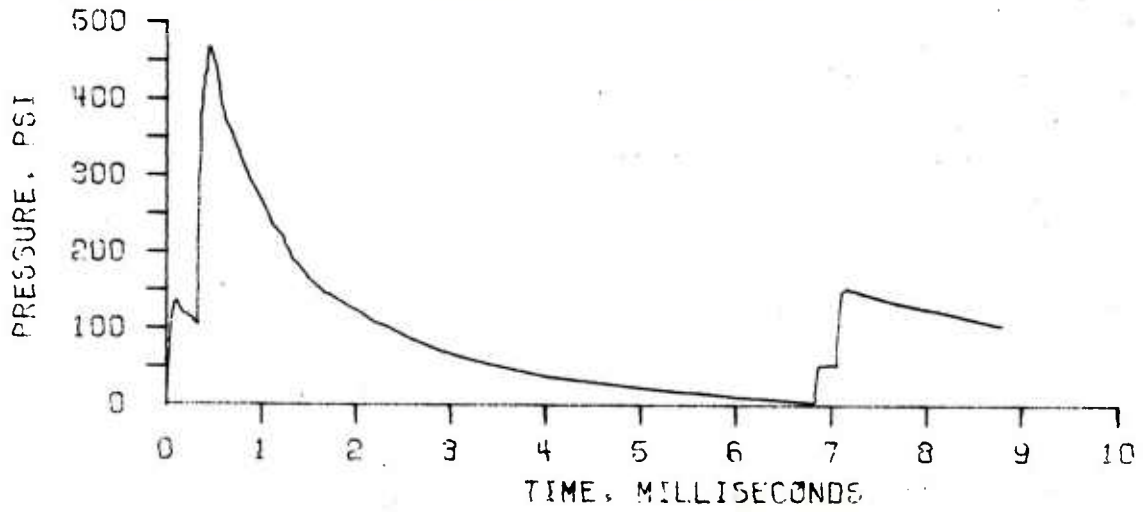


PLATE 2 - INPUT PRESSURE

SHOT 81 CH6
SUPPRESSIVE STRUCTURES

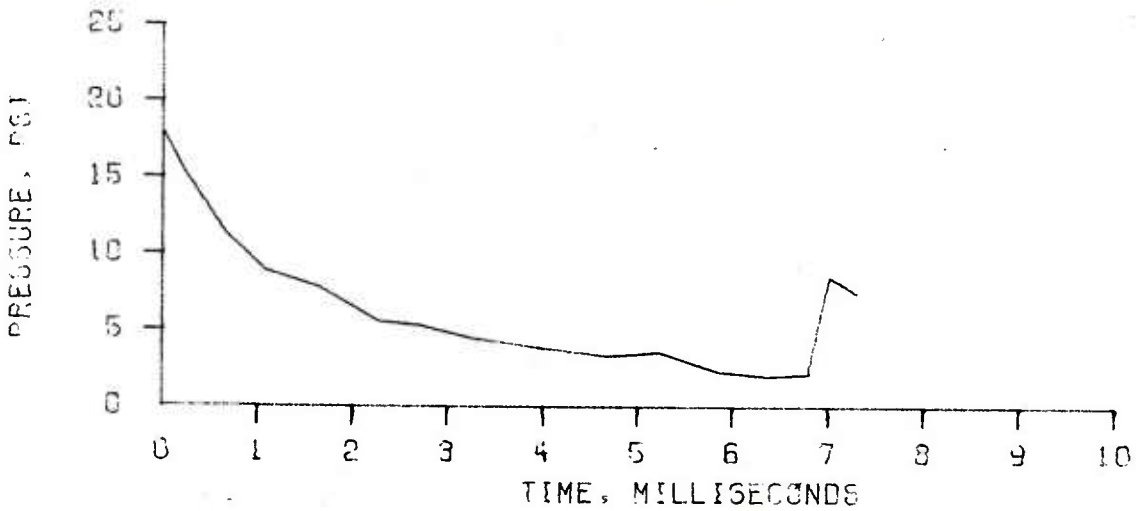


PLATE 2 - TRANSMITTED PRESSURE

Figure A-2. Pressure-Time Traces Recorded at Stations 3 and 6 - 5.1 Percent Open

SUPPRESSIVE STRUCTURES

SHOT NO. 297

CH. 3

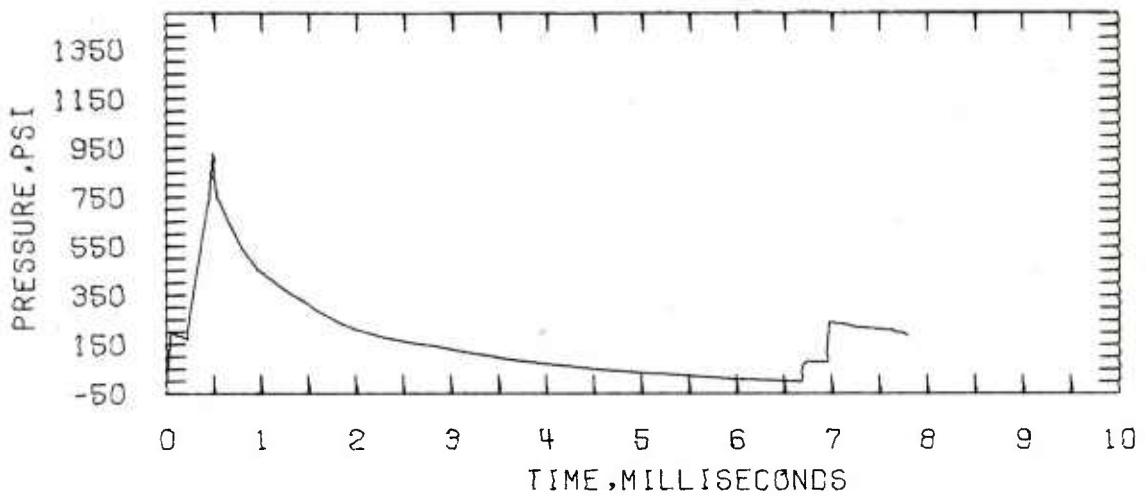


PLATE 3 - INPUT PRESSURE

SUPPRESSIVE STRUCTURES

SHOT NO. 297

CH. 6

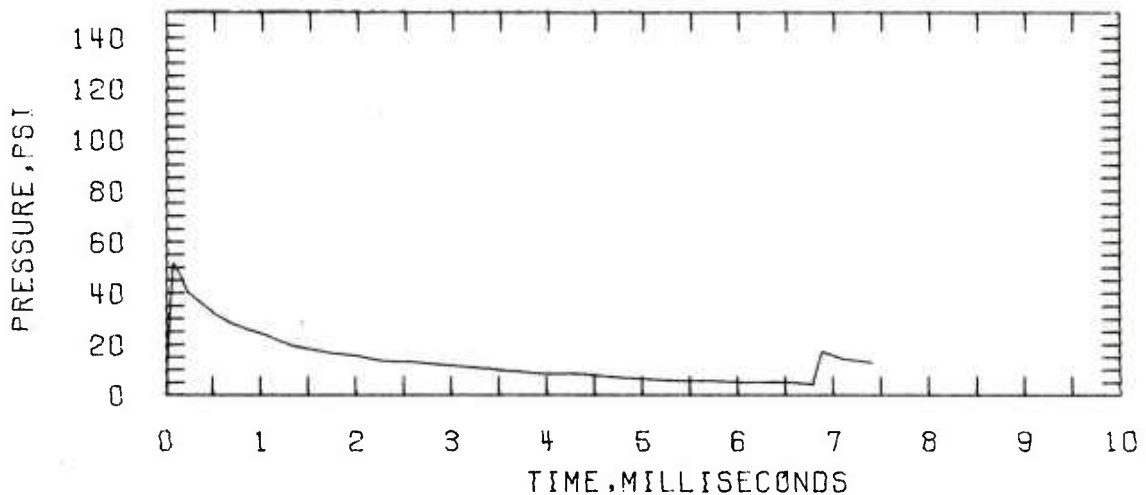


PLATE 3 - TRANSMITTED PRESSURE

Figure A-3. Pressure-Time Traces Recorded at Stations 3 and 6 - 7.8 Percent Open

SHOT 29 CH3
SUPPRESSIVE STRUCTURES

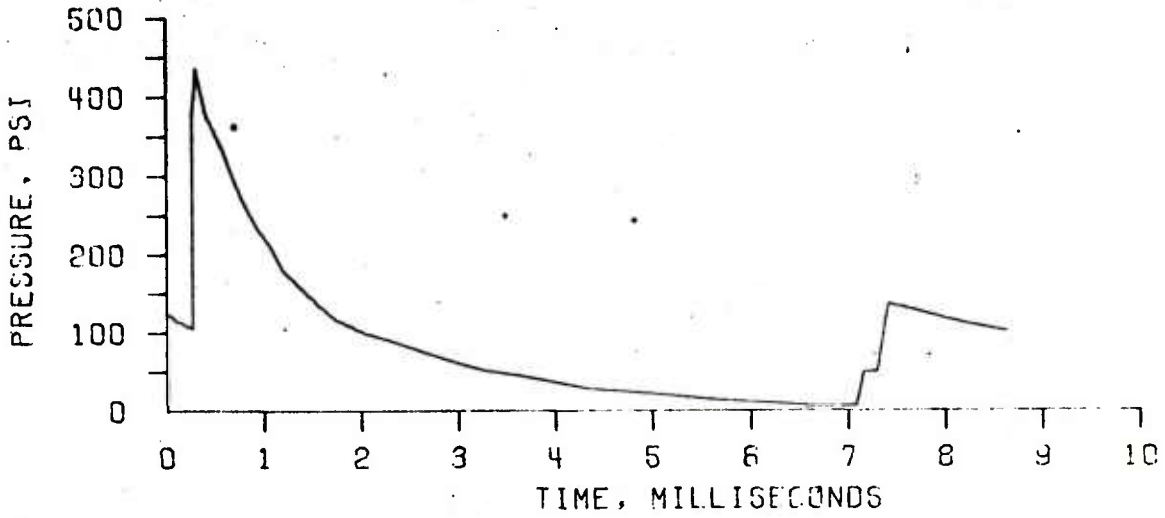


PLATE 4 - INPUT PRESSURE

SHOT 29 CH6
SUPPRESSIVE STRUCTURES

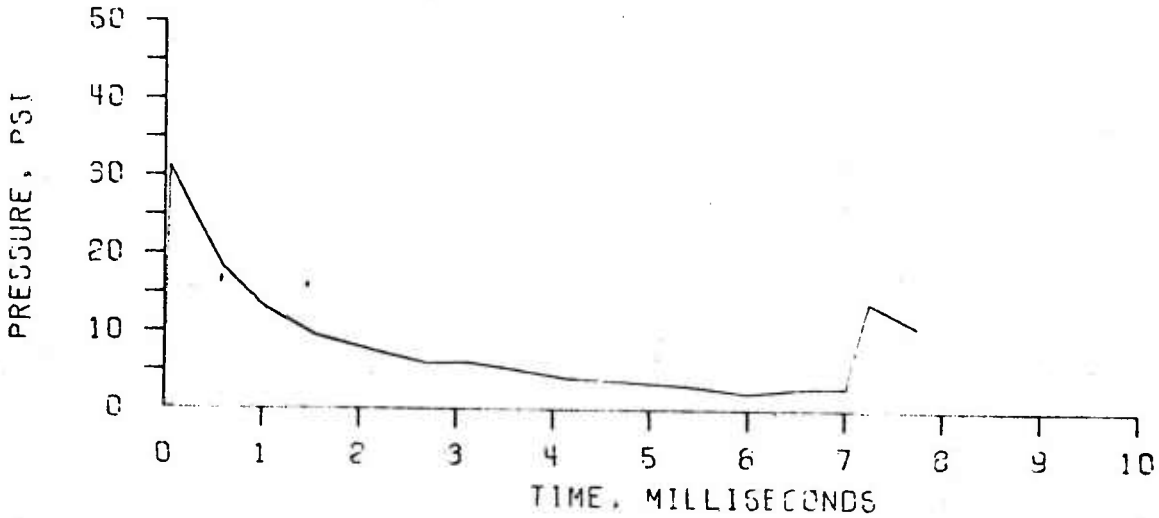


PLATE 4 - TRANSMITTED PRESSURE

Figure A-4. Pressure-Time Traces Recorded at Stations 3 and 6 - 9.37 Percent Open

SHOT 76 CH3
SUPPRESSIVE STRUCTURES

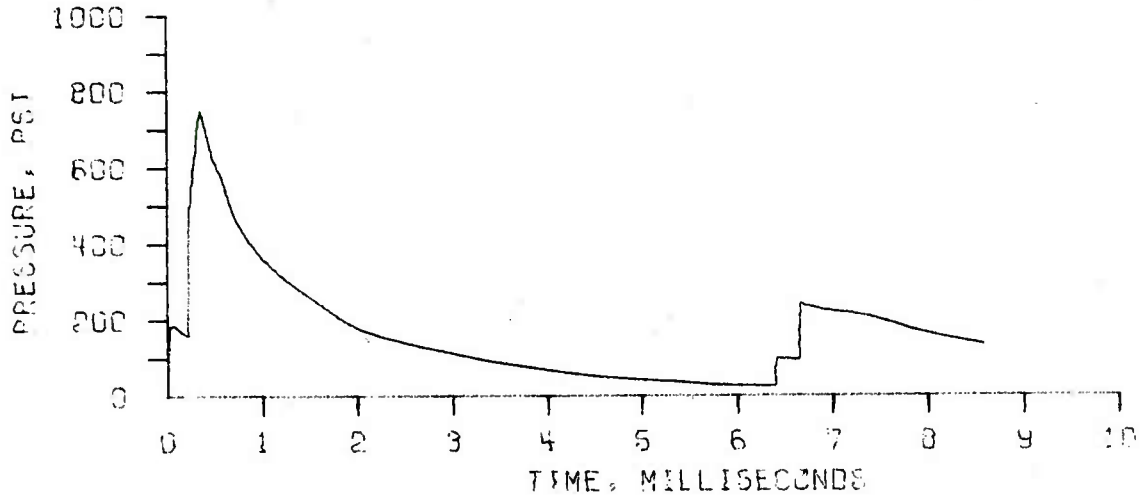


PLATE 5 - INPUT PRESSURE

SHOT 76 CH6
SUPPRESSIVE STRUCTURES

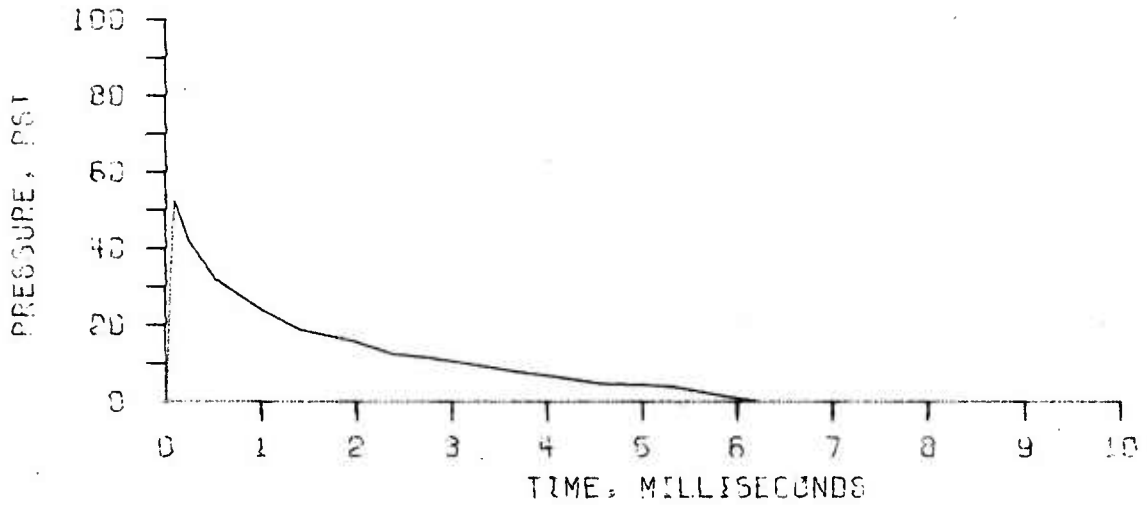


PLATE 5 - TRANSMITTED PRESSURE

Figure A-5. Pressure-Time Traces Recorded at Stations 3 and 6 - 10.2 Percent Open

SHOT 32 CH3
SUPPRESSIVE STRUCTURES

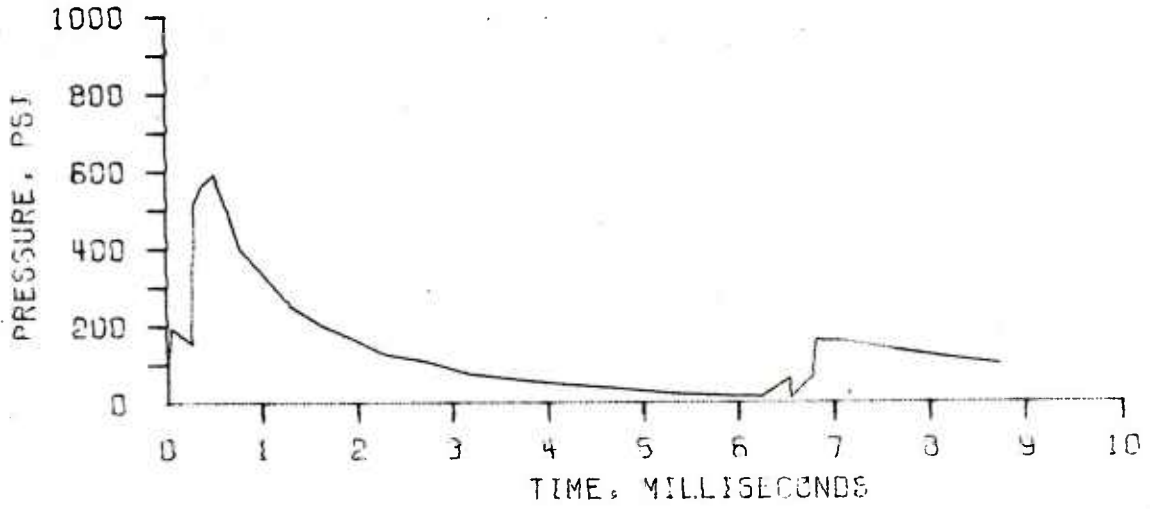


PLATE 6-INPUT PRESSURE

SHOT 32 CH6
SUPPRESSIVE STRUCTURES

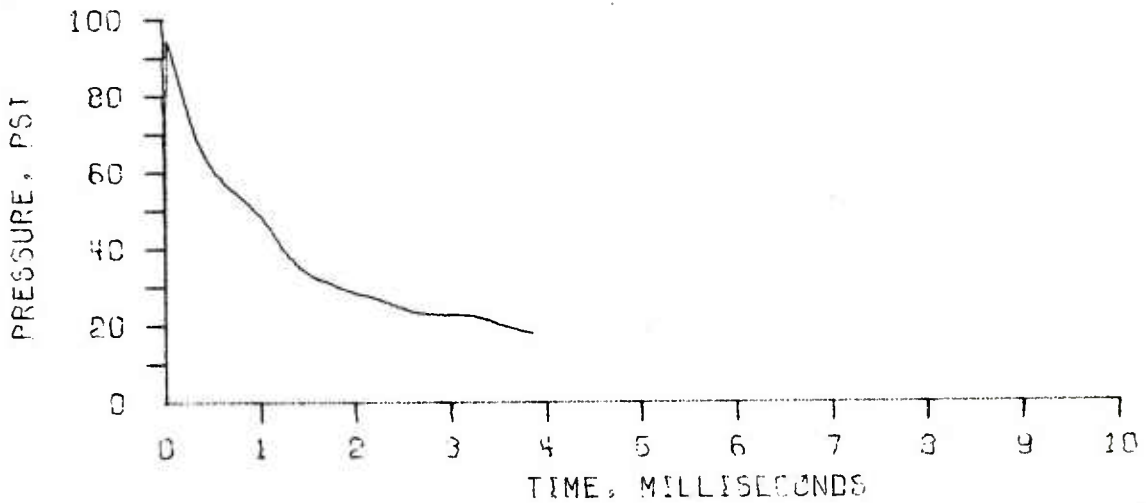


PLATE 6-TRANSMITTED PRESSURE

Figure A-6. Pressure-Time Traces Recorded at Stations 3 and 6 - 25 Percent Open, 1/2-Inch Holes

SUPPRESSIVE STRUCTURES
SHOT NO. 160
CH. 3

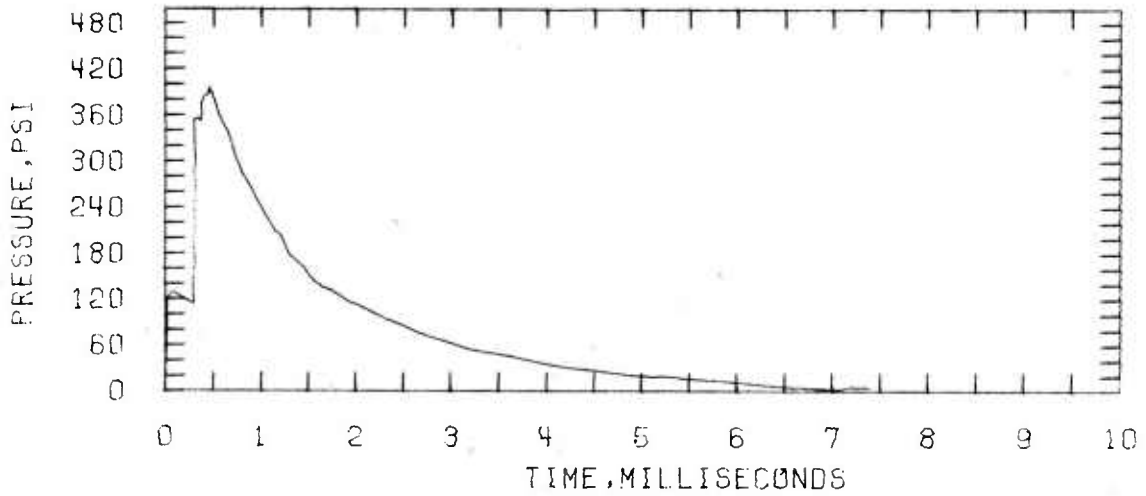


PLATE 7 - INPUT PRESSURE

SUPPRESSIVE STRUCTURES
SHOT NO. 160
CH. 6

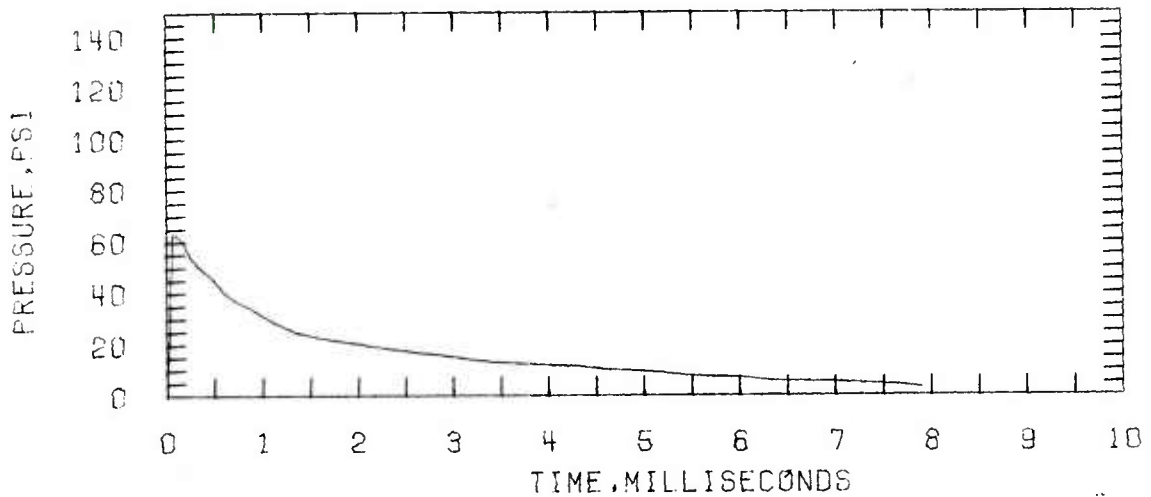


PLATE 7 - TRANSMITTED PRESSURE

Figure A-7. Pressure-Time Traces Recorded at Stations 3 and 6 - 25 Percent Open, 1/8-Inch Holes

SHOT 63 CH3
SUPPRESSIVE STRUCTURES

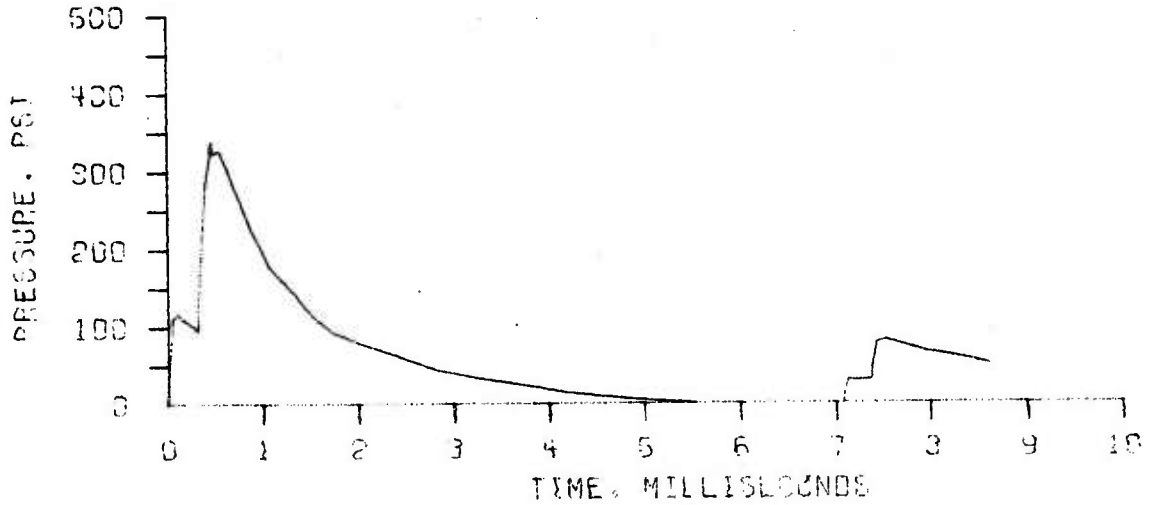


PLATE 8 - INPUT PRESSURE

SHOT 63 CH6
SUPPRESSIVE STRUCTURES

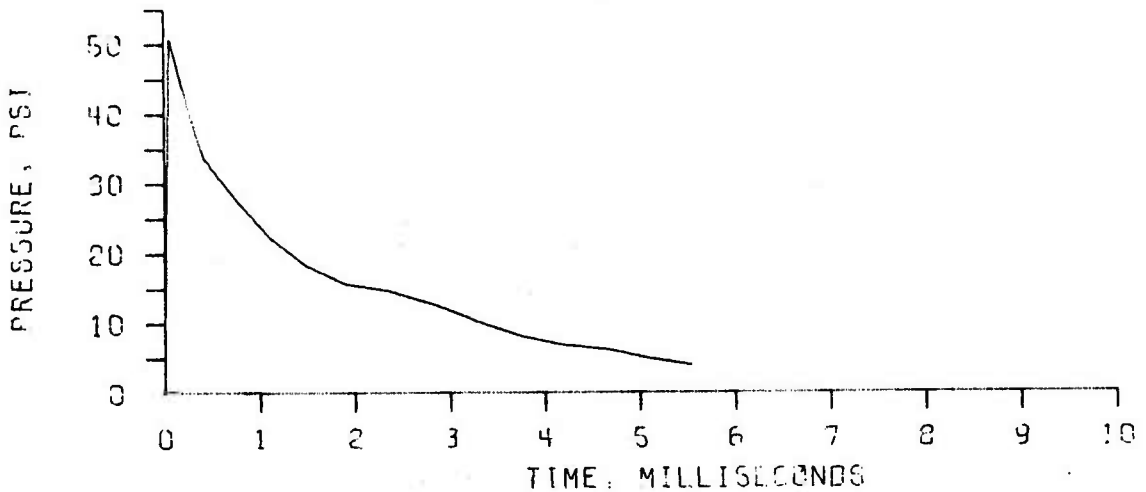


PLATE 8 - TRANSMITTED PRESSURE

Figure A-8. Pressure-Time Traces Recorded at Stations 3 and 6 - 26.6 Percent Open

SUPPRESSIVE STRUCTURES
SHOT NO. 153
CH. 3

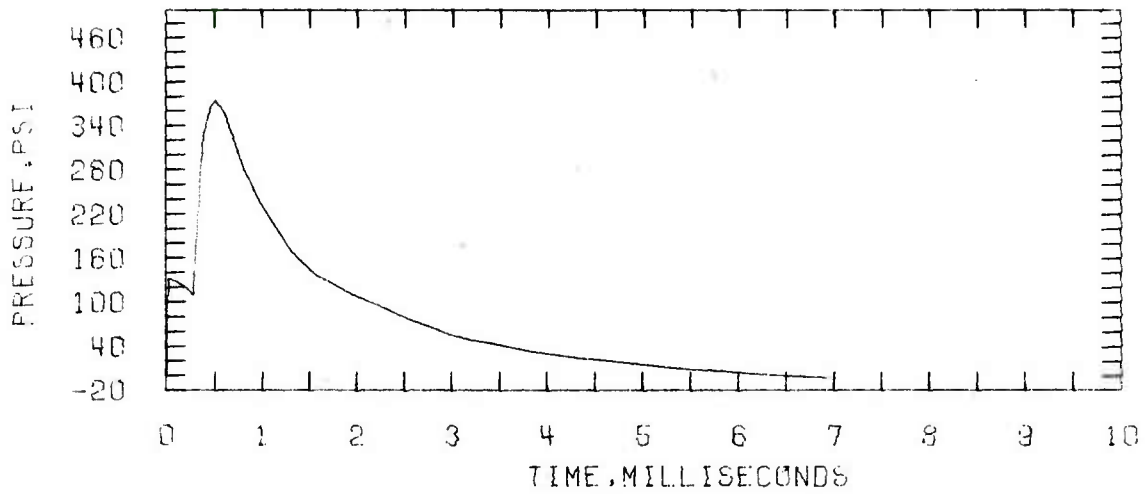


PLATE 9 - INPUT PRESSURE

SUPPRESSIVE STRUCTURES
SHOT NO. 153
CH. 6

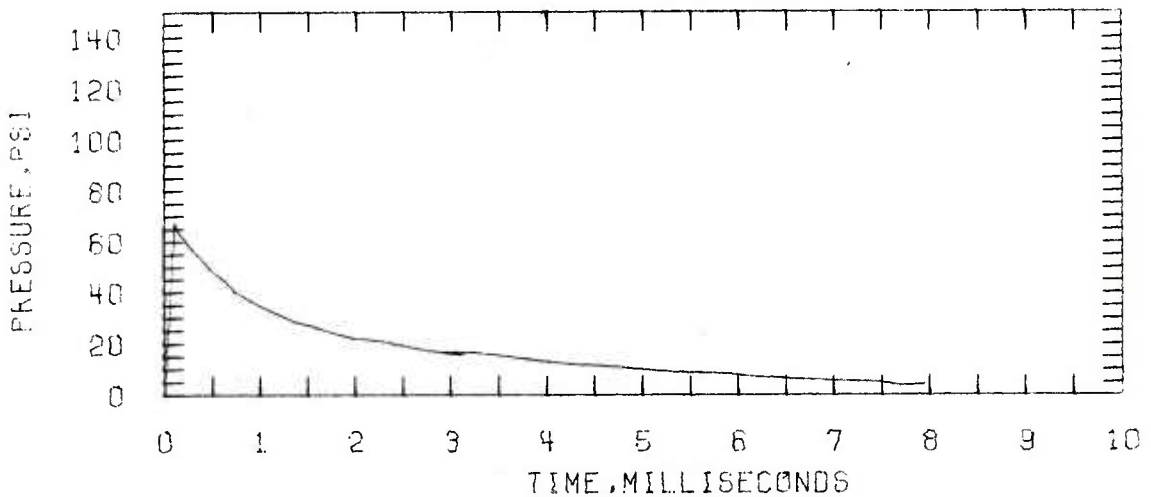


PLATE 9 - TRANSMITTED PRESSURE

Figure A-9. Pressure-Time Traces Recorded at
Stations 3 and 6 - 30 Percent Open

SUPPRESSIVE STRUCTURES
SHOT NO. 168
CH. 3

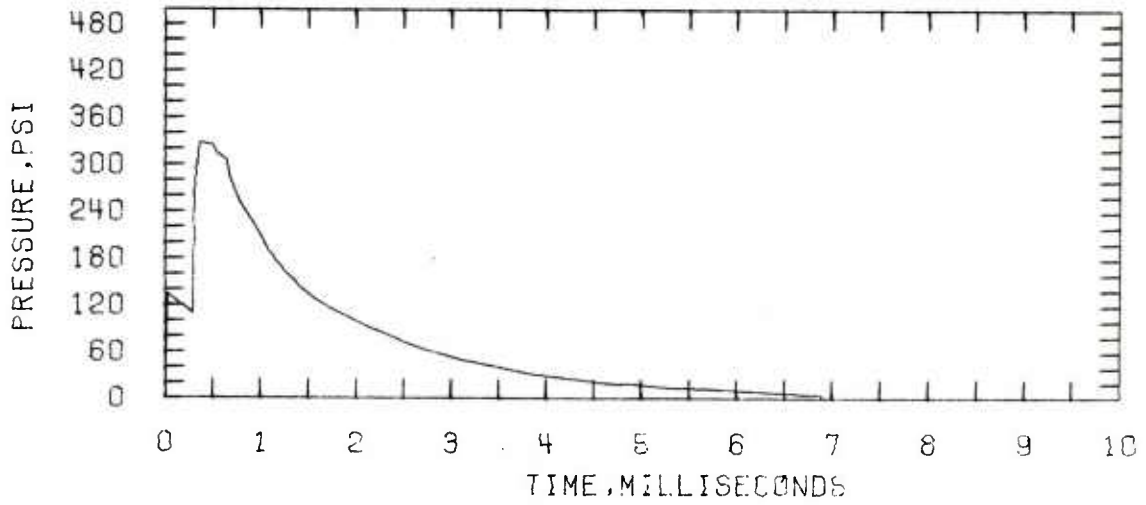


PLATE 10 - INPUT PRESSURE

SUPPRESSIVE STRUCTURES
SHOT NO. 168
CH. 6

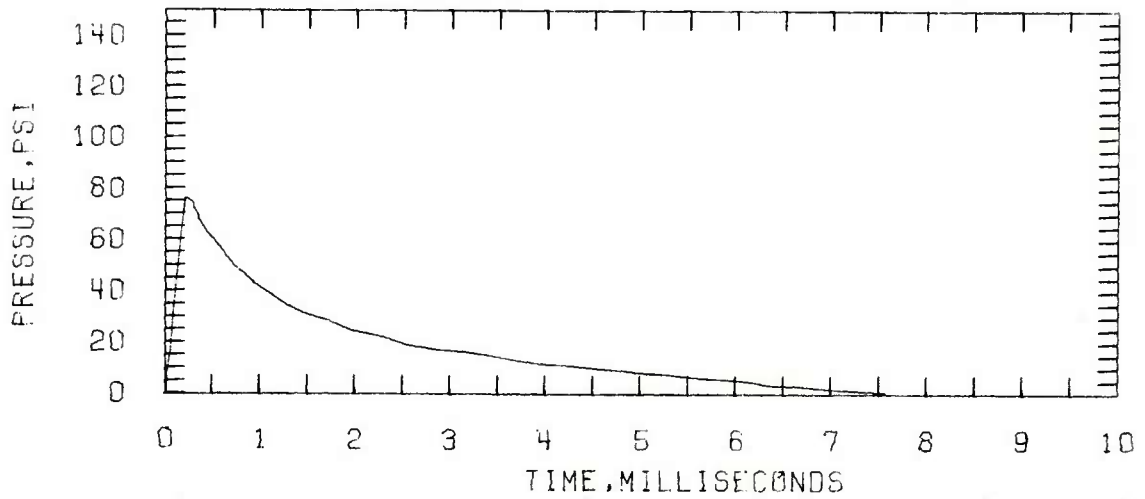


PLATE 10 - TRANSMITTED PRESSURE

Figure A-10. Pressure-Time Traces Recorded at Stations 3 and 6 - 38.2 Percent Open

SHOT 54 CH3
SUPPRESSIVE STRUCTURES

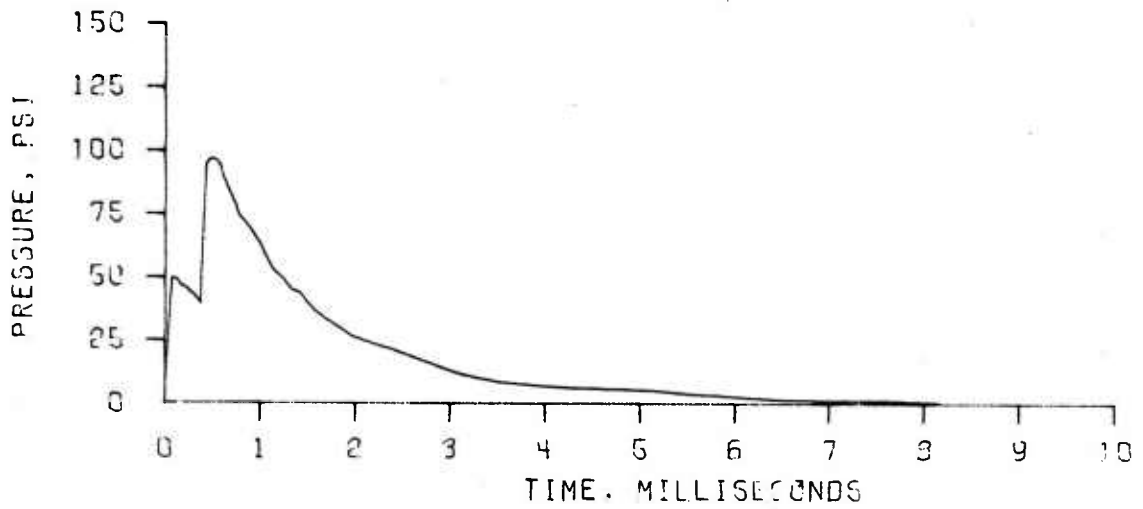


PLATE II - INPUT PRESSURE

SHOT 54 CH6
SUPPRESSIVE STRUCTURES

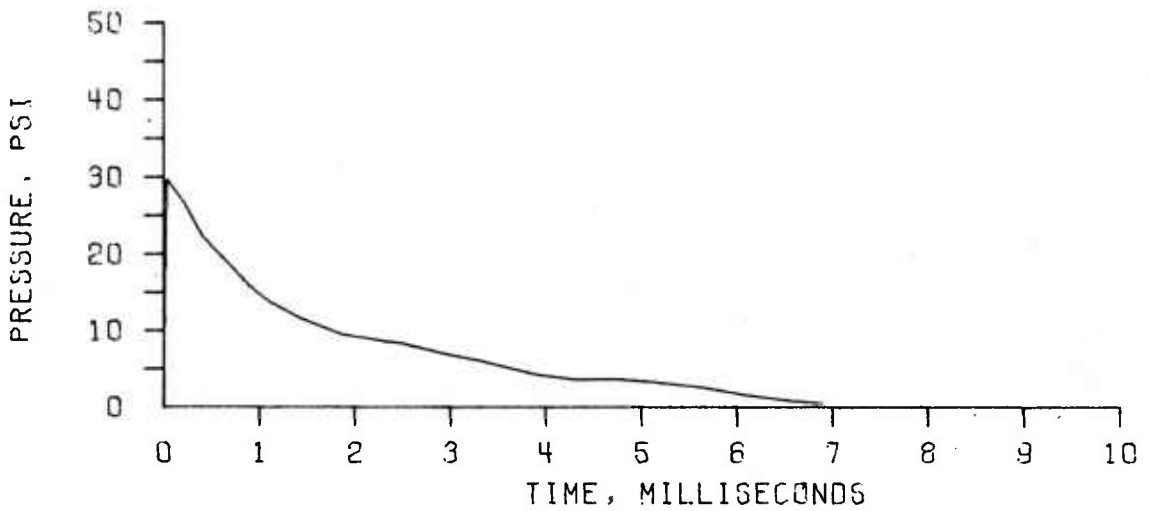


PLATE II - TRANSMITTED PRESSURE

Figure A-11. Pressure-Time Traces Recorded at Stations 3 and 6 - 41.0 Percent Open

SHOT 51 CH3
SUPPRESSIVE STRUCTURES

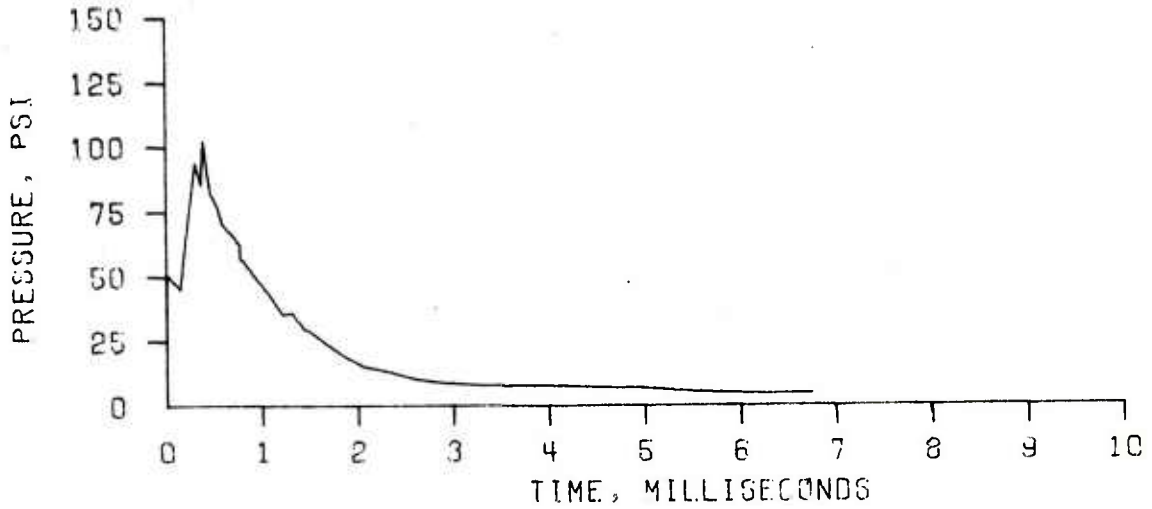


PLATE 12 - INPUT PRESSURE

SHOT 51 CH6
SUPPRESSIVE STRUCTURES

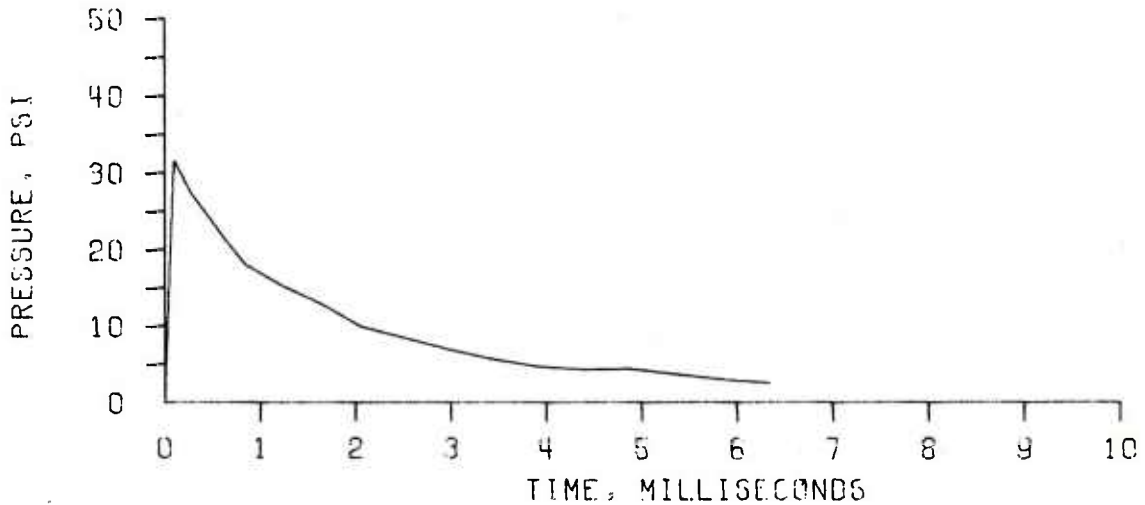


PLATE 12 - TRANSMITTED PRESSURE

Figure A-12. Pressure-Time Traces Recorded at Stations 3 and 6 - 49.4 Percent Open

SHOT 7 CH3
SUPPRESSIVE STRUCTURES

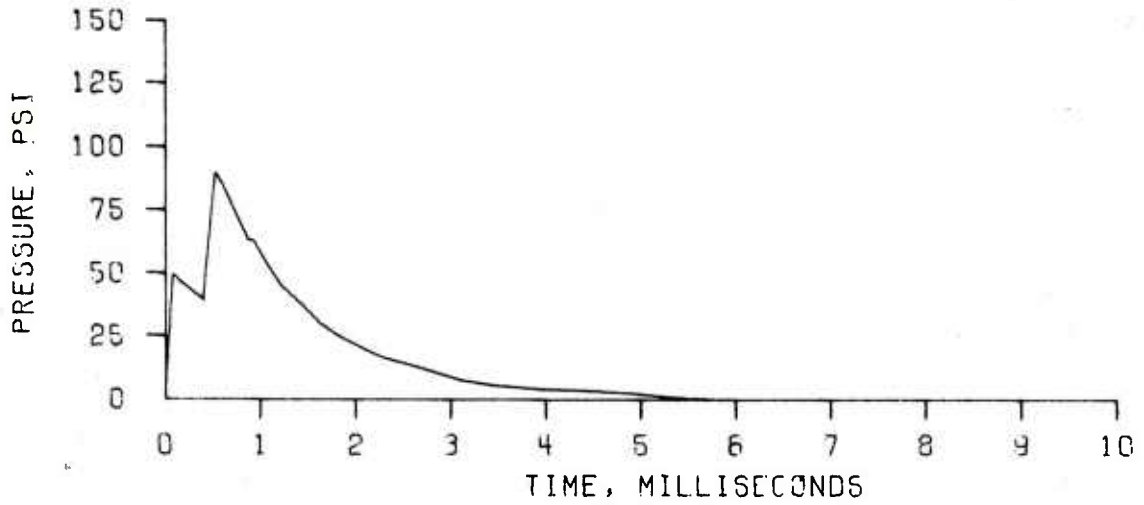


PLATE 13 - INPUT PRESSURE

SHOT 7 CH6
SUPPRESSIVE STRUCTURES

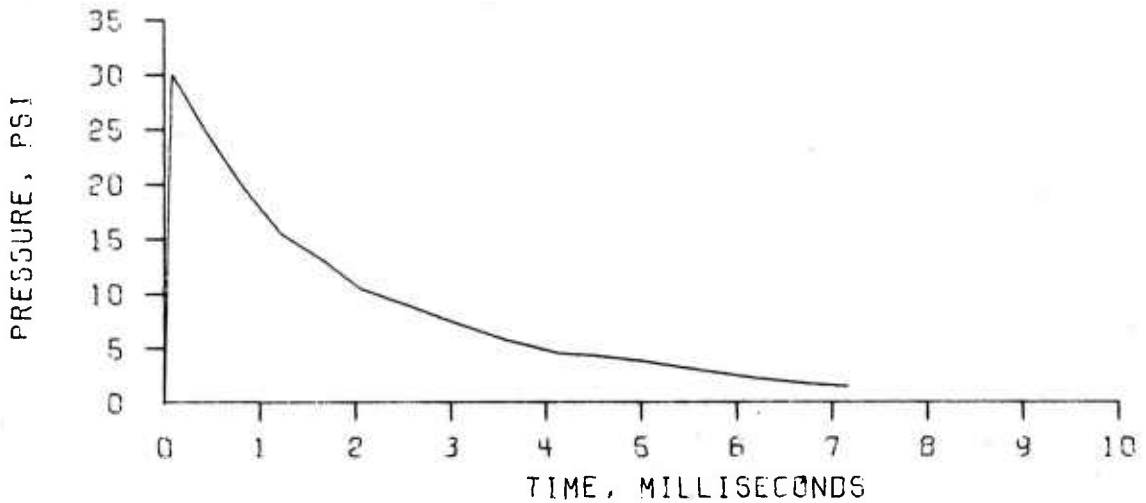


PLATE 13 - TRANSMITTED PRESSURE

Figure A-13. Pressure-Time Traces Recorded at Stations 3 and 6 - 50 Percent Open

LIST OF SYMBOLS

| | |
|-------------|---|
| A_V | Percent of plate vented = $\frac{\text{area vented}}{\text{area of tube}} \times 100$ |
| P_I | Input peak overpressure |
| P_T | Transmitted peak overpressure |
| $P_{T 100}$ | Transmitted peak overpressure for unobstructed tube |
| P_{TR} | Pressure transmission ratio = $\frac{P_T \text{ for Plate}}{P_{T 100}}$ |
| Psi | Pounds force per square inch |
| Pa | Pascal (newtons per square metre) |

NOTE: Psi x 6.894757 = kPa.

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